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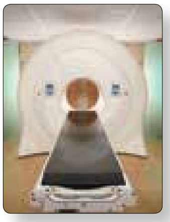

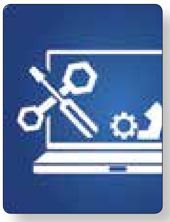

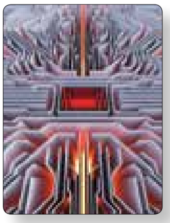

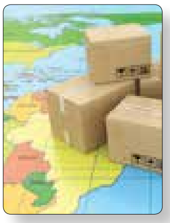

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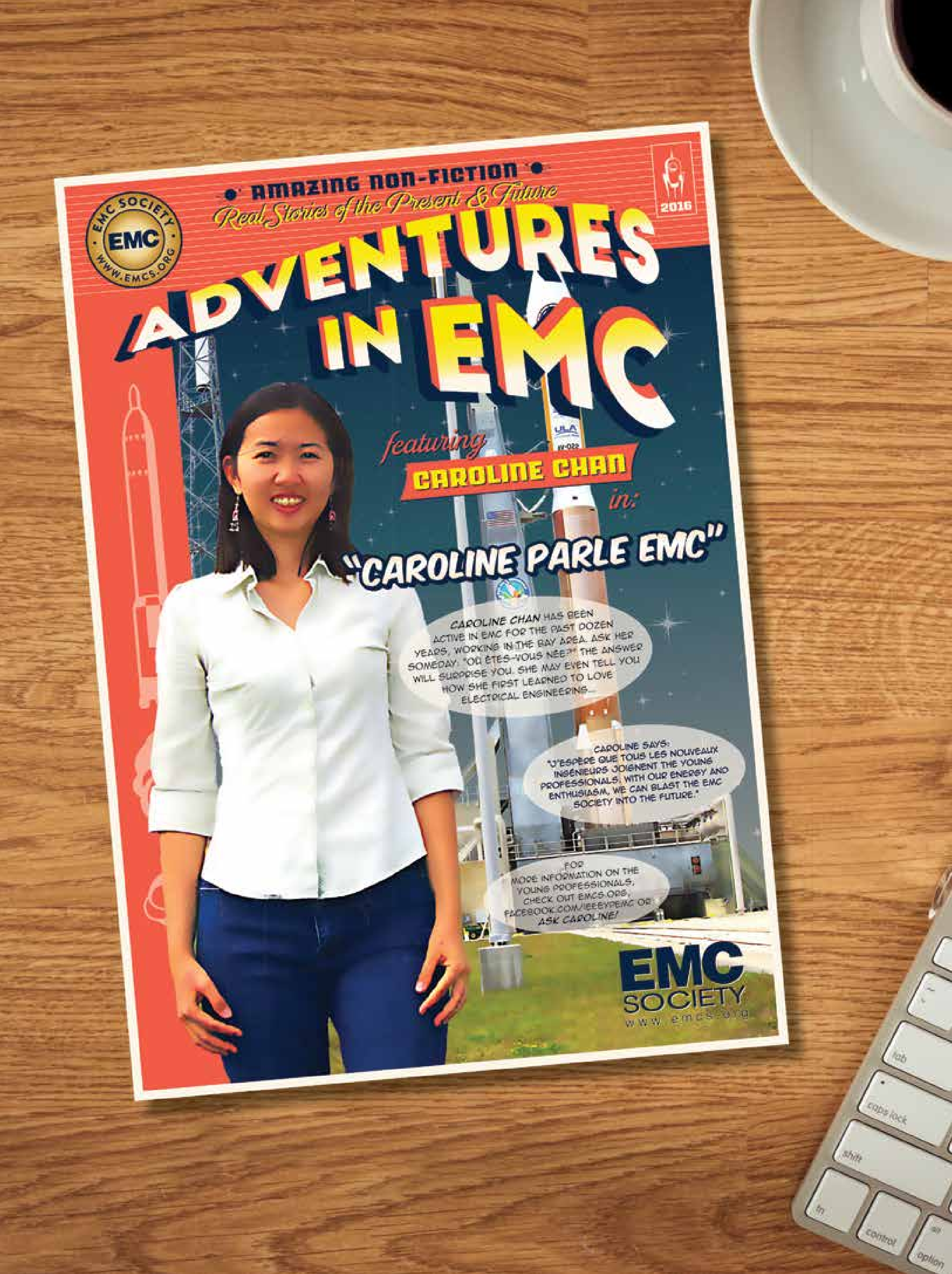

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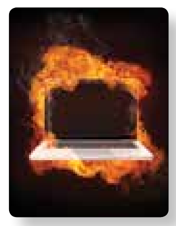

PRODUCT SAFETY

LETTER From the Editor

Welcome to the 2016 Annual Reference Guide

Dear Readers,

As I sit here at my computer this February morning, reflecting on what witty topic to write about in my Annual Guide letter to you, my thoughts move to a more poignant topic. While wit is a charming attribute (one shared by many of our electrical engineering friends) I am moved to write on another topic today, the topic of connection.

Now, when I mention connection I know it's very easy to conjure thoughts of electronic devices and the multitude of options available to us in 2016 to remain connected. But I'm thinking of a less technical use of the word, connection as it relates to the basic human need to belong. Many of us like to think we are immune to the pull of connection, but the sense of belonging created from connection has undeniable benefits to our well-being. Social connection is believed to strengthen our immune systems, decrease our anxieties, ward off depression and perhaps even lengthen our lives. Good stuff, right?

When my partners and I embarked on our quest to create In Compliance, we were keenly aware that we were adopting a mission to foster a deep sense of community and connection through our pages (both physical and virtual) and face-to-face events. Today this mission is still at the heart of all we do.

And so, in the spirit of community and connection, it is with great pride that we offer you the *2016 Annual Reference Guide*, a collection of invaluable technical articles contributed by community thought leaders in the areas of EMC, International Product Compliance, ESD, Telecom & Wireless and Product Safety. Toward the back of the Guide you'll find a comprehensive Directory section offering products and services used in achieving product compliance. Throughout the Guide, you'll see advertisements from trusted industry suppliers who are committed to supporting the efforts of education and information for the betterment of our community and our world. We extend to them our sincerest gratitude, for without their support we could not continue to fulfill our mission.

And to you, our readers… our community, we thank you for your continued interaction, encouragement and support. It is a pleasure to serve you as an integral part of the electronics engineering community.

Until next time,

Lorie Nichols

Lorie Nichols, Editor

IN COMPLIANCE

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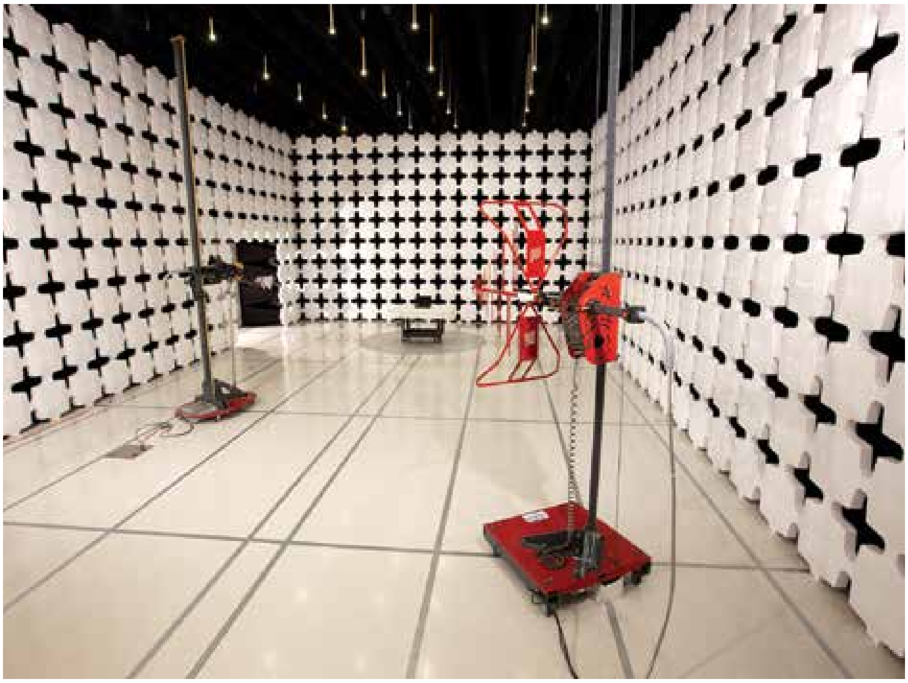

Company Roots

We trace our earliest roots to the 1930's when the Ray Proof Company began producing x-ray shielding for the medical market. In 1995, EMCO, Rantec and Ray Proof joined together to form EMC Test Systems, known then as ETS. Later, other companies were acquired; Euroshield Oy, Lindgren RF Enclosures, Holaday Industries, and Acoustic Systems. Today our company is known as ETS-Lindgren.

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Our diverse and highly skilled global workforce consists of approximately 750 employees in North America, South America, Europe, and Asia. We have manufacturing facilities and service centers strategically located around the globe.

Our sales network of more than 60 independent representative and distributor organizations provides knowledgeable sales, service and support around the world.

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Our growth is propelled by meeting our customer's need for systems and components that provide reliable service, repeatable results, and value at a fair price. Our history of success and proven track record virtually eliminates risky outcomes for our customers.

ETS-Lindgren believes in making investments that enable us to serve our customers better. Our manufacturing facilities use efficient, cost reducing systems. Our engineers work with state-of-the-art equipment. We continue to expand our locations to better serve our customers, such as our newest office in Bengaluru, India.

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Our persistent efforts to improve on our safe work environment continue to pay off. We provide ongoing safety training and awareness, and a safe place to work.

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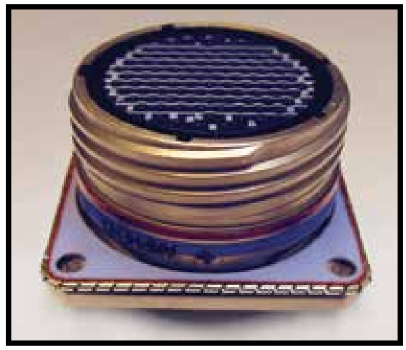

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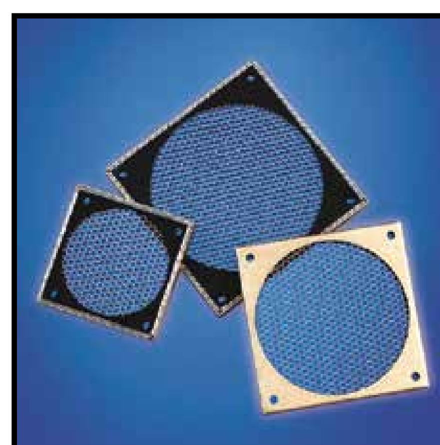

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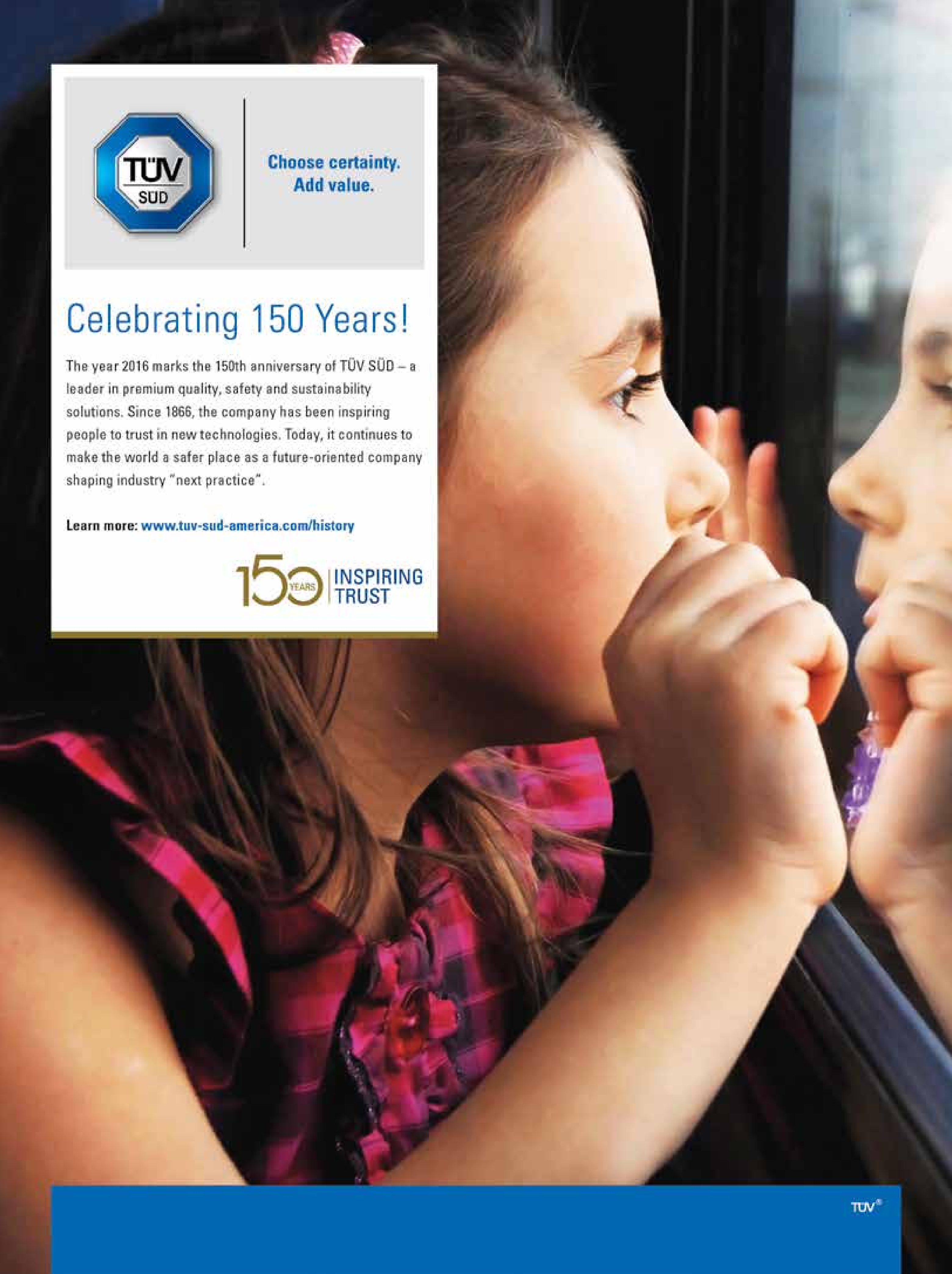

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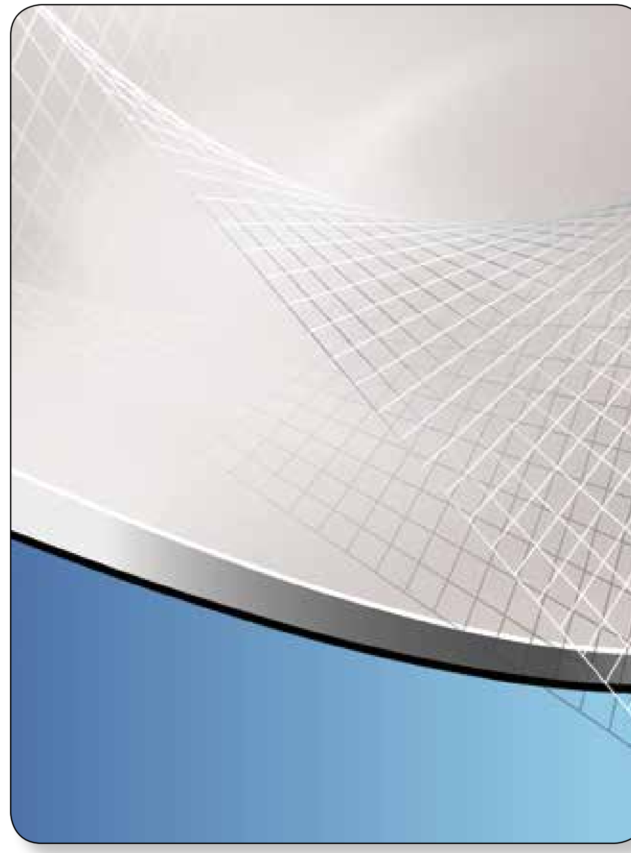


A Theory of Shielding Electromagnetic Waves

Revisiting Shielding Effectiveness Equations

BY GEORGE M. KUNKEL

In this article, we analyze the shielding effectiveness equations (SE = R + A + B) as defined by Ott, Schnelkunoff, White, and Frederick. The analysis consists of deriving the values of R and A, and evaluating and comparing the values of R, A and B with test results obtained by Al Broaddus and George Kunkel in their paper entitled "Shielding Effectiveness Tests of Aluminizing Mylar."[1] The analysis and test data presented clearly demonstrate that the equations have been misinterpreted by Schelkunoff and others, and that there is no reflected loss inside a shielding barrier. The contribution to shielding theory by Schelkunoff is also evaluated. An analysis of circuit theory versus wave theory is performed, and the results conclude that wave theory does not represent the actual phenomena associated with a conducted wave on a transmission line, and that wave theory is only a theory.

SHIELDING EFFECTIVENESS EQUATIONS

Most of the literature dealing with the shielding theory of electromagnetic (EM) waves defines the level of attenuation of the wave through a barrier by the use of shielding effectiveness equations. These equations are:

SE (shielding effectiveness) = R + A + B

Where:

R (reflection loss) = $20 \log \frac{(k+1)^2}{4k}$ (dB)

A (absorption loss) = $20 \log e^{-t/\delta} = 8.686\, t/\delta$

B (re-reflection coefficient) = $20 \log \left[1 - \left(\frac{k-1}{k+1}\right)^2 e^{-2t/\delta}\right]$

& $k = Z_{wave}/Z_{barrier}$

Table 1 illustrates the analysis results using the shielding effectiveness equations (as given in the Sidebar "Shielding Effectiveness Equations") on the test conditions used by Broaddus and Kunkel. The test results obtained by Broaddus and Kunkel (and shielding effectiveness analysis) are based on the following test conditions: 1) the test barrier has a resistance of 1.4 ohms (impedance of 2.0 ohms); 2) the EM wave sources are a high impedance (electric dipole) antenna and a low impedance (magnetic dipole) antenna 20 centimeters from the barrier; and 3) the frequency range is between 100 kHz and 10 MHz.

Comparing the results of the analysis with the test results (as illustrated in Figures 1 and 2 and Table 1) yields significant insight into the meaning and value of the equations.

The reflective loss "R" is derived from transmission lines as obtained using the equations associated with "wave theory." It is assumed that the reflection coefficient (R) using the wave theory equation on a transmission line is identical to that of when a radiated wave is reflected from a shielded barrier, where the loss is equally the same for the E and H fields. Figures 1 and 2 compare the results obtained using the "SE"

equations with the E field attenuation obtained by Broaddus and Kunkel. No loss in the H field was detected during the test.

The term "absorption loss" implies a power loss (or an $I^2 R$ loss as defined in our high school physics classes). It is actually an attenuation factor. When an EM wave is impinged on a shielding barrier, current (surface current density $-J_s$) is coupled to the barrier. This current generates an H field at right angles to the direction of the current. The H field in turn creates a back EMF (voltage) which forces the current flowing in the barrier to flow close to the incident surface of the barrier. This phenomenon is classified as "skin effect" where the average depth of the current flowing on the surface of an infinitely thick (greater than an extinction depth or $2\Pi\delta$ meters) is one skin depth where δ is one skin depth.

The "re-reflective coefficient" is applicable when the thickness of the barrier is "thin" (less than $2\Pi\delta$). In the literature on shielding, this function is to be applied due to the wave bouncing back and forth inside the barrier. The equation is actually a correction factor for assumptions made in applying the reflection loss equation. These assumptions are:

1. The wave impedance Z_w is greater than the barrier impedance Z_b. The equation for "R" yields a reflective loss when $Z_w < Z_b$. As illustrated in Figure 1 and Table 1, there is not a loss of shielding under these conditions. The equation for "B" is a correction factor when Z_w is less the Z_b (as is the case at 100kHz using the low impedance source).

2. The thickness of the barrier is greater than $2\Pi\delta$ meters. The equation for the impedance of the barrier (consistent with shielding effectiveness theory) is:

$$Z_b = \frac{(1 + j)}{\sigma\delta}.$$

When this equation is applied to the test conditions used by Broaddus and Kunkel, the impedance of the 2.0 ohm barrier results in impedance of .0001, .0005 and .0015 ohms for 100 kHz, 1MHz and 10 MHz respectively. The actual impedance for a barrier of any thickness is:

$$Z_b = \left[\frac{(1 + j)}{\sigma\delta(1 - e^{-t/\delta})}\right]$$

Using this equation, the impedance is 2.0 ohms for all three frequencies. The "B" equation containing $(1 - e^{-2t/\delta})$ is used as a correction factor when the thickness "t" is less than $2\Pi\delta$ (see Table 1).

Most of the literature on the shielding of EM waves states that the attenuation of the E and H fields through a barrier is equal. This is justified because the reflection loss "R" equation provides for a loss when $Z_w < Z_b$. The impedance inside a barrier is less than the 377 ohm impedance of free space. However, we know from Table 1 that the shielding equations predict zero shielding under these conditions. As a result there is no reflected loss inside the barrier. Any H field attenuation is the result of skin effect or the absorption "A" equation.

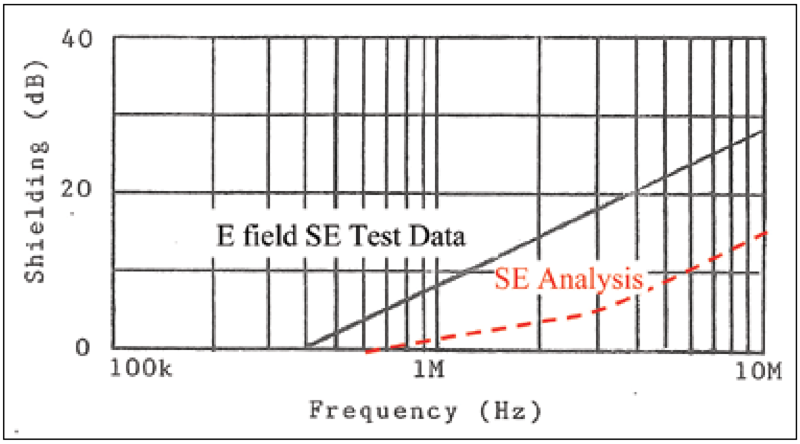


Figure 1: E Field Shielding Effectiveness Test Data versus SE Analysis of 2.0 ohm Barrier Using a Low Impedance Source 0.20 Meters from the Barrier.

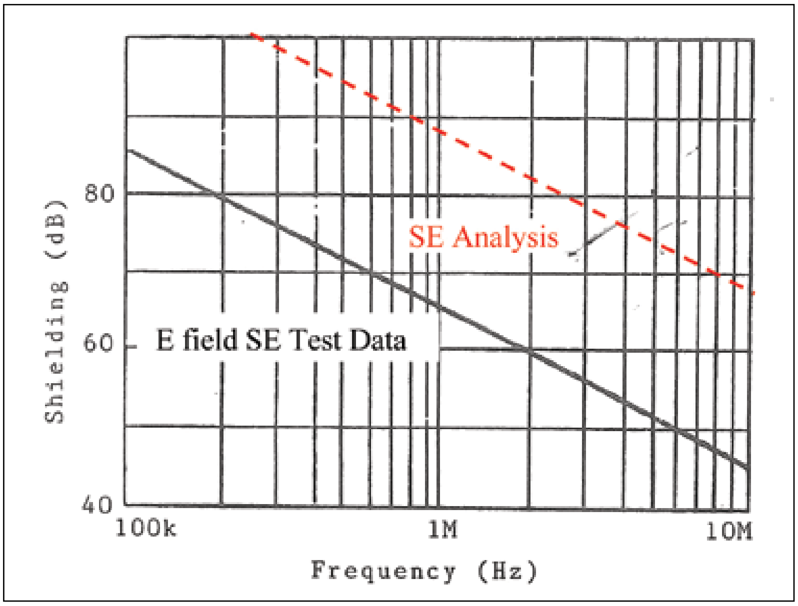


Figure 2: E Field Shielding Effectiveness Test Data versus SE analysis of 2.0 ohm Barrier Using a High Impedance Source 0.20 Meters from the Barrier.

Antenna Source	Z_w	Z_b	K	δ	$e^{-2t/\delta}$	$\left(\frac{k-1}{k+1}\right)^2$	R dB	B dB	A dB	SE dB
@ 100 kHz										
High Z	$9\text{x}10^5$	.0001	$6\text{x}10^9$	.0003	.9998	1.0000	183.6	-76.4	0.0	107
Low Z	.158	.0001	1058	.0003	.9998	.9962	48.4	-48.1	0.0	0
@ 1 MHz										
High Z	90,000	.0005	$190\text{x}10^6$	.0001	.9995	1.0000	153.6	-66.4	0.0	87
Low Z	1.0000	.0005	2120	.0001	.9995	.9981	54.5	-52.5	0.0	2
@ 10 MHz										
High Z	9000	.0015	$6.03\text{x}10^6$	$2.67\text{x}10^5$	.9905	1.0000	123.6	-56.4	0.0	67
Low Z	15.79	.0015	$16\text{x}10^3$	$2.67\text{x}10^5$	.9905	.9996	68.5	-54.5	0.0	14

Table 1: Shielding Effectiveness Analysis of Test Conditions used by Broaddus and Kunkel in their Presentation at the 1992 EMC Symposium.

Shielding Effectiveness Equations

$SE = R + A + B$ (dB)

Where:

$R = 20 \log \dfrac{(K+1)^2}{4|K|}$ Reflection Loss (dB)

$A = 8.686\ \alpha d$ Absorption Loss (dB)

B (dB) $= 20 \log \left| 1 - \left[\dfrac{K-1}{K+1}\right]^2 e^{-2\alpha d} \right|$ Re-reflection Coefficient

$K = \dfrac{Z_{wave}}{Z_{barrier}}$, $Z_{barrier} = \left[\dfrac{j\omega\mu}{\sigma}\right]^{1/2} = \dfrac{1+j}{\sigma\delta}$

$Z_{wave} \approx -j\ 377\ \lambda / 2\pi r$, $(r < \lambda / 2\pi)$ High Impedance Source

$\approx j\ 377\ (2\pi r / \lambda)$, $(r < \lambda / 2\pi)$ Low Impedance Source

≈ 377, $(r \geq \lambda / 2\pi r)$ All Sources

$\alpha = \left[\dfrac{\mu\sigma\omega}{2}\right]^{1/2} = 1/\delta$

d = Thickness of Barrier (meters)

r = Distance from Source to Barrier (meters)

$\omega = 2\pi f$

μ = Absolute Permeability of Barrier (H/m)

$\mu = 4\pi \times 10^{-7}$

σ = Absolute Conductivity of Barrier (mhos/m)

$\sigma_{copper} = 5.82 \times 10^7$

$\sigma_{aluminum} = 3.55 \times 10^7$

$\lambda = c/f = 3 \times 10^8 / f$ (meters)

Extracted from "Handbook of RFI, Volume 3", Frederick Research Corp., Weaton, Maryland, 1962

SCHELKUNOFF'S CONTRIBUTION TO SHIELDING THEORY

Sergei Alexander (S.A.) Schelkunoff is credited with providing the electrical engineering community with the theory of shielding electromagnetic waves. In his book *Electromagnetic Waves* published in 1943, he provided the engineering community with the presently accepted shielding effectiveness equations, i.e.:

$$S = R + A + 20 \log \left[1 - \left(\frac{k-1}{k+1}\right)^2 e^{-2t/\delta}\right]$$

Where:

$R = 20 \log \dfrac{(k+1)^2}{4k}$ (dB)

$A = 8.686\ t/\delta$

& $k = Z_{wave}/Z_{barrier}$

Along with the equations, he also provided us with an example for which he developed the values of R and A. He also provided the following interpretation of the reflection loss equation "R:" "The wave is partially reflected at the outer surface of the shield and then partially re-reflected at the inner surface."

The reflection loss "R" is derived using "wave theory" as applied to conducted transmission lines. Schelkunoff believed that wave theory represented a physical representation of a wave on a transmission line. He also believed in a direct relationship to the reflective loss in a transmission line as predicted by wave theory and the reflective loss associated with a radiated wave striking a shielding barrier. The analogous relationships between the reflective waves are as follows:

1. The Impedance (E/H) of a radiated wave striking a barrier is analogous to the characteristic impedance (Z_o) of a transmission line.
2. The reflected E field of a radiated wave (when $Z_w > Z_b$) striking a shielding barrier is analogous to the reflected voltage of a transmission line when $Z_o > Z_L$.
3. The re-reflected wave at the inner surface of a shielding barrier is an H field and is analogous to the reflected current loss of a transmission line when $Z_o < Z_L$.

The third analogy of the H field being analogous to the reflected current is the justification for the wave being "partially re-reflected at the inner surface." As is illustrated in Figure 1 and Table 1, there is no predicted or measured shielding effectiveness (using the SE equations) when $Z_w < Z_b$. Therefore, the argument for a reflected wave inside the barrier is not valid, and does not exist.

SUMMARY

The hypothesis upon which the shielding effectiveness, and accepted shielding theory, are based is: 1) that wave theory represents the actual physical phenomena associated with a transmission line; and 2) the reflective coefficients as predicted using wave theory on a transmission line are identical to that of a radiated wave striking a shielding barrier.

This hypothesis is incorrect. As illustrated in the Sidebar to this article, "Circuit Theory vs. Wave Theory," wave theory does not produce accurate circuit results when the load and source impedance are not resistive. The reflected E and H field form a radiated wave striking a barrier cannot be predicted using wave theory, as there is no H reflected wave when the wave impedance is less than the barrier impedance ($Z_w < Z_b$).

Circuit Theory vs. Wave Theory

In the mid-1800s two principal methods of solving electrical circuit problems were proposed. They were wave theory and circuit theory as formulated by Gustav R. Kirchoff. Kirchoff's laws and subsequent equations proved to be easier to understand and use, and considerably more applicable. Wave theory was discarded but not forgotten. A cursory look at wave theory is taught in nearly all graduate-level courses on electromagnetic theory. This consists of informing the student that, when the load impedance of a transmission line varies from that of the characteristic impedance of the transmission line, the conducted wave is reflected. The basic laws and equations governing the reflection are provided. Detailed analysis as contained below is not performed. As a result most electrical engineers refer to the reflection of conducted waves.

We prefer to use the logic and equations described by Walter C. Johnson in his book *Transmission Lines and Networks*. Using Johnson's laws and equations, the load impedance (as viewed from the source) varies as a function of the length of the line versus the wave length of the frequency of concern (as illustrated in a Smith Chart). A good example of using Johnson's laws and equations over that of wave theory is the radiation pattern of a mono pole antenna when the frequency approaches a quarter (1/4) wave length (see Figure A1).

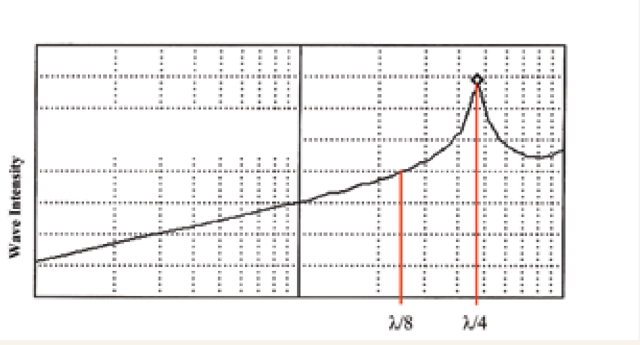


Figure A1: Radiated Field Strength from a Monopole Antenna as a Function of its Wave Length

As can be seen from Figure A1, the radiated intensity spikes when the length of the antenna is at ¼ wave length. This is due to the fact that the open circuit of the antenna appears as a short at the antenna input. Using wave theory, you obtain the same reflection regardless of the length where the predicted radiation is directly proportional to the length of the antenna and has nothing to do with wave length.

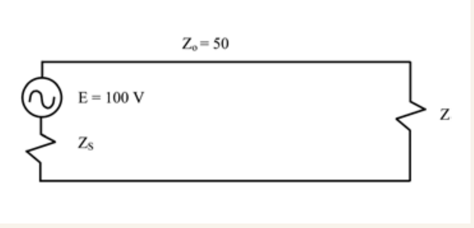
As can be seen by the analysis below, not only are the wave theory equations more difficult to use than those formulated by Kirchoff, but they also have strict boundary conditions. These are:

1. The circuit must be a simple circuit consisting of a voltage source with a source and load impedance.
2. The source and load impedances are resistive.

Wave theory will provide accurate results to a circuit problem, but only when the above constraints are met.

Consider the following illustration:

Given Circuit:



Let Z_L and Z_S equal the following:

a) $Z_S = 50\ \Omega$, $Z_L = 50\ \Omega$
b) $Z_S = 50\ \Omega$, $Z_L = 1\ \Omega$
c) $Z_S = 50\ \Omega$, $Z_L = 2500\ \Omega$
d) $Z_S = 50\ \Omega$, $Z_L = 1 + j49.99\ \Omega$
e) $Z_S = 1 - j49.99\ \Omega$, $Z_L = 1 + j49.99\ \Omega$

REFERENCE

1. Broaddus & Kunkel, paper entitled "Shielding Effectiveness of Aluminized Mylar."

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Using circuit theory:

a) Z_S & Z_L = 50 Ω, I = 1.0 Amps

b) Z_S = 50 Ω, Z_L = 1 Ω, I = 1.9608 Amps

c) Z_S = 50 Ω, Z_L = 2500 Ω, I = 0.0392 Amps

d) Z_S = 50 Ω, Z_L = 1 + j49.99 Ω, I = 1.4105 Amps

e) Z_S = 1 – j49.99 Ω, Z_L = 1 + j49.99 Ω, I = 50.0 Amps

Using wave theory:
Reflected Loss (RL) = $(K+1)^2 / 4(K)$
where K = Z_o / Z_{Load}

a) Z_S & Z_L = 50 Ω, RL = $(1+1)^2 / 4(1)$ = 1.0

b) Z_S = 50 Ω, Z_L = 1 Ω, RL = $(50+1)^2 / 4(50)$ = 13.005

c) Z_S = 50 Ω, Z_L = 2500 Ω, RL = $(.02+1)^2 / 4(.02)$ = 13.005

d) Z_S = 50 Ω, Z_L = 1 + j49.99 Ω, RL = $(1+1)^2 / 4(1)$ = 1.0

e) Z_S = 1 – j49.99 Ω, Z_L = 1 + j49.99 Ω,
RL = $(1+1)^2 / 4(1)$ = 1.0

The reflective coefficient (RC) is as follows:

a) Z_S & Z_L = 50 Ω, RC = 0 or 0% Reflected

b) Z_S = 50 Ω, Z_L = 1 Ω,
RC = .923106 or 92.3106% Reflected

c) Z_S = 50 Ω, Z_L = 2500 Ω,
RC = .923106 or 92.3106% Reflected

d) Z_S = 50 Ω, Z_L = 1 + j49.99 Ω, RC = 0 or 0% Reflected

e) Z_S = 1 – j49.99 Ω, Z_L = 1 + j49.99 Ω,
RC = 0 or 0% Reflected

When:

a) Z_S & Z_L = 50 Ω

d) Z_S = 50 Ω, Z_L = 1 + j49.99 Ω

e) Z_S = 1 – j49.99 Ω, Z_L = 1 + j49.99 Ω

The reflected power is zero (0)

b) Z_S = 50 Ω, Z_L = 1 Ω

c) Z_S = 50 Ω, Z_L = 2500 Ω

The reflected power is:

(.923106) (50) = 46.1553 watts

Therefore the power absorbed by the load impedances when Z_S = 50 Ω and Z_L = 1.0 or Z_L = 2500 Ω is:

50 – 46.1553 = 3.8447 watts

The current through the load impedance using wave theory is:

a) Z_S & Z_L = 50 Ω, I = 1.0 Amps

d) Z_S = 50 Ω, Z_L = 1 + j49.99 Ω, I = 1.0 Amps

e) Z_S = 1 – j49.99 Ω, Z_L = 1 + j49.99 Ω, I = 1.0 Amps

b) Z_S = 50 Ω, Z_L = 1 Ω, $I^2(1.0)$ = 3.8447
I = 1.9608 Amps

c) Z_S = 50 Ω, Z_L = 2500 Ω
I^2 = 3.8447/2500
I = 0.0392 Amps

Therefore:

1. Wave theory provides accurate circuit results only when the source and load impedances are resistance.
2. Wave theory does not represent a physical representation of an EM wave in a transmission line (i.e., there is not a reflection of the wave due to a mismatch between the characteristic impedance of a transmission line and the load impedance).

Based on the above arguments, Figure A1, and the results of the above illustration, it can be concluded that "wave theory" is only a theory.

CISPR 11: An Historical and Evolutionary Review

BY DANIEL D. HOOLIHAN

CISPR is the International Special Committee on Radio Interference which was founded in 1934. The International Standard for electromagnetic emissions (disturbances) from industrial, scientific and medical (ISM) equipment is CISPR 11. The official title of the standard is "Industrial, Scientific, and Medical Equipment – Radio-Frequency Disturbance Characteristics – Limits and Methods of Measurement." The premiere edition of the standard was released in 1975 and the current edition (fifth edition) was released in 2009. The standard includes both limits and methods of measurement for conducted-emissions and radiated-phenomena. This article traces the history and development of the content of the standard over the last 40 years.

FIRST EDITION—1975

The title of the Premiere Edition was "Limits and Methods of Measurement of Radio Interference Characteristics of Industrial, Scientific, and Medical (ISM) Radio-Frequency CISPR Subcommittee B (Interference from Industrial, Scientific, and Medical Apparatus)." It summarized the technical content of a number of CISPR publications, recommendations and reports over a period of eight years, from 1967 to 1975.

The frequency range covered by the first edition of the standard was 150 kHz to 18 GHz. The terminal voltage limits were quoted in millivolts and covered the frequency range 150 kHz to 30 MHz. Terminal voltage limits from the first edition are reproduced in Table 1.

The radiated limits were quoted in microvolts per meter for the frequency range 0.150 MHz to 1000 MHz. They were quoted at antenna-measurement distances of 30, 100, and 300 meters from the equipment or 30 meters or 100 meters from the boundary of the users' premises. Limits of radiation in microvolts/meter and decibels (uV/m)] from the first edition is recreated in Table 2.

Frequency Range - MHz	Limits in mV for microwave ovens with RF power of 5 kW or less	Limits in mV for all other ISM equipment
0.15 – 0.20	2	3
0.20 – 0.50	2	2
0.50 – 5.0	1	1
5.0 – 30.0	2	1

Table 1: Terminal voltage limits, CISPR 11, First Edition (Table I)

There was a special limit for radiation from microwave equipment used for heating and medical purposes in the frequency range from 1-18 GHz; it was 57 dB above a picowatt effective radiated power (ERP), referred to a half-wave dipole.

Methods of measurement quoted CISPR Publications 1, 2, and 4 for quasi-peak measuring sets. Measurement of the radio-frequency voltage on supply mains (AC voltage lines) was conducted with a V-network with an intrinsic impedance of 150 ohms.

Magnetic field measurements are made with a balanced loop antenna below 30 MHz. For signals greater than 30 MHz, an “electric aerial” would be used as per CISPR Publications 2 and 4. The center of the “aerial” would be 3 meters above the ground.

Above 1 GHz, the “receiving aerial” was to be made with a directive aerial of small aperture capable of making separate measurements of the vertical and horizontal components of the radiated field. The height of the aerial had to be the same as the height of the approximate radiation center of the equipment under test.

SECOND EDITION—1990

The second edition of CISPR 11 was released in 1990, and it contained numerous changes from the original 1975 edition, as well as two amendments.

In this edition, ISM Equipment was divided into two groups and two classes. Group 1 equipment included all ISM equipment that used RF energy only for internal functioning of the equipment, while Group 2 equipment included ISM equipment used for external treatment of material and similar processes. Class A equipment is equipment suitable for use in all establishments other than domestic buildings, while Class B equipment is equipment suitable for use in domestic surroundings.

The frequency bands for conducted emissions were stated as covering 150 kHz to 30 MHz. The second edition included new separate limits for Class A and Class B equipment. The Class A equipment limits in dBuV are shown in Table 3.

The Class B equipment Limits in dBuV are shown in Table 4.

Electromagnetic radiation disturbance limits in dBuV/m for Group 1 equipment in Edition 2 are shown in Table 5.

Frequency Range - MHz	On a Test Site, at a distance from the equipment of 30 m	On a Test Site, at a distance from the equipment of 100 m	Not on a Test Site, at a Distance of 30 m from the boundary of user’s premises	Not on a Test Site, at a Distance of 100 m from the boundary of user’s premises	Not on a Test Site, at a Distance of 300 m from the equipment
0.15 – 0.285	-	50 uV/m			
(34 dBuV/m)	-	50 uV/m			
(34 dBuV/m)	-				
0.285 – 0.49	-	250 (48)	-	250 (48)	-
0.49 – 1.605	-	50 (34)	-	50 (34)	-
1.605 – 3.95	-	250 (48)	-	250 (48)	-
3.95 – 30	-	50 (34)	-	50 (34)	-
30 – 470	30 (30) – In TV Bands				
500 (54) – Outside TV Bands	-	30 (30)*	50 (34)**	200 (46)	
470 - 1000	100 (40) – In TV Bands				
500 (54) – Outside TV Bands	-	100 (40)*			
500 (54)**	-	200 (46)			

* - Compliance with these limits is required only for the TV channels in use at any time at the site

** - Limits for use outside the TV channels in use at the time at the site

Table 2: Limits of radiation, CISPR 11, First Edition (Table II)

Frequency - MHz	Group 1 – Quasi-Peak	Group 1 – Average	Group 2 – Quasi-Peak	Group 2 - Average
0.15 - 0.50	79	66	100	90
0.50 - 5.0	73	60	86	76
5 - 30	73	60	90 decreasing with logarithm of frequency to 70	80 decreasing with logarithm of frequency to 60

Table 3: Class A limits for conducted emissions, CISPR 11, Second Edition

Frequency Band – MHz	Quasi-Peak	Average
0.15 – 0.50	66 decreasing with logarithm of frequency to 56	56 decreasing with logarithm of frequency to 46
0.50 – 5	56	46
5 – 30	60	50

Table 4: Class B limits for conducted emissions, CISPR 11, Second Edition

Frequency Band MHz	Group 1 – Class A – 30 meters	Group 1 – Class B – 10 meters	Group 1 – Class A – 30 meters from wall
0.15 – 30	X	X	X
30 -230	30	30	30
230 – 1000	37	37	37

Table 5: Electromagnetic radiation disturbance limits, CISPR 11, Second Edition

There were additional limits for radiated emissions for Group 2 equipment.

In the frequency range 1 GHz to 18 GHz, the limit for radiation disturbance power was 57 dB above a picowatt (effective radiated power), referred to a half-wave dipole in the narrow frequency range 11.7 GHz to 12.7 GHz.

The standard used statistics for compliance conclusions. Clause 6.1 stated "it cannot be shown that equipment in series production fails to meet the requirements of this publication without a statistical assessment of compliance being carried out."

In the General Measurements Requirements clause, the standard provided for the measurement of Class A equipment either on a test site or *in situ* as determined by the manufacturer. However, the standard mandated that Class B equipment be tested and measured in a testing laboratory only.

Measuring equipment used by a testing lab had to comply with CISPR 16. Receivers needed both average and quasi-peak capability. An artificial mains network (LISN) was needed for conducted emissions, and it was a 50 ohm-50 microhenry network. Antennas used included a loop antenna below 30 MHz and a balanced-dipole antenna from 30 MHz to 1000 MHz. Measurements were made in both horizontal and vertical polarizations. Class A equipment was measured with the center of the antenna three meters above ground while, for Class B equipment, the center of the antenna had to be adjusted to between one and four meters.

The testing laboratory had to meet special provisions for measuring radiated emissions, including a minimum-sized ground plane, and an area free of reflecting structures and also large enough to allow for the appropriate separation of the equipment under test and the receiving antenna.

Amendment 1 to the second edition was released in March of 1996. It changed some conducted emission limits, especially for Class A equipment. Amendment 2 was also released in March of 1996 and it contained limits for induction cooking appliances for both conducted limits and radiated magnetic field limits. Amendment 2 also modified radiation limits for Group 2 equipment.

THIRD EDITION—1997

The third edition of CISPR 11 was also developed by CISPR Subcommittee B and was released in 1997. It replaced the second edition and its two amendments.

The main content of CISPR 11 standards are based on the original CISPR Recommendation No. 39/2, entitled "Limits and Methods of Measurement of Electromagnetic Disturbance Characteristics of Industrial, Scientific, and Medical (ISM) Radio-Frequency (RF) Equipment." The Recommendation states "The CISPR, considering a) that ISM RF equipment is an important source of disturbance; b) that methods of measuring such disturbances have been prescribed by the CISPR; c) that certain frequencies are designated by the International Telecommunication Union (ITU) for unrestricted radiation from ISM equipment, recommends that the latest edition of CISPR 11 be used for the application of limits and methods of measurement of ISM equipment."

The third edition of the standard reorganized the first Clause, changing it from "Scope and Object" to "General," and comprised of two Sub-clauses, "Scope and Object," and "Normative References."

Clause 6 of the second edition was renumbered as Clause 11 in the third edition, and Sub-clause 6.1, "Equipment in series production," was replaced with Sub-clause 11.2, "Equipment in small scale production."

A new Sub-clause 5.4, "Provisions for Protection of Specific Sensitive Radio Services," was added in Clause 5, "Limits of Electromagnetic Disturbance."

Clause 7 in the second edition became Clause 6 in the third edition; Clause 8 became Clause 7, Clause 9 became Clause 8, Clause 10 became Clause 9, and Clause 11 became Clause 10.

Annexes A – D remained the same in the third edition as in the second. Two new annexes were added, Annex E, "Safety-Related Service Bands," and Annex F, "Sensitive Service Bands."

The classification of equipment remained the same from the second to the third edition, that is, Group 1 and Group 2, and Class A and Class B.

Frequency Band – MHz	Class A – Group 2 Equipment Limit - dBuV	Class A - Group 2 Equipment Limit - dBuV
	Quasi-Peak	Average
0.15 – 0.50	130	120
0.50 – 5.0	125	115
5.0 - 30	115	105

Table 6: Special case limits for conducted emissions, CISPR 11, Third Edition

With respect to the limits of electromagnetic disturbance, Class A equipment could still be tested either at a testing laboratory or *in situ*, while Class B equipment had to be measured in a testing laboratory.

The limits for conducted emissions on the power leads were measured from 150 kHz to 30 MHz using a 50-ohm/50-uH network. The limits remained the same for Class A and Class B equipment from the second edition of the standard, except that another category was added for Class A-Group 2 equipment for mains supply currents in excess of 100 amps per phase when using the CISPR voltage probe. The limits for this special case are shown in Table 6.

However, new limits were added in Table 2c in the standard ("Mains terminal disturbance voltage for inductive cooking appliances") for Group 2-Class B equipment for both domestic and commercial cooking appliances.

Table 3 in the standard ("Electromagnetic radiation disturbance limits for group 1 equipment") had a major change, as the measurement distance for Group 1-Class A equipment was changed from 30 meters to 10 meters with a corresponding increase in limits of 10 dB (assuming an inverse distance fall-off of the radiated electromagnetic field). Clause 5.2.2 of the third edition also introduced the concept of measuring products at shorter distances than the specified measurement distances for radiated disturbances. For example, it allowed Group 2-Class A equipment to be measured at a distance of between 10 and 30 meters instead of 30 meters. Also, it allowed Group 1 and 2-Class B, equipment to be measured at antenna distances between three and 10 meters. However, it stated that "in case of dispute, Class A-Group 2 equipment shall be measured at a distance of 30 meters; Class B-Group 1, Class B-Group 2, and Class A-Group 1 equipment shall be measured at a distance of 10 meters."

Tables 3a and 3b were added in the third edition to cover Group 2 induction cooking appliances for Class B and Class A, respectively. Table 3a ("Limits of the magnetic field induced current in a 2-m loop antenna around the device under test") was intended to use the Van Veen Loop Method measurement method as per CISPR 16-2. Table 3b ("Limits of the magnetic field strength") is measured at a three meter antenna distance with a 0.6 meter loop antenna as described in CISPR 16-1.

Table 4 in the standard (“Electromagnetic radiation disturbance limits for Group 2-Class B equipment measured on a test site”) added a new column of requirements, that the quasi-peak magnetic field (measured at three meters) will not exceed 39 dBuAmp/meter decreasing linearly with the logarithm of the frequency to 3 dBuAmp/meter from 150 kHz to 30 MHz.

Table 5 in the standard changed the measurement distance from 30 meters to 10 meters and increased the limits by 10 dB from the limits found in the second edition.

Table 6 was added to the third edition of CISPR 11. It was entitled “Electromagnetic radiation disturbance peak limits for Group 2-Class B ISM equipment producing CW-type

CISPR 11 – Edition 1 – 1975	CISPR 11 – Edition 5 - 2009
Foreword	Foreword
Preface	Introduction
1 – Scope	1- Scope
2 – Object	2 – Normative References
3 – Definitions	3 – Terms and Definitions
4 – Limits of Interference	4 – Frequencies Designated for ISM Use
5 – Methods of Measurement	5 – Classification of ISM Equipment
6 – Safety Precautions	6 – Limits of Electromagnetic Disturbance
Appendix A – Precautions to be taken in the use of a Spectrum Analyzer	7 – Measurement Requirements
Appendix B – Propagation of Interference from industrial RF equipment at frequencies between 30 MHz and 300 MHz	8 – Special Provisions for Test Site Measurements (9 kHz to 1 GHz)
Appendix C – Artificial Mains Networks for currents between 25 amps and 100 amps	9 – Radiation Measurements – 1-18 GHz
	10 – Measurements in situ
	11 – Safety Precautions
	12 – Assessment of Conformity of Equipment
	13 – Figures and Flowcharts
	Annex A (Informative) – Examples of Equipment Classification
	Annex B (Informative) – Precautions to be taken in the use of a Spectrum Analyzer (see 6.3.1)
	Annex C (Normative) – Measurement of Electromagnetic Radiation disturbances in the presence of signals from radio transmitters
	Annex D (Informative) – Propagation of Interference from industrial radio frequency equipment at frequencies between 30 MHz and 300 MHz
	Annex E (Informative) – Recommendations of CISPR for protection of certain radio services in particular areas
	Annex F (Informative) –Frequency Bands allocated for safety-related radio services
	Annex G (Informative) – Frequency Bands allocated for sensitive radio services
	Bibliography

Table 7: Comparison of the first and fifth editions of CISPR 11

disturbances and operating at frequencies above 400 MHz." Table 7 ("Electromagnetic radiation disturbance peak limits for Group 2-Class B ISM equipment producing fluctuating disturbances other than CW and operating at frequencies above 400 MHz") and Table 8 ("Electromagnetic radiation disturbance weighted limits for Group 2-Class B ISM equipment operating at frequencies above 400 MHz") were also added.

Clause 5.4 ("Provisions for protection of specific sensitive radio services") was added to the third edition. It referenced a new Annex F which gave examples of bands to be protected.

The same general measurement conditions existed as in the previous edition which is that Class A equipment could be measured at a test lab or *in situ*. Class B equipment had to be measured on a test site (in a test lab).

For equipment on a turntable, the distance to the antenna was measured from the center of the turntable. For equipment not on a turntable, the distance to the antenna was measured from the edge of the equipment. Paragraph 6.5.6 ("Single and multiple-zone induction cooking appliances") was added to the third edition.

Amendment 1 to the third Edition added requirements for ISM lighting apparatus operating in the frequency bands of 915 MHz, 2.45 GHz, and 5.8 GHz. It also added IEC 60705:1999 ("Household microwave ovens – methods for measuring performance") to the normative standards. It also added new words in Clause 5.2.2 (discussed earlier) and it added a new Table 5 ("Electromagnetic Radiation disturbance limits for Group 2 – Class A equipment"). All new wording was added to Clause 5.2.3 by Amendment 1. In Clause 6.2.1, it added the requirement that "for measurements at frequencies above 1 GHz, a spectrum analyzer with characteristics as defined in CISPR 16-1 shall be used." Additionally, in Clause 6.2.4, it added the words "for measurements at frequencies above 1 GHz, the antenna used shall be as specified in CISPR 16-1." Also, Clause 6.5.4 ("Microwave cooking appliances") was added by Amendment 1.

An important (and somewhat controversial) Sub-clause was added by Amendment 1 in Clause 7.1.3 ("Radiation measurements [9 kHz to 1 GHz]"). It added two sentences that impacted the third edition and subsequent editions. The first sentence said "for the test site measurements, an inverse proportionality factor of 20 dB per decade shall be used to normalize the measured data to the specified distance for determining compliance." Also, it added the parenthetical sentence, "care should be taken in measuring a large test unit at 3 meters at a frequency near 30 MHz due to near-field effects." It deleted a key sentence from the second edition that said "at the closer measurement distance the electromagnetic disturbances measured shall not exceed the limit values specified in Clause 5." In Sub-clause 8.2 it added the sentence "the distance between the receiving antenna and the EUT shall be 3 meters." Sub-clauses 8.3 ("Validation and calibration of test site") and 8.4 ("Measuring Procedure") were completely rewritten. Finally, Amendment 1 added Figure 5 ("Decision tree for the measurement of emissions from 1 GHz to 18 GHz of Class B-Group 2 ISM equipment operating at frequencies above 400 MHz").

Amendment 2 replaced "spark erosion equipment" with "electro-discharge machining (EDM) and arc welding equipment." It also made additional editing changes to a number of Sub-clauses.

FOURTH EDITION—2003

The fourth Edition of CISPR 11 was published in March 2003. The fourth edition superseded the third edition (1997), along with its first amendment (1999) and its second amendment (2002).

There were a limited number of changes in the fourth edition from the third edition. The first two sentences in Clause 4 were changed to read "the manufacturer and/or supplier of ISM equipment shall ensure that the user is informed about the class and group of the equipment, either by labeling or by the accompanying documentation. In both cases, the manufacturer/supplier shall explain the meaning of both the class and the group in the documentation accompanying the equipment."

Clauses 7.1 and 7.2 were interchanged from the third edition.

Clause 6.2.5 ("Artificial Hand") was added to the fourth edition, as well as Figure 6 ("Artificial Hand, RC Element"). The concept of an artificial hand was introduced to simulate the effects of the user's hand during the conducted emission measurements

The definitions of Group 1 ISM equipment, Group 2 ISM equipment, Class A equipment, and Class B equipment remained basically the same as the third edition.

With respect to limits of electromagnetic disturbance, Class A equipment could once again be measured either in a testing laboratory or *in situ* (as preferred by the manufacturer). However, the fourth edition continue to require Class B equipment to be measured in a testing laboratory.

The limits of terminal disturbance voltage (conducted emissions) gives the manufacturer two choices: 1) meet the average limit with an average detector and the quasi-peak limit with a QP detector; or 2) meet the average limit when using a QP detector. This was the same as stated in the third edition.

For radiated disturbances from 150 kHz to 1000 MHz, the limits stayed basically the same as those found in the third edition. Measurements were allowed at closer distances than the specified distances under certain considerations. In case of dispute, however, Class B (Group 1 and Group 2) and Class A (Group 1) were to be measured at a distance of 10 meters, while Class A (Group 2) were to be measured at a distance of 30 meters.

Receivers used for the measurements were expected to meet the criteria of CISPR 16-1. Requirements for the artificial mains network (LISN) remained the same as those in the third edition, that is, a 50 ohm/50 microhenry V-Network as specified in CISPR 16-1. The antennas used for measuring CISPR 11 products were also expected to meet CISPR 16-1 requirements. In a testing laboratory, the antenna must be raised and lowered from one to four meters in the frequency range 30 MHz to 1000 MHz. For measuring products *in situ*, the antenna's center must be fixed at two meters above the ground.

Amendment 1 to the fourth edition was released in 2004. Primarily, Amendment 1 replaced Table 6 in the fourth edition with a new table that addresses Group 2 (Class A and Class B) ISM equipment producing CW type disturbances and operating at frequencies above 400 MHz.

Amendment 2 added CISPR 16-4-2:2003 to the Normative References. It also added a new Table 2c for Mains Terminal disturbance voltage for induction cooking appliances. It also modified Clauses 6.5.4 ("Microwave Cooking Appliances") and 6.5.6 ("Single and multiple-zone induction cooking appliances") to more closely match the IEC Product Standard. Amendment 2 also added Clauses 6.6 ("Recording of test-site measurement results"), 6.6.1 ("Conducted Emissions"), and 6.6.2 ("Radiated Emissions"). Also, Clause 11.4 ("Measurement Uncertainty") was added, stating that "determining compliance with the limits in this standard shall be based on the results of the compliance measurement, not taking into account measurement instrumentation uncertainty." However, results of measurements of emissions from ISM equipment were supposed to reference the measurement uncertainty considerations contained in CISPR 16-4-2.

FIFTH EDITION—2009

Released in 2009, the fifth edition of CISPR 11 is the current edition of the standard. It continues the long-standing practice of Group 1 and Group 2, Class A and Class B equipment classifications. The limits stated in the fifth edition are similar to the limits found in the fourth edition.
Table 7 presents a side-by-side comparison of the table of contents for the first edition and the fifth edition of CISPR 11, which clearly shows the growth in the length and complexity of the standard over a period of 35 years.

Clause 6 in the fifth edition represents a major overhaul from that in the fourth edition. Its Main Clause and Sub-clause headings are as follows:

Clause 6 – Limits of Electromagnetic Disturbance

- 6.1 – General
- 6.2 – Group 1 Measured on a Test Site
- 6.3 – Group 2 Measured on a Test Site
- 6.4 – Group 1 and Group 2 Class A Measured *in situ*

Clause 7 added a new Sub-clause 7.1 ("General") and a new Sub-clause 7.7 ("Recording of Test Site Measurement Results").

Clause 12 ("Assessment of Conformity of Equipment") added a new Sub-clause 12.1 ("General") and then the next three Sub-clauses were the same as Sub-clauses 11.1–11.3 in the fourth edition.

The CISPR 11 standard for measuring disturbances (emissions) from ISM equipment has been in existence for 40 years. It has grown from a simple document to a complex document involving a number of types of products.

Clause 13, titled "Figures and Flowcharts," is new to this edition, as is Annex E.

The entire fifth edition was written to provide a more transparent structure. Table 17 in the standard was added with a title of "Electromagnetic Radiation Disturbance Limits for Class A (Group 1) Equipment Measured *in situ*." It specifically addresses equipment with input power greater than 20 KVA.

An Amendment 1 to the fifth edition was released in 2010. It created a new subset of equipment, "Small Equipment." Small Equipment is defined as "equipment, either positioned on a table top or standing on the floor which, including its cables, fits in a cylindrical test volume of 1.2 meters in diameter and 1.5 meters above the ground plane."

Using this definition, Tables 4, 5, 9, 10, and 11 in the standard were modified to allow testing of Class A and B products meeting the "Small Equipment" definition to be tested at a three meter test distance. The limit at three meters would be extrapolated from the typical test distance of 10 meters using an inverse-distance fall-off assumption (free-field).

TOWARD THE SIXTH EDITION—2015

Since the release of Amendment 1 to the fifth edition of CISPR 11 in 2010, Subcommittee B of CISPR has been working on the sixth edition of the standard. At its most recent meeting in Frankfurt Germany in October 2014, Subcommittee B made significant progress on the merging of several new elements into CISPR 11 toward the release of a Final Draft International Standard (FDIS). This FDIS is scheduled for National Voting beginning in April 2015.

New elements or supplements found in the FDIS for CISPR 11 are expected to include:

- Emission requirements for grid-connected power converters (GCPCs)
- Use of the amplitude probability distribution (APD) method and associated limits for the assessment of fluctuating RF disturbances in the range above 1 GHz
- Alignment of emission requirements for disturbance sources generating fluctuating disturbances with those from sources generating continuous wave (CW)-type disturbances
- Emission requirements for GCPCs with greater than 20 KVA rated throughput power.

The FDIS will also include general maintenance items to address other issues in the fifth edition of the standard.

SUMMARY AND CONCLUSIONS

The CISPR 11 standard for measuring disturbances (emissions) from ISM equipment has been in existence for 40 years. It has grown from a simple document to a complex document involving a number of types of products. It has grown from measuring products at a larger distance (100 meters and 30 meters) for Class A equipment to measuring them at three meters. Class B equipment measurement distances have shrunk to three meters, the distance used in the U.S. since the release in 1979 of FCC's rules on computer emissions. This steady erosion of the "laws of physics" for Class A products is worrisome and a trend to reverse this erosion is overdue in the engineering field of EMC and the EMC standards arena.

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EMC Lab Selection Revisited

BY DANIEL D. HOOLIHAN

Designers of electronic products are frequently faced with the question "how do I find a high-quality EMC testing laboratory where I can confidently test my products?" The emphasis of the great majority of design entities is on obtaining: 1) quality preliminary testing of EMC characteristics to refine the design of their products; and 2) quality final testing of their product for regulatory approvals. The final design, of course, is what gets manufactured and released to the general population for their use in daily life. This article is intended to aid designers in finding and utilizing high-quality EMC testing laboratories.

FCC RULES IMPACT

The United States is a "target rich" environment for electronic equipment designers and most designers know that their products will have to meet U. S. Federal Communications Commission (FCC) rules in order to legally market their designs in the U.S. Recently, the FCC passed some new requirements that directly impact EMC testing labs.

The FCC's new equipment authorization rules were adopted in ET Docket No.13-44 and published in the U.S. *Federal Register* on June 12, 2015, with an effective date of July 13, 2015. Two new standards were incorporated by reference in the rules, ANSI C63.4-2014 and ANSI C63.10-2013. Those two new standards have a one year transition period, and they will become fully active on July 13, 2016.

The new rules provide for new test site validations for EMC labs used to make radiated emission measurements above 1 GHz. The new test site validation criteria has a three year transition period that ends July 13, 2018. During that three year transition period, EMC labs can continue to meet the validation criteria in ANSI C63.4 (which has two alternatives). But, after the July 13, 2018 deadline, all EMC labs must meet the criteria in CISPR 16-1-4 in order to test products for FCC compliance for radiated emissions above 1 GHz.

INTERNAL AND EXTERNAL EMC LABS

If the designer is part of a large organization, they most likely will have an internal EMC lab that they can approach and schedule time for a preliminary or final (qualification) test of their product. However, if the internal EMC lab is tightly-scheduled, the project manager may be invited to look outside the company for an external source of EMC lab expertise in order to meet his/her project schedule. In the ideal case, the project manager may have the opportunity to investigate several competing labs and solicit bids from the same.

If the designer is not part of a large organization, then the project manager for the development project is immediately put into the position of soliciting bids and information from independent third-party EMC labs.

FIRST IMPRESSIONS

When soliciting bids from external EMC testing labs, first impressions are significant. If the EMC testing lab does not return phone calls, that is an indication of a lack of interest in new business or a lack of an organizational structure to

respond to customer inquiries. Either way, you may want to seek another EMC testing lab.

If the testing lab returns your phone call, then the next step is to ask for a bid to do certain tests that will allow you to verify your design or qualify it for shipment to customers. The EMC tests needed for your commercial product will, in general, consist of both emission and immunity tests. These tests will encompass U.S. emission requirements, European Union (EU) and international emission requirements, and EU and international immunity requirements.

Once the bids are received and compared, you are ready to make an on-site visit to the potential EMC lab. Again, the first visit to the EMC lab is critical for both you and the lab. First impressions of the lab are just as important as the first phone-call impression. The first Impression of the lab consists of both a "gut check" and an "intellectual check."

The "gut check" is a feeling about the lab and its people. If you don't feel right about the lab personnel or the lab's facilities or equipment, you might surmise that your uneasiness is based on a deeper issue you will uncover when you use the lab.

The "intellectual check" is more of a technical checklist concept where you either have a mental checklist or a written checklist on specific administrative or technical items that you want to investigate. These items could include test equipment, calibration of the test equipment, test facilities, technical personnel resumes and sample test reports.

GEOGRAPHICAL PROXIMITY

Most EMC testing labs used by designers are geographically situated in close proximity to a concentration of intended users. This should allow for an easy inspection of the lab. The EMC lab should be proud to show you their lab and to discuss their capabilities. They should also have an open-door policy that allows their customers to observe the testing of their products through the entire battery of EMC tests.

A lab that is geographically close to its customers also allows engineers and technicians who designed and developed the product the freedom to troubleshoot the product conveniently if it fails one of the EMC tests during preliminary testing. That is, they can readily make modifications to the products because the electrical engineers, mechanical engineers, and power-supply engineers are close at hand. An EMC lab that is distant from the design center makes it more difficult (telephone consulting), more time-consuming (extra travel time), and more costly (travel costs).

If the lab is geographically close, the first visit leaves you with a positive impression, and the financial bid is in the acceptable range, then it is time to check on some of the other attributes that a high-performing EMC lab should possess.

ACCREDITATION

One of the key qualities that a high-performing EMC testing lab will possess is that it hold suitable laboratory accreditations. In the U.S., there are four accreditation bodies recognized by the FCC for EMC testing. They are: 1) the American Association for Laboratory Accreditation (A2LA); 2) the U.S. Department of Commerce's National Institute of Standards and Technology (NIST) National Voluntary Laboratory Accreditation Program (NVLAP); 3) the Laboratory Accreditation Bureau (LAB); and 4) ANAB, an ANSI-ASQ National Accreditation Board Company. A2LA, LAB, and ANAB are private organizations, while NVLAP is part of the U.S. government.

It should be noted that there are other qualified accreditation bodies outside of the U.S. that can accredit labs internationally. In some cases, EMC testing labs in countries other than the U.S. maintain accreditation from one of the four U.S. accreditors. The International Laboratory Accreditation Cooperation (ILAC) is the international-body that designates accreditation bodies around the world and assures that accreditation bodies that are members of ILAC are meeting standard accreditation requirements. This enables accreditation bodies to accept one another's accreditation results.

Accreditation bodies will assess EMC testing labs to the requirements of ISO/IEC 17025, General Requirements for the Competence of Testing and Calibration Laboratories. The latest version of this standard is dated 2005. It superseded the first edition of ISO 17025 released in 1999 (it replaced ISO/IEC Guide 25 and European Norm (EN) 45001).

Laboratory accreditation has been incorporated into U.S. law by the FCC. The Commission allows a large number of electronic products that are tested in accredited EMC testing labs to be placed on the market with no further government approval for EMC criteria. The specific process using accredited EMC testing labs is called the Declaration of Conformity (DoC) by the FCC. It is preceded by a Manufacturer's Declaration of Conformity or a Self-Declaration of Conformity before the official declaration based on testing in an accredited testing lab. Oftentimes, an accredited EMC testing lab will issue a Declaration of Conformity certificate, indicating that the product complies with the appropriate FCC rules. The responsibility for continued compliance of the product as it is manufactured, of course, lies with the designer of the product.

Declarations of Conformity can apply to such digital/electronic devices as Class B personal computers, Class B computer peripherals, citizens band (CB) receivers, television interface devices, consumer and industrial, scientific and medical (ISM) equipment. The DoC concept has allowed products to be marketed more quickly while at the same time protecting licensed communications services in the U.S.

INTERNATIONAL RAMIFICATIONS

Because the laboratory accreditation process is built around an international standard, this allows products to potentially flow more smoothly in the world trade arena. This is accomplished by an EMC lab obtain accreditation for appropriate test methods, by the lab writing a test report that complies with ISO/IEC 17025 report requirements, and by the lab properly using the accreditation body's symbol and logo on the test report.

The accreditation body's "mark" on the test report signifies that the testing was done in an accredited lab and that the tests performed by the lab were within the scope of its accreditation. (Note – the test report must also indicate in the body of the report whether tests were performed that were not on the testing lab's scope of accreditation). This sends a clear signal to any importing country that the product is in compliance with the stated requirements. Oftentimes, this means that the product will be cleared quickly through customs and be placed on the market. Without the appropriate certification mark on the test report, the product could be destroyed, returned to the country of origin (originating designer/manufacturer), or retested in an accredited laboratory in the country where the product is to be marketed.

ISO/IEC 17025 – MANAGEMENT REQUIREMENTS

The international standard on criteria for testing labs is ISO/IEC 17025 which includes both management requirements and technical requirements. Management requirements are very similar to those found in ISO 9001:2008, *Quality Management System – Requirements*, and encompass the following areas:

1. Organization
2. Management System
3. Document Control
4. Review of Requests. Tenders, and Contracts
5. Subcontracting of Tests (and Calibrations)
6. Purchasing Services and Supplies
7. Service to the Customer
8. Complaints
9. Control of Nonconforming Testing (and/or Calibration) Work
10. Improvement

11. Corrective Action
12. Preventive Action
13. Control of Records
14. Internal Audits
15. Management Reviews

The “organization” of the EMC testing lab is its management structure (for example, who is the president of the lab and who has key areas of responsibility under the president such as quality control). It is also the organizational entity that can be held legally responsible for the actions of the EMC testing lab. A potential user of the EMC lab should look at the organizational structure and be comfortable with the organizational chart and with the qualifications of the individuals filling the key slots.

The EMC lab’s “management system” must be appropriate to the scope of the EMC activities offered. The management system must be documented, and should have detailed policies, procedures, programs, and specific work instructions sufficient to assure a high-quality test effort on a consistent basis. The management system must be in written form, and can be available in hard-copy format or stored electronically on a server.

The “document control” portion of the management requirements can be checked by looking at the EMC testing lab’s quality manual and by examining some representative documents. The key element is that the lab should demonstrate a process that is “under control,” that is, a process in which all documents are identifiable and controllable.

The fourth management requirement is “Review of Requests, Tenders, and Contracts,” and it is very important for a potential user of the testing lab. This requirement will encourage the lab to review your request for a test and establish a contract between the lab user and the lab. The contract should specify the requests of the lab user and it should allow for amendments to the contract assuming agreement by both parties.

For testing labs, the management requirement that is stated as “Subcontracting of Tests and Calibrations” should be read as “Subcontracting of Tests.” That is, because ISO/IEC 17025 is written for both testing labs and calibration labs, the testing lab must read the requirements as stated for a testing lab and not as stated for a calibration lab. (For example, calibration labs would read the management requirement as “Subcontracting of Calibrations.”) An accredited testing lab may subcontract some of its tests to another accredited testing lab due to a temporary lack of test equipment or other similar legitimate reasons. In general, a long-term subcontract relationship is not allowed since an accredited testing lab must have the capability to perform the tests on its scope of accreditation.

For an EMC testing lab, the management requirement “purchasing of services and supplies” - which are critical to the operation of the lab - is most often focused on its purchase of calibration services. The calibration of the EMC testing lab’s equipment is a key factor in making proper measurements that are traceable to national metrology institutes. A user of the EMC testing lab should feel confident that the calibration labs being used by the EMC testing lab are accredited for calibration services.

“Service to the Customer” is that aspect of the EMC testing lab’s operation that makes a user feel comfortable about the lab. For example, the user should be allowed to observe the lab’s performance in testing their products. Excellent communications between the customer and the EMC Lab is also consistent with this area of the management requirements.

If you, as a customer, complain to the EMC testing lab, how does the lab react? Do they investigate the complaint and make changes? Or, do they ignore your complaint and continue on with the approach that “this is the way we always do this test.” A high-quality lab will respond to customer complaints and, if warranted, make appropriate changes in their procedures after a thorough investigation.

“Control of Nonconforming Testing” is that area of the administrative requirements that addresses mistakes made by the EMC lab in its testing service. Does the lab offer to redo the test that was done incorrectly for no additional charge? A user of the lab should familiarize himself with the testing lab’s philosophy in this area.

The next area of management requirements is “Improvement.” The EMC testing lab should have a “continual improvement” philosophy consistent with quality assurance theory and practice. One location that this emphasis on “Improvement” can be illustrated is in the EMC testing lab’s quality policy statement, which should be prominently displayed in the lab, and clearly understood by lab employees.

The next part of the management requirements, “Corrective Action,” is closely related to “Complaints” and “Improvements.” This part of the management requirements addresses the actions the lab takes to satisfy customer complaints. When a user identifies a problem, it is essential that the lab institute a root cause analysis and follow their logical trouble-shooting to a solution to the problem. A fair question for a potential user to ask the EMC lab is “what corrective actions have been taken in the past to satisfy customer requirements?”

"Preventive Action" is more difficult for a potential user of the EMC testing lab to identify. It involves the continuous improvement aspect of the ISO/IEC 17025 standard. One example of a preventive action situation is a lab that has calibration complaints on antennas in the frequency range below 1 GHz should also investigate potential calibration problems on antennas above 1 GHz as a preventive measure.

The next management requirement is "Control of Records." In the context of ISO/IEC 17025, the records can be either a quality record or a technical record. Quality records include reports from internal audits, minutes of management reviews, records of corrective actions, and records of preventive actions. Technical records include accumulations of data and information which result from carrying out tests and which indicate whether specified quality or process parameters are achieved. They may include forms, contracts, work sheets, work books, check sheets, work notes, control graphs, external and internal test reports, customers' notes, customers' papers, and customers' feedback.

The records should also identify personnel responsible for the performance of tests and checking of the test results. How does the lab protect and control its records? What evidence do you see that the lab has its records held securely and in a manner to maintain confidentiality? Your test results will become part of the record-keeping system, so make sure your privacy and confidentiality are protected.

Every EMC testing lab should perform an internal audit at least yearly. This is a semi-formal audit done by member of the lab and it is intended to review the operations of the lab including both management and technical requirements. The lab should have a record of its past internal audits and a plan and schedule for future audits.

"Management Reviews" are intended to be performed by the lab's upper management. There are 11 specific areas that shall be reviewed in a management review. They include:

- The suitability of policies and procedures
- Reports from management and supervisory personnel
- The outcome of recent internal audits
- Corrective and preventive actions
- Assessments by external bodies
- The results of inter-laboratory comparisons of proficiency tests

- Changes in the volume and type of work
- Customer feedback
- Complaints
- Recommendations for improvements
- Other relevant factors such as quality control activities, resources, and staff training

Minutes of annual management reviews should reflect the status of the above eleven items.

ISO/IEC 17025 – TECHNICAL REQUIREMENTS

The additional technical requirements section of ISO/IEC 17025 is what differentiates it from the ISO 9001 requirements. An EMC testing laboratory can meet ISO 9001 and still not be in full compliance with ISO/IEC 17025 unless it also meets that standard's technical requirements. On the other hand, a lab that is accredited to ISO/IEC 17025 can be considered to be in full compliance with ISO 9001 and its management requirements.

The ISO/IEC 17025 technical requirements are:

1. General
2. Personnel
3. Accommodation and Environmental Conditions
4. Test (and Calibration) Methods and Method Validation
5. Equipment
6. Measurement Traceability
7. Sampling
8. Handling of Test (and Calibration) Items
9. Assuring the Quality of Test (and Calibration) Results
10. Reporting the Results

"General" is the first section of the technical requirements. It is basically a listing of the requirements in the technical requirements portion of ISO/IEC 17025 plus a comment on the "total uncertainty of measurement."

"Personnel" is the next section of the technical requirements. People make a testing lab successful. An EMC testing lab provides an engineering service, and a service business must be people-oriented. So, as a customer of a testing lab, you should feel comfortable with the technical personnel you are going to be working with. You should check their technical qualifications, such as engineering degrees, technical associate degrees, years of experience in EMC, personnel certificates from iNARTE and other similar personnel certification bodies.

On-going education is also important. Do you see the individuals from the EMC lab attending local meetings of the IEEE EMC Society? Are the technical personnel actively attending workshops and seminars on EMC? Test results on your product are a function of the technical training of the technical personnel coupled with excellent test equipment and test facilities. The customer of the lab should make sure the lab personnel have had adequate training and that they are keeping up to date on the latest changes in standards, design, test equipment and other issues pertinent to EMC testing.

An EMC testing lab relies heavily on its laboratory facilities. So, the technical requirement titled "Accommodation and Environmental Conditions" is a key aspect of a testing lab. For example, does the lab have both 50 Hz and 60 Hz power available? Does it have a variety of voltages for alternating current available? Make sure that the lab has a power source for alternating current that will satisfy your product design. You will also want to see a separation of emission and immunity testing activities so that the immunity testing does not adversely affect the radiated and conducted emission profiles of the product. Does the lab have the capability to test for radiated emissions at a 10 meter antenna distance? As mentioned earlier in this article, good housekeeping can be an indication of the quality of the lab. Look for a well-maintained lab and the lab results will usually reflect a high-quality lab.

A testing lab should read the next technical requirement as "Test Methods and Method Validation." (Again, calibration labs would read the requirement as "Calibration Methods and Method Validation). It is important to ask the lab about their scope of test methods. How many tests do they have the capability to run?

The test methods should be documented, including frequency ranges and amplitudes of various tests. The testing lab should have a verification process for each test method so that the lab knows the test equipment is operating properly for the test on the customer's product. This verification is a system check that assures the EMC test equipment and the corresponding test method are both in synchronization. This verification process can be combined with daily and intermediate checks of test equipment to assure a repeatable and reproducible test of the customer's products.

Equipment for EMC testing labs is expensive especially for large semi-anechoic (SAC) and fully-anechoic chambers (FAC). As a potential user of the EMC lab, you may want to ask for a list of the lab's EMC test equipment as well as a description of the lab's test facilities. Once you arrive at the lab, you should double-check the calibration status of the lab's test equipment. Each piece of equipment that is being used for the testing should have a calibration tag on it with a current calibration status indicated on the tag.

High-quality test equipment will help assure a high-quality testing experience.

The next technical criterion for an ISO/IEC 17025 accredited lab is “Measurement Traceability” which is closely associated with the lab’s test equipment. A calibrated piece of test equipment has to be traceable to the international system of units through a direct path to a national metrology institute. In the U.S., the national metrology institute is the National Institute of Standard and Technology (NIST). The best way to do this is to assure that the calibration labs used by the testing lab are accredited to ISO/IEC 17025. This assures that the calibration lab’s measurement standards and measurement instruments are linked to relevant primary standards through an unbroken chain of calibrations.

Sampling is an important aspect of the technical characteristics of a testing lab. However, most independent testing labs will test products brought to the lab not knowing what sampling plan, if any, was followed by the customer in selecting the product to be tested. Internal EMC labs sometimes have more input to a sampling plan of manufactured products and their selection for occasional testing of their company’s manufactured products.

“Handling of Test Items” is the eighth technical requirement of ISO/IEC 17025. This deals with how test items are delivered to the EMC lab for testing, for example, are they hand-carried, delivered by a company truck, delivered by a common carrier such as UPS, Federal Express, etc. This topic also covers identity of the products while they are in the lab, security and confidentiality of the products while they are in the lab and, finally, the shipment of the test items back to the customer.

Assuring the quality of test results is usually combined with daily and intermediate checks. The EMC lab may also participate in inter-lab proficiency testing and other techniques for checking and verifying the quality of the lab’s test results.

The last part of the technical requirements is the “Test Report” or, as ISO/IEC 17025 refers to it, “Reporting the Results.” A prospective user of a test lab should ask to see a test report template for the lab. The test report should comply with the requirements of Clause 5.10 (“Reporting the Results”) of ISO/IEC 17025.

SUMMARY

Look for laboratory accreditation to ISO/IEC 17025 as a first step in finding a high-quality EMC testing lab. However, it should be noted that even accredited testing labs can make mistakes.

It is important to check the scope of tests for an accredited lab to make sure the scope encompasses the tests required for the customer’s product.

An accredited lab that is qualified to perform the necessary scope of tests will provide the customer a complete test report that will ease the acceptance of the product in national and international markets.

In general, you will be satisfied with accredited EMC labs because there is a higher probability of a successful test using calibrated and high-quality test equipment. This should allow easy marketing of your product relative to EMC requirements.

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EMC

EMC Design Reviews

Some Lessons from Our Design Review Career (to date!)

BY DARYL GERKE, PE

One of our favorite EMC sayings is “an ounce of prevention is worth a pound of shielding.” Like vaccinations for children, an EMC design review can prevent serious problems later, such as a failed EMC test. Or worse, a failed product in the field.

When we began full time EMC consulting in 1987, most of our clients were already in EMC trouble. Within a year or two, however, we started doing EMC design reviews on new projects for many of those same clients. Most realized it was far less painful (and costly) to design for EMC in the first place, rather than to simply test for EMC at the end of a project.

Since that time, we have done hundreds of design reviews for a wide range of clients with very positive results. In our experience, a little effort during design goes a long way towards EMC success. We’ve discussed this several times in our newsletter (Kimmel Gerke Bullets). Here are some general thoughts and comments (both old and new) on EMC design reviews.

SO, JUST WHAT IS AN EMC DESIGN REVIEW?

First, an EMC design review is NOT a full blown review. Rather, it focuses on specific EMC issues. It does not address other issues like reliability, thermal, power, weight, etc. These are better left for more formal reviews.

Depending on the product, and EMC design review can address circuit boards issues, mechanical issues, or systems-level issues. At the same time, it addresses requirements (regulations and/or threats), constraints (costs, volumes, etc.) and design strategies.

We prefer an interactive approach to EMC design reviews. Rather than dictate directions, we like to get the design team (both electrical and mechanical) actively involved. Together, we identify and assess the risks, and discuss the design options and tradeoffs. We understand EMC issues, while our clients understand their products and constraints. Together, we can come up with practical EMC solutions.

WHAT IS THE BEST TIME FOR AN EMC DESIGN REVIEW?

For most projects, an ideal time for an EMC design review is during the initial electrical and mechanical design phases. For, circuit boards, a good time is when the board layout is complete, and the first artwork is ready. At this stage, the design is usually solid enough to make recommendations, but fluid enough to make changes.

In some cases, you may want to consider EMC issues in the early concept stage. This is particularly helpful when dealing with packaging issues, such as cabling and shielding. This can extend to circuit boards when considering connector placement, or bus or I/O design.

Most EMC reviews can be done in a day or less. For simple systems or a single circuit board, even a few hours may be adequate. But don't do it all by yourself. Grab a colleague and go over the issues together. Often the act of explaining the design to someone else uncovers unexpected issues. Of course, your colleague may have unexpected suggestions too.

FOUR GENERAL TASKS

Before jumping into the design assessments, there are four preliminary tasks that must be done, as follows:

1. ***Identify and assess the EMC threats***—Typical threats include radio frequency (RF) energy from nearby transmitters, electrostatic discharge (ESD) from humans or other sources, power disturbances, and conducted/radiated emissions (which may adversely affect other electronics).

   These are often specified as test requirements, but you may need to modify them based on the actual anticipated environment. For example, at one review for a medical device, we asked if it would be used in ambulances, both land and air. When the answer was yes, the original office/home requirements were deemed inadequate.

   Incidentally, that manufacturer ultimately developed two product lines. The ambulance product was hardened to higher levels than the home/office products and sold at a premium. What could have resulted in some sticky EMC issues yielded additional profits while preemptively solving unexpected customer problems (an example of good engineering!).

2. ***Identify the key circuits or assemblies that affect or are affected by these threats***—Digital circuits (particularly resets and control circuits) are very vulnerable to spikes and transients, and analog circuits are very vulnerable to RF. Digital clocks (and other highly repetitive sources) are rich sources of radiated emissions. Power circuits are vulnerable to power disturbances, and can also contribute to conducted emissions.

3. ***Identify other design constraints that may affect EMC design decisions***—These include costs, volumes, weight, space, and the cost of noncompliance (CONC). Incidentally, in very cost sensitive situations, we often advocate designing in place holders (such as pads for capacitors) that can be populated later as needed with EMC components. Don't overlook the latter – as engineers, we always need a fallback plan.

4. ***Identify the appropriate EMC design features***—This is where the design fun begins. The circuit board is an ideal place to start. After all, all EMC problems ultimately begin and end at a circuit. Of course, if you don't design the boards, you will work at the system level. That may include mechanical issues (shielding) along with cables, connectors, power, and grounding. Many (but not all) defense projects fall into the latter category.

Here are some comments on both levels. At the board level (inside the box) we like to work from the inside-out. We look at both the circuit schematic and the board construction, along with the board interfaces (power/signal/grounding.) At the systems level (outside the box) we like to work from the outside-in. We look at the cables/connectors, enclosure construction, and systems interfaces (once again, power/signal/grounding.)

PRINTED CIRCUIT BOARD REVIEWS

The majority of our past EMC design reviews were at the board level, so we will start there. We divide board reviews into two parts: a schematic (circuit) review, and a construction (artwork) review.

Here are ten key points to check on your circuit boards. Much of this is from a short tutorial we gave several years ago. Feel free to use it as a design review check list.

1. ***Clock circuits***—These are the primary sources of high frequency radiated emissions. Also, check any clock-like circuits that are highly repetitive. Some memory control and bus control signals fall into this category.

   Design recommendations include:

   - High frequency decoupling at Vcc (series ferrites provide even more protection)
   - Series resistors in clock outputs (10-33 Ohms typical)
   - Crystals or resonators located adjacent to the oscillator

2. ***Reset/interrupt/control circuits***—Resets are very vulnerable to ESD, EFT, and transients. Interrupts and control (read/write) are also vulnerable. External reset lines to mechanical switches are extremely vulnerable. Design recommendations include:

   - High frequency decoupling of Reset Vcc, reference, and output with trace lengths over two inches of trace length. Consider series ferrites for additional protection.
   - Similar fixes as needed for vulnerable interrupt/control circuits

3. ***Analog circuits***—Very vulnerable to RF energy. In addition, parasitic oscillations may cause unwanted radiated emissions.

Design recommendations include:

- High frequency decoupling of Vcc
- High frequency filtering of both circuit inputs and outputs (1000 pF typical)
- Similar protection at all analog sensors

4. ***Voltage regulators***—Like analog circuits, these are also vulnerable to RF. Due to increasing component bandwidth, parasitic oscillations are now common in VHF/UHF frequency ranges.

   Design recommendations include:

   - High frequency decoupling of Vcc
   - High frequency decoupling directly at input and output pins to chip neutral pin (1000 pF typical). Highly recommended to prevent those pesky parasitic oscillations.

5. ***RF transmitters and receivers***—These circuits bring a whole new set of potential EMC problems. Onboard receivers can be jammed or desensed by digital harmonics (GPS receivers are extremely vulnerable). On board transmitters can jam nearby analog circuits. Multiple radios may result in intermodulation and cross modulation problems.

   Design recommendations include:

   - Protect receiver inputs (may need special design).
   - Internal shielding of RF modules
   - Clock management (avoid harmonics on receiver inputs).
   - Check antenna locations and cable routing.
   - DSP or other software techniques may also be necessary.

6. ***Board stackup***—Good board construction critical for good EMI control. Fortunately, most of these fixes are free.

   Design recommendations include:

   - Keep every signal layer next to an adjacent plane.
   - Keep respective power/ground planes adjacent.
   - Maintain a symmetrical stackup.
   - Consider outer buried planes.

7. ***Split planes***—Traces crossing cuts and mismatched planes can seriously negate even the best EMI controls on the board. We've seen 10x improvements (20 dB) after fixing these problems. So it is in your best interest to prevent them in the first place.

   Design recommendations include:

   - Check high speed traces with "over and back" routing across cuts in adjacent planes.
   - Note that low speed traces across cuts can also cause problems if high frequency energy sneaks onto these traces.
   - Always align the power/ground planes as mirror images.

8. ***Floor planning and routing***—Random placing of components, and random trace routing can result in EMC problems. Given the opportunity, autorouters often route to maximize EMI (a variation on Murphy's Law).

   Design recommendations include:

   - Segregate components according to frequency. Group digital, audio, power, and RF circuits together, rather than sprinkling them all over the board. Separate the traces too.
   - Pay attention to routing of critical traces (clocks, resets, control lines).
   - Avoid placing critical circuits near I/O ports.
   - Consider manually routing critical traces for better EMC control.

9. ***Protect the periphery***—Since power and I/O connect to the outside world, they need special attention. This begins at the board level, and may also be applied at the systems level.

   Design recommendations include:

   - Filters and transient protection as needed. As a minimum, place 0.01 uF capacitors across all power inputs.
   - Pay attention to ESD protection on external I/O lines.

10. ***Grounding***—Another issue that needs to be addressed at both the circuit board and systems levels. This could be the subject of a whole other article, or even a book. But there are a number of things to check at the board level.

    Design recommendations include:

    - Consider separate ground paths for digital, analog, and power.
    - Multi-point ground connections are preferred for high speed digital (and RF) circuits.
    - Single point ground connections are preferred for low level/low frequency analog circuits.
    - Hybrid grounds (caps and inductors) can be used for mixed technologies.
    - Note that additional grounding constraints may apply in harsh environments.
    - NEVER violate safety grounding to solve an EMC problem.

SYSTEMS LEVEL REVIEWS

At this level, we often work from the outside-in, focusing on mechanical construction, interfaces (both power and signal), and system grounding. Much of this assumes shielded enclosures. For unshielded equipment, the EMC design goals must be met at the board level.

1. ***Mechanical***—At this level we are interested in the EMC shielding performance. As such, we look at the materials, mechanical joints (seams/covers/ventilation) and discontinuities (penetrations and openings).
   Design recommendations include:

   - Check the material. Thin conductive coatings (including foils, paints, and plating) are effective for high frequencies, but often inadequate for power frequency magnetic fields. In the latter, permeable material (steel or mu-metals) may be needed.
   - Check the discontinuities. Any seam over two inches is problematic for ESD or RF above 300 MHz. At 1 GHz, even 1/2 inch can be pretty leaky. You may need to fill the seams with conductive gaskets. See the next paragraphs for penetrations due to cables.

2. ***Interfaces***—At this level, we examine both the signal and power and their connections. This includes internal cable placement and routing.

   Design recommendations include:

   - For signal interfaces, use bulkhead connectors for shielded cables. Filtered connectors are even better. No holes. Passing cables through a hole in the enclosure can completely destroy EMC shielding at high frequencies. We've seen it happen too many times.
   - For power interfaces, bulkhead filters are preferred at the point of penetration. If internal modular filters are used, they must be placed as close to the penetration as possible.

- External cables—If possible, examine the mating cables. Connectors are a key area of concern. Full circumferential bonding of the cable to the connectors is preferred. If it leaks out the external cables or connectors, all your efforts at the box level are for naught.

3. ***System grounding***—Most EMC grounding issues are addressed inside the box at the circuit level. The main concern here is not violating system grounding guidelines, particularly for safety grounding.

IS ALL THIS EFFORT WORTH IT? ABSOLUTELY!

In one case, we had a design team "dancing in the lab" when they passed their EMC tests on the first try. Never having tasted that kind of success, they became firm believers in EMC design reviews. They also beat their competition to market by a month, which pleased their management to no end. After all, engineering is also about economics.

In another case, we supported a defense client that had already implemented a formal EMC design review process, with numerous "EMC check points" throughout the design. We reviewed several dozen boards as part of a multi-year contract. Their chief EMC engineer revealed they rarely failed their EMC tests - and when they did, they were easy to fix. Each check point review typically lasted a couple of hours.

After an EMC review, we usually document the findings in a memo. You can and should do this too, often in an hour or two. But keep it simple. Grab a buddy—two sets of eyes are better than one. Or you can always call your favorite EMC consultant for help. Either way, the payback is there. Remember, an ounce of prevention...

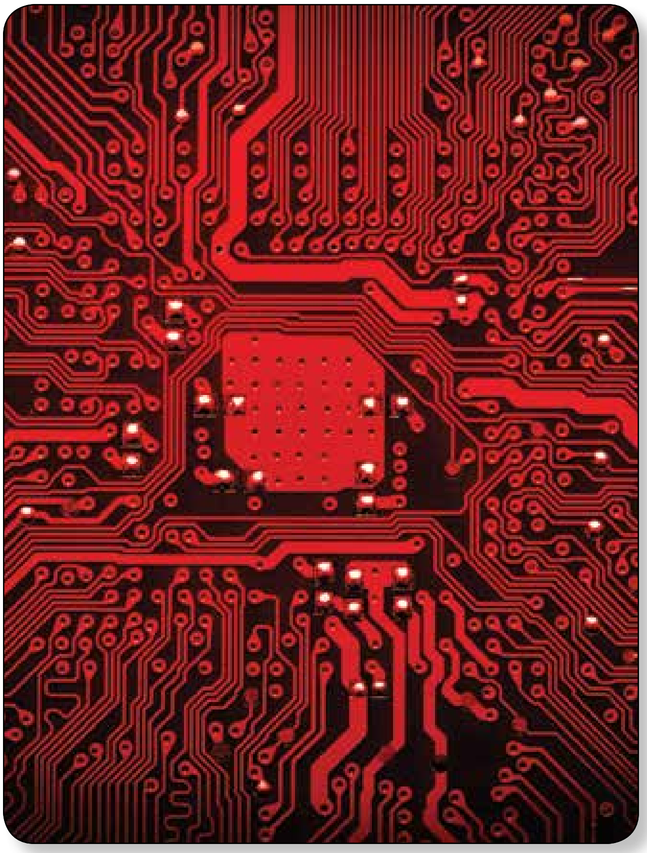
Daryl Gerke, PE*, is the surviving partner of Kimmel Gerke Associates, Ltd. Sadly, Bill Kimmel, his good friend and business partner of almost 40 years, passed away in April 2015 after a short battle with pancreatic cancer. This article is dedicated to Bill. You can reach Daryl at dgerke@emiguru.com.*

EMC

EMI and Signal Integrity

How to Address Both in PCB Design

BY WILLIAM D. KIMMEL, PE AND
DARYL D. GERKE, PE



Let's do a comparison of EMI (electromagnetic interference) design and signal integrity. EMI focuses on the associated specifications and testing requirements and interference between neighboring equipment. Signal integrity addresses the degradation of signal quality to the point where erroneous results occur. But the overlap in design techniques at the board level is considerable. Note that the IEEE EMC Society has a subcommittee devoted to signal and power integrity.

We consider signal integrity to be EMI at the circuit board level. Our experience is that a circuit board that is well designed for signal integrity is generally pretty good for EMC as well. Let's take a closer look at these issues, and see where they differ and where they overlap.

DIFFERENT FOCUS, SIMILAR TECHNIQUES

With signal integrity, the focus is on printed circuit board and associated interconnections between circuit boards. The objective is clean signals along with adequate operating margins (timing, supply voltage, and environmental variations). This has become a major factor with the increasing serial I/O speeds, headed to 100 GHz. The key concerns are signal reflections, crosstalk, ground bounce and power decoupling. The solutions are careful circuit layout and attention to timing. The interference levels of interest are millivolts and milliamps.

EMC focuses on the entire system, including printed circuit boards, enclosures and cables and power supply. The objective is to pass relevant EMC test requirements and to make sure it works in its intended application. The key concerns are emissions, immunity, and mutual compatibility of equipment, including digital and analog circuits, motor controls, relays, etc. The remedial solutions are careful circuit layout, grounding and shielding, filters and transient protection. The relevant signal levels are microvolts and microamps for emissions, and kilovolts and amps for immunity.

The common area is at the circuit board and local interconnect area. Even here, there are some clearly different aspects of interest. First, note that the key signal levels of concern are very different. For signal integrity, the key factor is to keep noise levels substantially below the signal levels, so our noise margins are in the millivolt range for digital circuits. But, for EMI, emission levels must be kept in the microvolt and microamp range, typically three orders of magnitude lower than acceptable internal noise levels. For immunity, external levels may well be in the kilovolt and amp range, again, orders of magnitude higher than logic levels and analog circuit levels.

This means that parameters entirely acceptable with signal integrity can be grossly higher than that needed for emissions and grossly lower than needed for immunity.

Parasitic coupling paths are more critical for EMI, but signal losses are more critical for signal integrity.

Let's see how these factors affect board design.

GROUND IMPEDANCE

Ground impedance is at the root of virtually all signal integrity and EMI problems; low ground impedance is mandatory for both. This is readily achieved with a continuous ground plane, and exceedingly difficult with traces, as would be used in a two layer board. We'll deal with multilayer boards, where it is feasible to implement a ground plane.

Ground impedance is an important issue for both signal integrity and especially for high frequency emissions in EMI. A ground plane serves well as a signal return, provided the ground is continuous under the signal path. But, even with a continuous return path, there will be enough voltage drop across ground to generate a common mode voltage. This is not significant for signal integrity, but is the primary cause of common mode voltages which, left unchecked, will escape as an EMI emitter via the signal or power ground conductor.

Here, we note that common mode currents are purely parasitic. They contribute nothing to the desired signal but can be difficult to block as EMI emitters. Differential mode currents are the normal signal path, and are more of an issue with signal integrity than with EMI. These considerations are driven by the loop area; inductive impedance of the signal/return loop is proportional to the loop area, as is the antenna efficiency (a consideration for radiated emissions and immunity). But signal/ground loop areas on a multilayer circuit board are small, providing the return path in ground is continuous, and is usually not a problem with EMI.

Copper thickness is not an important factor. At high frequencies, skin effect dominates, so currents are squeezed to the surface, rendering extra thickness irrelevant.
In fact, the principal problem with ground impedance is the discontinuities that occur in the signal return path, and that has major impact on characteristic impedance control.

IMPEDANCE CONTROL

At higher frequencies, characteristic impedance control becomes necessary for signal integrity and, to a lesser extent, for EMI control. Now we are operating well into the GHz range, and impedance control requires meticulous care just to maintain signal integrity. For EMI, it is usually sufficient to minimize overshoot and undershoot, especially with signals leaving the circuit board.

The biggest problem with maintaining impedance control is the signal path discontinuities, including return path on ground plane:

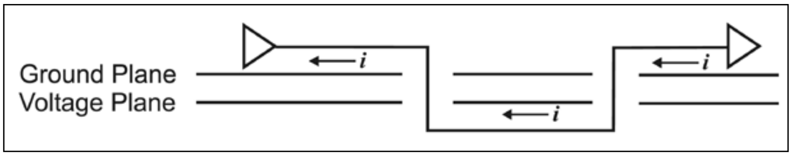


Figure 1: Return current path is discontinuous when switching reference planes

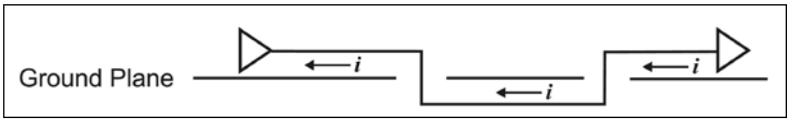


Figure 2: Return current past discontinuity is minimized when keeping same reference plane

1. The ideal signal path has a continuous copper plane immediately underneath. In such a case, impedance control is confined to proper terminations, usually at the load end. For slower signals, where EMI control is the predominant issue, source termination is often an appropriate choice, as it also limits the emission currents from leaving the driver chip. Source termination does slow the signal, which may not be acceptable for highest speeds.

2. The worst discontinuity occurs if the signal changes reference planes from a ground plane to a voltage plane, as illustrated in Figure 1. Clearly, ground to voltage vias can't used to provide a return path, so the only option is to insert decoupling capacitors at the perimeter in order to provide a low impedance high frequency return path across the boundary. Unfortunately, this is not a fully acceptable solution at high frequencies, but will be reasonably good for lower frequency signal paths.

3. A lesser discontinuity occurs if the signal is transitioning from one ground plane to another. Here, the return

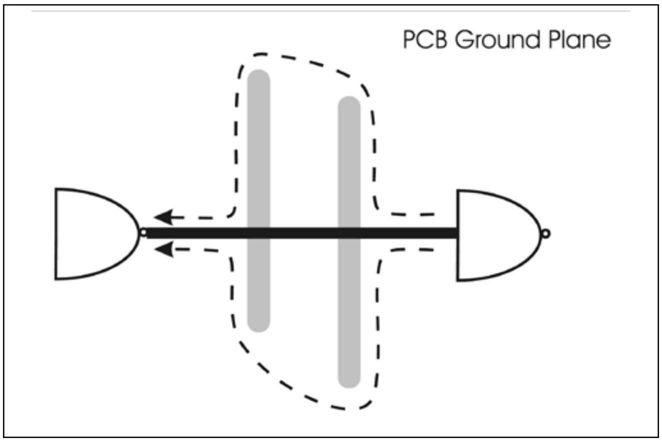


Figure 3: Signal return path is disrupted by cut in ground plane

path from plane to plane must be made continuous and impedance control effected. Typically, this is handled by inserting ground to ground vias around the perimeter of the signal via, and controlling the keepout, pad size and via size and length in order to match impedances.

4. The least problem of layer changing occurs when the signal transitions from one side of the ground plane to the other (see Figure 2). Since we haven't changed reference planes, there is no issue with ground vias, so the impedance discontinuity is minimal. For highest speed signal integrity, you will need to minimize the impedance discontinuity by controlling the via size and length, and the diameter of the keepout.

5. Cuts in plane, as shown in Figure 3, shows a discontinuity in the signal return current path. The return path has to go around the gap in the plane, raising the characteristic impedance at the gap, and energizing the opening as a slot antenna. This can occur when a portion of the plane is stolen to accommodate another trace, at a split plane boundary, or at a connector cutout.

6. Signal path at mandatory discontinuities. This assumes that impedance control needs to be maintained across the boundary. Most notably, this will occur at the circuit board to connector boundary (see Figure 4), and is especially noticeable when the impedance of the cable doesn't match the impedance at the circuit board. In such a case, an impedance matching network needs to be placed at the boundary. This is handled by controlling the copper parameters at the boundary. Larger cutouts increase inductance while leaving more copper at the boundary increases capacitance.

PCB LAYOUT

For both EMI and signal integrity, good layout starts by identifying critical traces. In both cases, most of the problems lie with a very few of the traces. You don't have the time or

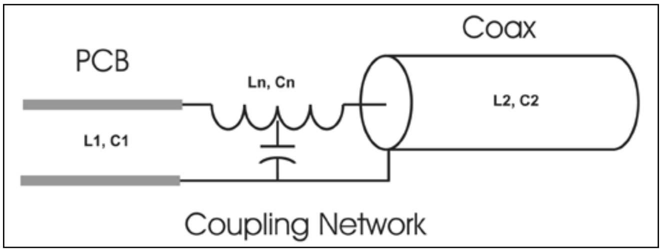


Figure 4: PCB to coax impedance matching

real estate to treat all the traces, so you concentrate on the few. But the critical traces are typically different for signal integrity and EMI.

For signal integrity, the problem is limited to the relatively few high speed signal traces. High speed serial data are the leader, and design will concentrate on the signal/return path and adjacent metallic members. For EMI, the problem concentrates on those lines entering or leaving the circuit board. The primary emitters are those that carry high speed clock and data lines, along with the parasitic coupling to slower lines, power lines and especially ground lines. The primary receptors are low level analog input lines for RFI and digital lines for transients.

Once these lines are identified, you can place the chips on board to facilitate good routing. The simpler the path for critical traces, the easier it is to maintain signal integrity and EMI control.

DECOUPLING

Starting with the supply voltages, the voltage tolerances are basically a signal integrity issue. This does not show up at the EMC level except to the extent that external interference corrupts voltage at the power supply or on-board regulators. The big difference lies with the demand for decoupling. Clock noise that shows up on the power rails and sneaks out the power cable will be an emission problem even if amplitudes are in the microvolt range, but won't be a problem for signal integrity until it reaches the millivolt range. So decoupling demands for EMI are a thousand times more demanding than for signal integrity.

The chip manufacturer recommends decoupling capacitors as needed for Vcc droop. This means that the target frequencies for signal decoupling are at the clock frequency and below, while the frequencies for emissions are at the clock harmonics, typically ten times the clock frequency or even higher.

Thus, the demands for decoupling for emissions are substantially higher than with signal integrity. This doesn't mean more capacitance, it means less inductance. At modern computer speeds, your high frequency harmonics are inevitably operating above the series resonant frequency of the typical decoupling capacitor. Just add one to two nanohenry of lead length in each decap and you will find that the impedance is too high for effective filtering. If the impedance is above one ohm, you should look for better filtering, or more decaps in parallel. The good news is that at higher frequencies, the interlayer capacitance of multilayer boards becomes the dominant factor above a couple hundred MHz.

CROSSTALK

Crosstalk can be an issue for both signal integrity and EMI. Crosstalk is unintended coupling to adjacent metallic members, usually to an adjacent signal, power or ground path.

Crosstalk includes field coupling from one line to an adjacent line. It is a major issue with cables that will usually need to be addressed, but may also be a problem with adjacent trace coupling at the circuit board level. Any coupling from very high speed signal lines can degrade signal quality (we see signal speeds well into the GHz range, and we hear 100 GHz is just around the corner), whether to an adjacent trace or any other metallic element on the circuit board. For EMI, crosstalk becomes a problem with I/O lines coupling energy to/from clock lines or sensitive on-board lines. Often, this problem can be eliminated by separating these lines. The spacing in between need not be wasted, but can be used for less critical lines. In both cases, increased spacing is beneficial, as coupling falls off with the square of the distance.

OTHER SIGNAL PATH ISSUES

In addition to crosstalk, other losses may come into play, with series resistance and shunt dielectric loses being the major issue.

Signal path losses would include series resistance in the conductive path and shunt conductance in the dielectric. For the most part, these losses are not a problem at the circuit board level, unless you are using a high resistance signal path, such as conductive epoxy (which is rarely used). These losses become much more of a problem at the cable level, especially with signal integrity, where losses track directly with eye diagram shrinkage, to the point of signal failure. For EMI, the problem is a bit less noticeable. But obviously, if the signal strength is weakened, it takes less external interference to create data errors.

Imbalance is an extension of crosstalk, becoming increasingly significant for differential signals as serial data speeds increase. Balance loss will occur with unequal coupling paths, as mentioned above, and will also show up due to unequal propagation times from driver to receiver. This is much more of an issue with signal integrity than with EMI.

Coupling to off-board elements is primarily an EMI issue, where coupling between elements on adjacent circuit boards may be significant. A typical case is where clock noise from a high speed microprocessor chip capacitively couples to an adjacent circuit board, then propagates to the outside world from there. A similar situation occurs if an internal cable is routed too close to this same chip. This situation is increasingly being handled by on-board chip shielding. This problem rarely occurs with signal integrity issues.

ANALYTICAL SOFTWARE

Let's take a look at analytical software, clearly, a topic of significant interest. Any modeling that reduces hardware redesign effort is like money in the bank. So what is the status?

Our observation is the modeling for signal integrity is much more developed than for EMI. It is a much simpler task to model the signal path, with consideration limited to the signal path/return, plus coupling to adjacent metallic members. The EMI predictions are much more complex, as it involves consideration of many more circuit board coupling paths and common mode noise generation, both of which are difficult to identify, much less quantify. Additionally, calculations need to consider enclosure and cable shielding effectiveness, which involves identifying all the relevant parameters and quantifying them. In actuality, almost all of the modeling is directed at emissions. (We've seen almost nothing on modeling of immunity issues.) The bottom line is, consider yourself as doing well if your predictions are good within 20 dB, or a factor of 10. Well, that is better than nothing, but it still leaves a lot to be done by test and redesign.

SUMMARY

Signal integrity has become an increasingly important part of EMI design. Good circuit board design is very important in both cases, but the emphasis is different. Most notably, signal integrity is primarily concerned with the critical high speed signal lines, and EMC is primarily concerned with the lines entering the circuit board.

Daryl Gerke and Bill Kimmel *are the founding partners of Kimmel Gerke Associates, Ltd., a consultancy specializing in EMC consulting and training. Gerke and Kimmel have solved or prevented hundreds of EMC challenges and problems in a range of industries, including computers, medical devices, military and avionics, industrial controls and vehicular electronics. They have also trained more than 10,000 engineers through their public and in-house EMC seminars.*

Bill passed away in April 2015 after a short battle with pancreatic cancer. You can reach Daryl at dgerke@emiguru.com.

Decoupling Capacitor Design on PCBs

to Minimize Inductance and Maximize EMI Performance

BY BRUCE ARCHAMBEAULT, BIYAO ZHAO, KETAN SHRINGAPURE, AND JIM DREWNIAK

INTRODUCTION

There are many different opinions about the best decoupling capacitor strategy for printed circuit boards (PCBs). Different strategies for capacitor value, distance to the IC, etc. have been proposed and while there are good arguments of one or the other proposal, usually either will be effective, depending on some of the other factors involved.

It is universally agreed that the mounting of the capacitor on the PCB will increase the effective inductance of that capacitor sometimes by an order of magnitude or more from the equivalent series inductance (ESL). This greatly reduces the ability of the capacitor to effectively provide charge to the IC and lower noise between the power and ground-reference planes. Often many additional capacitors are added to give an effective, overall inductance that is acceptable.

This article will first explain the various portions of the overall inductance between the decoupling capacitor and the IC pins, then explore some alternative capacitor mounting approaches to reduce the capacitor's connection inductance, which will significantly increase the performance of the decoupling capacitor in many situations. When these capacitor mounting approaches are effective, the total number of capacitors can be reduced without a decrease in performance.

ANATOMY OF THE INDUCTANCE IMPACTING DECOUPLING CAPACITOR CHARGE DELIVERY

The main purpose of the decoupling capacitor is to provide charge (current) to the IC during the time the IC requires it. The main time-varying current draw for most CMOS ICs is when the IC is driving signals onto I/O traces on the PCB. Internal transistor switching, internal clocks, etc. usually are more of a constant DC current requirement at the IC power pins because of the internal package/chip inductance and capacitances.

When the capacitors provide the charge the IC requires, the noise between the power and ground-reference planes is minimized and the effective impedance between the planes is low. The limitation of the impedance at low frequencies is the total capacitance and at higher frequencies the limitation is from the various portions of inductance in the current path. Figure 1 shows an example of a printed circuit board with an IC and some decoupling capacitors on the top and bottom of the power area. Figure 2a shows the impedance the IC pins 'see' looking into the PCB stackup for a couple of different cases of capacitors. The different curves are not important to this discussion, but it is clear that the low frequencies are dominated by the discrete capacitors and capacitance between the planes. Figure 2b shows the stack up for this particular PCB with the capacitance circled.

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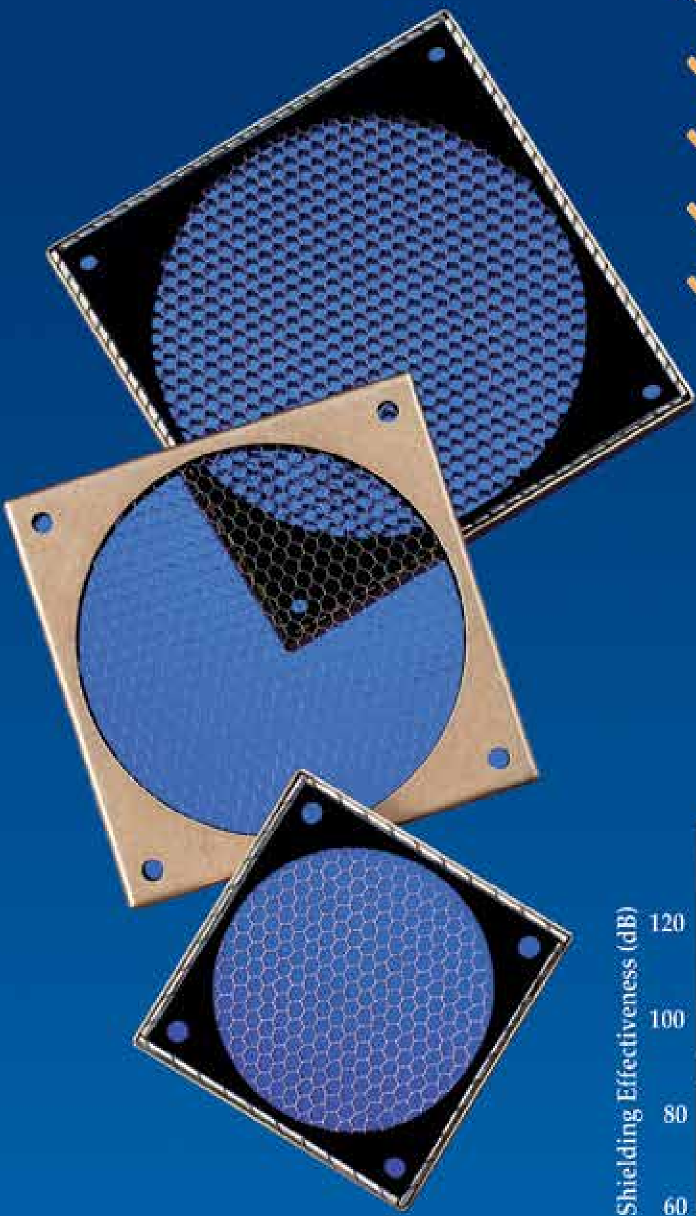

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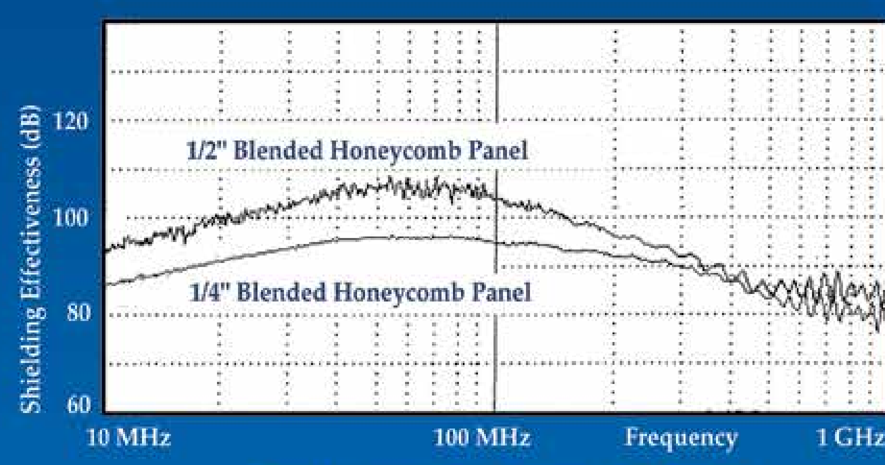

Typical Shielding Effectiveness Test Data of Spira Honeycomb Fan Filters

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Switching to the very high frequency portion of the impedance plot, Figure 3a shows the impedance and Figure 3b shows that this is only due to the inductance the IC sees from the power and ground-reference vias between the IC pads on the PCB surface and the power and ground-reference planes in the PCB stackup (in this case, the planes are in the middle of the stackup). The inductance of this connection limits the effectiveness of the decoupling capacitors at the very high frequencies.

The center portion of the impedance plots is also inductive, but this inductance is more complex. It includes the IC via inductance, the inductance between the power and ground-reference planes, and the inductance of the vias connecting the decoupling capacitors to the planes. Figures 4a and 4b highlight this inductance. Minimizing this inductance requires the power and ground-reference planes to be near the top of the stack up so that the IC via inductance is minimized. Then the inductance capacitor vias can be minimized when the capacitors are mounted on the top surface of the PCB.

MINIMIZING CAPACITOR VIA INDUCTANCE

Once the PCB stackup is defined, the discrete decoupling capacitors inductance can be further minimized with careful placement. The primary purpose of these discrete capacitors

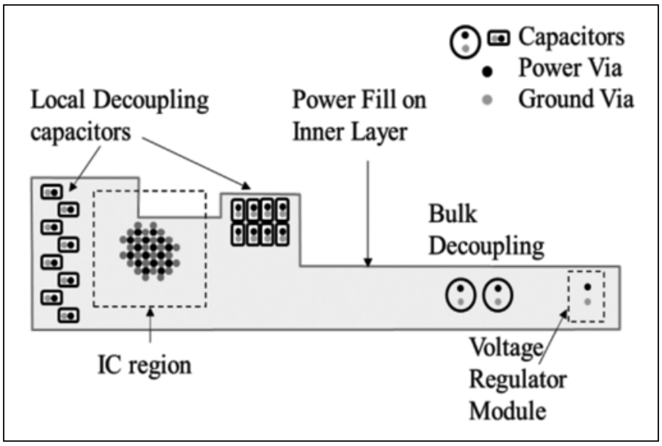

Figure 1: Example PCB with Decoupling Capacitors

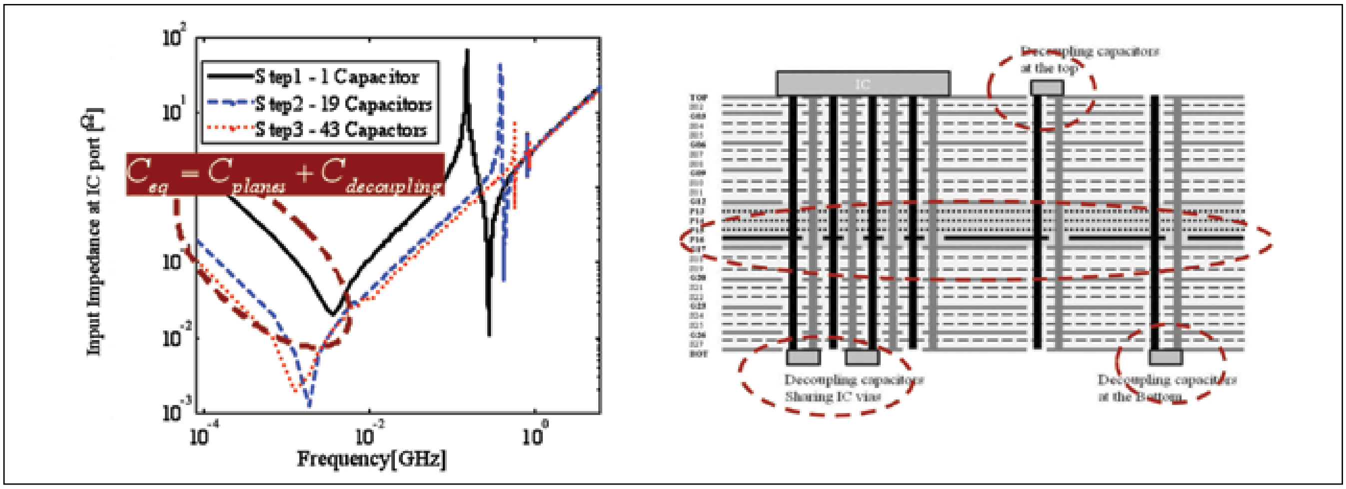

Figure 2a and 2b: Impedance Plot and Stack up showing capacitance effect

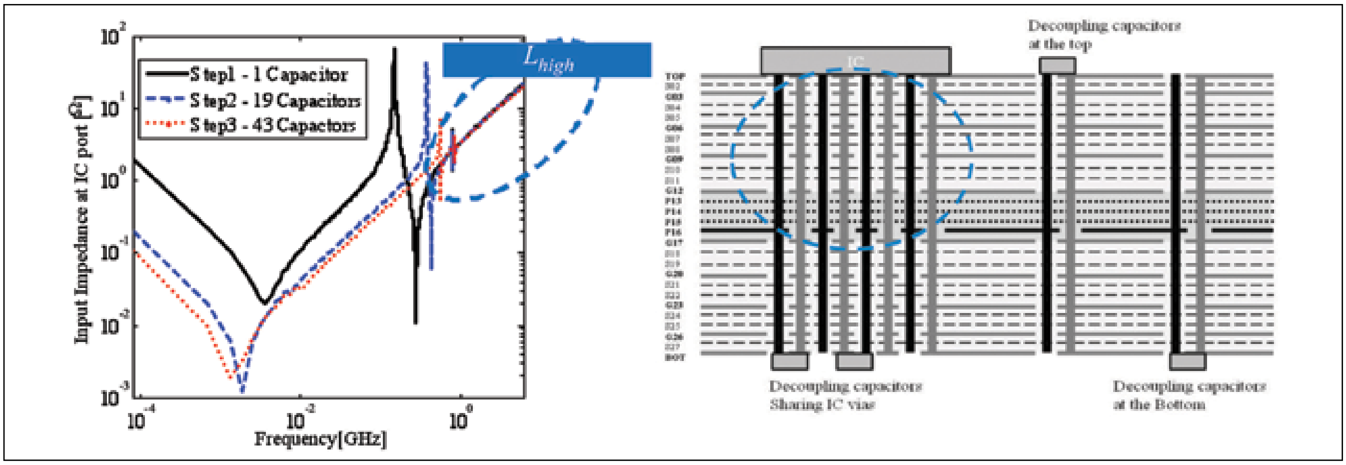

Figure 3a and 3b: Showing impedance plot and stackup for very high frequency effect dominated by inductance from IC vias

is to replenish the charge between the planes in time for the IC to draw more charge during the next cycle. Often designers will increase the number of capacitors hoping to reduce the inductance by adding more capacitors in parallel. However, it turns out that the apparent inductance seen between the planes and capacitor pads does not decrease as 1/N as might be thought. This is due to mutual inductance between the vias when the capacitors are closely spaced (as in common practice).

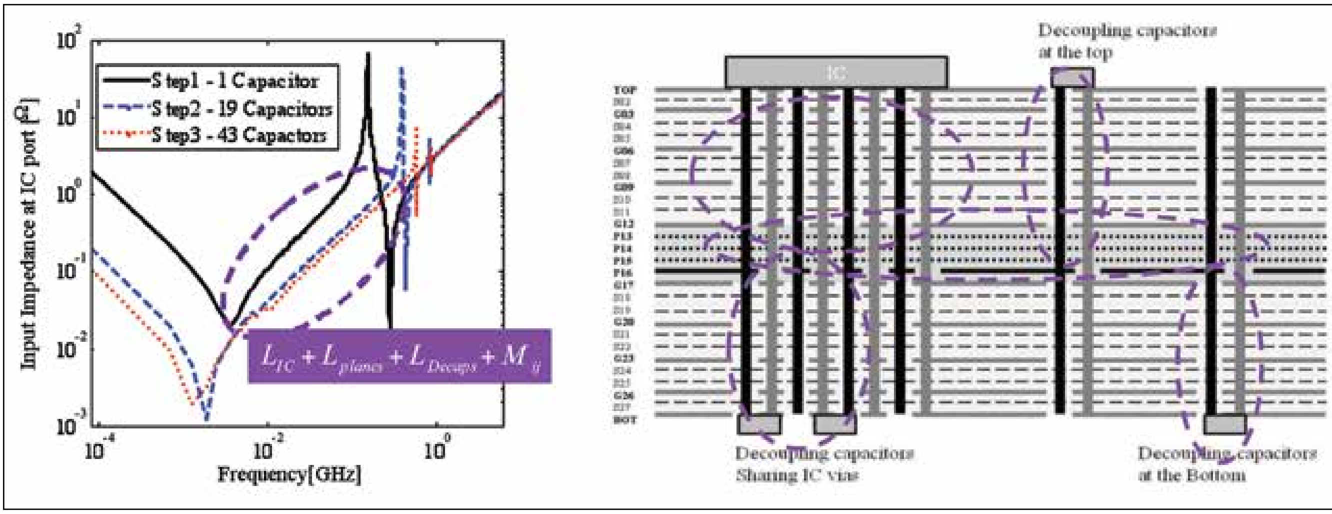

Figure 4a and 4b: Showing impedance plot and stackup for mid-range frequency effect with inductance contributions from IC vias, discrete capacitor vias and planes

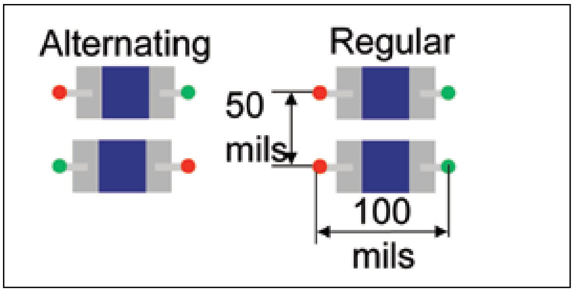

Figure 5: Decoupling capacitor geometry options

This mutual inductance can be cancelled for closely spaced decoupling capacitors by simply alternating the power and ground-reference pads on the PCB. Figure 5 shows an example of this alternating pattern. The red vias represent power, and the green vias represent the ground-reference vias.

Figure 6 shows the inductance when the power and ground-reference planes are at the top of the PCB stack up and the separation between planes is 5 mils. The values of inductance are very low because the planes are at the top of the PCB stack up. To calculate the actual inductance when the planes are deeper in the stack up, simply multiply the inductance values by the number of additional 5 mil increments to get to the planes.

In the typical mounting case (regular) of the power vias in a straight line when the number of capacitors is increased. Figure 6 shows the inductance decreasing, but not as fast as a simple 1/N indicates. However, when the alternating geometry is used for the vias, the inductance falls off much faster than 1/N! If the target impedance required a decoupling capacitor effective inductance as represented by the dashed line, 30 capacitors would be required with the traditional geometry, while only nine are required with the alternating geometry. This saves not only the capacitors themselves, but the wiring channels that would be disrupted on all layers with the added vias.

The effective inductance can be further reduced when two capacitors are mounted in a doublet fashion again with the power and ground-reference vias alternating (Figure 7). The effective inductance seen in Figure 6 is even less than the alternating configuration. In the optimized doublet configuration, the vias from each capacitor are placed closer together with short traces, while still maintaining the alternating power and ground-reference via configuration. This further reduces the effective inductance to the smallest possible value.

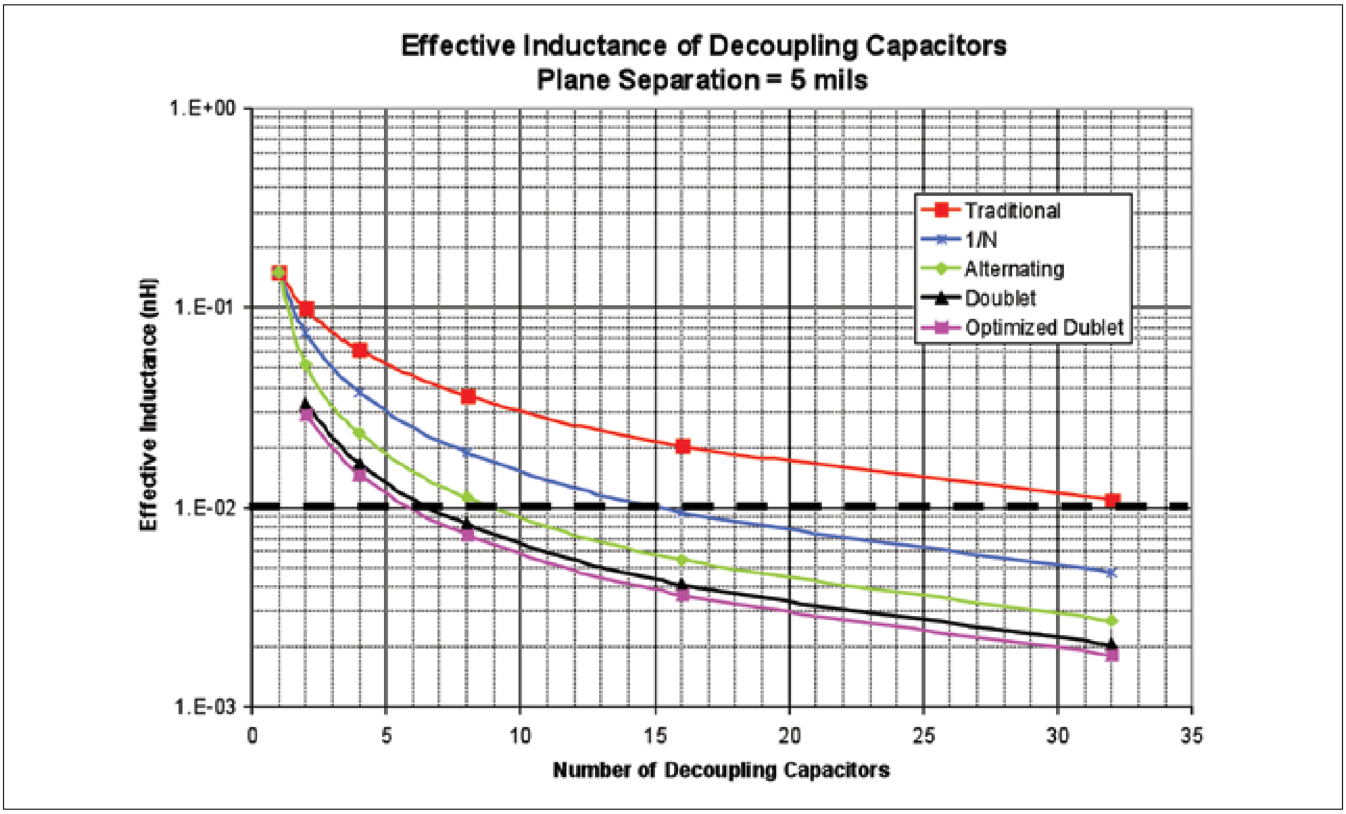

Figure 6 :Effective Inductance for plane separation = 5 mils for planes at top of PCB Stack up

SUMMARY

The inductive portion of the power distribution network (PDN) is limited by the inductance seen from the IC pads to the planes. However, the actual inductance provided by the discrete decoupling capacitors can be reduced by cancelling the mutual inductance by alternating the vias. This reduction in effective inductance is greater than a simple 1/N decrease. Finally using a doublet of two capacitors, with the alternating vias, the effective inductance of the discrete capacitors connecting to the planes is further reduced.

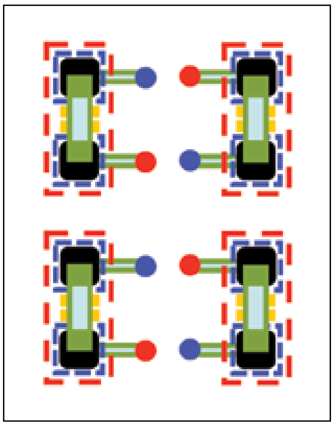

Figure 7: Decoupling capacitor doublet with alternating vias

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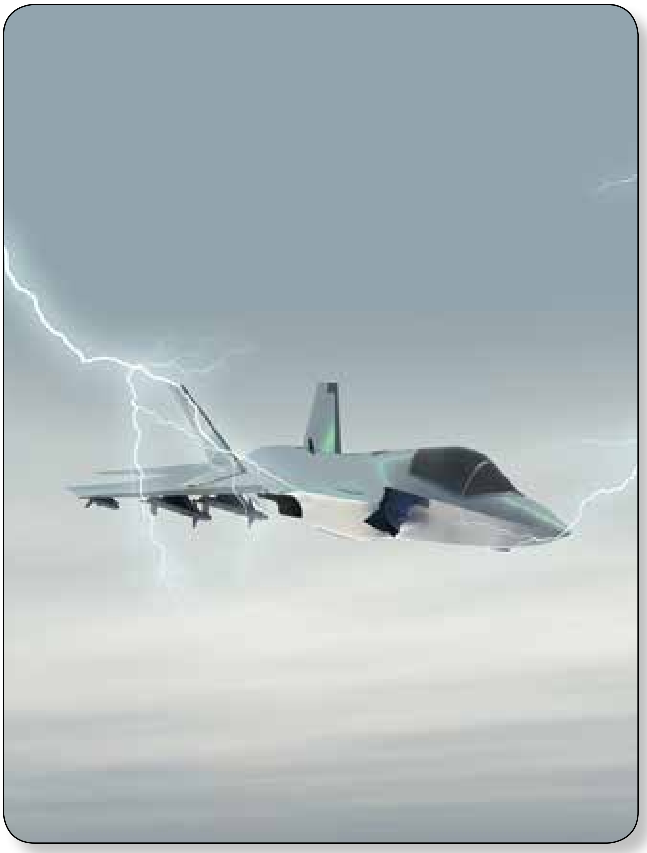
A Radio Frequency Application of Critical Damping Theory and Practice

BY KEN JAVOR



EMC is sometimes termed the study of secondary effects that are ignored in college curricula. This investigation hinges on subtle effects mostly ignored during EMI testing.

Certification of aircraft to the high intensity radiated field (HIRF) environment in part involves comparing rf current levels coupled to aircraft cables from an electromagnetic field to levels bulk cable-injected during equipment-level qualification. The process is sometimes termed low-level swept cw testing (Carter 1990).[1] As in other aspects of the correspondence between electromagnetic field-to-wire coupling and bulk cable injection (BCI), this works best when cables are electrically short. As cables become electrically long, aspects of the difference between the distributed field coupling and the lumped element BCI coupling manifest themselves as non-idealities. A solution to one such problem – uncertainty due to standing waves – is discussed in this article.

Bulk cable injection (BCI) type requirements such as MIL-STD-461 CS114, RTCA/DO-160 section 20 rf conducted susceptibility, IEC 61000-4-6 and others exist because of shortcomings in radiated susceptibility/immunity testing particularly at lower frequencies where cables are electrically short (Javor 1997). The limits in these requirements are based on a simple algorithm computing the correspondence between radiated field intensity and the resultant conducted cable stress (Javor 1997). These algorithms predict average current on a matched transmission line, but cannot predict standing wave patterns and amplitudes when a cable is not a matched transmission line.

Normally this is not a major issue because standing waves don't significantly alter the average coupled current/potential over the entire cable length, and it is the average that counts, at least on a shielded cable, through the shield transfer impedance. But there is one qualification scenario where the relationship between coupled current from an electromagnetic wave and that induced using BCI has to match up very closely, and standing waves are a potential problem. This is when aircraft are certified or cleared for operation against a high intensity radiated field (HIRF) environment.

In qualifying an aircraft for HIRF exposure, the aircraft is illuminated by a low-level electromagnetic field, and coupled

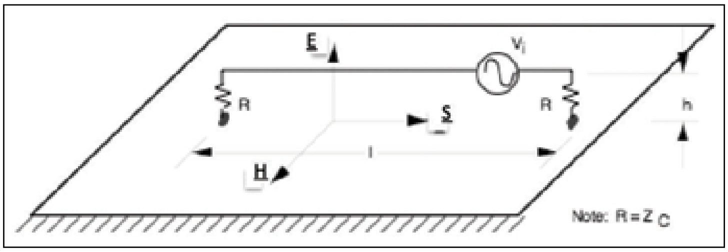


Figure 1: Field vectors and cable over ground plane

currents on selected cables are measured. The coupled current, scaled to the actual threat level, is compared to the connected equipment BCI level of qualification. If the measured and scaled current due to field illumination is higher than the qualification level, the equipment must be retested at the higher level (Carter 1990). So it is critical here to ensure that the *lumped element* bulk cable injection test gives similar results to the distributed coupling from an electromagnetic wave.

BACKGROUND

In the world of HIRF qualification, MIL-STD-461 and RTCA/DO-160 assume cables to be 5 cm above a ground plane, and that results in a field-to-wire coupling efficiency of 1.5 mA per Volt/meter when the cable is at least one-half wavelength long, assuming plane wave illumination with the vectors lining up for maximum coupling efficiency (see Figure 1).

Everything works well if the cable-under-test (CUT) is either electrically short or a transmission line terminated in its characteristic impedance as in Figure 1, but the typical case is anything but that. Most HIRF certification focuses on circuits with flight- and/or safety-critical functions. These are typically not only shielded, but often carry an overbraid, with a 360 degree peripheral termination to aircraft structure, or to the face of an avionics enclosure, which amounts to the same thing on a conventional metallic aircraft. Here then we have a case of ultimate mismatch: a CUT with characteristic impedance around 300 Ohms, terminated in a milliohm impedance to ground, and with very low resistance in the shield material, leading to standing waves. We expect significant standing waves, with current maxima at either end of the cable at frequencies high enough to allow for that. Coincidentally, we place the current monitoring probe, whether for measuring coupling from the electromagnetic field or that induced by a BCI clamp, within 5 cm of the cable end, precisely where a current maximum can occur during illumination.[1]

1 Note the reason for this doesn't apply to a shielded cable at all; the reason is so that the probe measures the current going into the equipment-under-test (EUT) but that is only meaningful for an unshielded cable. With a shielded cable, the susceptibility mechanism is not the current at the shield termination point, but the average current over the entire cable length, which converts to a common mode potential on protected inner wiring through the shield transfer impedance.

The entire issue of standing waves and disparities between field-to-wire coupling was debated back in the 1990s (Perini 1993, 1995-1, 1995-2), (Trout 1996) and (Javor 1997). The upshot is that, for a shielded cable, it is only necessary for a BCI technique to capture the worst-case average stress coupled by an electromagnetic field. But greater fidelity is needed for HIRF clearance.

Now if the EM-wave illumination results in precisely the same standing wave pattern as when undergoing BCI testing, all is well. But that assumes that the effect of inserting a probe and/or clamp on a cable does not materially affect the results. This is about the inserted impedance when a probe or clamp is placed around a cable. We normally ignore that effect, but it is the purpose here to investigate it.

First, a little test and measurement philosophy. Typically it is highly desirable that the act of measurement not disturb the measured quantity. This is most likely to be achieved with a low-inserted impedance probe. But since the BCI test method forces the use of a near 50 Ohm inserted-impedance injection device at higher frequencies, it becomes necessary to compare and contrast the effect of low and high impedance devices, and perhaps compromise the purity of the EM-field coupled current measurement in order to achieve the more important aim of accurate field-coupled vs. BCI level comparisons.

A current probe is characterized by its transfer impedance (Z_T dB Ohms), which is the ratio of the output voltage to the current on the wire around which it is clamped. An injection clamp is characterized by its insertion loss (IL dB), which is the ratio of its input power compared to the power dissipated in one of the 50 Ohm loads in the calibration fixture in which it is placed. As a result of how it is defined, IL is always a negative value, and conservation of energy alone says it cannot exceed -3 dB. The mismatch between the 50 Ohms driving impedance and the calibration fixture 100 Ohm load impedance contributes another decibel, so that -4 dB represents lossless performance. A highly efficient probe has 5 dB insertion loss, and many hover between 5 – 7 dB over much of their useful frequency range. Because the fixture is the same for probes and clamps, and a clamp can be used as a probe, it works out that insertion loss is related to transfer impedance like this:

Z_T dB Ohms = IL dB + 34 dB Ohms

Further, the impedance inserted in a cable by the action of placing a probe or clamp around it is the transfer impedance divided by the turns ratio. The turns ratio is simply the number of windings around the probe/clamp toroidal core, because the other winding is just the wire through the window, which is one turn.

$Z_{inserted}$ (dB Ohm) = Z_T dB Ohms – 20 log (turns ratio)

The typical probe has a transfer impedance from well below 1 Ohm to about 5 Ohms, with turns ratios from as high as 20 on low frequency probes to maybe 2 or 3 on higher frequency probes. And the typical injection clamp used at high frequencies is a single turn device with an insertion loss of less than 6 dB, resulting in a transfer impedance approaching 30 dB Ohms and therefore an inserted impedance of the same magnitude.

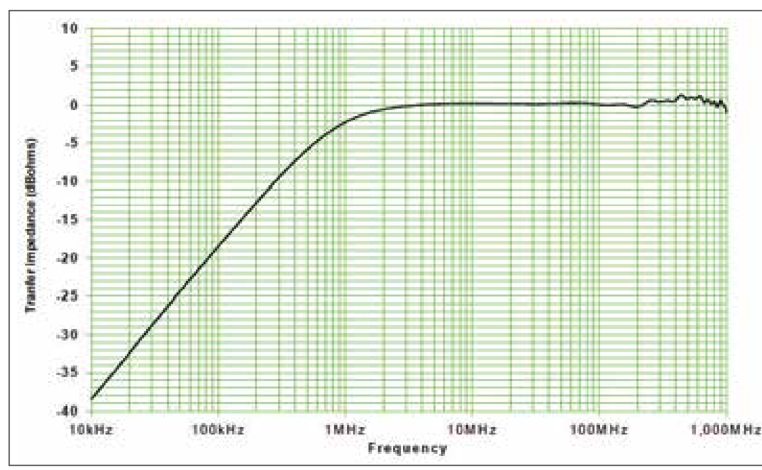


Figure 2a: Fischer Custom Communications F-65 probe transfer impedance (from FCC's website)

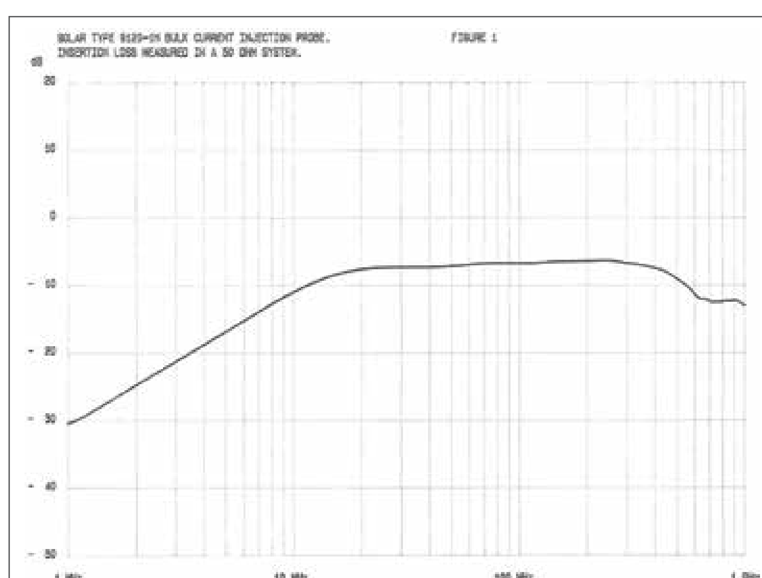


Figure 2b: Solar Electronics Model 9120-1N injection clamp insertion loss (from Solar's current probe/injection clamp catalog)

In the testing described below, a 1 Ohm transfer impedance probe was used inserting no more than 1 Ohm in a cable. Information on the turns ratio was not forthcoming, but we know that the inserted impedance is at or below 1 Ohm. Also an injection clamp inserted 30 dB Ohms. Relevant plots are shown in Figures 2a and 2b. Note that the 30 dB Ohms is a real or dissipative impedance representing the 50 Ohm load on the clamp coax connector reflected across the turns ratio, in parallel with clamp core losses. This lossy type of impedance will detune a resonance. The effect of placing these different inserted impedances at current maxima on the CUT is characterized herein.

INVESTIGATION OUTLINE/SUMMARY OF RESULTS

In order to demonstrate the problem and solution, this investigation performs the following steps:

- Illuminates a cable with a plane-wave from 2 – 200 MHz
- Measures the average coupled current to that cable with
  - no probe installed
  - a low impedance current probe installed
  - a high impedance injection clamp installed

The above steps demonstrate no effect on average coupled current due to probe or clamp installation. The next step illuminates the cable at a single frequency:

- Measures coupled current at current probe position and average current using both low impedance probe and high impedance clamp. A 12 dB difference in current at the probe location is seen, while there is no difference in average current.
- Measures average coupled current using BCI drives that equal the 12 dB apart currents measured with probe and clamp under the plate. Predictably, the average currents are also 12 dB apart, and the average current that is closest to that under the plate is when the current was measured with the high impedance clamp used as a current probe.

The above steps and results demonstrate that the use of the high-inserted impedance clamp as a probe during the HIRF low-level swept cw measurement does not perturb the measurement, and results in much closer agreement between said measurement and equipment-level BCI test results. This is where the concept of critical damping is a useful analogy. Achieving correct damping is a familiar concept to electrical, mechanical and even civil engineers (think the Tacoma Narrows bridge failure of 1940). Here we seek to add an optimal amount of dissipation to a high "Q" system such that what we measure better tracks the average system response instead of a localized peak response.

Figure 3: Cable-under-test. LNA connection visible at left.

Figure 4a: CUT under plate. LNA connection visible at left.

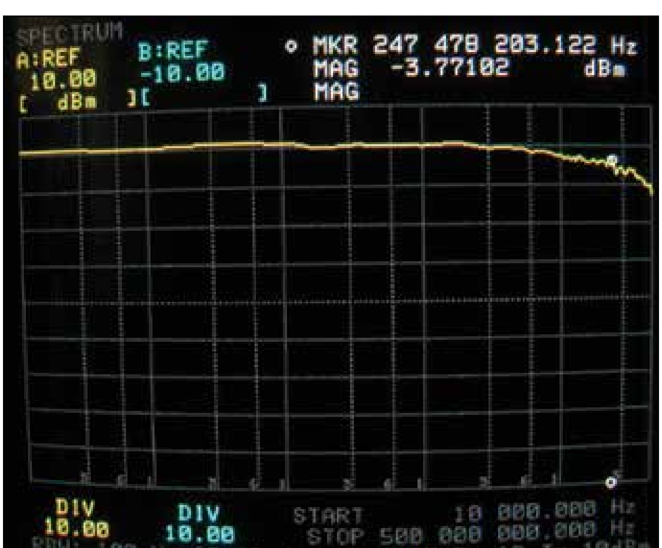


Figure 4b: Load end plate potential when driven by 15 dBm. The low frequency plateau represents resistive voltage division in the 50-to-90 and 90-to-50 Ohm adapters, but the high frequency roll-off represents plate and matching network frequency-dependent losses/mismatches.

MEASUREMENTS

Field-to-Wire Coupling

In this investigation, a parallel plate establishes the requisite field illuminating a cable 36 inches (90 cm) long, 5 cm above a ground plane. The CUT is shown in Figure 3, and is 50 Ohm RG-8 terminated in N-connectors which are connected to 50 Ohm loads on both ends. One end is a dummy load, the other end is a 50 Ohm input low noise amplifier (LNA) with 30 dB gain. A 50 Ohm transmission line was selected so that the coupled potential at either end would be the same throughout and thus be a measure of the average current coupled to the outer shield, through the transfer impedance of the shield. RG-8 was selected in particular because it is single-shielded and therefore has higher transfer impedance yielding a higher level signal to measure, and also because the shield material is just pure copper, as opposed to coated wires with lower transfer impedance. N-connectors were chosen for being threaded and maintaining low transfer impedance over the uhf range of this test, whereas a bayonet type connector would have leaked and compromised test results at just the points at which current maxima are to be expected.

Most measurements were made at 133.6 MHz, a frequency selected by placing a Fischer Custom Communications F-65 probe at the cable center point and sweeping from 100 – 200 MHz looking for a null, or current minimum. That defines the lowest frequency at which the cable is resonant: it isn't computationally a half-wavelength long, but is acting like it. The lowest frequency is useful in minimizing parasitic effects, of which there were many in this suite of measurements. Above 100 MHz, the set-up was very easily disturbed by a hand placed in the vicinity of the probe or the probe-connected cable. Hence, the probe cable termination point at the edge of the ground plane to allow fixed cable geometry between set-ups (seen in later figures).

For electromagnetic wave illumination purposes, the cable is placed within a parallel plate transmission line, as shown in Figure 4a. This plate has a 90 Ohm characteristic impedance and uses 50 – 90 Ohm adapters at both ends. Figure 4b shows plate performance vs. frequency, again indicating that the lowest resonant frequency is the optimum choice. We measure coupled current when driving the plate at a set level at a set frequency or over a frequency span, using the low impedance probe and high impedance clamp, and then comparing both the measured current and the potential coupled to the center conductor.

Measured current is the current at the place the probe is positioned, which is chosen to be a current maximum, while the coupled potential is a measure of the average current along the length of the cable, with the constant of proportionality being the RG-8 shield transfer impedance. This was approximately -30 dB Ohm at 133.6 MHz, an estimated measurement because, once the cable is electrically long, this method loses accuracy for the exact same reason as the subject of this investigation: standing waves.

The next measurement was core potential (potential between RG-8 center conductor and ground) when the cable was illuminated by the plate field. We don't expect (or want) differences here, because the 0.4" diameter RG-8 suspended 2"above ground represents a characteristic impedance of 360 Ohms and the insertion of 50 Ohms in series with that is about 1 dB change. In Figure 5, three traces are shown, representing no probe or clamp around cable, the 1 Ohm transfer impedance F-65 around the cable, and the near 50 Ohm Solar Model 9120-1N around the cable, these latter two at the same place along the cable, near one end.
Figures 6a and b show the placement the F-65 and the Solar Electronics Model 9120-1N with a measured 30 dB Ohm transfer impedance. Figures 7a and b show the measured currents with just the probe in place, and also the clamp. The clamp reduces the resonant current by 12 dB.

Detuning the resonance isn't much help if placement of the clamp also reduces the total or average coupled current. We need just the right amount of detuning, without inserting so much impedance that the overall current is reduced. Figure 5 has so indicated on a broadband basis; Figure 8a shows the

Figure 5: Core potentials (measured at output of LNA with 30 dB gain). All three traces are nearly coincident over most of the 2 – 200 MHz frequency range, but some differences are visible. The yellow trace is for no probe or clamp on the cable, the green trace is the F-65 around the cable, and the orange trace is with Solar Model 9120-1N clamped around the cable.

Figure 6a: FCC Model F-65 under plate

Figure 6b: FCC Model F-65 current probe with Solar Model 9120-1N to detune resonance

Figure 7a: Measured current with F-65 probe in place: dBuV = dBuA

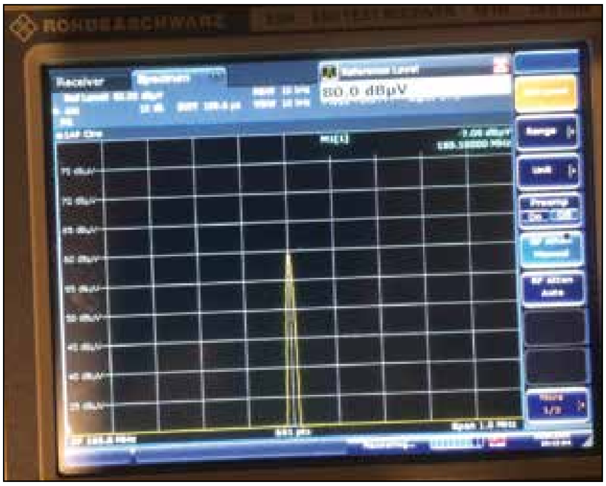


Figure 7b: Measured current with F-65 probe adjacent to Solar Model 9120-1N clamp: dBuV = dBuA

Figure 8a: Set-up for measuring potential coupled to RG-8 center conductor. In this figure, only the F-65 is placed under the plate.

Figure 8b: Coupled potential (measured at output of 30 dB gain LNA) with and without the clamp in place. There are actually two separate traces here, but they are coincident, demonstrating that the placement of the high impedance clamp has no effect on the average cable-induced current.

effect of the probe and clamp placement on the potential coupled to the inner conductor at 133.6 MHz, which is proportional to average current through the shield transfer impedance (-30 dB Ohm). Figure 8b can be interpreted using the equation below to mean that average coupled current is 55 dBuA.

$$I\ \mathrm{dBuA} = V_{measured}\ \mathrm{dBuV} - 30\ \mathrm{dB} - Z_{T\ RG\text{-}8}\ \mathrm{cable\ dB\ Ohm}$$

The next order of business is to use the Solar Model 9120-1N injection clamp as a probe instead of the combination F-65 current probe and clamp as a de-tuner.
Figure 9a shows the set-up, and Figure 9b shows the measured current.

The last thing to check is the coupled potential when the clamp alone is in place and the current induced on the cable is that in Figure 9b, as shown in Figure 9c.

BCI Measurements

Average current is in reasonable agreement under the plate using both high and low inserted impedance probes and clamps. It is time to look at how well bulk cable injection simulates the above results. Figure 10 shows the set-up.

The first task is to drive the Model 9120-1N hard enough to induce the same current as measured by the F-65 when the plate illuminated the cable. This is shown in Figure 11a. When this current has been induced, the coupled potential is measured (Figure 11b) and compared to that occurring under the plate. The coupled potential measured in Figure 11b means that the average current is 72 dBuA, which is much higher than was seen under the plate. When the 57 dBuA measured with the Solar 9120-1N under the plate is induced, as in Figure 11c, the resultant coupled potential is very similar to that measured under the plate.

Compare core potentials in Figures 11b and 11d to the 55 dBuV recorded in Figure 8b, which was the same whether the clamp was in place, or just the probe. This is the payoff: using the clamp to monitor current when the cable is plane-wave illuminated yields a measurement that gives core potentials (average current) 2 dB below what is obtained when that current is induced using BCI techniques. However, if only the probe is placed around the illuminated cable, and that current is induced using BCI, then BCI causes 15 dB higher coupling than plane wave illumination. It is clear that the use of a BCI clamp as a pickup probe detunes the resonance without reducing average cable current.

CONCLUSION

Direct comparison of illuminated cables vs. BCI levels of qualification can have significant errors when a low inserted-impedance probe is placed at a current maximum point during the illumination phase. Use of an injection clamp acting as a current probe during the illumination phase dampens constructive interference and minimizes the error when the cable is electrically long. The conclusion is that use of a BCI clamp as a pickup device is better than a low impedance probe for the purpose of establishing correlation with BCI qualification levels for electrically long, shielded cables.

Figure 9a: Solar Model 9120-1N injection clamp used as current probe

ENDNOTES

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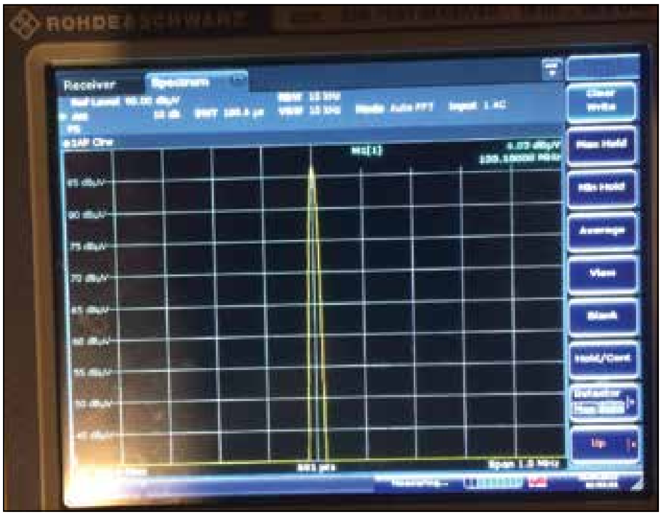

Figure 9b: Measured current using Solar Model 9120-1N injection clamp as a current probe. Unlike the FCC Model F-65 with 0 dB Ohm transfer impedance, the transfer impedance here is 30 dB Ohms, so the actual current is 87 dBuV – 30 dB Ohms = 57 dBuA, within 3 dB of current measured in Figure 7b.

Figure 9c: Potential coupled to RG-8 center conductor when 57 dBuA current as per Figure 9b is induced on cable shield. 5 dB higher than measured in Figure 8b, which was coupled potential with the F-65 and also the Model 9120-1N around the cable.

Figure 10: Overall view of the BCI set-up on the same cable that was illuminated under the plate. Solar Model 9120-1N on the left, FCC Model F-65 to its right.

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Figure 11a: Model 9120-1N BCI clamp driven hard enough to induce 72 dBuA current on CUT.

Figure 11c: Model 9120-1N BCI clamp driven hard enough to induce 57 dBuA current on CUT.

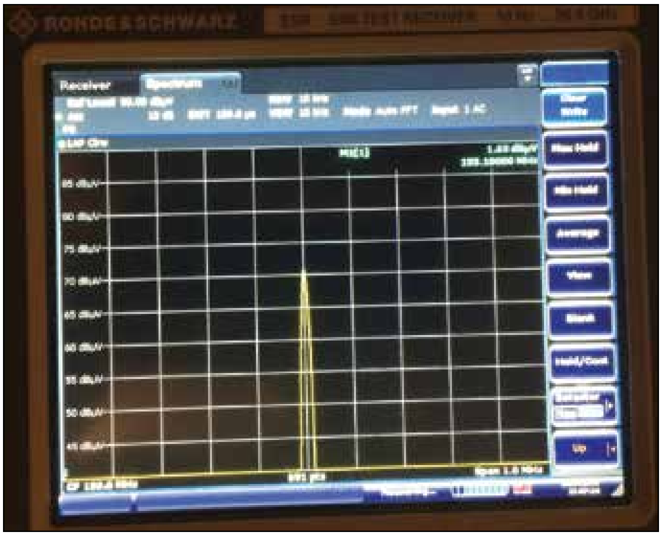


Figure 11b: Coupled potential when Model 9120-1N BCI clamp driven hard enough to induce 72 dBuA current on CUT.

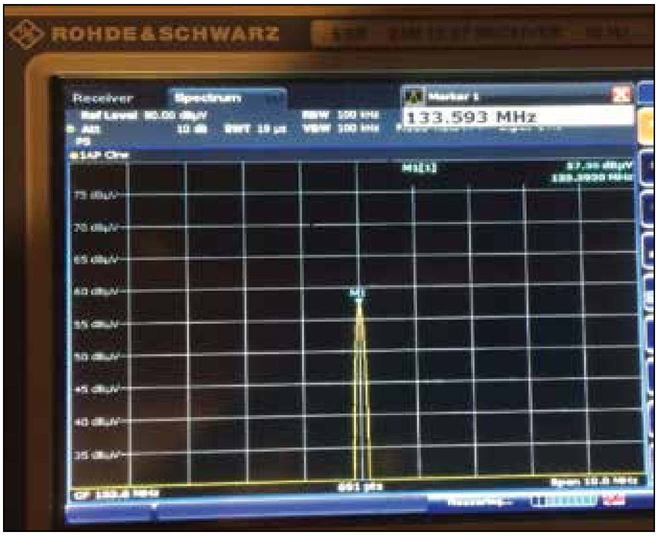


Figure 11d: Coupled potential when Model 9120-1N BCI clamp driven hard enough to induce 57 dBuA current on CUT.

High Temperature Thermoplastic Microwave Absorbers

for Control of Electromagnetic Interference

BY ROBERT BOUTIER AND ANDREW LABAK

For decades, the power of computers has grown rapidly as designers have managed to place more and smaller transistors onto a silicon chip, doubling the number every two years, leading the way to increasingly powerful and inexpensive personal computers, laptops and smartphones. As the number of transistors has increased, more power is required to run economically, and subsequently the service temperature requirements of microwave absorbers used to mitigate unwanted energy has increased. Additionally, if the absorber is to be placed on the circuit board, the material needs to be able to withstand the solder reflow process.

Microwave absorbers based on several thermoset polymers can be used, however when the need for high volume manufacturing exists, this class of materials can become costly because of the associated machining or die cutting processes. Thermoplastic absorbers based on high temperature polymers offer a solution to both of these needs. Certain polymers are capable of withstanding 200° C long term in addition to the short duration, higher temperature solder reflow conditions. Thermoplastic based absorbers can also be injection molded rapidly in large quantities, making the process economical.

This article reviews one thermoplastic polymer in particular, polyphenylene sulfide, that when combined with a soft magnetic filler, carbonyl iron powder, provides excellent microwave absorptive properties along with high temperature stability.

BACKGROUND

In 1979, as digital system interference in communication equipment was increasing, the U.S. Federal Communications Commission (FCC) required that the electromagnetic emissions of all digital devices be below certain limits in order to reduce the number of instances of EMI and "electronic pollution." Other countries also imposed similar restrictions. Many manufacturers already had internal limitations established to minimize interference; however, this regulation resulted in increased interest and the development of many varied solutions to overcome EMI.

Designing compliant and effective devices has become an increasingly difficult task as electronics have evolved into smaller, multi-functional packages. Increasing clock speeds and subsequent higher frequencies have transitioned electromagnetic control microwave absorbers from shielding components because of the associated higher emissions at shorter wavelengths. Emissions at high frequencies are beginning to approach the physical dimensions of many microwave cavities, which can lead to cavity resonance effects. Standing waves exist inside the cavity if the largest cavity dimension is greater than ½ wavelength, making the enclosure act as a resonator, affecting circuit performance. If a noise source has a frequency that corresponds to a resonant point, a large field can be generated due to the multiplication or amplification effect if there is not a high rate of energy loss relative to stored energy.

To address cavity resonance, microwave absorbers can be inserted onto a wall or roof of the enclosure with a pressure sensitive adhesive (PSA) to absorb standing waves, thereby keeping the electronics performing optimally. Absorbers can also be placed at the source, i.e., directly on the radiating element, in order to eliminate coupling of the electronic field with the chassis, so currents will not flow into the chassis and set up circulating currents within it. For moderate to high power chips radiating unwanted energy, the need for absorbers that can withstand high temperatures is becoming necessary.

An electronic load is a device that simulates loading on an electronic circuit. It can be any electronic device connected to a voltage source such as a radio, antenna, computer, a resistance, etc. When discussing electromagnetic control, a load is a passive device which will reduce or change the unwanted microwave voltage, power, current or phase in a microwave circuit. The load will act as a power drain, or as a microwave absorber for unwanted electromagnetic energy, but can also act as a wave tuning component because of its intrinsic magnetic and dielectric properties.

Terminations are especially fabricated for use at microwave frequencies. Molded resistive wedges are commonly employed and consist of a dissipative material dispersed in a dielectric medium. In moderate to high power waveguide terminations, a wedge of lossy dielectric absorbing materials is used, shown in Figure 1. The length-to-base width taper of

Load termination in the form of a wedge inserted into one half of a rectangular waveguide

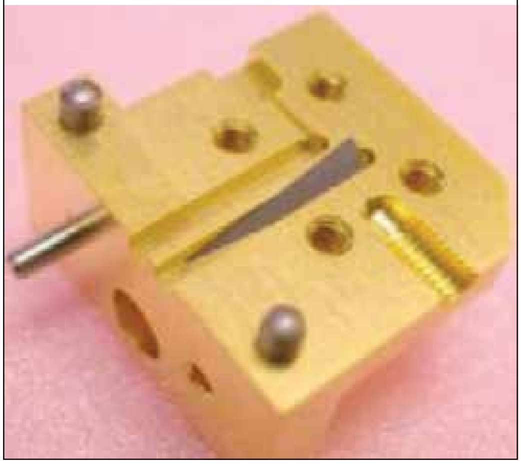


Figure 1: Microwave load termination

approximately 10:1 ensures very low return losses, mandatory in military radar systems and waveguides used in low signal to noise conditions. When high power is involved, resistance to high temperatures is important as the load can become extremely hot.

Microwave absorbers can come in a variety of forms, from rigid to flexible to foam. They can be made from virtually any polymer and contain a variety of fillers from magnetic or dielectric to control the electromagnetic performance. Magnetic fillers are most commonly used in enclosed electronic devices since the magnetic portion of the wave dominates in the near field. Carbonyl iron powder is commonly used when the frequencies of concern are anywhere between 1 and 40 GHz. Below this frequency, specialty alloys are used, and above this frequency dielectrics are typically employed.

Carbonyl iron powder is a highly pure iron prepared by thermal decomposition of highly purified iron pentacarbonyl. In the process, spherical particles form on a nucleus, thereby developing a shell structure. The particles give outstanding magnetization behavior for electronic applications and are frequently used as inductor core material in power supply converters. Typically, one desires the composite to be highly filled with carbonyl iron in order to attain good absorption or attenuation, although lesser loaded composites will exhibit resonances at higher frequencies, which can sometimes be advantageous.

The polymers employed in the composites are for the most part the binder that holds the filler together and are therefore selected based on their flexibility, thermal stability, compressibility, machinability, etc. The polymers often used are commonly thermosets such as epoxies or silicones. These materials are liquid in the uncured state and can therefore accommodate reasonably high filler loadings, thereby providing the necessary electromagnetic control, although large volume manufacturing of parts with specific shapes can become costly.

For large volume applications, thermoplastic polymers offer a more cost effective alternative because the secondary injection molding process is rapid and the cost per part decreases as the volume increases. Once the initial outlay of the tool cost is realized, the piece price can be minimal. Various thermoplastic based absorbers are on the market filling this niche, including polypropylene and thermoplastic elastomers (TPE) for lower thermal requirements. However as previously mentioned, the need for higher thermally rated materials is on the rise because of the close proximity of components and higher power requirements.

Several high temperature thermoplastic polymers for microwave absorbers have been investigated to fill this need, specifically polyphenylene sulfide (PPS) and liquid crystal polymer (LCP).

THE EXPERIMENT

PPS is a semi-crystalline polymer offering excellent high temperature resistance, chemical resistance, flowability and dimensional stability. PPS has a repeating molecular structure, as shown in Figure 2. It has a high melt flow index thereby having a very low melt viscosity, allowing for high filler loadings. It is very brittle, but this becomes minimized when filled. The polymer is also inherently flame retardant making it ideally suited for electrical applications.

LCP is also a semi-crystalline polymer, having long, rod-like molecules that are ordered in the melt phase, unlike other polymers whose chains become entangled in the molten state. A representative LCP structure is shown in Figure 3. The polymer has a very high heat deflection temperature, near 300° C, high melt flow, combined with high mechanical strength and dimensional stability. Like PPS, LCP is inherently flame retardant and promoted as being able to withstand solder reflow conditions.

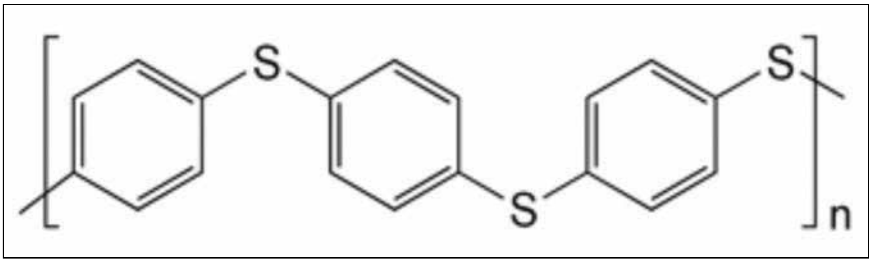


Figure 2: Polyphenylene sulfide

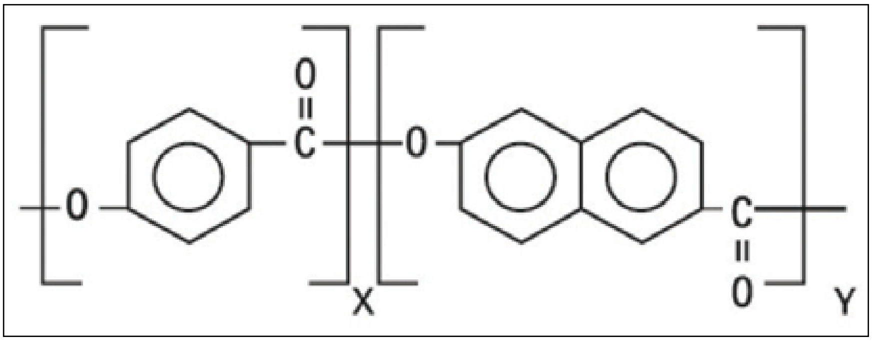


Figure 3: Liquid crystal polymer

Figure 4: X-band frequency antennas

In order to compare the two thermoplastic absorbers, it was necessary to make a number of sample batches of composite material with a compounding process and then produce test pieces with injection molding. The compounding work was done on a Micro-18 Leistritz co-rotating twin screw extruder and the injection molding was completed on a 40-ton injection molding machine. Specialized tools were used to create small samples (1.0 mm x 22.9 mm x 2.5 mm) for electro-magnetic testing and traditional tensile bar tests pieces for measuring mechanical properties.

A total of 23 individual batches were compounded, injection molded, and tested. For PPS, this consisted of five batches with a volume loading of 48.5 percent carbonyl iron powder, five batches with a volume loading of 50.3 percent and one batch each with a volume loading of 10, 20, 30, and 40 percent volume loading.

Nine batches were prepared using LCP as the binder, with five batches having volume loading of 48.5 percent carbonyl iron powder and one batch each with a volume loading at 20, 30, 40, and 50.3 percent volume loading. The small sample pieces were tested in the x-band frequency range (8 – 12 GHz) using a waveguide test fixture and a network analyzer, shown in Figure 4. The sample holder, which can be seen in testing position in Figure 4, is shown on its own in Figure 5. The density of each small sample piece was measured using a pycnometer and the volume loading of carbonyl iron for each sample piece was calculated using the known densities of the components.

Figure 5: X-band frequency sample holder

Using magnitude and phase of both transmission and reflection data, the real and imaginary components of the relative permeability (u^*) and permittivity (e^*) were calculated. Using these parameters the attenuation at 10 GHz for each sample was then calculated. Attenuation is a measure of how much the energy of a wave propagating through the material is reduced and is expressed as a rate per unit distance, usually expressed in dB/in or dB/cm. Attenuation in dB/cm is given in Equation 1.

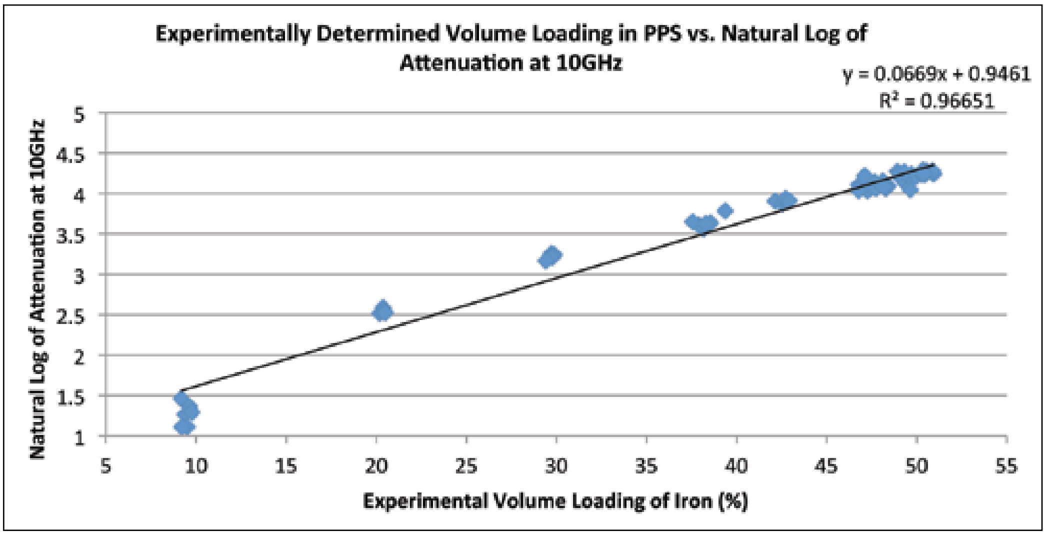
THE RESULTS

The loading levels at 48.5 percent and 50.3 percent were prepared because these levels of CIP are known to provide excellent attenuation in other composites. The lower loadings were prepared in order to establish a relationship with attenuation. The natural log of attenuation forms a linear relationship with the volume loading of a two component composite, therefore using the experimentally determined volume loadings and the calculated attenuation values for every sample piece, this relationship was determined for both the PPS and LCP composites, shown in Graphs 1 and 2.

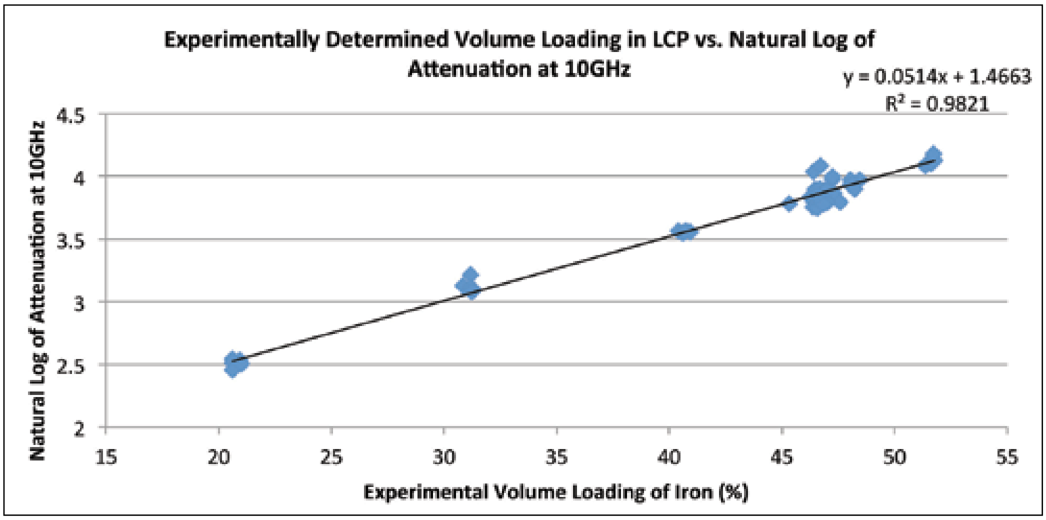
$$Attenuation\left(\frac{dB}{cm}\right)=\frac{2\pi(8.686)}{\lambda_0}\sqrt{\frac{\mu'\varepsilon'}{2}\left(\sqrt{(1+\tan^2\delta_d)(1+\tan^2\delta_m)}-(1-\tan\delta_d\tan\delta_m)\right)}$$

$$\varepsilon^*=\varepsilon'-j\varepsilon'' \qquad \mu^*=\mu'-j\mu'' \qquad \tan\delta_e=\frac{\varepsilon''}{\varepsilon'} \qquad \tan\delta_m=\frac{\mu''}{\mu'}$$

Equation 1



Graph 1: Ln of attenuation vs volume loading of PPS composites

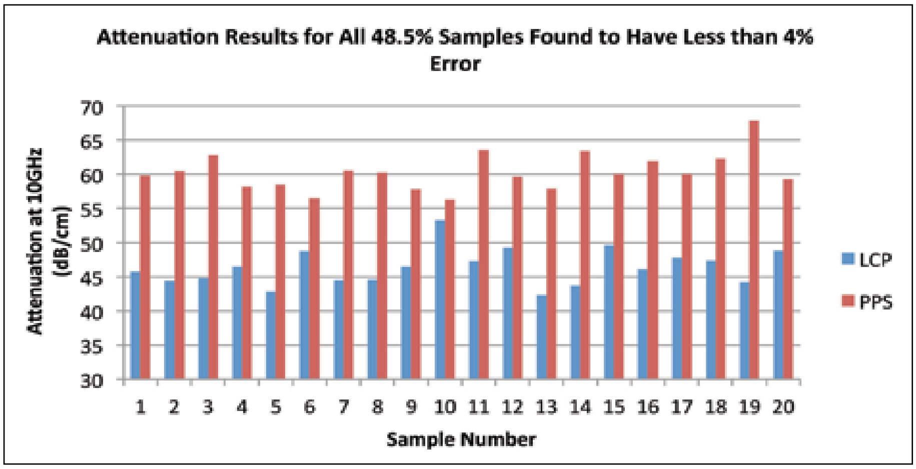


Graph 2: Ln of attenuation vs volume loading of LCP composites

Although it had been assumed that the carbonyl iron powder content was overwhelmingly the driving factor in attenuation, it can be seen that the thermoplastic binder played a significant role in attenuation from the difference in linear relationships shown above. Another way to examine this difference is a side by side comparison of attenuation for the LCP and PPS samples with the same volume loading. This can be clearly seen for samples where the measured density was less than 4 percent off from the theoretical value. The LCP samples had an average attenuation of 47.7 dB/cm while the PPS samples had an average attenuation of 60.4 dB/cm.

Tensile bar samples from both polymers at the 48.5 percent volume loading were used to determine average expected tensile as well as to help determine thermal stability. Samples underwent thermal aging at set temperatures for 500 and 1000 hours and then measured for tensile strength. By exposing test pieces to a series of elevated temperatures, the relationship between the rate of degradation and temperature can be determined. This test procedure is outlined in International Standard (ISO) 11346.

Different samples also underwent a slightly exaggerated solder reflow process simulation; spending five minutes in a furnace at 280° C, slightly over a typical maximum



Graph 3: Attenuation of PPS and LCP composites

Thermal Aging Conditions	Control	180°C 500 hr	180°C 1000 hr	200°C 500 hr	200°C 1000 hr	280°C 5 min
Average Tensile Strength	4370	5990	5630	5280	5120	3580
Variation from Control	N/A	+37%	+29%	+21%	+17%	-18%

Table 1: PPS thermal aging tensile results

Thermal Aging Conditions	Control	200°C 500 hr	200°C 1000 hr	230°C 500 hr	230°C 1000 hr	280°C 5 min
Average Tensile Strength	3850	2860	1000	800	0	380
Variation from Control	N/A	-20%	-67%	-74%	0	-90%

Table 2: LCP thermal aging tensile results

temperature of 260° C. For each condition, five samples were taken and the results averaged, shown in Tables 1 and 2.

There is no recorded result for the LCP samples which underwent 1000 hours at 230° C because all samples were too weak to withstand the pressure applied to test pieces in the grips of the tensile testing machine.

Physical changes to the thermally aged samples were also noted. All thermally aged samples, both PPS and LCP, underwent a color change becoming darker, shown in Figure 6. The PPS samples developed a brittle outer layer from oxidation. Some sections of this outer layer would flake off during tensile testing, but in general this layer remained intact on samples. This layer could in part explain the increase in tensile strength values measured for most of the PPS samples. The LCP samples which experienced higher temperatures (230°C and 280°C), developed small bubbles on the surface.

CONCLUSION

It is known that polymers filled with carbonyl iron will exhibit inferior thermal resistance compared to the virgin polymer because of the oxidation of the carbonyl iron. Polyphenylene sulfide (PPS) is a high temperature polymer, although actually rated below LCP. However, when filled with carbonyl iron, it was shown to demonstrate excellent long term thermal stability as well as surviving solder reflow conditions because of its inherent chemical

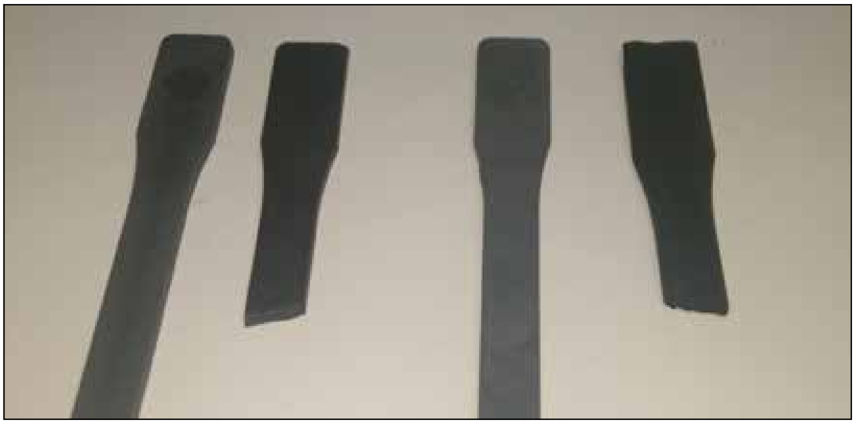


Figure 6: Visual comparison of samples (from left to right: unaged PPS, aged PPS, unaged LCP, aged LCP)

Figure 7: Various microwave absorber shapes

and thermal stability. Liquid crystal polymer (LCP), is one of the highest temperature polymers, capable of withstanding temperatures up to 230° C long term. However, when filled with carbonyl iron to function as a microwave absorber, it was unable to withstand continuous exposure at 200° C. This composite also was unable to withstand solder reflow conditions, yet unfilled material performs extremely well.

PPS is a polymer made up of alternating sulfur atoms and phenylene rings in a para substitution pattern, as shown in Figure 1. These highly stable bonds give the polymer stability toward thermal degradation and chemical reactivity. Also because of its molecular structure, PPS tends to char during combustion, making it flame retardant. Loading the PPS polymer with carbonyl iron powder allows it to function as an effective microwave absorber, essentially comparable to other carbonyl iron-filled materials with the advantage that it offers excellent short term and long term thermal stability. It has been demonstrated that these composites can also withstand solder reflow conditions as well as being resistant to long term exposure to 200° C. This composite can therefore realize applications as an absorber at the board level. Being thermoplastic, this material can be easily injection molded into complex parts in large production quantities.

PPS absorbers provide a variety of outstanding properties such as:

- High service temperature of 200° C
- Withstand solder reflow conditions
- UL94 V-0 flame rated
- High iron loadings translating to excellent RF properties
- Complex 3D shape designs
- High modulus and creep resistance
- Chemical resistant

These high performing absorbers based on PPS see applications not only as waveguide terminators in the form of a wedge, but can be molded into a variety of shapes for applications such as caps and covers, RF filters and cavity resonance absorbers, shown in Figure 7.

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A Novel Concept for EMC Radiated Immunity Testing Using Field Generators

BY AMMAR SARWAR AND VINCENT KEYSER

The pressure to bring new products to the market, with reduced time to market, high quality and reduced cost, has never been greater. For most electrical and electronic products, the necessity of complying with electromagnetic compatibility (EMC) regulations in order to sell in global markets adds to these pressures. Considering the increased importance of EMC testing for electronic systems, the associated challenges seem to grow simultaneously. These challenges range from increased importance of EMC in the product design phase, to improving EMC test standards for new technologies to developing more efficient instrumentation for EMC testing.

The RF immunity standard IEC-61000-4-3 specifies a requirement to generate a uniform field at a test distance of 3m between the tip of antenna and the device under test (DUT). Such an area with a uniform field is termed a quiet zone in the EMC industry. A certain level of E-field is applied to the DUT, placed in the quiet zone for immunity testing. The area of uniform illumination is 1.5 by 1.5 meters to ensure that portions of

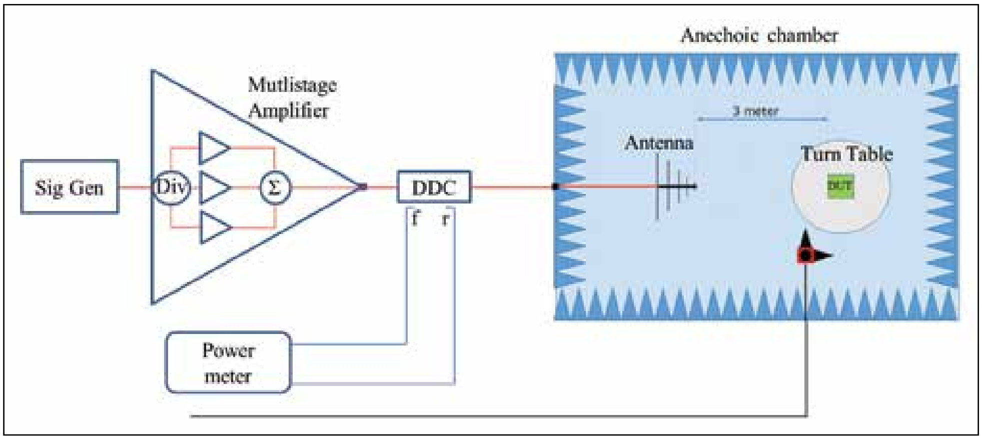

Figure 1: Conventional RI setup

Typical loss values (dB)					
Freq (GHz)	Combiner	Coupler	RF cable	Total Loss	
				3m cable	10m cable
1	0.6-0.8	0.2-0.4	0.1 dB/m	1.1-1.5	1.8-2.2
6	1.5-1.8	0.5-0.8	0.25 dB/m	2.75-3.35	4.85-5.1

Table 1: Loss values in an RI test setup

any interconnecting cable to the DUT is illuminated by the field. The field is deemed uniform when 75 percent of 12 points in this area comply with the 0 to +6 dB rule [1]. In RF immunity systems using traditional design techniques, the designer has to analyze a large number of individual specifications of the system components and take into considerations for their integration into the test system.

CONVENTIONAL SETUP

A typical radiated immunity (RI) test setup consists of many components including antennas, amplifier, signal generator, power meters, directional couplers and E-field probe. Figure 1 presents a typical RI setup according to IEC 61000-4-3. The DUT is placed on the turntable inside the chamber and is placed 3m away from the tip of the antenna [1]. Typically, long runs of RF cables are used to connect from the amplifier output to the input of the dual directional coupler (DDC), from the coupler's output to the feed-through connector on the chamber wall, and from the chamber feed-through to the antenna input.

The power amplifier is one of the most expensive components in an EMC test system. However, in the conventional EMC RI setup such as the one shown in Figure 1, up to 3-6 dB of an amplifier's rated power is lost at multiple stages in the setup itself (see Table 1).

The power loss in the test setup mainly comes from the connecting cables between different parts in the setup. Such pieces of cable from the amplifier output to the input of the DDC, between the coupler's output and feed-through on the chamber wall, and from the chamber feed-through to the antenna input. The amplifier itself also adds to these losses as it consists of multiple stages and a combiner which eventually combines the output of the multiple stages. In addition, the frequency dependent losses of the RF cables exacerbate the situation.

Therefore, on one hand EMC standards specify the test setup requirements in terms of E-field strengths within the quiet zone, while on the other hand such power losses force us to design systems in terms of amplifier rated power and safety margins. Eventually, a much higher rated power amplifier is required to overcome the power loss occurring from the inefficient test setup.

A typical alternate approach used to reduce such losses is to put the immunity rack inside the test chamber. This approach is not only non-compliant with the standard, but it can also impact the immunity measurement results.

FIELD GENERATORS

The Concept

To achieve high output power, the traditional approach is to combine power from small amplifiers, and then this high power is supplied to a single antenna through a path comprising of a directional coupler and a long RF cable.

The proposed model is comprised of active antenna arrays, integrated amplifiers, and directional couplers. Each antenna element in the array has its own amplifier and directional coupler. Instead of adding power in a multi-stage amplifier, field generators combine the E-fields generated by each chain of antenna and amplifier. The amplifiers and antennas are coupled together in the design. Therefore, such field generators not only remove the internal loss within multiple stages of the amplifier rack, but also remove the losses due to the cabling within the amplifier and antenna themselves.

In the following sections, the design of such field generators for the RI test setup in compliance with IEC 61000-4-3 is presented with simulation and measurement results.

Design Considerations

There are several considerations which need to be kept in mind while designing such field generators, the important items are discussed in this section.

Antenna selection

Log-periodic dipole array (LPDA) antennas used in broadband applications can achieve high directivity and low cross-polarization ratio over a very large frequency range. Such wideband antennas have typically been constructed using metallic booms and dipole radiating elements. In applications where space and weight is restricted, antennas need to be light-weight and have a small physical size and increase frequency.

Microstrip antennas that operate as a single element usually have a relatively large half power beamwidth, low gain and low radiation efficiency. In order to improve on these parameters, microstrip antennas are used in array configurations to increase the gain and range of the radiating structure [2]. There are many effects such as mutual coupling between elements which must be taken into consideration

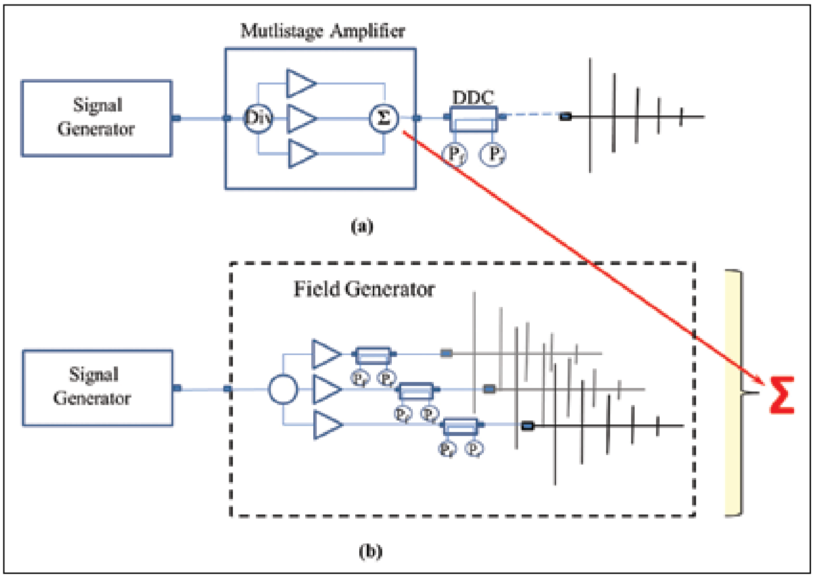

Figure 2: Difference between the typical set up (a) and the new proposed set up (b)

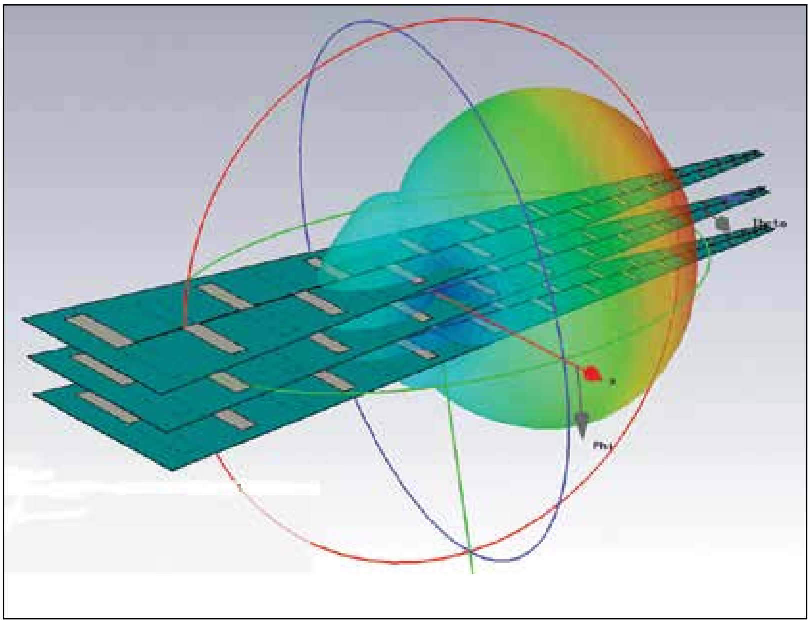

Figure 3: 3D model of the antenna array with highlighted radiation pattern (at f = 1GHz)

when analyzing an array structure. As a result, full wave analyses are usually used to model arrays.

The log periodic antenna structure is similar to a proximity coupled antenna; however, the elements are designed such that they follow logarithmic sizing and spacing [3]. These structures have relatively broad bandwidth. The antenna array in such field generator is comprised of three log-periodic antennas. The antenna array has been designed and simulated in software specifically designed for the purpose. The simulation model of the designed array is shown in Figure 3. The LPDA antennas have 29 elements, resulting in a very low "ripple" on the frequency response. The spacing between the antenna array elements has been optimized for gain and phase matching.

The far field realized gain polar plots of the simulated antenna array are shown in Figure 4, with some results summarized in

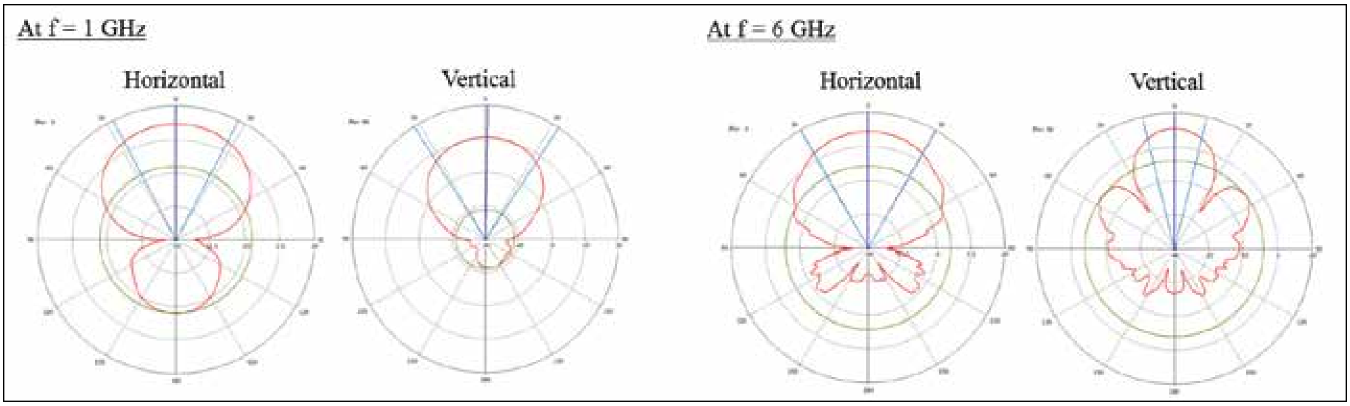

Figure 4: Simulated antenna array aperture

Table 2. It has been shown that the gain of the antenna array is slowly increasing from 1 GHz to 6 GHz (around 11 dB @ 1 GHz and 13 dB @ 6 GHz).

	At f = 1GHz		At f = 6 GHz	
	Horizontal Pol.	**Vertical Pol.**	**Horizontal Pol.**	**Vertical Pol.**
Main lobe mag.	11 dB	11 dB	13.1 dB	13.1 dB
Angular width (3dB)	53.8°	65.7°	59°	27°
Side lobe level	-22.1 dB	-21.8 dB	-12.8 dB	-14.1 dB
Aperture	~30°x30°		~20°x30°	

Table 2: Simulation results of LPDA antenna array

Amplifier Selection

For a trouble-free and long life operation of power semiconductor devices (such as BJT, MOSFET, IGBT), it is critical to keep the overall power dissipation of the device within a safe operating area (SOAR) [4]. In this regard, much emphasis is given on choosing the optimal class of the amplifier for heat generation and dissipation. The class of the amplifier mainly influences its overall efficiency and the load driving capability of an amplifier's output stage. Theoretically, in Class A amplifiers 50 percent of the power is heat whereas in Class AB designs it is only 12.5 percent. Class A amplifiers can achieve efficiency from only 20 percent to 30 percent in reality as compared to 60 percent efficiency in the case of class AB. The Class AB amplifier is chosen for such field generators as it offers the higher efficiency for given output levels.

A field generator presented here has three amplifiers, one for each antenna. Each amplifier has three amplifiers stages, where the final stage is a GaN amplifier. Each amplifier module has its own microcontroller, in order to control all amplifier parameters independently for each amplifier module (bias currents, protections, amplifier gain etc.).

Apart from this, each amplifier module has its own coupler, forward power meter and reflected power meter. The gain

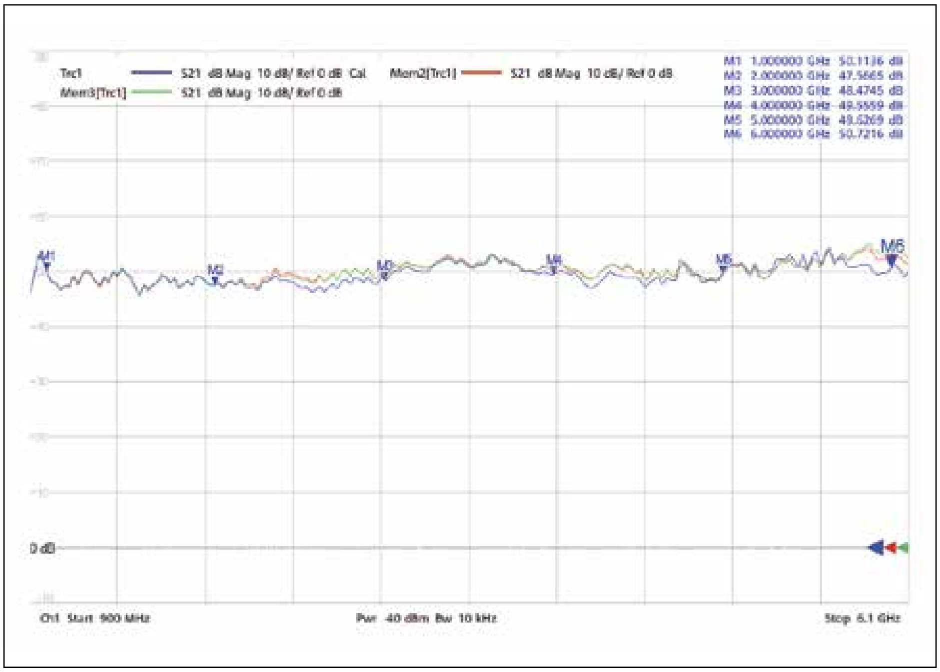

Figure 5: Frequency response measurement of an amplifier

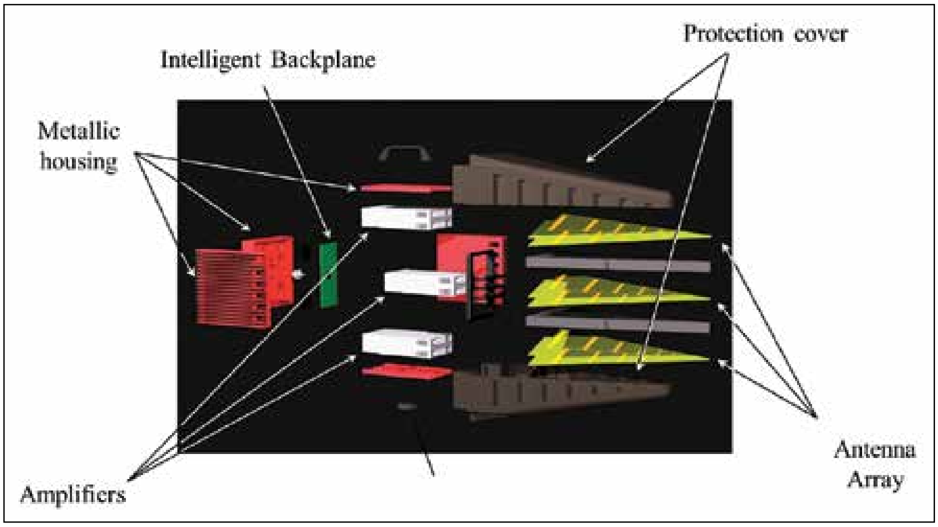

Figure 6: Field generator design

A single coaxial cable performs a dual function. It carries RF input signal to the amplifier, and it also carries the DC power supply signal to power up the electronic circuitry inside the unit.

of each amplifier can be adjusted independently to ensure all antennas are fed with the same RF power. Also, the phase difference between all amplifiers has to be minimized to maintain the desired beam shape.

Figure 5 shows a graph for the overall frequency response from the input connector (at the power supply side) to the output of one of the amplifiers, including a 3 meter N type cable. As can be seen, the frequency response has a slight up tilt at the higher frequency end. This compensates for the frequency response of longer N-type cables.

Integration of the parts

The rectangular metallic housing at the back side is designed as part of the overall radiating element. Therefore, this block does not negatively affect the antenna array performance. A single coaxial cable performs a dual function. It carries RF input signal to the amplifier, and it also carries the DC power supply signal to power up the electronic circuitry inside the unit. Figure 6 shows the complete assembly of a field generator design.

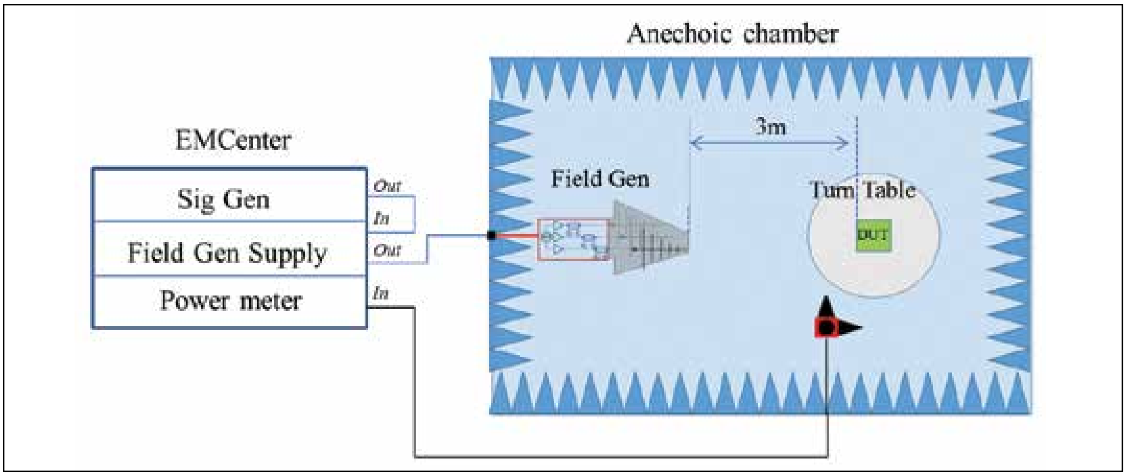

Figure 7: Test setup with field generator

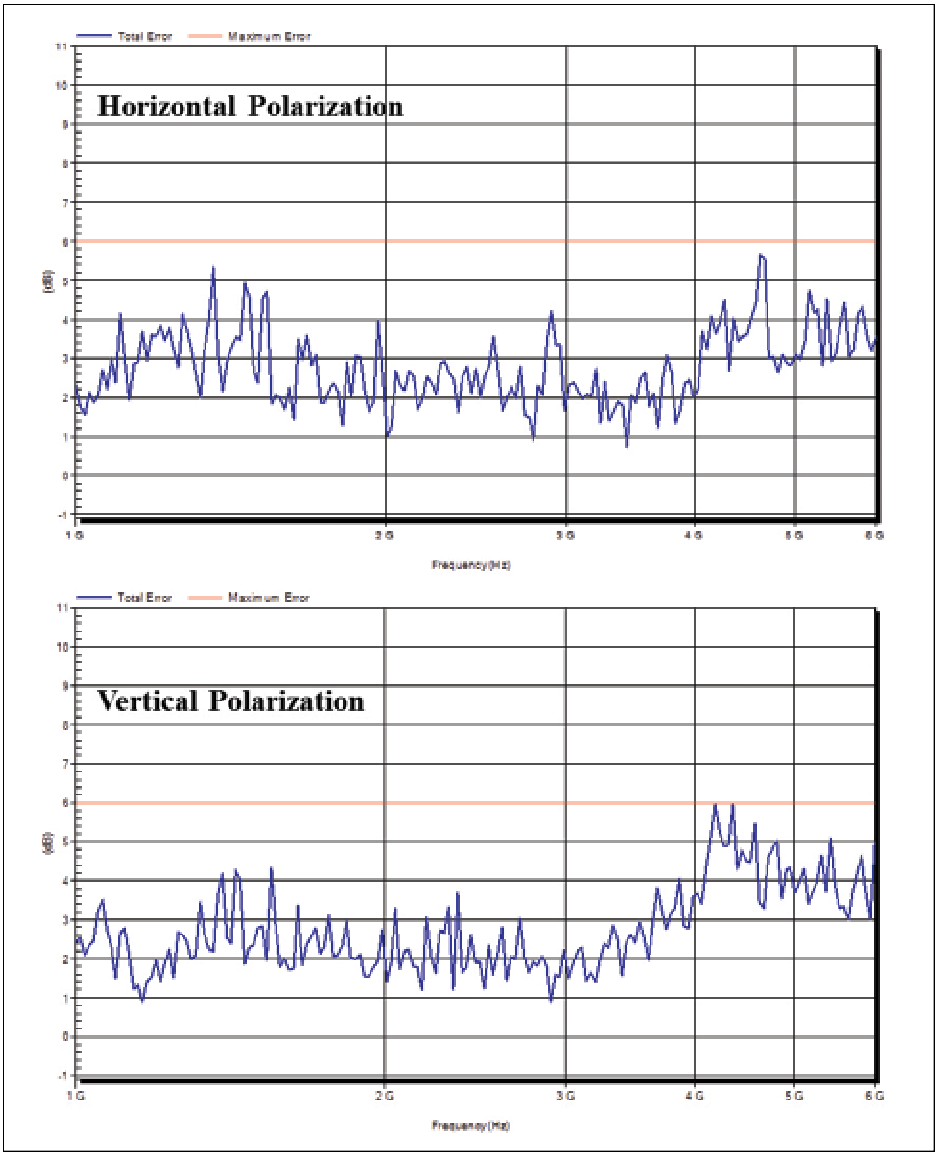

Figure 8: Error graph for the forward power required for the uniform 10V/m

PROPOSED RI TEST SETUP

The new proposed setup with a field generator comes with a slightly different setup than a traditional setup. It is still in full compliance with IEC 61000-4-3. The new setup uses less equipment, and is thus less complex and requires less installation time.

Figure 7 shows the new setup for RI testing according to IEC 61000-4-3. The field generator is placed inside the chamber at a 3 meter distance from the DUT. Our company's proprietary modular platform is used as the main supporting equipment in the new setup. This platform has seven slots for plugin cards, thus is capable of providing seven functionalities at the same time. In the current setup, the platform is configured to be used as a signal generator, power meter, and power supply for the field generator.

The field uniformity tests have been performed at 10 V/m to validate the performance and to ensure sufficient linear behavior of the system. In order to determine if the system produces enough field level, the available power of the system must be at least 5.1 dB (factor 1.8) higher than the highest recorded power of the 16 points at each frequency. This is because, although the validation is performed using CW signals, the standard requires the final tests be performed with a 80 percent amplitude modulation applied. According to IEC 61000-4-3, the available power may be determined at 2 dB compression of the output. The available power of the field generator is 10W per amplifier or 30W in total (44.7 dBm) which means the maximum power in the measurement should not exceed 44.7 dBm – 5.1 dB = 39.6 dBm so that the system has enough headroom to allow for the 80 percent amplitude modulation.

The red line in both the graphs in Figure 8 represents the maximum error limit for 6dB error. The error graph for 75 percent of the measured points in the vertical and horizontal planes are shown in Figure 8. It shows that 12 out of 16 points are within the specified 6 dB error limit.

CONCLUSION

In this article, the concept of field generators is presented and validated as per the RI testing requirements specified in IEC 61000-4-3, i.e. 10V/m at a 3m distance between the DUT and the tip of the antenna. They simplify the test setup in terms of setup complexity and also allow easy installation. The concept is scalable to much higher field strengths and different frequency ranges with design modifications, e.g. varying the number of antenna array elements and modifying the integrated amplifier design. Such field generators not only introduce a new instrument category in the world of EMC testing but also provide a cost-effective solution to the existing challenges in RI testing.

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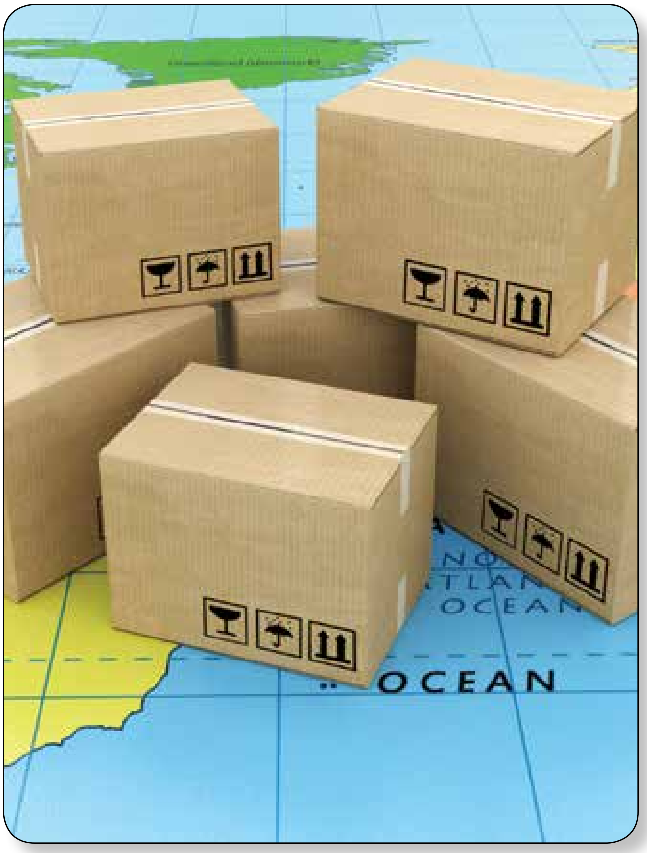
EMC

Product Compliance Limiters and Their Impact on Product Shipments

BY PETER S. MERGUERIAN



THE PROBLEM

It's time for ship authorization and production shipments to begin. But, to everyone's surprise the system does not have the GREEN light to proceed. For some unexplained reason there is a gap in the evidence needed that proves the product meets all of its regulatory obligations. But no one caught it, no one knows the reason, and finally no one appears to be responsible for the situation the business is in. The product is STOPPED at the shipping door pending resolution which is costing the company time, resources and money.

Or, take this example. Is your product design centered on a few hundred units or can it support shipments in the 1000s? Is there an internal compliance process that is flexible yet simple that can support low and high volume products? Many companies do not totally embrace the limiters in their life cycle process or simply do not consider them at all. This poses real threats to the company's future as well as its business model.

What are these limiters? Here are just a few: product environmental, labeling and instructions to be included in the product documentation, knowing the actual regulatory requirements, external laboratory testing and evaluation, effective communication with the manufacturing side of the business and their assembly and production line testing of the product, the need for an importer to register and or submit the product to the regulator, the frequency range and power limitation settings for radio products in some countries, the cycle times involved to actually get a product approved by a regulator (i.e., FCC (U.S.), Anatel (Brazil), CCC (China), BIS (India), IFETEL (Mexico), ICASA (South Africa), etc.).

Unfortunately many businesses find themselves in the exact predicaments presented above, or something rather close depending on the maturity of the business, the talent behind the product compliance activity, and the support structure within the business. On the surface it appears daunting to resolve, yet there are a number of key steps that can be taken to prevent future occurrences. With a small change in focus the solution can become visible on the horizon. The topics discussed next are in this author's opinion some of the more critical first steps, but certainly each company most likely have many more to address.

IT STARTS AT THE TOP: THE REQUIREMENTS

Probably the most import factor is to inventory or categorize exactly what the product needs to meet. Sounds easy, but it can be problematic if not approached in a manner that is both repeatable and traceable over time. Just why would a business need such an activity? For two reasons: 1) to meet the legal obligations for the product itself; and 2) to ensure the consumer/user gets a quality product that was designed and built from a known set of criteria.

"Regulatory" includes all items that are based on a law or directive in a given country. Typical examples of this are

the FCC in the U.S., the CE process in the European Union, etc. Within the scope of regulatory there could be various criteria for electrical, mechanical, software, radio frequency, encryption, product environmental, energy efficiency, marking and labeling, plugs and several others depending on the country where the product is intended to be marketed. One error many companies make is not keeping current on what the country requirements are. For example, a particular country may have one set of regulatory requirements on April 1st 2014, yet on April 1st 2015 that regulation has been updated or changed. Surprises like that can create havoc on the production line and force engineering into panic mode to assess the product's performance against the new/revised requirement, make any necessary changes to the product, and finally adjust the inventory to separate compliant products from non-compliant versions.

Avoiding such problems is quite simple, but it does take focus in order to remain diligent. Compile all the known regulations into a single location and organize by country and product. Where possible, setup a database or spreadsheet to categorize the information for simple interrogation and use by engineering and other pertinent parties. On a routine basis survey each country to determine if any changes are in process or are likely to occur in the near future. Feed this information into the database and date code accordingly to reflect the new requirement.

Once complete, send out a notice to all interested parties regarding the change of requirements. This will provide a heads-up to engineering and will hopefully allow the time needed to update the products if needed. It is highly recommended that representatives from other different functions in a company, such as manufacturing, technical operations, specifications department, factory representatives, incoming inspection, quality, distribution, marketing and sales be notified of these changes. Their roles in the overall scheme to transition products to the latest requirements must be mapped out clearly and distinctly well ahead of time, and their specific duties and obligations regarding the new requirements and how to handle them needs to be documented in a process that they can follow on a daily basis.

There is a word of caution, however, that anyone who is responsible for requirements gathering needs to be aware of. It is critical to have a competent person or organization that is plugged into the aggregate scheme of requirements gathering and organization of the material.

The word 'REAL' is the best word to describe the challenges a client faces and how the staff doing the job can mislead an entire organization into thinking all the requirements are justified, i.e. REAL. Many clients trick themselves into having their product meet requirements only to find that some were actually market-driven as opposed to legally required, not based on any regulatory scheme in a country(s) or not based on any factual evidence at all. This is not to say that market requirements are not required, rather, it points out where focus is needed to separate out legal from market-driven. It also implies that the organization's management team may have different views which need to be understood. For example, some companies may not want to have any market-driven requirement be a "product compliance limiter," while others have an entirely opposite viewpoint.

GETTING THE JOB DONE: THE RIGHT PERSON AND TEAM

With the requirements set in place, having the right leader(s) and the organization to support them is critical. Too many companies assign the task of "product compliance" as a part time job, assign it to staff whose expertise does not reside anywhere in the spectrum of compliance, or totally ignore it until a problem arises. Saying that, some have the talent depth to use a team of individuals to get the job done and rely of their specific assets to build a robust platform of product compliance. Whatever the level of talent, consider these facts as integral to a successful product compliance team:

1. Establish an owner whose function can be viewed as this: if there was a knock on the door and a country regulator presented information about a product failing, who would the company turn to that has the entire picture of product compliance? This person is the leader and driver for the product compliance function in the company. He or she will be responsible for setting up the product compliance system and ensure that the right organizations inside the company are engaged as they should be.

2. Look across the company and the processes used to design, build, test and ship the product, and identify the leader or responsible person who is capable of supporting the product compliance team. Ensure those individuals are engaged with their peers in other parts of the company.

3. Embed a reporting structure and accountability system that has top management support and awareness. If this is not done, there will be most likely some individuals in the company who will view product compliance as a second or third priority to the other tasks that need to be done.

The strength and depth of the product compliance function is the backbone and quarterback of the system, i.e. the person/team who is there to make sure the products get shipped on time as well as meet all requirements. As noted in the opening portion of this article, a company is at a severe disadvantage if no one is at the wheel overlooking what is happening to the product or is only able to react to a problem after the fact.

CHANGE CONTROL: KEEPING THE BILL OF MATERIAL SAFE AND SOUND

One of the more common threads behind product performance issues and customer complaints can be found in how a company manages the bill of materials (BOM) used in the product. Industry on average mishandles the BOM a substantial amount of the time. The reasons range from severe to relatively minor, but the impact of such a defect can be very problematic for the company and/or their customers.

Take for example a common resistor which, for arguments sake, is a 10,000 ohm chip onboard component soldered to a printed wiring board. Depending on where that item is used in the design, many types of product performance issues can arise, again from relatively minor or drastic. If the resistor is used in an audio amplifier circuit, the audio from the circuit may deviate slightly and the user may not even recognize the issue at all. However, if the resistor is also used in the transmit audio circuit (which is a controlled parameter in many country regulations), the product could fail the transmit audio response curve and therefore the product is technically out of compliance. Depending on the country where the product is sold, there may be regulatory sampling being performed where the country regulator pulls products from the shelf and tests it for compliance. Hence a problematic situation could arise for the manufacturer.

Keeping track of the BOM appears complex but is actually quite easy to implement when broken down into its key aspects. By following the guidelines listed below any manufacturer can implement a solution for controlling and managing changes to the BOM:

1. All parts in the manufacturer's product must have a part number assigned. This would include software and firmware if applicable.

2. If a part is used multiple times always have a designator for each time it is used (i.e., R104, R105, etc.).

3. Examine all the circuits of the product and map the performance of each circuit to key its components that are used in the design. These are commonly called a critical parts list (CPL). When the mapping is done, it is prudent to understand how a particular component on the CPL can impact performance of that circuit. Look for regulatory or other business requirements, such as safety, EMC, radio frequency, product environmental, energy efficiency, and determine which parts need to be on the CPL and link their impact with a specific performance characteristic.

4. Once the CPL is identified, embed in the BOM a special designator in order to be able to quickly identify the CPL components in the BOM. If this is not practical to do, a simple list that is maintained by the compliance manager could be used. If this is the approach you choose, it should be included in all change notices that are routed for signature.

5. Design a simple change notice document that is intended to manage the addition or subtraction of a part to and from the BOM. Generally, at the high level, this would include the part number of the component, its description, circuit designator, value, evidence of compliance or other testing that has been completed, crossover date for implementation, information on what to do with old products that may be in inventory, where it is used, other information that would advise groups such as engineering or manufacturing about the change and any related controls or processes that may be impacted (i.e., testing) and, finally, a signoff list of all persons or groups that need to be made aware of the change even though their specific role may not be impacted. It is important to identify all of the teams that need to see a change notice and to include them in the signoff process. It is neither acceptable nor desirable to leave a group or team out of the signoff process.

6. For any change to the BOM, the change notice document is needed-no excuses. Each change notice must be routed for approval to all parties on the signoff list, even though it may be out of scope for their particular group. As the change is routed for signature, each party can assess if the change impacts them or not and, if not, the correct steps can be taken to ensure the change is adequately covered (i.e., maybe a change in testing is required, etc.).

7. Any change notice needs to have an owner. That owner is responsible for routing the change, ensuring it gets completely through all signatures, and finally collecting the signed change notice. Once entire loop is complete, the BOM can be changed.

PRODUCT TESTING: MANAGING AND DEPLOYING

Virtually all products in the electrical and mechanical world require some form of testing. Testing can be required for quality, product environmental, regulatory, engineering, manufacturing or other purposes. One of the more important testing aspects involves the use of external resources, such as an ISO 17025-accredited testing laboratory. Accredited testing labs are the life line of the product life cycle and can provide invaluable information to the manufacturer of the product regarding a products' performance to specifications. Unfortunately this is not always recognized as a critical activity in all the ways it should be.

Many manufactures view testing labs as partial or as-needed activities. However, few manufacturers plan ahead in a way that testing organizations can understand and deal with. It tends to be "do this now and we will be back in a week" type of interaction. A healthier approach is to agree internally on the entire testing strategy, the timeline expectations, and the deliverables expected from the testing lab. Then, follow up that process by engaging the testing lab based on that information. This approach can save significant time and money in the overall testing process, and helps to set everyone's expectations well ahead of any actual testing.

Another key aspect is how to approach the testing lab about product changes. When a product is changed and needs to be tested to validate performance, different testing organizations can take different approaches. For example, some testing labs will repeat the entire list of all tests even though the product change only impacted certain performance characteristics. Prior to going to a testing lab, the product change should be evaluated internally to determine the areas that may potentially be impacted by the change. These "at risk" areas should definitely be tested by the labs, and it may not be necessary to repeat any other non-related testing that is not at risk.

Using a test lab usually generates a huge amount of data. One of the common problems is that testing data goes into the deep, dark file cabinet, never to be seen again. A better approach is to keep this data organized, link it to product changes and time lines, and have it readily accessible for engineering or other teams to study. There is a scheme in the industry called "delta testing." This means that, if the manufacturer has a set of data, it establishes a reference point that can help determine whether additional delta tests are actually needed or whether the entire suite of tests need to be conducted all over again. Testing data is often lost or is untraceable to a product or activity, resulting in the need to retest everything, often at an additional and unnecessary expense.

Testing labs also have different skill sets and equipment. These are used to determine the capability of the lab to perform tests and is part of their scope of capabilities. A given testing lab's scope can be complicated as well as costly to implement, requiring some labs to contract out certain tests, typically adding to the time and cost required for testing. Any manufacturer should ensure the lab that is used has the scope and accreditation to perform the testing that is needed, and to understand upfront which if any testing needs to be outsourced to another testing lab. Outsourcing can create some added risks, but can be managed if the primary testing lab has a quality system in place to ensure that outsourced tests are done correctly.

SCHEDULE: WILL THE REAL ONE PLEASE STAND UP?

So many times in the life of the product, the scheduling or timing of events or activities, rears its ugly head. "When are we shipping- oh- it is that early?" or "does anyone know when we can expect material to arrive?" These are just a few of the examples that most of us have probably heard. The moral of the story here is to have one, that is, a schedule that everyone is aware of and is measured by.

In looking at a schedule, one area most frequently underestimated is the time required to get a product approved in a country. Did you know that some countries can take over 10 weeks to get approval, while others can approve your product in just a few days? And, if the product is a medical device, the timeframe for regulatory approval can run as long as two years, depending on the country.

The key to a robust schedule is simple—have an owner. In order to drive an organization or project, the team needs a target, one that is traceable to everyone's activities and also to the product itself and its readiness to ship to the customer. But customer shipments can be stopped dead in the water if the country where the product is going to be marketed has not approved the product. And this situation can really complicated really quickly if more than one country is targeted.

The schedule owner needs to plan the timeframes for all the regulatory approvals. Each product and its variations should have a link to the regulatory timeframes. Again, simple project management tools and spreadsheets can help keep track of the timeframes. The schedule should be communicated to all interested parties and subject to strict version control requirement.

SUMMARY: JUMP RIGHT IN - THE WATER IS FINE!

Patience is a virtue. But, in the world of product compliance, it also pays to be diligent. Although this article addressed five specific limiters, each business should carefully determine others based on their business model. If there is any doubt, bring in third party to do a cross-check with the internal efforts. A good gap assessment is healthy almost every time.

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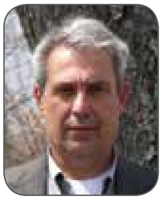

ISO/IEC 17065: The Standard for Certification Bodies

A Review of the Key Requirements

BY MIKE BUZARD

Many readers of *In Compliance Magazine* have seen the word "certification" bandied about in their professional lives. A smaller subset of those readers likely have some indirect exposure to the formal certification process, either through involvement in their company's product compliance programs, as an engineer or technician in a testing laboratory, or maybe as an inspector or factory line auditor. We can likely further narrow the readership into an even smaller subset that knows that an international conformity assessment standard exists for the operation of a certifying organization (known as a Certification Body, or CB), and possibly even fewer that have direct experience with the requirements of that standard.

The standard we speak of is ISO/IEC 17065, "Requirements for bodies certifying products, processes and services," and its most recent revision was published in September 2013. Its predecessor, ISO/IEC Guide 65, had been in existence since the mid-1990s and was referenced and used by industries and regulators around the world. Many of these industries and governments are shifting towards requiring third-party accreditation of the CBs which certify the products, processes, or services entering or being used in the country or region where the regulators have oversight responsibilities.

THE ROLE OF CERTIFICATION SCHEMES

Before we investigate the inner workings of the ISO/IEC 17065 standard, we must be aware of one overarching fact: Certification Schemes, the set of requirements put in place by industry, regulators or other entities, are the driving documents for all certifications. Without a Certification Scheme, there is no information about the criteria with which the certified product, process, or service complies. The end user of the certified "thing" does not know if the "thing" is safe, or if it will provide a desired output, or if it will lead to a savings in energy consumption, or … the list goes on and on about what Certification Schemes can define as the requirements the product, process, or service must meet.

These Schemes also typically include additional requirements above and beyond those outlined in ISO/IEC 17065. These additional items could include (but are not limited to) requiring management system registration/certification at the manufacturer level, periodic audits of the factory line, accreditation or other recognition of the testing/inspecting/auditing body, and specifications on how to demonstrate that a product, process, or service is certified by a legitimate body.

Beyond the requirements for the certified product, process or service itself (safety limits, efficiency requirements, and so on), and possibly restrictions on participants in the overall process, Schemes generally also include instructions for how the certified product, process, or service can maintain its certification after its initial certification is granted, an activity known as "surveillance." Ensuring that the certified product, process, or service continues to meet applicable requirements after the initial evaluation is extremely important in many cases, although there may be some things that are certified but for which the concept of surveillance is not relevant.

The importance of a Certification Scheme cannot be understated, as the ISO/IEC 17065 standard itself makes reference to the Scheme more than thirty times in its normative text and accompanying notes. Some Schemes with which many *In Compliance* readers are likely to be familiar include the Telecommunication Certification Body (TCB) program of the U.S. Federal Communications Commission (FCC), the IECEE “CB Scheme,” the CQC Certification program for the People’s Republic of China, and the ENERGY STAR program of the U.S. Environmental Protection Agency (EPA).

ISO/IEC 17065 IN DETAIL

Let’s move on from the individual Certification Schemes (as there are many in the world, and each is unique to its own interests) to the contents of the ISO/IEC 17065 standard itself so that readers can understand the requirements with which CBs abide. ISO has begun harmonizing the general layout of its international standards and is moving towards an 8-section layout with which future standards (new documents as well as revisions to current standards) will align.

Preliminaries

The first three sections of ISO/IEC 17065 are informative in nature, and include references to other international standards which are used by ISO/IEC 17065.

Section Four—General Requirements

Section Four of ISO/IEC 17065 deals with the activities and setup of the CB on a general level. This section includes requirements for legal stature, presence of a “Certification Agreement” with the clients of the CB and the minimum contents of the agreement, use of certification marks and licenses, financial support and liability coverage, non-discrimination practices, a description of information that must be made available by the CB upon request and, finally, requirements on confidentiality and impartiality.

Impartiality is stressed throughout the standard, and the deviation away from requiring complete independence from other bodies is a positive change in the modern world. The writers of this international standard acknowledged the intricate web of relationships between businesses (including their employees and contractors) and other people and organizations, and realized that

Ensuring that the certified product, process, or service continues to meet applicable requirements after the initial evaluation is extremely important in many cases.

to require pure independence would create significant barriers to the certification of products and to their final market destinations.

There are some independence-like restrictions placed on certain personnel within the CB in Section Four of the standard, but these are generally set forth in such a manner as to clearly ensure that the final certification decisions are made by persons without a material interest in the product receiving its desired certification. Business relationships between the CB and other interested parties are permitted so long as the CB can account for any potential risks to its impartiality, and can address those risks in an appropriate manner.

Section Five—Impartiality

Section Five of ISO/IEC 17065 addresses the organizational layout requirements of the CB. This section is relatively short and straightforward, but the 2012 publication of this standard incorporated something that was not present in previous iterations, that is, the mechanism for impartiality. This mechanism (typically formed as a group of persons which are stakeholders in the certification process for the products being certified) is created and enabled to provide input to, and oversight of, the CB's impartiality status.

This mechanism is required to have balanced interest representation, and the standard indicates that the CB's personnel (if included in the mechanism) are only to be considered as a single interest point. The mechanism is empowered by the standard to report to outside bodies, such as the Scheme owner/writer, regulators, and accreditors, if the CB is ignoring the inputs and warnings given to the certifier, but the mechanism must meet the same confidentiality requirements as the personnel within the CB.

Section Six—Resources

Section Six of the standard begins accounting for the people (known as "resources" in the standard) involved in the certification process. Requirements are set in place for personnel competencies, training and monitoring, and compliance with the CB's rules and procedures. In addition, the standard also discusses the requirements that must be met for the CB's "internal resources" (full- or part-time employees, and persons operating under contract) to ensure compliance with all rules and procedures the CB has in place, as well as "external resources" (another term for "subcontractors") that provide evaluation services to the certifier. Evaluation is discussed in more detail in section seven of the standard, but typically involves process(es) such as testing, inspecting, auditing, or otherwise gathering information on the characteristics of the product being certified (in order to later compare that information against the scheme requirements).

These resource requirements call out other international standards, including ISO/IEC 17025 (for testing), ISO/IEC 17020 (for inspection), and ISO/IEC 17021 (for audits of management systems). If a CB chooses to use an external resource (subcontractor) for its testing or other evaluation tasks, the standard further defines the requirements that the CB must meet in order to justify use of that external resource. ISO/IEC 17065, for the first time in its normative text, mentions the concept of independence when it accounts for the use of non-independent bodies as external evaluation resources, and what the CB must do in order to use that outside entity. Ultimately, the CB is responsible for the evaluation results it chooses to use in its decision-making process, but the standard has laid out steps that must be followed in all cases.

Section Seven—the Certification Process

Section Seven of the standard covers the requirements the CB must follow while performing the various steps in the certification process. This includes receiving and reviewing the client's application for certification (which, in many cases, is different from the previously mentioned certification agreement that must be in place), ensuring the product, process, or service is appropriately evaluated, and then having a person or persons independent of the evaluation review and make a final decision upon whether or not all certification requirements have been met.
This section also includes the required information on documents given to the client to signify that their product, process, or service has been certified.

Furthermore, Section Seven of the standard discusses the situations when surveillance activities are necessary. The section ends with the inclusion of the CB's responsibilities when it comes to ensuring that certified products, processes, or services continue to meet Scheme requirements if the Scheme is changed, what tasks the CB must take when an adverse decision is made, (such as suspending or withdrawing certification), and finally what duties the CB has for handling complaints and appeals related to its certification activities.

Section Eight—Management Systems

Section Eight of ISO/IEC 17065 covers the requirements for a management system that must be in place within the CB. Many of the requirements are similar to those found in ISO 9001. The CB must have a collection of management system documents (note that this standard has done away with the concept of requiring a central quality manual, an idea present in many previous conformity assessment standards), controlled documents and records, and must perform management reviews and internal audits in accordance with defined procedures and schedules. Finally, the CB is required to address corrective as well as preventive actions, two tasks that should be familiar to any readers that implement their own internal quality system regardless of their organization's purposes.

ACCREDITING THE CERTIFICATION BODIES

We have mentioned previously the fact that many regulators are beginning to (or currently do) leverage existing conformity assessment infrastructures in their regions, leaning on recognized third-party Accreditation Bodies (ABs) to accredit CBs for certain types of products, processes, and services that are the responsibilities of those regulatory agencies. Even when laws don't require accreditation of certifiers, many industries and unique-scheme CBs have chosen to pursue accreditation from a third party AB in order to demonstrate the quality, competence, and impartiality of their certifications.

Most of the regulatory agencies, and many of the voluntarily-complying CBs, recognize the benefits of the International Accreditation Forum Multi-Lateral Agreement (IAF MLA), and choose to specify or select only those ABs which are signatories to this international agreement. Each AB that is a signatory member of this MLA is rigorously peer evaluated (against ISO/IEC 17011) on a regular basis to ensure that appropriate and consistent assessments against the ISO/IEC 17065 standard (along with particular scheme requirements implemented by the CB being assessed) are being performed. Oftentimes these regulators also attend the peer evaluations as observers in order to form their own opinions of the AB before beginning a business relationship to recognize the accreditations granted.

The IAF MLA is separated into Scopes, and the IAF has separated its recognition into "Main Scopes," covering the accreditation of conformity assessment activities like Product Certification Bodies (addressing accreditations to ISO/IEC 17065), and Management System Certification Bodies (under ISO/IEC 17021 and its associated documents). The MLA is further divided into a tiered set of sub-scopes of certain types of management systems (Level 4 being applicable to Quality Management Systems under ISO 9001, covering certain well-known schemes such as Global GAP, and Level 5 applicable to further sub-sets of management systems such as Information Security under ISO/IEC 27001, Environmental Management Systems under ISO 14001, Food Safety under ISO 22000, and Supply Chain Security under ISO 28000). IAF's stated goal is "Certified Once, Accepted Everywhere."

As mentioned previously, ISO/IEC 17065 underwent significant revision and was published in September 2012. The IAF has stated that all ABs which are signatory members of the IAF MLA must have their accredited Product Certification Bodies transitioned over from ISO/IEC Guide 65 to the current ISO/IEC 17065 no later than September 15, 2015, as the old Guide 65 accreditations would cease to be recognized past that date. Interested parties can find more information on the IAF, the IAF MLA and the mandatory transition period at www.IAF.nu.

CONCLUSION

Many ABs and other independent organizations offer training on the standard to educate CBs, their clients, and other stakeholders in the certification process about these requirements in depth. If your organization has an interest in learning more about the process of becoming accredited, or the requirements of the ISO/IEC 17065 international standard, we encourage you to reach out to one of the recognized ABs, such as A2LA, for more information.

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New European Union Directives and Their Impact on Notified Bodies

BY DANIEL D. HOOLIHAN

The European Union (EU) released revised versions of three important directives in 2014, namely the Electromagnetic Compatibility Directive (EMCD), the Radio Equipment Directive (RED) and the Low Voltage Directive (LVD). Each of these three revised directives will be discussed and compared/contrasted to their earlier versions. We'll then analyze the impact of these directives as to their influence on strengthening EU Notified Bodies. The article concludes with a summary of the directives and Notified Bodies.

A BRIEF REVIEW OF THE HISTORY OF THE THREE KEY EUROPEAN DIRECTIVES

The European Commission recently released a reference document title "Application of Directives 2014/53/EU, 2014/35/EU, and 2014/30/EU." That reference document provides guidance on the dates of applicability and the transitional periods for the three 2014 directives.

EMC DIRECTIVE

The latest EMCD (2014/30/EU) was released on 26 February 2014 and published in the *Official Journal of the European Union* on 29 March 2014. It addresses "the harmonization of the laws of the Member States relating to electromagnetic compatibility." The 2014 EMCD is a "recast" of the 2004 EMCD (2004/108/EC). It also reflects a 2008 law-change by the European Parliament that modified the requirements for accreditation and market surveillance relating to the marketing of products. The EMCD also states that "provisions of national law ensuring protection against electromagnetic disturbance need to be harmonized in order to guarantee the free movement of electrical and electronic apparatus without lowering justified levels of protection in the Member States."

The equipment covered by the updated EMCD includes separate provisions for both apparatus and fixed installations. The Directive makes clear that "economic operators" (defined as "the manufacturer, the authorized representative, the importer and the distributor") should be responsible for the compliance of apparatus with the Directive. For example, all economic operators intervening in the supply and distribution chain should take appropriate measures to ensure that they only make available on the market apparatus which are in conformity with the EMCD.

An important concept highlighted by the EMCD is "ensuring traceability." Traceability must be assured throughout the whole supply chain to make market surveillance simpler and more efficient. As part of this traceability, Member States should encourage economic operators to include a website address in addition to their postal address.

Clause 38 of the preface to the EMCD highlights the fact that:

> *"Experience has shown that the criteria set out in Directive 2004/108/EC that conformity assessment bodies*

have to fulfill to be notified to the Commission are not sufficient to ensure a uniformly high level of performance of notified bodies throughout the Union."

This concern has led to stricter requirements for Notified Bodies, which will be discussed more fully in the last part of this article.

RADIO EQUIPMENT DIRECTIVE (RED)

Directive 2014/53/EU of the European Parliament and of the Council was released on 16 April 2014 and was published in the *Official Journal* on 22 May 2014. It harmonizes the laws of EU Member States relating to the making available on the market of radio equipment, and repeals Directive 1999/5/EC.

Directive 1999/5/EC had been substantially amended several times and additional amendments were pending. Therefore, the EU Commission decided it should be replaced in the interests of clarity. The 1999 Directive had the unwieldy title of "Radio Equipment and Telecommunications Terminal Equipment" which was abbreviated as "R&TTE." This acronym has been replaced with the much simpler "RED" (for "Radio Equipment Directive").

An important change in the RED is covered in Clause 4 of the Directive's Preface, where it says:

"The essential requirements laid down in Directive 1999/5/EC which are relevant to fixed-line terminal equipment, i.e. to ensure the protection of health and safety of persons and of domestic animals and the protection of property and an adequate level of electromagnetic compatibility, are appropriately covered by Directive 2014/35/EU of the European Parliament and of the Council and Directive 2014/30/EU of the European Parliament and of the Council. This directive should therefore not apply to fixed-line terminal equipment."

Clause 10 of the RED Preface gets to the heart of the issue:

"In order to ensure that radio equipment uses the radio spectrum effectively and supports the efficient use of radio-spectrum, radio equipment should be constructed so that, in the case of a transmitter, when the transmitter is properly installed, maintained, and used for its intended purpose it generates radio waves emissions that do not create harmful interference, while unwanted radio waves emissions generated by the transmitter (e.g., in adjacent channels) with a potential negative impact on the goals of radio spectrum policy should be limited to such a level according to the state of the art, harmful interference is avoided, and, in the case of a receiver it has level of performance that allows it to operate as intended and protect it against the risk of harmful interference in particular from shared or adjacent channels, and, in so doing, supports improvement in the efficient use of shared or adjacent channels."

Also, radio equipment which complies with the relevant essential requirements should be allowed to circulate freely, such equipment should be allowed to be put into service and used for its intended purpose where applicable in accordance with rules on authorizations for the use of radio spectrum and the provision of the service concerned.

Clause 48 of the preface to RED says that "certain conformity assessment procedure set out in this Directive require the intervention of conformity assessment bodies which are notified by the Member States to the Commission."

Directive	Year Released	Directive Number
LVD	1973	73/23/EEC - replaced by 2006/95/EC
EMC	1989	89/336/EEC - replaced by 2004/08/EC
R&TTE	1999	1999/5/EC - will be replaced as of 13 June 2016 by 2014/53/EU
EMC	2004	2004/108/EC - will be replaced as of 20 April 2016 by 2014/30/EU
LVD	2006	2006/95/EC - will be replaced as of 20 April 2016 by 2014/35/EU
EMC	2014	2014/30/EU
LVD	2014	2014/35/EU
RED	2014	2014/53/EU

Table 1: EMC, Radio, and Low-Voltage Directives - A Historical Review

Furthermore, Clause 49 says:

> *"Experience has shown that the criteria set out in Directive 1999/5/EC that conformity assessment bodies have to fulfill to be notified to the Commission are not sufficient to ensure a uniformly high level of performance of notified bodies throughout the Union. It is, however, essential that all notified bodies perform their functions to the same level and under condition of a fair competition. That requires the setting of obligatory requirements for conformity assessment bodies wishing to be notified in order to provide conformity assessment services."*

Also, Clause 52 concludes:

> *"The system set out in this Directive should be complemented by the accreditation system provided for in Regulation (EC) No. 765/2008. Since accreditation is an essential means of verifying the competence of conformity assessment bodies, it should also be used for the purposes of notification."*

The above Clauses are similar to what is found in the EMCD and they are what is driving a renewed emphasis on the competency of Notified Bodies, which will be covered in the last section of this article.

LOW VOLTAGE DIRECTIVE

The third new version of a directive affecting electronic products accepted into the EU market is the Low Voltage Directive (LVD). The LVD was released on 26 February 2014 (the same date as the EMCD) as Directive 2014/35/EU, and its official title is: "the harmonization of the laws of the member States relating to the making available on the market of electrical equipment designed for use within certain voltage limits." The Directive was published in the *Official Journal* on 29 March 2014.

A number of amendments had been made to the existing LVD (2006/95/EC) of 12 December 2006 on the harmonization of the laws of Member States relating to electrical equipment designed for use within voltage limits. Therefore in the interests of clarity, the EU Commission determined that the LVD should be recast.

The new LVD states:

> *"The purpose of this Directive is to ensure that electrical equipment on the market fulfils the requirements providing for a high level of protection of health and safety of persons, and of domestic animals and property, while guaranteeing the functioning of the internal market."*

The new LVD also notes that economic operators should be responsible for the compliance of electrical equipment with the LVD in relation to their respective roles in the supply chain so as to ensure a high level of protection of public interests, such as health and safety of persons, of domestic animals and property, and to guarantee fair competition within the EU.

The LVD goes on to say in Clause 9 of the Preface:

> *"The manufacturer, having detailed knowledge of the design and production process, is best placed to carry out the conformity assessment procedure. Conformity assessment should therefore remain solely the obligation of the manufacturer. There is no conformity assessment procedure in this Directive which requires the intervention of a notified body."*

The new LVD is limited to the expression of the safety objectives. Furthermore, electrical equipment should be considered as non-compliant with the safety conditions of use which can be reasonably foreseen, that is when such use could result from lawful and readily predictable human behavior.

NOTIFIED BODIES

Notified Bodies are defined as "Conformity Assessment Bodies that have been notified to the European Commission and the European Member States that they are authorized to carry out third-party conformity assessment tasks for specific European Directives." Notifying Authorities are designated by Member States and they "shall be responsible for setting up and carrying out the necessary procedures for the assessment and notification of conformity assessment bodies and the monitoring of notified bodies compliance with appropriate sections of selected Directives."

Both the EMCD and the RED allow and encourage the use of Notified Bodies. The LVD has no conformity assessment procedure requiring the use of a Notified Body.

A Notified Body must meet a number of requirements to be acceptable to a Notified Authority. For example, it must be "established under national law of a Member State and have legal personality." Also, it "shall be a third-party body independent of the organization or the apparatus it assesses."

All Notified Bodies are required to be re-notified if they wish to continue serving as Notified Bodies under the revised EMCD and the new RED. The process of re-notifying Notified Bodies in the U.S. is being administered by the National Institute of Standards and Technology (NIST) in the U. S. Department of Commerce. The specific office in NIST that is heading this effort is the Telecom Mutual Recognition Agreement (MRA) Program Office which is part of NIST's Standards Coordination Office.

The EU has been updating its documentation to aid the transition to implementing the new or revised directives introduced in 2014. One of these publications is "The 'Blue Guide' on the Implementation of EU Product Rules - 2014." Its Preface says:

> *"The Guide to the implementation of directives based on the New Approach and the Global Approach (the 'Blue Guide') was published in 2000. Since then, it has become one of the main reference documents explaining how to implement the legislation based on the New Approach, now covered by the New Legislative Framework.*
>
> *"Much of the 2000 edition of the 'Blue Guide' is still valid but it requires updating to cover new developments and to ensure the broadest possible common understanding on implementation of the New Legislative Framework (NLF) for the marketing of products. It is also necessary to take account of the changes introduced by the Lisbon Treaty (in force since 1st December 2009) with regard to the legal references and terminology applicable to EU-related documents, procedures, etc.*
>
> *"This new version of the Guide will therefore build on the past edition, but include new chapters, for example on the obligations of economic operators or accreditation, or completely revised chapters such as those on standardization or market surveillance. The guide has also been given a new title reflecting the fact that the New Legislative Framework is likely to be used, at least in part, by all types of Union harmonization legislation and not only by the so-called 'New Approach' directives."*

The Guide is intended to aid a better understanding of EU product rules and to their more uniform and coherent application across different sectors and throughout the single market. It is intended solely as a guidance document.

A second complementary document to the "Blue Guide" is the "European co-operation for Accreditation (EA) Document on Accreditation for Notification Purposes." It is referenced as "EA-2/176 M:2014." This document presents the policy agreed by EA members for accreditation of Conformity Assessment Bodies for notification purposes. It is a mandatory document except for Annex B which shall be used on an informative basis. Annex B is titled: "Criteria laid down in the harmonized standards used as a basis for accreditation that deal with the requirements for notified bodes laid down in Decision (EC) 78/2008 of the European Parliament and of the Council on a common framework for the marketing of products."

A third document from the EU relative to accreditation and notification is the "RED Notified Body Accreditation/ Notification Assessment Guide Document" (V1.0c) which is dated December 2014. It was issued through the Radio and Telecom Terminal Equipment Compliance Association (RTTE CA) and is also known as the "RED NB Assessment Guide." It is written in a checklist format. The intent of the checklist is to improve the uniformity of the assessments of Notified Bodies throughout Europe and MRA countries. It is recommended that Accreditation Bodies use it.

The RED NB Assessment Guide states that "a Notified Body does not have to assess equipment that has been tested to harmonized standards. However, they must assess against Article 3.2 where harmonized standards have not been followed in full." Article 3.2 of the RED says that "radio equipment shall be so constructed that it both effectively uses and supports the efficient use of radio spectrum in order to avoid harmful interference."

The RED NB Assessment Guide also points out that "the Radio Equipment Directive Article 3.1 (a) - Low Voltage Directive and Article 3.1 (b) - EMC Directive do not require a Notified Body to be involved where the equipment has not followed the harmonized standards."

The EU Commission and other relevant stakeholders are still working on development of additional guidance documents, including the Commission EMCD Guide and the Commission RED guide. Additional checklists are being developed by European experts and by NIST for both the EMCD and RED.

SUMMARY

The directives released by the EU in 2014 encompassing EMC, product safety and radio regulations have been thoroughly updated and modernized, and will affect many electronic products imported into Europe.

In addition, two of the three directives (the EMCD and RED) are driving major changes in the process for qualifying Notified Bodies in Europe and Notified Bodies outside of Europe that are handled through Mutual Recognition Agreements. Formal accreditation of the Notified Bodies is now the preferred route for demonstrating Notified Body competence. In the U.S., organizations seeking Notified Body status should contact the NIST Telecom MRA Program Office to obtain the full list of requirements.

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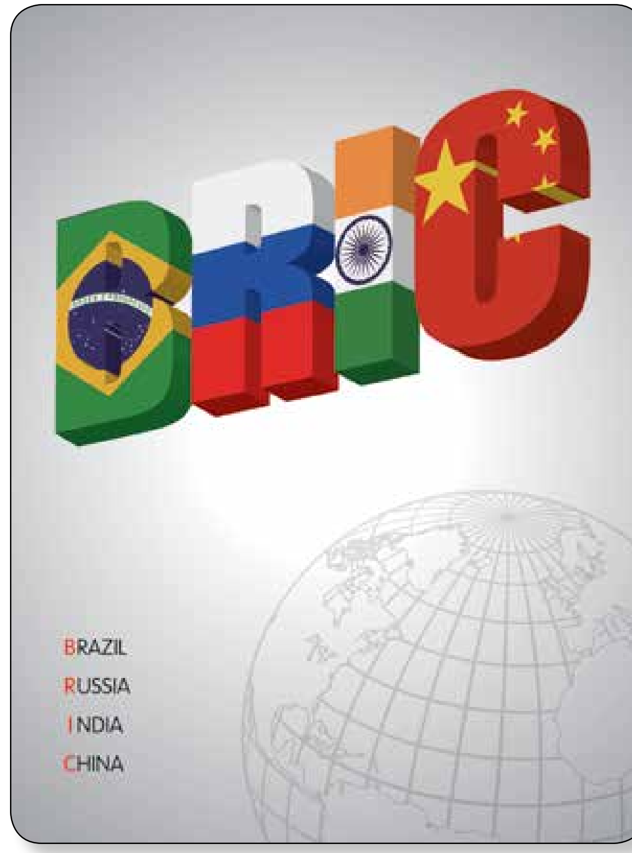
Compliance in Brazil, Russia, India, and China for Information Technology Equipment



An Overview of ITE Compliance Requirements for BRIC Market Countries

BY MARK MAYNARD

"Exploration is the engine that drives innovation. Innovation drives economic growth. So let's all go exploring." – Edith Widder

Brazil, Russia, India, and China have over 40% of the world's population, making this large pool of potential customers a key target for companies eager to enter these potential high-growth markets, which are commonly referred to by the acronym "BRIC." With close to three billion inhabitants, and their growing middle classes eager to have the same popular electronic products as their US and European global neighbors, these nations have demonstrated healthy economic growth rates for the most part, even with the ongoing global recession. These four countries have been recently ranked in the top seven global economies, based on gross domestic product at purchasing power parity (GDP PPP) per capita, and it has been estimated that the BRIC economies could overtake the block of G7 economies in the next ten to fifteen years. Gaining access to these customers with rising wages has become a priority for increasing global market share.

What these countries share in common are having recently arrived at similar advanced stages of economic development, with a desire to be in the leading economic powers of the twenty-first century, but being held back by old government bureaucracies and weak infrastructures that hinder progress. It has only been in the last fifteen years or so that they have begun to attain accelerated economic growth and rising wages, which have resulted in mass consumerism of high-tech products. Companies importing electronic products can find a maze of confusing and changing requirements, as well as unfamiliar and inefficient methods of conducting business.

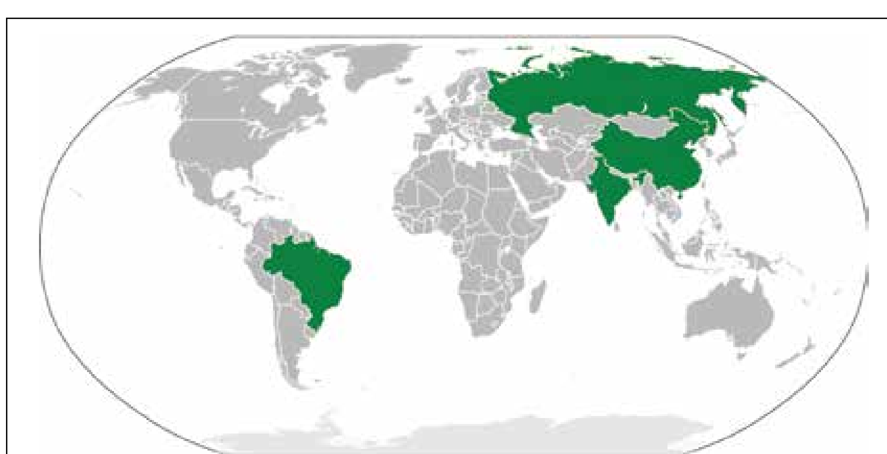


Figure 1: BRIC Countries (image by Felipe Menegaz)

To successfully enter the BRIC markets with information technology equipment (ITE) products, it is necessary to understand the legislated compliance requirements, as well as the application of the regulations and test criteria for compliance, including identifying the regulatory bodies, the certification approaches, and the means and effectiveness of enforcement activities. Additionally, information regarding the efficiency and norms of the systems in each country and recommendations for accessing each market are also needed. Let's get started by taking a look at our first country in the list, Brazil.

Figure 2: Brazil INMETRO and ANATEL logos

BRAZIL COMPLIANCE

There are two main regulatory bodies in Brazil for electronic and electrical product certification, INMETRO and ANATEL. Each has their own specific focus, but they coordinate their activities to ensure compliance in this South American country, where the official language is Portuguese.

INMETRO is the National Institute of Metrology, Standardization and Industrial Quality, which develops and implements the certification systems in Brazil. Tasked with maintaining the national standards, INMETRO is also the national developer of conformity assessment programs as well as the main accrediting authority for certification bodies and laboratories.

ANATEL is Brazil's national telecommunications agency, responsible for the establishment of authorized bodies for certification and testing activities for EMC compliance. ANATEL is the more dynamic of the two regulatory bodies in Brazil, requiring more activities to keep up with the rapid pace of technological developments.

Established in 1998, ANATEL promotes the development of Brazil's telecommunication industry by exercising standardization, homologation, and market surveillance for compliance. Legislated regulatory compliance requirements are disseminated through several types of legal documents:

- Resolution 242 is the general regulation for the certification of telecommunication products. This resolution established the current certification and homologation schemes, authorizing the creation of the certification bodies designated by ANATEL, as well as authorized test laboratories.
- Resolution 323 represents improvements made to the original Resolution 242. Both Resolutions give the legislated regulatory compliance requirements in Brazil, along with the Instrumentos de Gestão and Oficios Circulares issued by ANATEL.
- *Instrumento de Gestão*, or "Management Tools", are also called IGs. These publications give additional details on processes and providers for Brazil approvals. These are published on ANATEL's web site.
- *Oficios Circulares* are offical letters from ANATEL, with the purpose of clarifying and giving information on Resolutions and official rules concerning the certification processes. These are used to quickly publish updates when ANATEL deems it urgent.

ANATEL has regulations for the various categories of regulatory compliance, issued as ANATEL Regulations and technical bulletins. Resolution 442 contains Brazil's EMC compliance regulations, and is based on the international CISPR 22 and CISPR 24 standards, with EMC requirements similar to the CE Mark in the European Union (EU) for radiated emissions and immunity. These test requirements should be followed closely to successfully obtain certification.

Special attention should also be paid to labeling requirements, including warning statements in Portuguese either on the label or in the user instructions. For ANATEL product certification labels, bar codes are assigned, which are known as GS1 or EAN codes. ANATEL uses the database of GS1/EAN Brazil to identify the organization obtaining ANATEL approval, for purposes of market surveillance audits and tracking reported issues.

In Brazil certification and testing must be performed by authorized organizations. The homologation certificate will be issued by ANATEL, and have no expiration date. In addition, the product must be certified by a Designated Certification Body.

The certification process follows this progression:

- Application and product sample submittals
- Required tests and report production
- Issuance of official test reports
- Issuance of product certificates
- Registration of the certificate in the Federal Register
- Periodic inspections to ensure continued compliance

Organismo de Certificacao Designado, or "Designated Certification Body," is referenced by the acronym "OCD." These are companies authorized by ANATEL to perform product evaluations, in order to certify the product according to ANATEL rules. To obtain ANATEL product certification, it is necessary to interface with one of the authorized Brazilian OCDs. During certification, testing must be performed by a test lab that has been accredited either by INMETRO, an OCD, or a foreign laboratory member of the International Laboratories Accreditation Cooperation.

Manufacturers and importers are responsible for continued compliance of their products in Brazil. They must comply with all regulations and any special stipulations given in the approved reports and certifications, or they can face legal repercussions. Any changes to the product as approved is in violation and subject to penalties. Resolution 242, Title VI, Article 54, gives the sanctions which can be levied against violators. These may be applied separately or in combination. Article 61 of Resolution 242 gives the limits on fines that can be assessed for non-fulfillment of any ANATEL provision.

There are several "unwritten rules" for successful product certifications in Brazil. These key items concern the local representative, labeling, and language issues. First, ANATEL certification requires that companies placing their products on the market in Brazil have an authorized local representative. For companies that do not, there are agents available. It is highly advised to acquire the services of one experienced with the ANATEL requirements and processes. Second, the ANATEL agency is very strict on product labeling requirements. It is recommended that you ask for a review of your label design if you have any doubts about the label regulations, and also that you use black and white labels, as color labels must pass a very strict review on matching the mandated color scheme. And third, the technical sections of the ANATEL and OCD websites are in Portuguese, without an option for English-language versions. This is an area where your local representative can be extremely helpful in ensuring that the translated requirements are accurate.

RUSSIA COMPLIANCE

In Russia, navigating the compliance agencies, local requirements, and compliance programs can present numerous challenges. This makes understanding the legislation, regulation, certification, and enforcement activities critical for successfully obtaining product certifications.

A new regulatory compliance process was initiated in 2013, called the "Technical Regulations – Customs Union" (TR-CU) program, and it replaced the previous GOST product approval scheme utilized in Russia. As part of the Eurasian Economic Commission (EEC), a trade agreement was established that allows one set of approvals to cover the compliance requirements for selling ITE products not only in Russia, but also in the former Soviet-bloc countries of Armenia, Belarus and Kazakhstan. The intent of the EEC is for more neighboring countries to be added to this Customs Union over time, creating a system of economic cooperation between member states similar to the EU.

To enter Russia, electronic products must be in compliance with Federal Law. These laws are developed and enacted by the three branches of their federal system, the executive, legislative, and judicial branches. However, these laws are introduced as a series of serial laws, making it very important for companies to have an in-country expert. The current laws for regulatory compliance are given in the Russian Federal Law "On Technical Regulating," which are incorporated into the TR-CU approval program. This legislation provides for the establishment of the agencies which establish the EMC, product safety, and hygienic regulations in Russia.

The new EMC compliance certification program in Russia has introduced its own system of regulations and bureaucracy. All ITE products approved after February 15, 2013 must follow the new TR-CU program and requirements. The new TR Regulation applicable for EMC compliance of ITE products is TR CU № 879, entitled "Electromagnetic compatibility of hardware." Careful study of the new TR-CU requirements is advised as there are some major differences from the old GOST approval scheme.

The typical approval process for TR-CU certification follows the same progression:

- Application and product sample submittals
- Required tests and report production
- Issuance of official test reports
- Factory audits, if required
- Issuance of product and/or factory certificates
- Registration of the certificate in the Federal Register
- Periodic inspections to ensure continued compliance

A major difference from the old GOST system is that the TR-CU scheme requires a local representative in Russia to hold the certification. This person must be authorized to act as an official company representative by the importing organization, and will be legally liable in the event of any non-compliance. Another difference is that a TR-CU factory inspection is mandatory for product certifications, inspections which must be performed by auditors authorized by TR-CU.

The following documents are required for TR-CU certifications:

- The CB certificate and CB test report
- EMC test report
- User manual and instructions in Russian language

- Label drawing with certification body code
- Factory ISO certificates
- TR-CU authorized factory inspection report
- Ergonomics test report/certification (for displays)

Once the TR-CU certificate is issued, it is valid for one to five years, with the term chosen by the manufacturer. After the initial term, it must be renewed annually for as long as the product is offered for sale in Russia. If the product is modified during the validity period, it must be resubmitted for approval by the agency.

All products imported to Russia must carry the new EAC mark of conformity, shown in Figure 3. The EAC logo is required on the product.

Figure 3: The TR-CU EAC Compliance Mark

Russia Compliance Enforcement

The manufacturers and importers are responsible for continued compliance while their products are placed on the market in Russia. This means that they must comply will all regulations and any special stipulations given in the approved reports and certification documents. Any changes to the product as approved is considered a non-compliance, unless it has been resubmitted for approval and granted certification.

In Russia, special attention must be given to the laws and regulations in place, as penalties for non-compliance can be very harsh. In addition to civil penalties, such as fines, there are also criminal charges that can be filed in cases of human health and safety, or for defrauding customers. Since these regulations are based on federal laws, enforcement is by federal police. In addition to charges against the local company representatives, company officers can be held liable, and company assets can be seized and forfeited to pay off civil penalties. It is vital to thoroughly understand customs.

Russia also has some “unwritten rules” that must be followed to ensure imported products will successfully pass through customs, which is the top complication for companies. Failure to master the customs process often means cost overruns beyond the cost of the duties and taxes. In addition, the new TR-CU regulations and certification programs mean that close attention must also be paid to the new customs requirements and criteria for the three additional EEU countries. For these reasons, it is highly recommended that companies procure the services of a customs agent experienced with Russian requirements as well as the importation requirements of Armenia, Belarus and Kazakhstan prior to entering the EEU market.

INDIA EMC COMPLIANCE

India has made great strides in aligning their compliance standards and processes with those of more established markets. Their regulatory organizations are government departments, seeking to coordinate their activities as they modernize and help promote the development of industry in India. One indication of this effort is the wealth of information freely available online at these agencies, translated in English.

India has a parliamentary form of government, based on the British system. Two ministries have been authorized by Parliament to be responsible for the generation of rules and requirements covering electronic products manufactured and sold in India, the Ministry of Consumer Affairs, Food, and Public Distribution (MCAFPD) and the Ministry of Communications and Information Technology (MCIT).

The MCAFPD oversees the Bureau of Indian Standards (BIS). The Bureau of Indian Standards Act of 1986 gave BIS statutory authority in creating national standards. With the mandate to develop standards, regulatory markings, and certification programs, this agency seeks to create a culture of quality, and encourage consumer participation in creating and implementing these product requirements.

The MCIT is the government ministry over the Department of Electronics and Information Technology (DeitY), which oversees the Department of Telecommunications (DOT). DOT in turn is the department in charge of the Telecommunications Engineering Center (TEC).

TEC is the designated subject-matter expert group that is authorized to prepare and publish the standards and regulations for the EMC aspects of wired telecom equipment, in cooperation with BIS. The EMC regulations for wired telecom equipment can be found in TEC/EMI/TEL-001/01/FEB-09, “Electromagnetic Compatibility Standard for Telecommunication Equipment,” which can be downloaded from the TEC website. In addition, new specific absorption rate (SAR) requirements came into effect in India in 2012, and TEC is the SAR regulations-making body for this country.

The TEC branch under MCIT is the authorized agency for issuing EMC certifications for telecom equipment. The “IR” certification is the most common type of approval, and all certified equipment must be labeled per the TEC requirements.

Figure 4: TEC and DeitY logos

The submittal package for certification should contain the following:

- TEC Form A application sheet
- EMC report per TEC/EMI/TEL-001/01/FEB-09 criteria
- Product safety report
- Schematics, bill of materials, and user manual
- Local representative authorization letter
- Technical specification/datasheet
- TEC Form B with two samples of the equipment

India performs market surveillance enforcement activities to ensure that products are certified and manufactured as originally approved. Penalties for non-compliance can range from fines to civil and criminal penalties. Non-approved and non-compliant imported products are frequently seized by customs agents, who are diligent in their review of product documentation and labeling. All aspects of EMC enforcement are directed by TEC, performing market surveillance and reviewing renewal applications to ensure compliance.

Difficulties in clearing customs is one of the most common issues encountered in India. Without the proper importation paperwork and certifications, significant delays can keep products from reaching consumers. Understanding this critical process and the specific requirements will definitely pay off. Hiring an experienced customs agent is recommended, who can ensure proper documentation for customs, and expedite customs clearance. A local agent can also provide schedules for customs clearance, as lead times can fluctuate during the year.

CHINA COMPLIANCE

China has a culture and a market shrouded in mystery for many companies entering this large and growing consumer market. If you want approvals for electronic products, then you will face some unique obstacles in this country. There are several barriers to imported products, including distance, language, unfamiliar culture and unsophisticated commercial market condition.

The authority of all laws in China lies with the central ruling body, responsible for establishing the authorized government agencies. After entry to the World Trade Organization (WTO), the Chinese government has undertaken a massive effort to revise its laws and regulations in accordance with WTO rules.

The China Certification and Accreditation Administration (CNCA) was established in 2002, with responsibility for developing the legal regulatory compliance requirements for electronic products. The CNCA was given the authority to govern all aspects of the China Compulsory Certification (CCC) program, the certification program for EMC and product safety for these regulated devices. CNCA publishes a catalog for 22 types of products, covering a total of 159 categories. All products in the CCC product catalog, whether manufactured by a foreign or a Chinese company, must comply with the same CNCA regulations for the specific CCC product program to enter the Chinese market.

Figure 5: CNCA and CCC logos

Standards are published in Mandarin Chinese language, and official English translations are not always readily available. In addition, changes are frequent as technology changes and China attempts to align more with WTO standards. The standards are referred to as "Harmonized Standards," but it should be noted that there are some major differences from the international code system for harmonized standards used by such international standards bodies as the IEC. The current Chinese EMC Standard is GB 9254:2008, implemented in 2009 and entitled "Test Method and Limits for Radio frequency disturbance from ITE." This standard includes requirements for testing at the highest frequency above 108 MHz, and the testing of telecom ports.

The China Compulsory Certification (CCC Mark) under the CNCA is the EMC and product safety compliance program. CNCA accredits CCC certification bodies, who are then authorized to issue CCC certificates. Under CNCA, there are three separate certification organizations, as follows: China National Accreditation Board for Certifiers (CNAB), China National Accreditation Board for Laboratories (CNAL), and China National Auditor and Training Accreditation Board (CNAT). CNAB has accredited nine certification bodies, all of which are in China. Each is accredited and authorized to certify particular types of products and issue the CCC Mark.

A CCC certification body is not allowed to perform CCC testing. All CCC testing must be performed at CNAL-accredited test laboratories. CNAL has accredited over 800 testing laboratories in China, each of which is accredited for CCC testing on certain types of products. Because CNCA has not achieved any mutual recognition agreements (MRA) with any other accreditation body, CCC testing must be performed at CNCA-accredited laboratories in China.

The CCC Mark requires the following steps to be taken to accomplish the whole process:

- Application to a CNCA-accredited certification body
- Sample testing at a CNCA-accredited test laboratories
- Factory inspection by certification body engineers
- Verification of remittance of CCC certification fees, including fees for application, testing, and inspections
- Granting of CCC certification by the certification body
- Purchasing the CCC Mark product label (CCC stickers) or applying for permission to print CCC labels

All applications must be made using the standard form or electronically with a Declaration of Conformity to Chinese standards. The application must be in Chinese. Applications must be accompanied by product samples for EMC testing. A CNCA-accredited lab will be assigned by the certification body to perform EMC tests according to Chinese standards.

One key note about manufacturing. If a factory has never been inspected under either the CCIB or CCEE systems, factory inspection is mandatory before a CCC Mark is granted. The certification body assigns a technical engineer and a quality assurance engineer to inspect the facility. Details of factory inspection criteria are defined in the official publication of CCC Implementation Rules for each category of products.

In general, the items included in an application package will include the following:

- TAB NAL application form
- Business license of applicant
- Power of attorney for local representative
- Description of manufacturer and local representative
- Manufacturer/factory quality system documents
- Equipment specifications
- Block diagrams, circuit diagrams, and assembly diagrams
- User manual and installation instructions
- Details of post-sales support program and commitment
- Photos of interior and exterior (minimum of 5 photos)

Be sure to keep in mind the specific recommendations that have been provided for each country, to help expedite the approvals processes for electronic product certification.

The CNCA has its own enforcement agency, and criminal findings will be turned over to law-enforcement agencies. Market surveillance and auditing is performed to ensure continued compliance, and customs, retail outlets, and manufacturers in China are all subject to this oversight, and can be required to provide test samples.

The laws and regulations in China must be absolutely followed, as penalties for non-compliance can be very harsh. In addition to monetary penalties, criminal charges can be filed in cases of human health or safety, up to and including the death penalty. The court system is China is very different from most western countries, and the right to appeal is not always allowed. Since these regulations are based on federal laws, enforcement is by federal authorities. In addition to charges against the local company representative in China, company officers can be held liable, and company assets can be seized and forfeited to pay off civil penalties.

Navigating the regulatory landscape can be very difficult, unless you obtain the services of a knowledgeable regulatory consultant in China. Who you hire is critical, because they will be operating as an authorized representative of your company in China, with the power of attorney that is provided for the application process. Spending the time to find a reputable agent with experience in your company's product categories will be well worth the investment.

Replacement part regulations are another confusing area. Generally, separate certifications are required if a part also falls into a certification category, such as replacement power supplies for ITE. Also, additional help can be obtained by procuring the services of an experienced customs expert is highly recommended. Clearing customs in China can create customer fulfillment and supply management issues, an important area for global firms, and should be included in the planning for any project launch in this country.

NEXT STEPS

Although the regulatory schemes in these countries can seem excessively bureaucratic, over time the processes have become more streamlined, and international standards continue to be the models these countries are following and adopting. Be sure to keep in mind the specific recommendations that have been provided for each country, to help expedite the approvals processes for electronic product certification.

Please note that the content in this article should not be the sole source of information when submitting for certification. The official standards should be obtained for the authorized agencies, and an experienced regulatory agent should be utilized if in-house expertise is not available. Also remember customs facilitators can be a valuable source of information on the importation of products.

Finally, engineering and regulatory compliance affinity groups are an invaluable resource in staying current on the latest changes to the regulatory compliance requirements and processes. The local chapters of the Institute of Electrical and Electronics Engineers (IEEE), such as the IEEE EMC Society and the IEEE Product Safety Engineering Society, provide presentations and opportunities for networking with regulatory compliance engineers on the changing certification requirements. In addition, social media site Linked In has a wealth of different regulatory compliance-related groups that can be joined at no cost, such as the "International Approvals/Certifications" group, where the latest news on BRIC and other countries regulatory criteria is shared with other group members.

INTERNET RESOURCES

- Brazil INMETRO website: www.inmetro.gov.br/english
- Brazil ANATEL website: www.anatel.gov.br
- Eurasian Economic Commission website: http://eurasiancommission.org/en
- India DeitY website: www.deity.gov.in
- India TEC website: www.tec.gov.in
- China CNCA website: www.cnca.gov.cn
- IEEE website: www.ieee.org
- Linked In: www.linkedin.com

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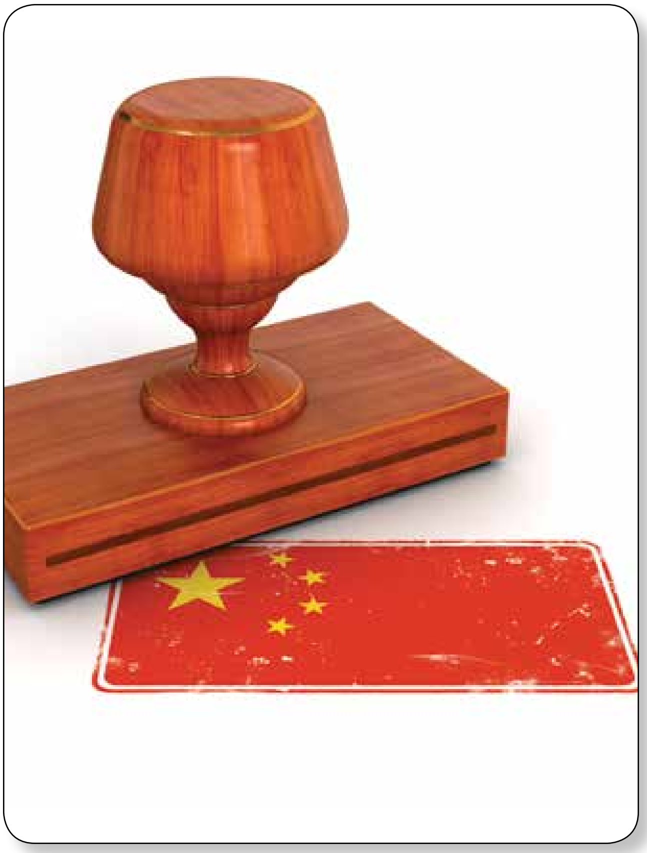
New CCC Regulations in China

Recent Changes Promises to Streamline the Certification Process

BY PAUL WANG



The Chinese government is implementing a series of reforms in various industries, including the process of certifying product for sale there. The purpose of these reforms is to open the certification and testing market, accelerate the certification process, and reduce the burden on manufacturers and importers seeking access to China's vast and lucrative marketplace. The Certification and Accreditation Administration of the People's Republic of China (CNCA) has announced several changes in its certification requirements for different product categories, and those changes are now in effect.

GENERAL CHANGES

The China Compulsory Certification (CCC) scheme requires manufacturers to obtain approval for their products before they can be legally marketed in China. CCC testing and certification can only be performed by certification bodies that have been approved by the CNCA. CNCA regulations serve as a general guide for certification bodies in China, and CNCA-approved certification bodies like CQC, ISCCC, CESI, CCAP, CCCF and CVC had previously issued their own detailed regulations which may differ from one another in some respects.

There are 21 product types in the current CCC category and each product category has its own set of requirements. The new regulations published in 2014 cover most product categories, and generally include the following changes:

- Certification mode varies depending on the classification levels assigned to the manufacturer's factory
- Type test can be conducted in manufacturer's own lab
- Initial factory inspection can be arranged after obtaining CCC certification
- There are fewer requirements for critical components

FACTORY CLASSIFICATIONS

Factories are now classified into different levels according to the following factors:

- Initial factory inspection and follow up inspection result
- Market survey results
- Reputation or product quality accident

CQC (a CNCA-approved certification body) has listed the factory level classification factors as follow:

- Class A
    - No serious failure found in initial factory inspection or in follow-up inspections within the past two years
    - No test failure during or after certification test
    - No non-conformances identified in the national or state market survey within the past two years
    - No product quality accident within the past two years
- Class B: Factories other than Class A, C and D

Post-certification audits can consist of follow-up inspection, on-site sampling and tests or market sampling and tests. Certification bodies will determine the extent of post-certification audit activities based on the assigned factory levels.

- Class C
  - Initial factory inspection and follow-up inspection failure caused by product quality, which has been corrected and verified through on-site inspection
  - Product quality disqualification, but not a cause for certificate suspension or withdrawal
  - Other negative factors, including product information or input from the manufacturer
- Class D
  - Failure of initial factory inspection and follow-up inspection
  - Failure of post-certification product testing
  - Refusal to conduct inspection or post-certification testing
  - Serious quality issues that may result in certificate suspension or withdrawal
  - Non-conformance in the state or national market survey
  - Suspension or withdrawal of product certification for other reasons
  - Other negative factors, including product information or input from the manufacturer

Some certification bodies have a different number of factory classifications (for example, three class levels instead of four). Generally, however, a new factory will be initially categorized at a middle level, and moved to a higher or lower level based on the factors mentioned above. A manufacturer's factory classification level may affect a number of other certification factors, including certification mode, factory inspection frequency and product series classification

CERTIFICATION MODES

Certification mode involves the sequence of the CCC certification process, including the required factory inspection. Under the new regulations, most product categories now permit the awarding of a CCC certificate without waiting for the initial factor inspection to be conducted. For many manufacturers, this means receiving certification once the results of type testing have been approved.

As an example, Class I and Class II information technology, audio, video and telecom equipment (per GB 4943/IEC 60950) can now be certified upon the conclusion of type testing, with factory inspections to be conducted following certification. For equipment and devices other than Class I and Class II, certification can also be issued following successful type testing, with factory follow-up inspections to follow.

Generally, the first factory inspection must be completed within three months after the issuance of the CCC certificate. This means that any corrective actions identified during type testing must be addressed within that time as well.

Post-certification audits can consist of follow-up inspection, on-site sampling and tests or market sampling and tests. Certification bodies will determine the extent of post-certification audit activities based on the assigned factory levels. In addition, follow-up inspection frequency depends on the assigned factory Class level, with better factories likely to require fewer follow-up inspections.

For some product categories like automotive parts, fire protection devices, and security protection devices, an initial factory inspection must still be completed in advance of product certification.

TYPE TESTS CAN BE CONDUCTED IN MANUFACTURER'S OWN LAB

Manufacturers can choose to have required type testing performed at their own testing laboratories or at the factory's testing laboratories. Such testing laboratories must be accredited to the requirements of ISO/IEC 17025, "General requirements for the competence of testing and calibration laboratories," and owned by the manufacturer or the factory. There are two options to conduct the test:

- *Testing on Manufacturer's Premises (TMP)*: Testing is conducted by the test engineer from the authorized CCC test lab.

- *Witness Manufacturer's Testing (WMT)*: Testing is conducted by the manufacturer and witnessed by the authorized CCC test lab engineer.

Note that, in utilizing these options, manufacturer will still be responsible for the cost of travel expenses and witness fees for the representative from the authorized CCC testing laboratory. Further, TMP or WMT accreditation require periodic auditing by the certification body. Finally, the capacity of the laboratory may be too limited to conduct all aspects of the required testing. In these cases, remaining tests will still need to be conducted by the CNCA-approved testing laboratory.

OTHER CHANGES

Other CCC regulatory changes cover the following issues:

- *Critical Component Requirements*—Some EMC-related components were removed from the original list of critical components requiring testing. In addition, voluntary certification marks may be accepted for some critical components, which means that, if the component is outside of CCC category, the manufacturer can provide evidence of a voluntary certification mark to avoid component level test.
- *Self-Made Components*—Self-made components that come under a CCC category may be tested as part of the end product, rather than requiring a separate CCC certificate first. For example, if the end product is a server, and the manufacturer also produces the server power supply that will only be used in the server, the power supply does not require separate certification.
- *Product Series Classification*—The new regulations clarifies the product series identification for group application. For example, displays should be grouped by screen size, power supplies should be grouped by power ratings, etc. Factories with higher level classification may have more flexibility for group application.
- *Other Issues*—There are also some minor changes in the new regulation. Specifically, OEM/ODM agreements need to signed by the applicant, the manufacturer and the factory. Also, "factory quality control capability self-declaration" needs to be submitted in advance of the actual factory inspection.

PREPARING FOR THE CHANGES

For new factories…

If your factory maintains an ISO 9001-certtified quality control system and the product consistency is stable, you can take the advantage of the new regulation and apply for the new certification mode, that is, conduct the factory inspection after CCC certification. This is a good change especially for new factories located outside of China, since it may save a minimum of two to three months compared with the original process. On the other hand, your factory must be well prepared for the inspection, since an inspection failure may delay the release of the CCC certificate. Of course, if you have doubts about the ability of your factory to pass inspection, you can also choose to pursue the original certification route, and have the initial factory inspection conducted first.

For existing factories…

Regulations applicable to existing factories will be updated as new or existing products are recertified. The main challenge here is to maintain complete and accurate records of factory inspection results, and to work toward elevating your factory classification level according to the factory classification requirements. The benefit of obtaining Class A factory classification means fewer factory inspections, reduced inspection scope and more flexibility regarding group applications.

For factories with test labs…

You can expand your test lab capabilities to conduct WMT or TMP testing. This is good for companies that manufacturer large equipment that is difficult to ship or complicated to configure. But the test lab capability must cover all related GB standards to avoid the need to ship samples to a separate testing laboratory for additional testing. Testing fees may also be less compared with the cost of testing products in China-based testing laboratories, but you will still incur witness fees and travel expenses related to WMT or TMP testing. If you have multiple models to be certified, you can apply for this test mode and conduct witness test at one time. If the test sample is easy to ship, testing in China-based testing laboratories may still be a good choice.

Update component list…

If you have an alternate component to be replaced or added, and if that component has been removed from the new regulation, you can simply apply to update to the new regulation and the component will be removed. If your component has a valid voluntary certificate, you can also apply for a new regulation update and avoid verification testing.

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An Overview of Automotive Vehicle and Component Regulations in China

Recent Changes Expand Testing Requirements

BY PAUL WANG

The market for automotive vehicles is growing rapidly in China, especially the market for passenger vehicles. Understanding the regulations in this automotive industry and preparing in advance are important for automobile manufacturers as well as manufacturers of automotive components. This article provides an overview of the general regulations and new rules that will come into effect.

CCC CERTIFICATION

CCC is short for China Compulsory Certification. All automotive vehicles and automotive parts need to obtain CCC certificate to legally enter China. Entire vehicles include passenger cars, trucks, trailers, motor cycles and fire engines. Components that require CCC certification include tires, window glass, external and reflective lighting, rearview mirrors and cameras, and horns and other audible signals. Interior automotive safety and performance features include safety belts, door locks and retention systems, seats and headrests, interior trimming materials and child safety seats. Other items subject to CCC certification include motorcycle engines, break hoses and fuel tanks.

The process of obtaining CCC certification process for automobiles and automotive components is similar to that applicable to other products that require CCC certification. A product sample is selected from the factory by a nationally-accredited auditor and is evaluated by a testing laboratory authorized by China's Certification and Accreditation Administration (CNCA). Manufacturers based outside of China can save time by forwarding samples for type testing in advance. Initial factory inspections are also conducted to evaluate the quality control system of the factory as well as product consistence.

Once type testing and the initial factory inspection has been satisfactorily completed, the certification body (CQC or CCAP) issues the CCC certificate. Once a manufacturer has obtained CCC certification, it can apply the CCC mark to their product, either by printing or silk screening the CCC logo on the product label or by purchasing CCC stickers to attach to their product.

Follow-up factory inspections are required to maintain the validity of the CCC certificate. The scope and content of follow-up inspection is similar to the initial inspection. Manufacturer need to prepare an annual verification test report as evidence of product consistency, based on verification testing conducted according to GB standards by the manufacturer or by an independent testing laboratory. Radom sample tests may also be conducted on site. The follow up inspection frequency is usually once a year, but the inspection frequency may be reduced if a factory has routinely demonstrated compliance during past inspections.

When applying for a change to an existing CCC certification, manufacturers may use their own test facilities to conduct random testing and differential testing. In-house testing facilities must be accredited by the national certification body, and must maintain their certification through frequent audits. In-house testing is be conducted or witnessed by a testing engineer from an accredited CCC laboratory, and the report is issued by the CCC lab based on data derived from in-house testing.

MAIN CHANGES TO CCC REGULATIONS IN 2015

In August 2014, the CNCA announced 15 new regulations applicable to automotive CCC products, which came into effect on January 1, 2015. Some new products were added to existing CCC categories, the scope of some categories were extended and some GB standards were updated to incorporate new requirements. The changes include:

- *Children's safety seats:* Children's safety seats must now be tested to the requirements of GB27887 which is adopted from ECE R44 with national deviations. Similar types of children's seats utilizing the same construction and materials and intended for use by children within the same weight group can be grouped together as a family of products for the purposes of CCC certification.
- *Rear view cameras and monitoring devices:* These products have now been added into the indirect vision devices category. The test standard is GB15084 (refer to ECE R46). Cameras, monitoring systems and recorders used to indirectly view zones in close proximity to the exterior of a vehicle can now apply for CCC certification.
- *Interior trimming materials:* Interior trim materials like trunk carpet, trunk side panels and scuff plates, heat insulation trimming materials in engine compartments, and sound insulation materials used in bus engine compartments are now covered in an existing CCC category.
- *Seat belts:* The seat belt mechanical parts assembly cannot contain the material Polyamide VI, and the airbag warning label for safety belts is required
- *Passenger car tires:* The standard for passenger car tires has been updated to GB 9743-2015, replacing GB 9743-2007. Truck tires are now subject to the requirements of GB 9744-2015, replacing to replace GB 9744-2007. The effective date of these changes is February 1, 2016, and manufacturers will need to update the CCC certificate and test report to verify compliance with the new standards.

MIIT VEHICLE PUBLIC ANNOUNCEMENT--BULLETIN REGISTER

Vehicles aimed to sale on China market must be listed on the website of China's Ministry of Industry and Information Technology, or MIIT (www.miit.gov.cn). This listing is mandatory for all vehicles as well as components, and is in addition to CCC certification. In addition, the listing requirement applies to other automotive products and components that fall outside of current CCC certification categories. These products and components include engines, wiper motors, heater motors, flash relay motors, front light cleaners, batteries on electrical vehicles, electrical motor and controllers and conductive charging connector sets for electric vehicles.

To comply with this requirement, manufacturers must submit an application for listing with MIIT-authorized agencies. The agencies will request test reports from the applicant for review. If the report demonstrates compliance with all applicable requirements, it will then be listed in the MIIT system. A separate factory inspection is not a requirement for listing an automotive product on the MIIT website.

Manufacturers of automotive components that have already received CCC certification can simply reformat their CCC test report to comply with the Bulletin Register Report format as part of their MIIT listing application. Uncertified components need to be tested at authorized testing laboratories in China.

Samples can be prepared by the manufacturer for test conditions. As an example, testing requirements for electrical motors and controllers include performance testing and environmental testing. This testing requires the motor to run at a certain speed and torque to produce a torque-speed map curve. So it's recommended that motor and controller manufacturers provide a CAN bus or a programmed controller with shielded cables to perform the test. Two sets of motor and controller samples are recommended to facilitate conduct testing in parallel and to avoid the risk of potential testing failures.

NEW STANDARDS FOR MIIT ANNOUNCEMENT

The MIIT has adopted GB/T (recommended GB) standards and QC/T (recommended automobile) standards for testing. Therefore, when applicable standards are updated, manufacturers are required to retest or conduct additional testing to meet the new requirements. A number of standards have been recently updated to replace older versions, including the standards for electrical motors and controllers, GB/T 18488.1-2015 (which replaces GB/T 18488.1-2006) and GB/T 18488.2-2015 (which replaces GB/T 18488.2-2006), along with the standard for zinc-air batteries, GB/T 18333.2-2015 (which replaces GB/Z 18333.2-2001. The effective date for meeting the requirements of these updated standards is September 1, 2015, so manufacturers should take action now to meet the new requirements.

NEW ENERGY CAR

So-called “new energy” cars are still not common in China but there number is growing significantly. A number of electrical companies are considering the production of electric vehicles (EVs), and the government is also encouraging consumers and government departments to purchase new energy cars through tax incentives and by the broader development of EV charging stations and facilities.

Currently, entire EVs can be CCC certified. But some key components are outside of existing CCC categories. The CQC has issued some voluntary certification regulations for batteries, chargers and charging stations. The MIIT has also issued a list of tests required for new EVs and EV components, as noted in Table 1.

Manufacturers should prepare for these regulations accordingly. With the development of the new energy vehicle industry, certain components may also require CCC certification in the near future.

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Number	Test Items		Standard	Sample
E1	Onboard energy	Zinc-air batteries	GB/Z 18333.2-2015	8
		Ultracapacitors for vehicles	QC/T 741-2006	16
		Lead-acid batteries	QC/T 742-2006	8
		Lithium-ion batteries	QC/T 743-2006	28/10 modules
		Nickel-metal hydride batteries	QC/T 744-2006	
E2	The electrical machines and controllers for electric vehicles		GB/T 18488.1-2015 GB/T 18488.2-2015	1
E3	Electric vehicles safety specification	On-board energy storage Functional safety and protection against failures Protection of persons against electric hazards	GB/T 18384.1-2001 GB/T 18384.2-2001 GB/T 18384.3-2001	1
		Hybrid electric vehicles safety specification	GB/T 19751-2005	1
E4	Magnetic and electric radiation emission strength from electric vehicles		GB/T 18387-2008	1
E5	Electric vehicles—Symbols for controls，indicators and signal devices		GB/T 4094.2-2005	1
E6	Instrumentation for electric vehicles		GB/T 19836-2005	1
E7	Electric vehicles—Energy consumption and driving mileage	Electric vehicles	GB/T 18386-2005	1
		Light duty hybrid electric vehicles energy consumption	GB 18352.3-2005 GB/T 19753-2013	1
		Heavy duty hybrid electric vehicles	GB/T 18386-2005 GB/T 19754-2005	1
E8	Electric vehicles—Windshield demisters and defrosters system		GB/T 24552-2009	1
E9	Battery electric passenger cars—Specifications		GB/T 28382-2012	1
E14	Connection set of conductive charging for electric vehicles—Part 1: General requirements		GB/T 20234.1-2011	6
E15	Connection set of conductive charging for electric vehicles—Part 2: AC charging coupler		GB/T 20234.2-2011	1
E16	Connection set of conductive charging for electric vehicles—Part 3: DC charging coupler		GB/T 20234.3-2011	1
E17	Communication protocols between off-board conductive charger and battery management system for electric vehicle		GB/T 27930-2011	1

Table 1: MIIT-required tests for new energy vehicles and components

Certification of Medical Devices in China

A Complex Process Results in Long Lead Times for Market Access

BY JULIAN BUSCH

Manufacturers of medical products who want to export their devices to China need to consider the local requirements for product certification and registration. These requirements are created and published by the Chinese authority, the China Food and Drug Administration (CFDA). Prior to 2013, the institution was known as State Food and Drug Administration (SFDA). The regulatory system relies on provisions issued by the Chinese State Council, on CFDA orders and normative CFDA documents that provide detailed guidelines for medical device registration and licensing practices. With hundreds of departments and divisions, the CFDA is a huge and powerful administration body based in Beijing. It carries out certification processes of drugs, medical devices and food with a wide range of responsibilities.

One of CFDA's main tasks is to regularly update the catalogue of medical products requiring registration. Currently more than 700 devices are listed in the database and the list grows longer every year.

For manufacturers of medical devices, it is often difficult to find out whether their products require a CFDA registration for the Chinese market. Unfortunately, all of the standards and requirements are available only in the Chinese language. In addition, contacting the CFDA directly does not always result in a correct, definitive answer. Therefore, the criteria to determine need for CFDA registration can be complicated.

CFDA – A COLORFUL PAST

Several scandals at the CFDA, including corruption and fraud at the highest levels, caused extensive reorganizational changes in 2003, 2008 and 2013. The most publicized and well-known was the scandal involving the CFDA's Chairman Zheng Xiaoyu. For years, he reportedly took bribes in exchange for circumventing product testing of medical products. According to the Chinese news agency Xinhua, Zheng received an estimated 6.5 million Chinese Yuan (about $850,000.00 USD at the time) in bribes and other illegal inducements.

During Zheng's leadership of the SFDA, hundreds of medical devices and drugs were approved for the Chinese market without passing the necessary administrative procedures and, more importantly, testing and clinical trials. As a result, many of the products approved were connected with consumer injuries and even deaths. The most notorious examples included unsafe eggs and milk products that reportedly resulted in the deaths of as many as 1000 people. Ultimately, Zheng's greed cost him his life. The Chinese government made an example of this case, accusing Zheng of being a danger to both China and China's reputation, and sentencing him to death.

Unfortunately, even with the threat of severe penalties, more scandals followed. In 2013 the SFDA changed its name to the CFDA and management given to the State Council of the People's Republic of China. That same

Communication between the applicant, testing laboratories and CFDA is crucial for the success of the certification process. The authority frequently changes the requirements for the approval process mid-stream, and can request additional documents and/or test reports throughout the process.

year Zhang Young was named the new director of the newly formed CFDA. The restructuring and rebranding were meant to increase accountability and to give the organization a fresh start.

THE CFDA APPROVAL PROCESS

In the past, some medical products required China Compulsory Certification (typically referred to as CCC certification). However, the General Administration of Quality Supervision, Inspection and Quarantine (AQSIQ) changed this policy and no longer requires CCC certification for certain product groups (e.g., ECG devices, artificial heart-lung machines). For manufacturers, this facilitates their research for necessary product certifications for China.

The first step manufacturers need to manage is to clearly identify whether CFDA approval and/or other certification is necessary for exporting their product to China. Without any support or contacts with the Chinese authority, this can difficult. If the medical device is determined to require CFDA approval, the applicant needs to classify his product into Class I, Class II or Class III. This is another challenge for the manufacturer, because the CFDA product catalogues and corresponding instructions are only available in the Chinese language.

The criteria for classification into Class I, Class II or Class III are based on the European Union's (EU's) Medical Device Directive (MDD), 93/42/EEC. The higher the potential risk of a medical product, the more stringent the security and performance requirements. Class I devices can get CFDA registration by passing simple administrative procedures. This is a relatively quick process and typically takes about six months. For more complicated Class II and Class III products, long-term product testing and clinical trials may be required. Further, the clear distinction between Class IIa and IIb devices in the EU's MDD does not exist within the Chinese regulatory framework. Only CFDA can draw the line between the middle hazard classes, estimate the potential product risk and determine the necessary approval process.

After all completed application and supporting documents have been submitted to CFDA, the authority will either confirm the applicant's classification or correct it. Submitting all of the requested application documents does not automatically mean that the product can obtain CFDA registration. Only after acceptance of the application will the CFDA determine whether registration of the medical device is possible. Once registration is deemed possible, the CFDA will then prescribe the necessary certification process including tests and, if needed clinical trials.

If testing is prescribed for Class II and Class III products, it must typically be conducted by an accredited testing laboratory located in China. Test reports issued by foreign testing laboratories are generally not accepted. In rare instances, the CFDA will permit some testing to be performed outside of China. However, such testing is only permitted on a case-by-case basis, and is not even considered until after the CFDA has evaluated the initially application for registration and determined the terms of the registration process.

Communication between the applicant, testing laboratories and CFDA is crucial for the success of the certification process. The authority frequently changes the requirements for the approval process mid-stream, and can request additional documents and/or test reports throughout the process. These requests are often time sensitive, and delays in complying with them can halt progress or complicate the coordination of the approval process.

Only after laboratory testing has been successfully completed can clinical trials begin (if needed). Depending on the product, clinical trials typically last six to nine months or longer. After all test reports and clinical trial records are available, it can take up to additional six months for the CFDA to fully evaluated the results and issue their own report. The CFDA report is usually a comprehensive technical and administrative review. Based on the conclusions presented in the CFDA's report, the device will finally receive approval for licensing, certification and registration.

REVISED REGULATIONS FOR THE CFDA APPROVAL PROCESS

The CFDA frequently publishes new regulations and standards for the certification and registration of drugs and medical devices for China's market. In 2013 and 2014, numerous legislative changes were published, including two that potentially signify significant changes for CFDA applicants and certificate holders.

At the beginning of 2014, the CFDA published on its website a revised version of "The Regulations for the Supervision and Administration of Medical Devices." The revision includes a crucial change regarding the definition of medical devices that may affect the need for certification in general. Some products may no longer be considered medical devices, and therefore may not need CFDA approval. On the other hand, devices that were previously not considered to need CFDA approval may now be required to have it.

The CFDA notice also identified adjustments to device classification criteria. Like the changes in definition of medical devices, the revision of classification criteria may have a deep impact for applicants of CFDA certification. Required approval procedures may change in the future, due to the upcoming revisions. Depending on how a device or product is reclassified, the amount and degree of testing may increase or decrease, potentially requiring clinical trials where only simple laboratory testing was previously required.

104 NEW CHINESE INDUSTRY STANDARDS

In October 2013, the CFDA announced the introduction of 104 new standards that came into effect October 2014. At present, most of these new standards are not mandatory. However, they may become required in the future, and regulatory changes in China often occur with little or no advanced notice.

Chinese Industry Norms are abbreviated with "YY" and define the scope, parameters and prescriptive measures for product testing required for registration of medical products and devices by the CFDA. The YY Standards apply when there is no corresponding Chinese GB Standard (GB stands for Guobiao, the Chinese term for "National Standard") for the product. Therefore, GB Standards supersede YY Standards.
China's YY standards, as well as other regulations and standards that affect CFDA approval and registration of medical products, are typically based on international standards such as those of the International Electrotechnical Commission (IEC). However, China's standard many include national deviations from international requirements that must be considered in meeting technical requirements.

At the beginning of 2015, there were even more updates. On its website, the CFDA announced "Guiding Opinions on Enhancing the Construction of Food and Drug Inspection and Testing System." As of this writing, there are no official interpretations of these Guiding Opinions, and applicants for CFDA registration and certificate holders are still evaluating their implications. Nonetheless, the Guiding Opinions are likely to affect the CFDA's registration and certification process in the near future.

CONCLUSION

CFDA approval and registration is a time-consuming and labor-intensive process, and differences in language, culture, and time zones can make the whole process overwhelming. But once CFDA registration is granted, the medical product or device can be freely imported and sold throughout China. The opportunity is massive with China being one of the fastest growing markets for medical devices worldwide. With their growing economy, China is seeking to replace outdated medical equipment with world class, state-of-the-art technologies.

The medical device market in China has shown significant growth in the past years. For example, according to the China Pharmaceutical Industry Association, the industry output value increased by 20.2% in 2013 and reached 2.3 trillion Chinese Renminbi. For 2014, the Nanfang Research Institute for Pharmaceutical Industry, an institution that is associated with the CFDA, projected an output of even 2.7 trillion Chinese Renminbi, an annual growth rate of 19.7% over 2013.

For manufacturers of medical devices, there is even more good news. According to the China Association for Medical Devices Industry (CAMDI), more than 60% of the equipment in China's medical facilities is on the technological level of the 1980s or older. There is a massive sale potential that is waiting to be tapped!

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ANSI/ESD S20.20-2014

A Review of the Technical Revisions to the 2014 Edition

BY THE EOS/ESD ASSOCIATION

A five-year review of ANSI/ESD S20.20 was recently completed and the 2014 version of the standard was published in September 2014. The technical revisions in the 2014 version of the standard are highlighted in this article. A complimentary PDF copy of the new standard, and a table comparing the requirements of the 2014 version with those of the 2007 version is available at www.esda.org.

STANDARD SCOPE

The 2014 document scope now includes devices with withstand voltages greater than 100 volts HBM (no change), 200 volts charge device model (CDM), and 35 volts on isolated conductors. Changes in the standard were made to support these additions to the scope. The 200 volts for CDM is for the induced CDM event by insulators.

While some CDM control has always been implied in ANSI/ESD S20.20, the standard now explicitly states it in the scope. Changes in insulator control support the scope with the addition of controls within one inch of an ESD sensitive item. The 35 volts on isolated conductors acknowledges that all conductors may not be able to be grounded. There is a section added in ANSI/ESD S20.20 on the requirements for isolated conductors and what needs to be evaluated.

TAILORING STATEMENTS

The tailoring section of the document, Section 6.3, has been clarified to address misconceptions that tailoring is required if anything changes from the requirements of ANSI/ESD S20.20. This was not the intention. The section now clearly states that tailoring is needed only if the requirements are deleted or revised to exceed the limits in ANSI/ESD S20.20.

For example, the worksurface requirement of 0 to 1.0 x 10^9 ohms for point-to-point resistance does not need a tailoring statement if a company's internal control program document requires a point-to-point resistance between 1.0 x 10^5 to 1.0 x 10^9 ohms; these stated limits are within the ANSI/ESD S20.20 limits. However, if the point-to-point resistance in a company's internal control program document is between 1.0 x 10^5 and 1.0 x 10^{10} ohms, a tailoring statement is required because 1.0 x 10^{10} ohms is beyond the limit in ANSI/ESD S20.20.

PRODUCT QUALIFICATION

A new section on product qualification, Section 7.3, was added ANSI/ESD S20.20-2014 to emphasize the product qualification of ESD control items. The requirement to have ESD control items qualified was in the 2007 version but it was only in Tables 2 and 3 of the standard. Product qualification is an important part of ANSI/ESD S20.20 because all ESD control items need to be qualified to the ESD standards that are listed in Tables 2 and 3. Typically, product qualification requires ESD control items to work in low humidity conditions. All qualification testing or testing done at environmental conditions that do not meet the referenced standards must be technically justified with a tailoring statement.

Personnel Grounding Technical Requirement	Product Qualification[1]		Compliance Verification	
	Test Method	Required Limit(s)	Test Method	Required Limit(s)
Wrist Strap System	ANSI/ESD S1.1 (Section 5.11)	< 3.5 x 10^7 ohms	ESD TR53 Wrist Strap Section	< 3.5 x 10^7 ohms
Flooring/Footwear System – Method 1	ANSI/ESD STM97.1	< 3.5 x 10^7 ohms	ESD TR53 Flooring Section	< 3.5 x 10^7 ohms
			ESD TR53 Footwear Section	< 3.5 x 10^7 ohms
Flooring/Footwear System – Method 2 (both required)	ANSI/ESD STM97.1	< 10^9 ohms	ESD TR53 Flooring Section	< 1.0 x 10^9 ohms
	ANSI/ESD STM97.2	< 100 ohms	ESD TR53 Footwear Section	< 1.0 x 10^9 ohms

Table 1: 2007 Personal Grounding Requirements

Technical Requirements	Product Qualification (4)		Compliance Verification	
	Test Method(s)	Required Limit(s)	Test Method(s)	Required Limit(s)
Wrist Strap System	ANSI/ESD S1.1 (Section 6.11)	< 3.5×10^7 ohms	ESD TR53 Wrist Strap Section	< 3.5×10^7 ohms
Flooring/Footwear System (Both limits must be met)	ANSI/ESD STM97.1	< 1.0×10^9 ohms	ESD TR53 Foot-wear Section	< 1.0×10^9 ohms(6)
	ANSI/ESD STM97.2	< 100 volts Peak	ESD TR53 Flooring Section	< 1.0×10^9 ohms(6)

Table 2: 2014 Personal Grounding Requirements

FLOORING AND FOOTWEAR SYSTEMS

The 2014 version of ANSI/ESD S20.20 includes a change to the qualification of flooring/footwear systems for grounding personnel. The 2007 version allowed for qualification based only on resistance if the total resistance was less than 3.5×10^7 ohms from a person's hand to ground. A walking test was required for resistance greater than 3.5×10^7 ohms and less than 1.0×10^9 ohms.

In the 2014 version, the resistance method (Method 1) has been eliminated and the requirement is now both a resistance and walking test. There has been data presented at various symposia that, even with a total system resistance of 3.5×10^7 ohms, a person walking on the floor can generate sufficient voltage to exceed the 100 volt requirement. For comparison, the 2007 and 2014 tables for personnel grounding requirements are shown in Table 1 and Table 2.

PROCESS-REQUIRED INSULATORS

In the 2007 version of ANSI/ESD S20.20, the requirement for process-required insulators within 30 cm (12 in) of an ESD sensitive device is a field of no more than 2000 volts/in. In the 2014 version of the standard, there is a new requirement that process-required insulators within 2.5 cm (1 in) of an ESD sensitive device have a field of not more than 125 volts/in. The change supports the addition of 200 volts CDM in the scope.

ISOLATED CONDUCTORS

The 2007 version of ANSI/ESD S20.20 did not allow for any isolated conductors in an ESD control program. Therefore, no requirements on isolated conductors were included in the document. However, there are situations where an isolated conductor must be in the ESD protected area (EPA). Accordingly, in the 2014 version of ANSI/ESD S20.20, isolated conductors in the EPA cannot have more than 35 volts on the conductor. The measurement of isolated conductors requires either an electrostatic non-contacting voltmeter or a high impedance contacting voltmeter. A field meter alone cannot make this measurement on very small conductors. This requirement applies only to isolated conductors that are in the EPA, and is only a qualification requirement.

TABLE 3 CHANGES

Changes to Table 3 in the 2014 version include the following:

Ionization

Ionization now has one offset limit instead of the two requirements in the 2007 version. The 2007 version has separate limits for room ionization and local ionization. The 2014 version now has only one limit. The intent of room ionization is mainly for cleanliness rather than ESD control. As such, it is not necessary to include room ionization in the ESD control plan unless it is expressly configured for ESD mitigation.

Tool Additions

Electrical soldering/desoldering hand tools were also added as a requirement to Table 3. This is new to the 2014 version and was not in the 2007 version. Revisions have also been included in ANSI/ESD S13.1 and ESD TR53 to support the additions to the Table.

Wrist Strap Changes

Another addition to Table 3 is the requirement to check the wrist strap connection for non-continuous monitored wrist straps. This is the connection from where the wrist strap is plugged in to ground.

Packaging Materials

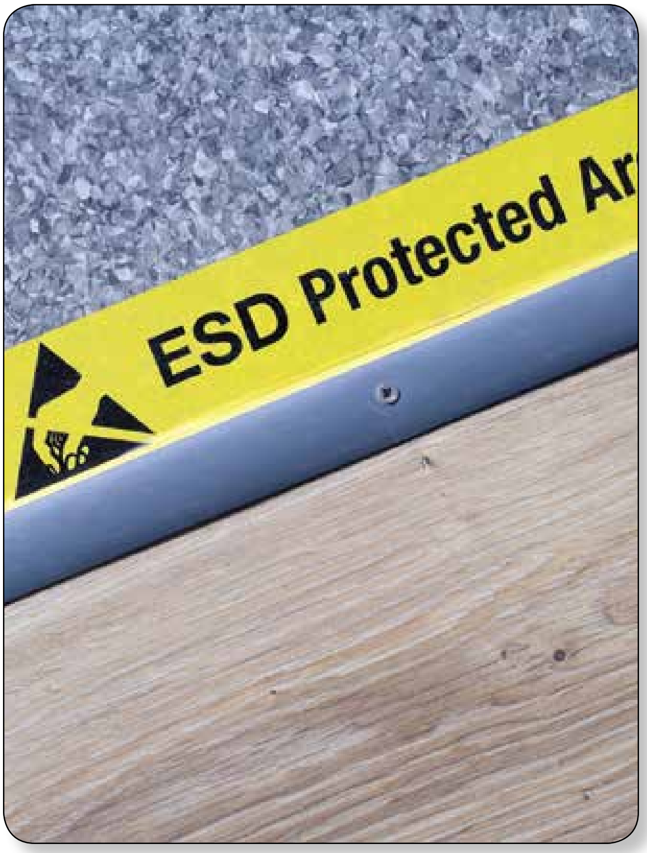
The requirements on packaging materials has not changed but there have been accounts of packaging materials used as worksurfaces, such as placing ESD sensitive parts on top of static shielding bags or static dissipative pink foams. A note has been added to the packaging section which says, "When ESDS items are placed on packaging materials and the ESDS items have work being performed on them, then the packaging materials become worksurfaces. The worksurface requirements for resistance to ground apply." This allows the use of packaging materials as long as they meet the requirements for worksurfaces and are tested as part of compliance verification.

VERSION TRANSITION

The updates in the 2014 version of ANSI/ESD S20.20 will be reflected in the requirements for facility certification. There is a transition period to give process owners time to understand the new requirements and to update internal ESD control processes. For 2015, facilities may be certified to either the 2007 version or the 2014 version of ANSI/ESD S20.20. For this reason, both standards will remain on the ESD Association web site for 2015.

Beginning in 2016, facilities will only be certified to the 2014 version of ANSI/ESD S20.20.

Achieving Perfect ESD Audits for S20.20 ESD Control Programs



A Disciplined Approach Leads to Dramatic Improvements

BY JOHN HENSLEY, JOHN TROTMAN AND ROGER PEIRCE

ESD

Many companies struggle with achieving perfect ESD S20.20 compliance to their ESD control program requirements when handling ESD sensitive (ESDS) devices. Sometimes it seems like perfect discipline is impossible in large electronic manufacturing facilities. There are just too many things that can go wrong on a daily basis. Lapses in discipline such as violating the 12" rule for charge generating materials, having the operators become ungrounded at times, having ESDS items placed on non-certified ESD work surfaces, failing to insure that Faraday shielding for ESDS items is accomplished at all times during product transportation and storage, failing to have the ionizers on - working to specification - and pointed correctly in their applications, using wrist strap constant monitors when they are not working properly, etc. The list can seem endless.

This article reviews some steps taken over the past several years by personnel at General Dynamics Mission Systems facility in Bloomington, MN (GD-MS) that have resulted in superior ESD discipline and a number of perfect ESD audits (zero violations). The ESD control program is described here, along with some of the many innovative actions that were taken to produce the continual improvement at the facility.

OVERVIEW OF THE BASIC S20.20 COMPLIANT ESD CONTROLS AT THE FACILITY

Similar to many typical electronic manufacturing facilities, the GD-MS facility has the usual set of ESD controls in place for excellent S20.20 compliance, as the end products are high reliability electronic assemblies with state of the art ESD sensitive devices. Even more stringent controls are provided in the areas where Class Zero devices (devices less than 250 volt sensitive) are handled. There are approximately 700 ESD workstations throughout the facility.

Typical ESD controls in place include:

- ESD smocks are required in all the manufacturing areas.
- Wrist straps are required for the primary means of grounding personnel in all areas. Constant monitors for the wrist straps are provided at every work station.
- Foot grounding devices (tester provided) are required on ESD floors throughout the facility in areas where Class Zero devices are handled.
- ESD mats are provided at every work station.
- Ionizers are provided at all Class Zero work stations, and at all other work stations where the 12" rule cannot be accomplished (such as taping operations).

- All transport carts have Faraday shielding containers or covers.
- The carts are grounded to ESD floor in Class Zero areas, but full Faraday shielding techniques still must be in place during transit.
- ESD chairs are also provided in Class Zero areas.
- Many posters and signs, noting ESD requirements, are in place throughout the facility.
- A myriad of discipline and handling requirements are conveyed to the operators.

OVERVIEW OF ESD TRAINING PROGRAM

Recurrent ESD training programs are in place:

Online training is mandatory once per year for all personnel to review the ESD rules and regulations. Online training for operators working in Class Zero areas is required every 6 months.

Instructor led courses are required every two years by an outside ESD consultant. These courses provide technical explanations on the reasons behind the basic rules and regulations at the facility, and to provide feedback on the recurrent ESD audit results. The ESD "state of the art" is reviewed so that personnel are kept current on why the continual changes and improvements are taking place. Updates are given to explain changing S20.20 requirements and why additional controls are needed to address the constantly increasing ESD sensitivities of modern day devices in the industry.

RECURRENT ESD AUDITING PROGRAM

The ESD program is continually monitored as follows:

Outside, independent audits and certifications are conducted by an outside ESD consultant on a four month basis. During these audits, along with reporting on any ESD discipline issues, 100% of the ESD hardware controls are electrically tested, certified to S20.20 requirements, and stickered. The hardware controls checked include: all appropriate ground connections (including machines, equipment, cabinets and shelves), ESD mats and laminates, ESD flooring, ESD carts and chairs, wrist strap constant monitors, ionizer decay and balance, and soldering irons. In addition, violations are noted if any aspect of S20.20 discipline is observed (i.e., open static shielding bags, ungrounded operators, 12" rule violations, etc.).

Most important, at the end of each of these outside audits, a wrap-up meeting is held with the 15-20 members on the ESD team to verbally share the results of the audit before the formal written report is supplied and circulated. At this time, an informal brainstorming session is always conducted to discuss innovative ways of eliminating each and every one of the audit violations identified. This has proven to be a critical step in the continual audit result improvements achieved by this facility (implementation of recommendations that have resulted from these brainstorming sessions are reviewed later in this article). Also of equal importance, senior members of the management team attend this ESD wrap up meeting. Upper management support is a critical component for continually improving any ESD program.

Internal audits are conducted on a monthly basis by members of the ESD team and similarly check for ESD violations to S20.20 of any kind. Results are reported and actions are taken to create greater awareness and to provide solutions to prevent future violations.

Daily operator ESD checks are accomplished by all personnel at their individual workstations. Before starting work, all operators are required to check the following to ensure compliance:

- All certification stickers on ESD workstations, chairs, carts, constant monitors, ionizers and soldering irons must be current. ESD smocks should have the current marking (verifying their certified status).
- Ionizers must be cleaned (brush off the needles with the dedicated twist knob) on a daily basis.
- Constant monitors for wrist straps must be tested by removing the wrist strap from the wrist and observing the visual and audio alarms. Company policy requires testing of the constant monitor each time the operator plugs into a constant monitor unit, no matter where that unit is located (not just their primary workstation).

Internal hardware checks: ESD smocks are tested on a yearly basis and outfitted with the appropriate new color "snap" on the collar. Ionizers are sent to metrology for testing and certification on a 6 month basis. All ionizers are also checked on the 4 month basis to identical performance requirements as part of the outside audits described above. When an ESD control is moved or disconnected for any reason, members of the ESD team recertify the control before it is allowed to be used again.

CHANGES MADE TO THE PROGRAM THAT IMPROVED DISCIPLINE AND AUDIT RESULTS

With all these ESD controls in place, "perfect" audits are still not possible without the essential discipline from the operating personnel. And many companies struggle with continuing ESD violations regardless of the additional ESD hardware controls implemented. At GD-MS, a number of important implementations were made to achieve better compliance to the program. Some notable implementations and their results include the following:

12" rule violations: Many companies struggle to get operating personnel to adhere to S20.20's requirement of keeping charge generating materials at least 12" away from exposed ESDS items. There are two common ways to implement the 12-inch rule (one works well, one does not). Unfortunately, the ineffective method is the one most commonly implemented in the industry. Specifically in this case, the facility implements ESD mats (or laminates) on the work surfaces, and instructs operating personnel to "remember to keep all charge generating materials at least 12 inches away from ESDS (ESD-sensitive) items" (called the 12-inch rule "by decree"). Operator discipline under this approach is usually poor, and it was an issue in the past at GD-MS.

A more effective technique to maintain a 12"inch rule is used at perhaps only 2 percent of facilities. In this technique (which has been implemented at GD-MS), an additional, smaller and differently colored ESD mat is placed on top of the existing ESD mat or laminate at the workstation.

The purpose of this additional mat is to designate the exclusive area where ESDS items can be safely placed. These additional, differently colored mats (light blue at GD-MS) are kept absolutely clear of all materials except for ESDS items. In addition, these blue mats are sized to provide a natural 12" clear area border when an ESDS item is placed in the center of the mat. Operators have a number of blue mats at their workstation for use with different size ESDS items. The mat can be placed conveniently anywhere on the ESD work surface. The blue mat mates electrically with the work surface mat or laminate beneath (no additional ground cord is needed) and the 12" border is inherently maintained when product is placed in the center of it. It is quite simple and obvious to monitor the 12" rule in this manner as the mats are highly visible and nothing but the ESDS item should be on them. Audit violations to the 12" rule are now close to zero during the recurrent audits. The continual improvements at the facility are depicted in Figure 1.

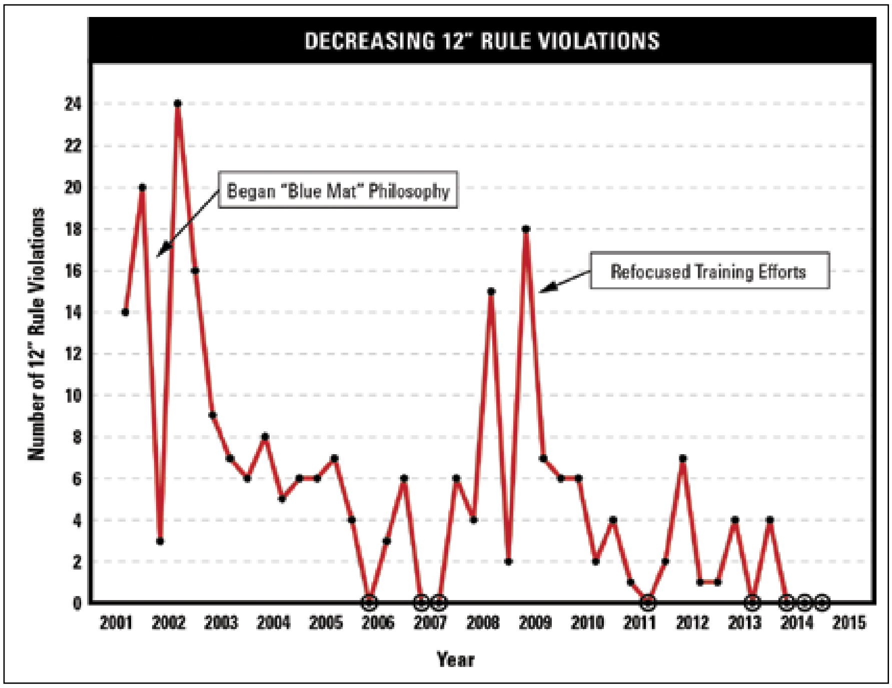


Figure 1: Decreasing 12" rule violations

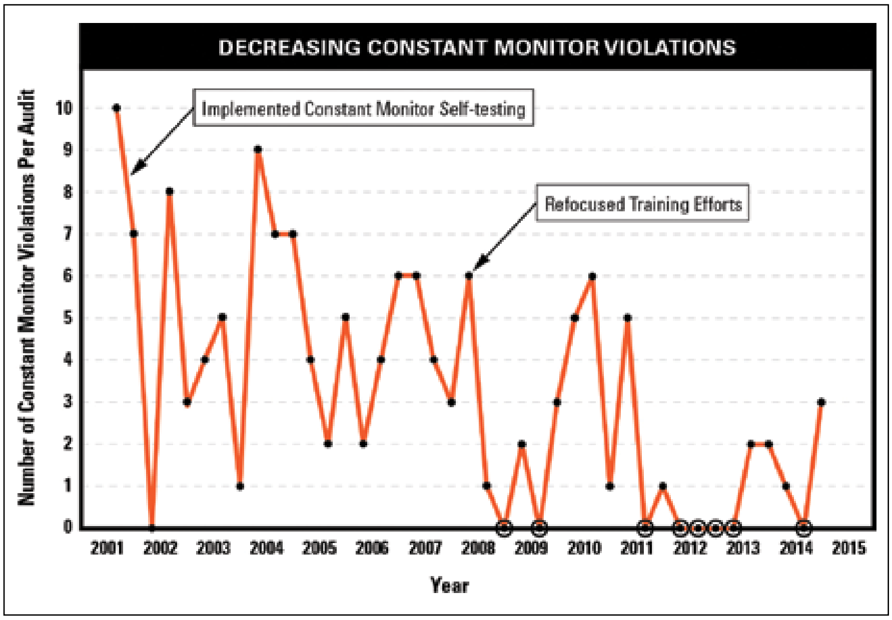


Figure 2: Decreasing constant monitor violations

Operators Using Defective or Unplugged Constant Monitors: Another discipline improvement example includes the requirement for operators to test their wrist strap constant monitors each time they plug into them. GD-MS employs wrist strap constant monitors at all locations where ESDS items are handled. Prior to the implementation of this requirement, we had observed constant monitor equipment failures that typically totaled 10 per audit during the external audits and certifications. The training/auditing closed loop system was used to educate operators to perform simple tests each time they plug into them to ensure that the constant monitor was working correctly. We found that an even further improvement in audit scores was realized when the requirement for testing the constant monitor was increased from once per shift to every time they plug in. Constant monitor violations are now always close to zero during the recurrent audits with that operator self-testing in place. Figure 2 illustrates the results stemming from this change.

Stop signs: Historically, during outside audit wrap up meetings, we reviewed numerous repeat violations in which operators would use ESD controls at an ESD workstation that were not working properly, such as a constant monitor jack that was not providing an audible alarm under a failure condition. These violations often took place when a previous user had identified workstation ESD controls as defective but had not yet contacted maintenance personnel to repair or replace it. Dedicated "stop signs" (see Figure 3) were developed and made easily available for operators to plug into a defective jack. The stop signs effectively alerted the next user not to use that defective station until it was repaired and re-certified by the in-house ESD team, eliminating that source of repeat violations.

Figure 3: Stop signs deployed throughout the facility

A host of other program changes were similarly implemented to address a wide variety of nagging ESD violation issues. These changes have resulted in continual improvement in the ESD audit scores. All the following issues were also responsible for substantial audit violations before the program changes (noted) were implemented:

Ionizer violations: Operator daily cleaning was implemented. Discharge times and balance are monitored on the four-month basis to more stringent standards than required. Performance "alerts" are detected and subsequently corrected before the performance reaches out of compliance levels.

Out of date calibration stickers: Color coding of new calibration stickers has made it easier for operators to spot out of date stickers on workstations, carts, and chairs during their daily checks.

Faraday shielding violations: Highly customized ESD training courses (with photos of the typical violations observed in the audits) and posters throughout the facility have routinely reduced to zero transportation and packaging violations.

ESD

ESD

Repeat violations: Brainstorming sessions during the outside audit wrap-up meetings have led to innovative solutions across the facility, such as dedicated holders with signs for materials (e.g., gloves for the ovens) that were frequent 12” rule violators when accidentally placed on ESD mats.

ESD smock violations: Color coded snaps were implemented to provide visual testing confirmation.

Heel strap violations: The facility went to complete sole grounders, resulting in a substantial reduction in violations at the footwear tester. In addition, computerized logging of the footwear test results (badge activated) eliminated manual logging miscues and violations on sign-in sheets.

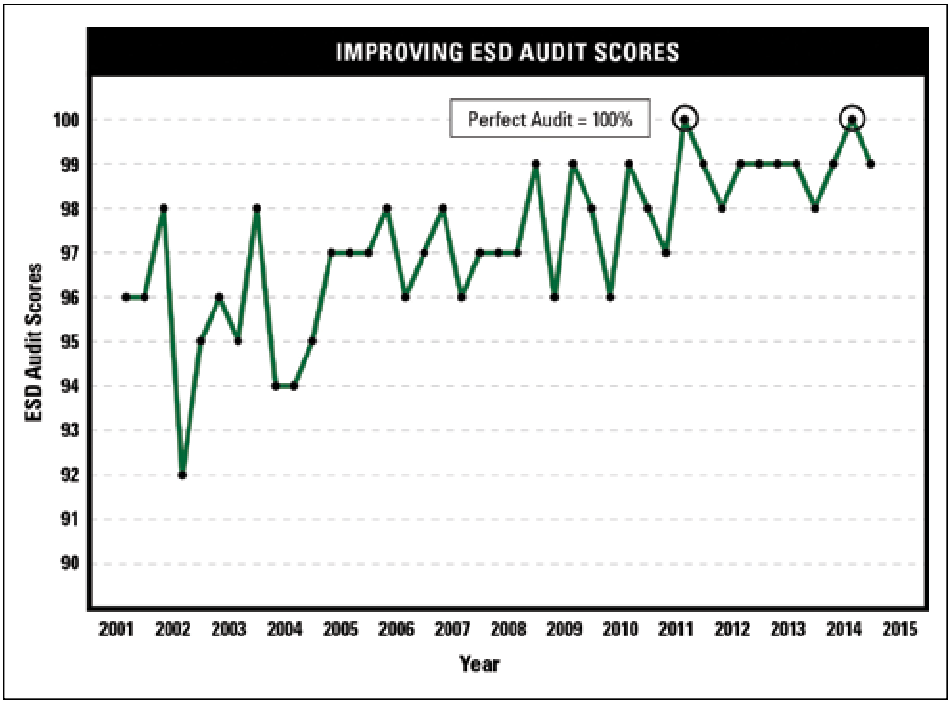


Figure 4: Improving ESD audit scores

ESD cart violations: Drag chains (a common root cause for high resistance failures of carts across the industry) were replaced with conductive wheels.

Soldering iron violations: Tips on the soldering irons were proactively replaced on a more frequent basis, operators self-test their irons each month, and certification stickers are now checked as part of an operator’s daily self-checks. ***ESD event monitoring***: New, state of the art, ESD event monitoring equipment is now used in routine sweeps throughout all process steps during hardware audits. HBM and CDM ESD events of 100 volts and above (S20.20 dictated level) are detected if and when they occur.

SUMMARY

The continual improvement efforts for the ESD program have been extremely effective. There have been even more implementations (not mentioned here) that have resulted from analyzing audit results and targeting the violations for improvements. The upward trend in audit scores since 2001 is shown in Figure 4.

As shown in Figure 4, the GD-MS facility has recently achieved two “perfect” 100% audits, and all personnel involved continue to meticulously track audit violations, thoroughly dissect root causes, and strive to eliminate them from future audits with a combination of the interactive ESD program elements discussed in this article.

The authors gratefully acknowledge the contributions made by all the members of the ESD team at GD-MS. In particular, we thank Brian Schubloom, Debbie Perry, Dean Lilliencrantz, Jesse Moralez, Craig Luedtke, Joe Graetz, John Olsen, and all the area ESD leaders for their valuable contributions.

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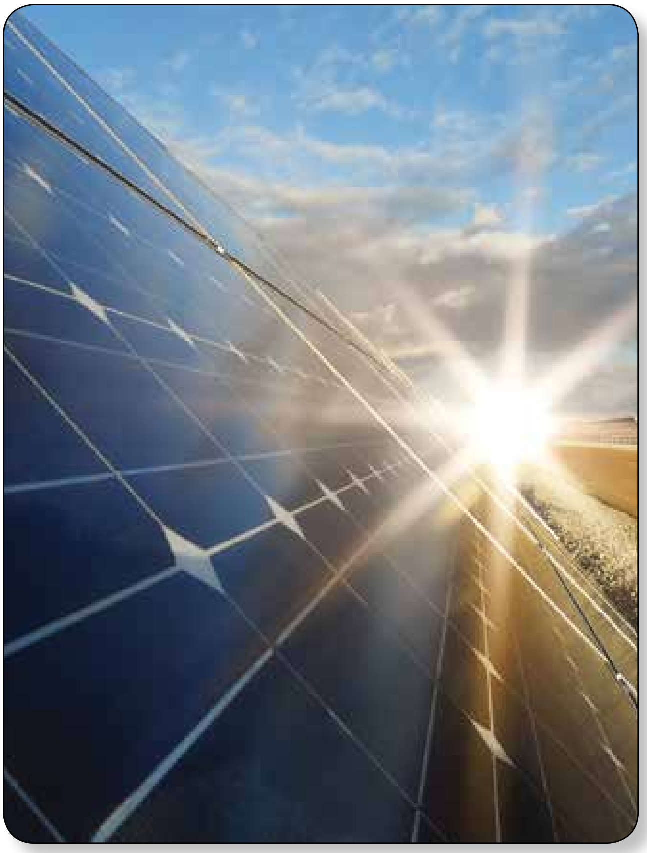
ESD Failure Analysis of PV Module Diodes and TLP Test Methods



BY WEI HUANG, DAVID POMMERENKE AND JERRY TICHENOR

ESD

Bypass diodes inserted across the strings of the solar panel arrays are essential to ensure the efficiency of the solar power system. However, those diodes are found to be susceptible to potential electrostatic discharge (ESD) events in the process of solar photovoltaic (PV) panel manufacture, transportation and on-site installation. Please refer to [1], where an International PV Module Quality Assurance Forum has been set up to investigate PV module reliability, and Task Force 4 has been setting guidelines for testing the ESD robustness of diodes used to enhance PV panel performance.

This article explains the theory behind the ESD damage and the proper test and analysis methods for ESD failure of diodes. To demonstrate the proposed testing methodology that follows, we will be evaluating six different types of diode models as supplied by our customer, who manufactures solar panel arrays.

BACKGROUND

Bypass and Blocking Diodes in Solar Panel Arrays

To help maintain the efficiency and performance of solar panel arrays it is common for bypass diodes to be inserted across individual PV panels, and blocking diodes to be inserted in series with a string of panels that are used in a parallel array (see Figure 1). The bypass diodes provide a current path around a shaded or damaged panel. If these are not installed, the panel will act like a high impedance load

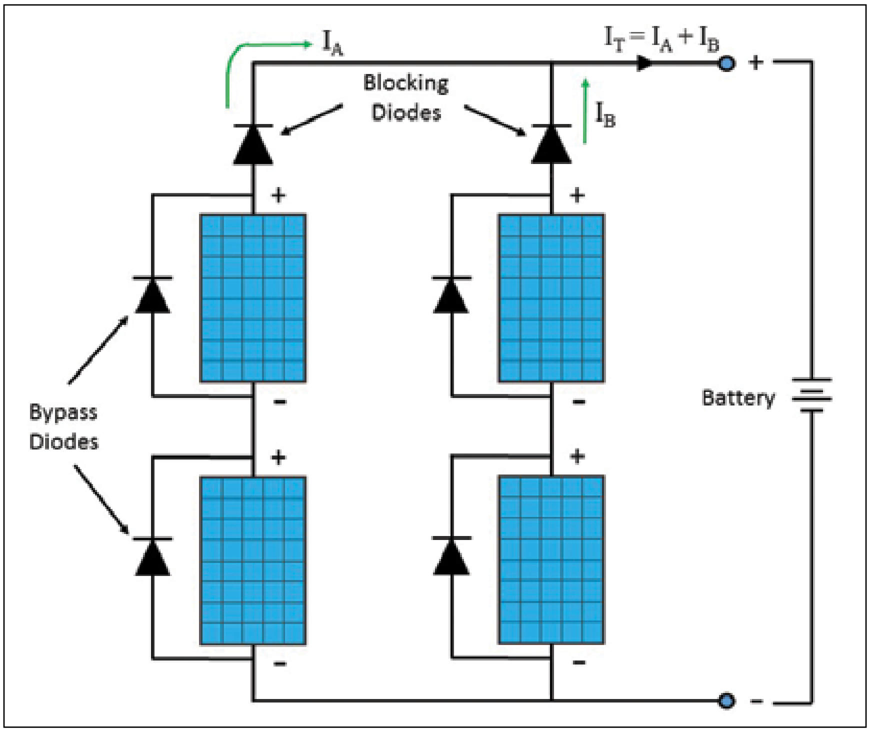


Figure 1: Solar PV module bypass and blocking diode connections

when shaded. This effectively reduces the series string output as the current produced by the remaining series connected panels will be forced to go through the shaded panel, thereby reducing the voltage output of the string.

If the bypass diodes are installed, and one of them fails due to ESD, it typically fails to a short circuit. When this happens (see Figure 2), the shorted diode does not allow any power produced by its panel to enter the system, thereby lowering system efficiency. Blocking diodes keep current from the battery pack, or a parallel panel string from entering a damaged string. This is important at night when the panel array cannot provide any power, thus providing a path for the battery to discharge. When installed, the blocking diodes may have leakage current on the order of nano- or micro-amps. However, if they fail due to ESD, they typically fail to a short circuit providing another path for the battery to discharge. This discharge current can be milli-amps or amps. (See Figure 3 for an example of this failure scenario.)

Failure of even one of these diodes in the field is very expensive for companies to replace due to the need for a qualified service technician, as most installations will require code requirements to be met. Continued operation of the panel array with a damaged bypass or blocking diode will, at best, hamper the array's efficiency and, at worst, cause permanent damage as it consumes power rather than produces power. It has been proposed that the damage to the diodes is caused by ESD stress.

What is ESD and how it damage the solar PV module diodes?

ESD is the sudden flow of electricity between two electrically charged objects caused by contact, an electrical short, or dielectric breakdown. Electrostatic discharge stress can occur in many forms and, depending on the characteristics of the stress, can damage different parts of solar PV module subjected to the stress. In particular, there are several ESD models with industrial standards that describe the pulse shape, source impedance, and determines levels at which the device should survive.

The commonly used ESD models (Table 1) are the Human-Metal Model (HMM) (IEC 61000-4-2 for system level ESD testing or ANSI/ESD SP5.6-2009 for component level ESD testing), the Human-Body Model (HBM) for component level ESD testing (ANSI/ESDA/JEDEC JS-001-2014), and the Charged-Device Model (CDM) for device level ESD testing (ANSI/ESDA/JEDEC JS-002-2014). There is also the Machine Model (MM), but it has been discontinued due to poor repeatability. Further, a new ESD model that currently has no established industrial standard, but has a different damage effect is the Cable Discharge Event (CDE).

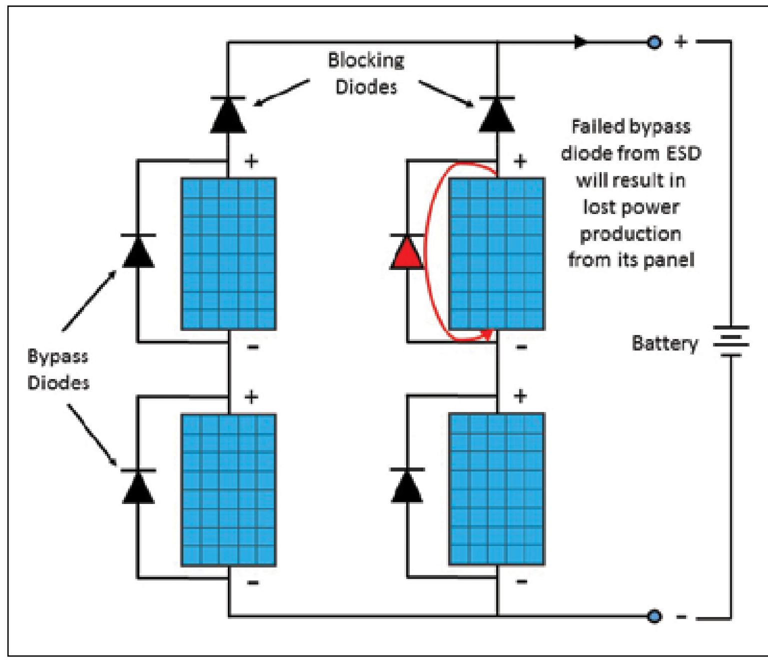


Figure 2: ESD damaged bypass diode fails short, disabling the PV module and lowering system efficiency

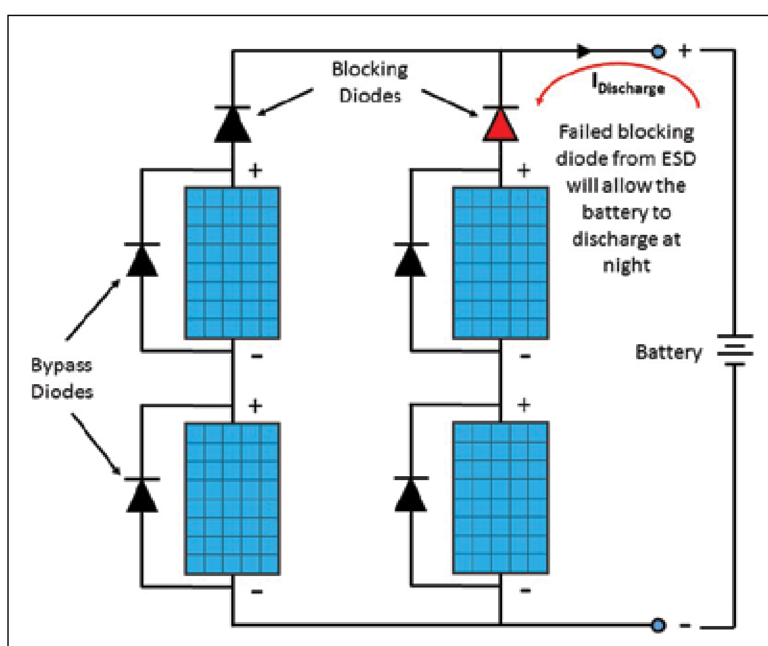


Figure 3: ESD damaged blocking diode fails short, allowing battery discharge path at night

ESD Model	Short	Applied DUT	Latest Industrial Standard	Comments
Human Metal Model	(HMM)	System level	IEC 61000-4-2 ED. 2.0 B:2008	Widely used standard
		Component level	ANSI/ESD SP5.6-2009	Pending to be a standard
Human Body Model	(HBM)	Component level	ANSI/ESDA/JEDEC JS-001-2014	Widely used standard
Charged Device Model	(CDM)	Device level	ANSI/ESDA/JEDEC JS-002-2014	Widely used standard
Machine Model	(MM)	Component level	ANSI/ESD STM5.2-2012	Discontinued
Transmission Line Pulse	(TLP)	Component level	ANSI/ESD STM5.5.1-2014	Widely used standard
Cable Discharge Event	(CDE)	System level	NA	Hard to be defined

Table 1: Widely used ESD models (as of September 2015)

Human Metal Model (HMM)

The human-metal ESD can take place when a charged person holding a pointed metal object, like a screwdriver or a ballpoint pen, rapidly moves the hand against an electronic device. In regard to PV module bypass and blocking diodes, this type of ESD events would most likely occur during junction box assembly with metal tools like tweezers, pliers, or screw drivers, etc. Figure 4 demonstrates a HMM event between a screwdriver and a screw that is part of an electrical installation in the junction box.

Human-Body Model (HBM)

Human-body model simulates the transfer of charge from a human to a component, such as through a fingertip as a device is picked up. This model is one of the most commonly used ESD tests for component qualification. In regard to PV module bypass and blocking diodes, this type of ESD event would also most likely occur during junction box assembly, especially if the operator picks a diode and mounts it by hand into the junction box. Figure 5 demonstrates a personnel picking up a PV module diode with bare fingers.

Figure 4: HMM event between a screwdriver and a screw that is part of an electrical installation in the junction box.

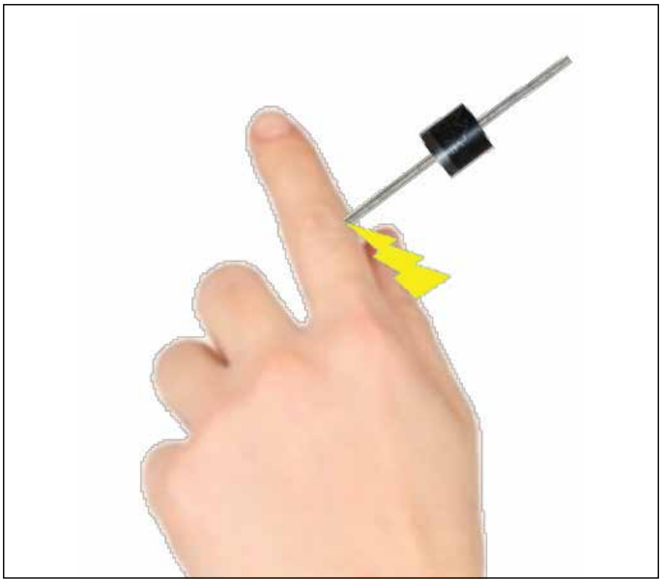


Figure 5: Potential ESD from HBM, picking up the diodes

ESD

Charged-Device Model (CDM)

Charged-device model simulates the transfer of charge from a device to ground. A device can collect charge by sliding across a surface and then discharged by contact to a metal surface or ground. In regard to PV module bypass and blocking diodes, this type of ESD event would most likely occur during junction box assembly.

Transmission Line Pulse (TLP)

The TLP technique is based on charging a transmission line to a pre-determined voltage, and discharging it into a device under test (DUT). The cable discharge emulates an ESD event that has better defined RF signal path, controllable rise-time, and pulse width. The test setup allows transient current and voltage waveform to be monitored. Therefore, the change of the DUT impedance can be monitored as a function of time in ps details. The DUT performance degrade or failure check can be automated with RF high voltage switch and help the system with faster ESD performance analysis. Regarding to the PV module diodes, this model is not a real-world event as the transmission line would not be well defined as the TLP model, but the type of waveform is relatively similar to cable discharge events (CDE) during the PV module on-site installation process.

Cable Discharge Event (CDE)

A cable discharge event is a frequent real-world electrostatic discharge event that occurs when a cable is connected onto a device and the cable has existing charge prior to making the connection. This can also happen by connecting a charged cable (open on one end) to a device. It occurs because there is a potential differential between the charge on the cable to be connected and the device. The resulting waveform is highly dependent on the real-world current return path and specifications of the cable.

However, these events usually have a fast rise time of less than 500ps, potential for high current that can reach over 100 Amperes, and a potential long pulse that can be several µs if the discharging cables are long. The fast rise time, high current, and long pulse duration can result in a permanent performance degrade or physical damage of device being subjected. Regarding to solar PV module, the cable connections between the panels can be very long, resulting the ESD current waveform could be very different from all previous cases. Because cable connection is an avoidable on-site installation process, cable discharge event should be treated as a special ESD case with special test setup for the PV module diodes quality assurance.

Although these ESD models describe how an ESD stress event may originate, the underlying physics of these models point to two basic damage causes. Damage may occur as the device cannot withstand the extremely fast voltage transient, or a device is not able to handle the current or the heating caused by the current. Here, the heating occurs within nanoseconds, such that there is no thermal exchange with the surrounding. Further, the current distribution within the conduction area of the device may not be homogeneous, such that local melting ("filament creation") leads to damage at current levels that the device could handle, if the current would flow with equal current density in the device.

The CDM model is used to qualify a device for the first of these damage types in that a very fast rise time as 100 ps with a short duration pulse. This test can determine if the gate oxide layer of a component is susceptible to a CDM type of event. The HBM model is used to qualify a device for the latter of the damage types in which a long duration (100ns) pulse is applied. The HMM, CDE and TLP models could possibly contain both types of damage. However, the CDE or TLP type of model would result in the worst possible damage in all of the cases discussed above.

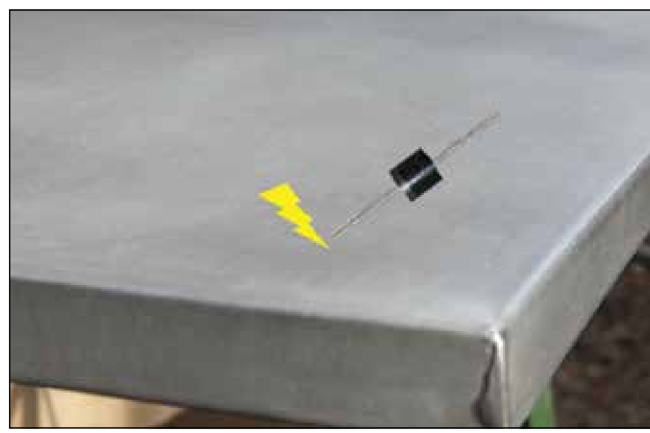


Figure 6: Solar PV module diode drops onto grounded metal surface

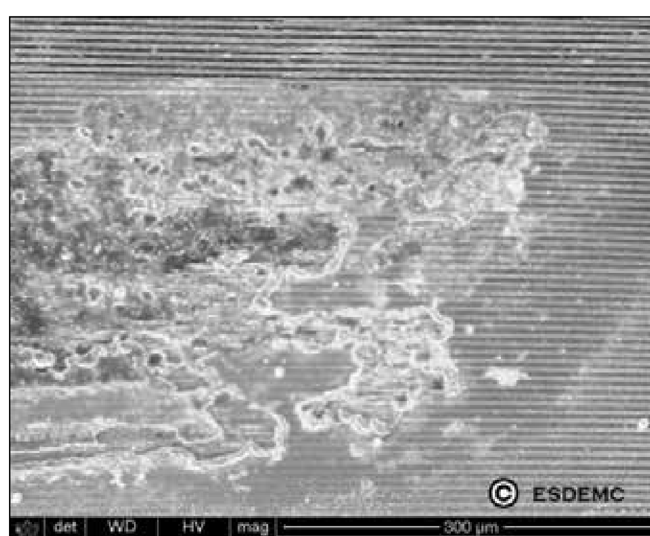


Figure 7: SEM image of die surface from ESD damaged PV bypass diode sample, melted metal and silicon observed.

Given the nature of how the bypass and blocking diodes could be exposed to and damaged by ESD events, the worst case that would be the cable discharge event, in which both fast rise-time and high energy pulses occur during the installation process.

An example of damage to the semiconductor components is shown in Figure 7 which illustrates burn track damage on a PV bypass diode caused by ESD.

THE TRANSMISSION LINE PULSE TEST METHODOLOGY

Given the nature of how the bypass and blocking diodes could be exposed to and damaged by ESD events, the worst case that would be the cable discharge event, in which both fast rise-time and high energy pulses occur during the installation process. Therefore, based on the existing industrial ESD testing methods, we propose to use the transmission line pulse test method that does not necessarily replace the IEC 61000-4-2 standard, which may have been be used in the current qualification process. Instead, the TLP test method subject a diode (a low resistance DUT) to a faster rise-time and higher energy pulse up to 180A (pulse reflections being allowed to approach the real-world CDE case). This provides a fully-automated device ESD performance characterization system for transient IV signal and degrade/failure inspection before and after each pulse. Compared to the other types of ESD models, the advantages of using a TLP test are:

- *Well Defined Consistent Waveform Shape:* Both circuit and waveform defined in ESD simulator standards are too flexible (no impedance control for test path, 30% tolerance at only certain time) This causes ESD simulators to provide very different ESD test results between different test sites. A TLP pulse is very clean and consistent.
- *Highly RepeaTable Test Setup:* Fatigue from holding ESD simulator by hand can lead to inconsistent test setups. In TLP testing with jigs for mounting the DUT, a more controlled test is obtained.
- *Fast Automatic Measurement and Reporting:* Typical TLP testing is done with full automatic control of oscilloscope scale adjustment, voltage pulsing, failure criteria checking, and IV curve update.
- *Important Device Behavior is recorded for ESD analysis and design:* Many useful parameters can be extracted from TLP tests for device transient behavior analysis, modeling and system-efficient ESD design (SEED). Traditional ESD tests only generate pulse for pass/fail results.

Test Setup

The TLP test setup is shown in Figure 8. A transmission line pulse (TLP) generator provides a rectangular voltage pulse by charging a 50Ω transmission line to a test voltage, and discharging the pulse to the DUT by a special relay which can withstand the voltage, and can switch to an on "on" status without bouncing. The pulse then travels out of the TLP through a coaxial transmission line where it first reaches a high voltage relay (A621-HVLKR).

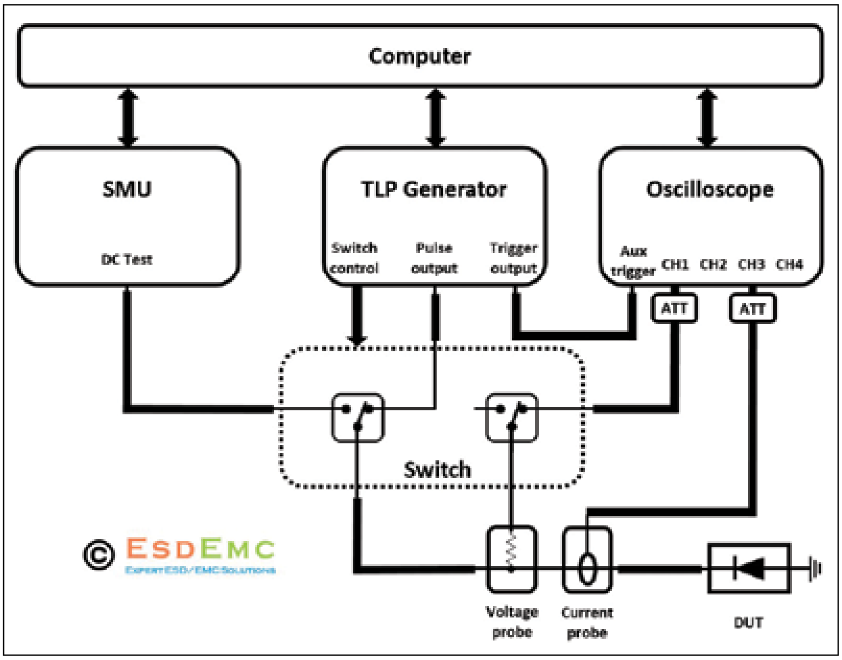


Figure 8: High current TLP test setup for solar PV module diodes

ESD

This relay is capable of withstanding up to 10kV, and is required for the high current TLP testing used with these high power diodes. The relay provides a means of transferring connection of the DUT between TLP measurement system and the failure detection system. In particular, during TLP pulsing, the relay connects the DUT to the TLP, the measurement probes, and the oscilloscope. After each TLP pulse test waveform has been captured, the system switches the DUT to the SMU to measure the diode reverse leakage current at maximum recurrent peak reverse voltage (VRRM). The A621-LTKSEM leakage test module also helps to facilitate these connection changes on the low voltage side of the measurement probes.

The DUT current is measured indirectly using a resistive tee to voltage measurement. The current is recovered by the overlapping reflection method. This method measures both the current through and the voltage across the DUT, but for low-resistance devices, such as a diode in the "on" state, this method is not well suited for measuring the device voltage. Instead, the DUT voltage is measured directly at the device, providing a highly accurate voltage probing measurement. The current measurement is performed by first measuring the pulse as it passes by the first pick-off resistor that goes to Ch1 of the oscilloscope. A short delay later (as determined by the length of coaxial cable between the pick off resistors), the pulse reflected from the DUT is measured at the same pick off resistor yielding an overlapped waveform. Using transmission line theory and a pre-measurement calibration pulse, the current into the DUT can be determined as:

$$IDUT = (V^{+} - V^{-})/Z_{o}$$

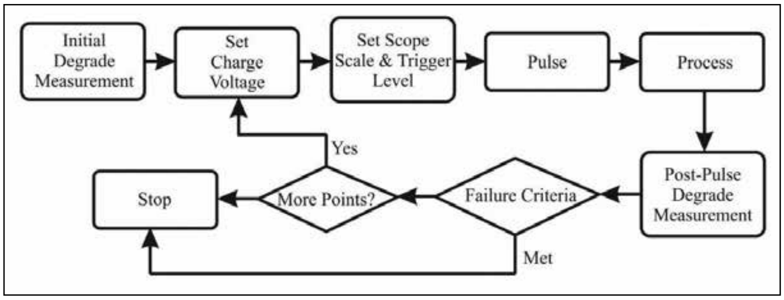


Figure 9: TLP test procedure flow chart

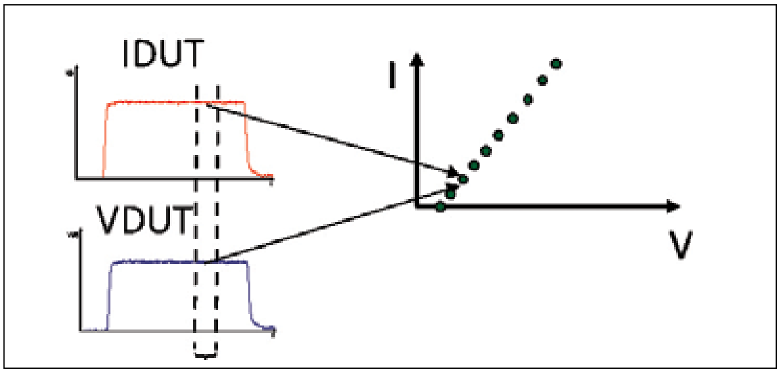


Figure 10: TLP test voltage and current waveforms during one pulse test

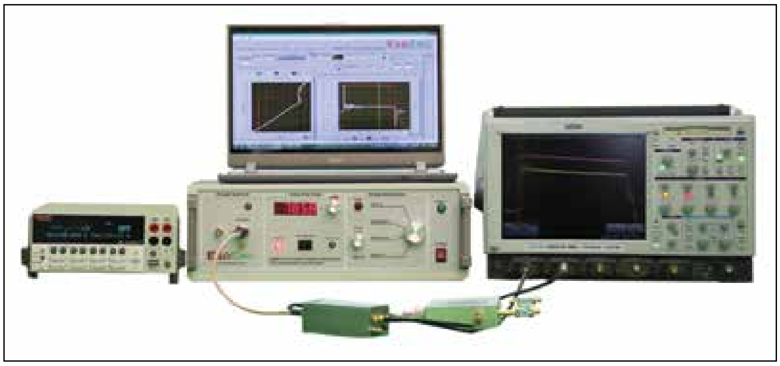


Figure 11: TLP System Setup

Equipment	Brand and Model	Specification and Comments
ESD Test	ES621-200 TLP System (A specially developed system, not a release model. The ES620-200 model may be released for a simplified turnkey solution)	<=1 ns rise-time, 100 ns pulse width, Max 10 kV charge line with no reflection rejection. The 10 kV charge voltage is achievable in the real world under dry conditions. The 100 ns pulse is represented approximately 10 meters of cable that is very close to the grounding conduit. Please note that during installation, a charged PV module connecting to a grounded cable will have the same effect as a charged cable discharging to a PV module. A 10 meter cable may not be the worst case since solar cables could be up to hundreds meters for certain systems.
Failure Test	Keithley Model 2400 or Keithley Model 6487	This configuration depends on the diode VRRM
Oscilloscope	LeCroy WaveMaster 8620A	6 GHz, 20 Gs/s (200 MHz min bandwidth per ANSI/ESD STM5.5.1-2014 standard)

Table 2: Solar PV module diodes TLP test equipment and settings

Upon entering the test loop, the system measures the leakage current of the DUT to obtain the initial degrade measurement. Next the TLP charge voltage is set. The charge voltage was set to sweep from 500V to 9600V, in 100V increments.

Where V^+, V^-, and Z_o are the incident pulse, reflected pulse, and characteristic impedance (50Ω) of the transmission line system, respectively.

Test Procedure

The test procedure is demonstrated in the flowchart shown in Figure 9. Upon entering the test loop, the system measures the leakage current of the DUT to obtain the initial degrade measurement. Next the TLP charge voltage is set. For the testing reported in this article, the charge voltage was set to sweep from 500V to 9600V, in 100V increments. For the first test point, the oscilloscope scale and trigger level are set based on the initial charge voltage and a 50Ω DUT. As testing progresses, the scale and trigger level are set based on if the waveforms clip, or is under scaled. If the waveforms do not clip or are not under scaled the settings are kept.

After setting the oscilloscope parameters, the DUT is pulsed and the captured data is compared to the oscilloscope display range for each captured channel to check for clipping and whether the scale is appropriate. If any of the waveforms are clipped, the scale is adjusted and the DUT is pulsed again. If the waveforms are ok, or under scaled, the data is accepted and processed. Any under scaled waveform corrections are made on the next pulse level. Processing is completed by scaling the data by the measurement attenuator and probe values.

Another DUT degrade/failure measurement (measure the PV diode leakage current under reverse working voltage) is made to determine if the DUT has failed or not. If failure occurs, the test is stopped. If. If not, the next pulse point is performed. This repeats until all pulse points are done, or failure occurs.

Dynamic IV Curve Measurement Principles

One of the goals of the measurement system described above is to obtain the dynamic IV curve of the DUT over the voltage range pulsed. Current and voltage waveforms resulting during pulse test are demonstrated in Figure 10. The dashed lines near the end of the pulses represent the start and stop points of the dynamic IV measurement window. The measurement window is typically 70 to 90% range of the pulse but other ranges can be selected. Over this window, the average value of the time waveform is taken as the current and voltage, respectively. This value is then plotted for each voltage pulse applied.

Degrade/Failure Measurement (Leakage Current Measurement)

The leakage current was measured using the source meter unit (SMU) and, depending on the diode tested, the bias voltage was varied between two and three different voltages with the maximum bias voltage set to the maximum recurrent peak reverse voltage (VRRM) for each diode. The VRRM voltage is listed in each individual diodes datasheet.

Diode Model	VRRM, [V]
Sample set #1	60
Sample set #2	50
Sample set #3	45
Sample set #4	40
Sample Set #5	150
Sample set #6	200

Table 3: Diode models tested and their VRRM

Also, for the results reported below, for any diode that failed the leakage current upper limit was set to 2.5mA (a value that is very high and can be treated as failure criteria). This is the compliance limit of the SMU and is not an indicator of diode characteristic after failure, other than they appear to fail to a short.

SOLAR PV MODULE DIODES TESTS

Over the years, ESDEMC Technology has tested several diode models for solar PV module companies. The VRRM (from device datasheet) of the diodes are listed in Table 3. The VRRM values are important because they provide the maximum bias voltage applied to the diode for leakage current measurement. This value is supplied by the device manufacturer, and is typically found in their respective datasheets.

In the following sections, the test results will be presented in terms of the best performer to the worst performer in regard to diode failure during TLP testing.

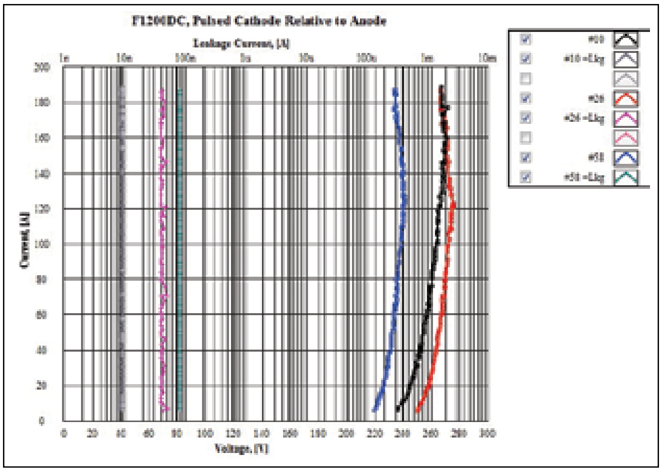


Figure 12: Sample Set #5, dynamic IV and leakage current @ high current TLP test

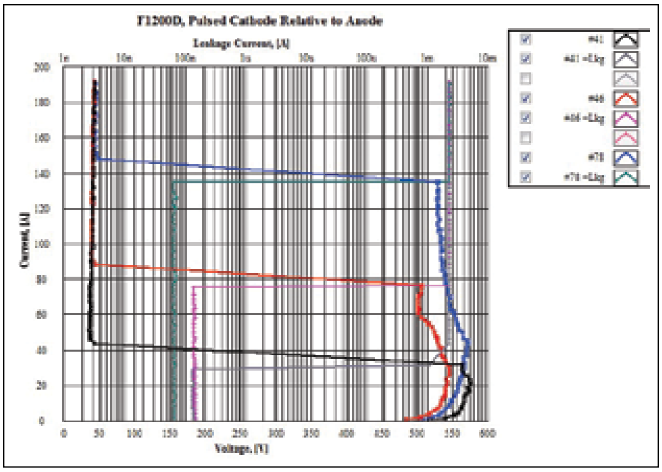


Figure 16: Sample Set #6, dynamic IV and leakage current @ high current TLP test

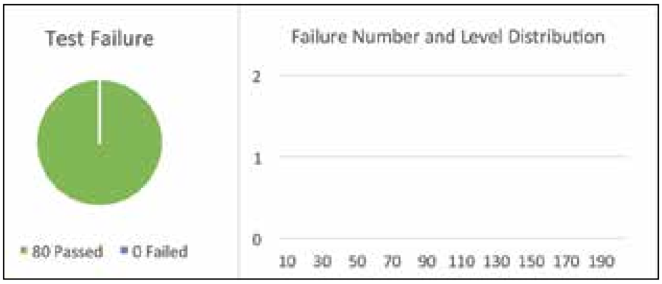


Figure 13: Sample Set #5, failure rate @ high current TLP test

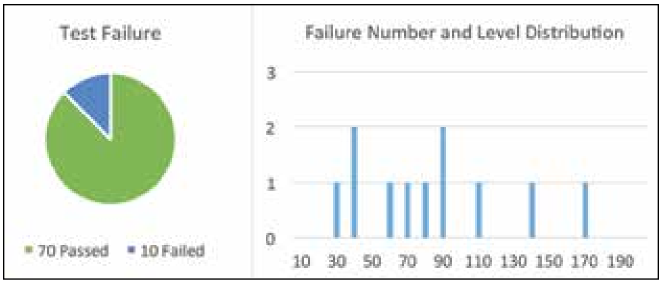


Figure 17: Sample Set #6, failure rate @ high current TLP test

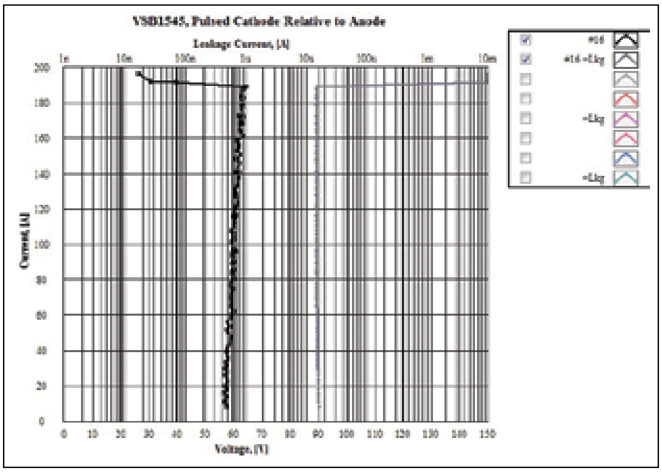


Figure 14: Sample Set #3, dynamic IV and leakage current @ high current TLP test

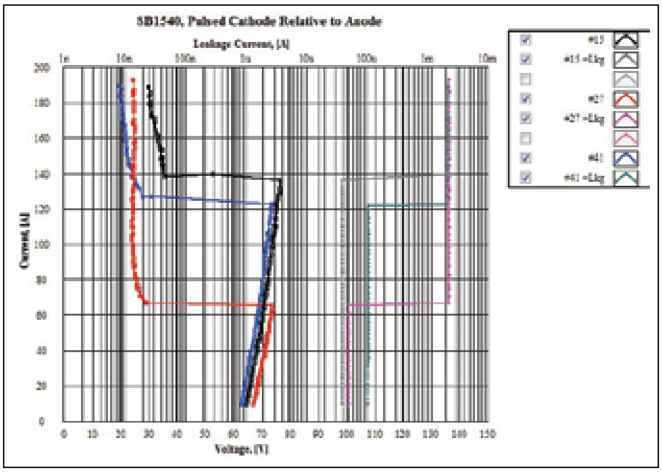


Figure 18: Sample Set #4, dynamic IV and leakage current @ high current TLP test

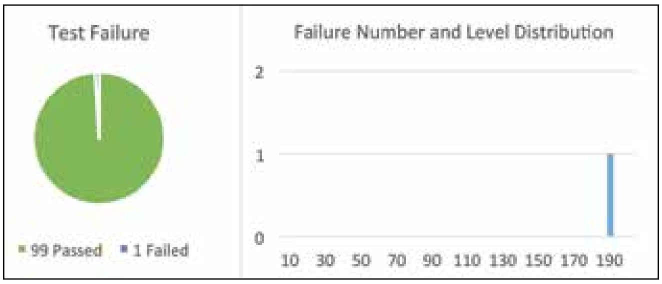


Figure 15: Sample Set #3, failure rate @ high current TLP test

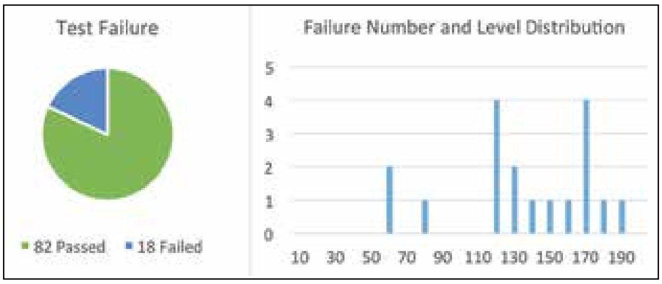


Figure 19: Sample Set #4, failure rate @ high current TLP test

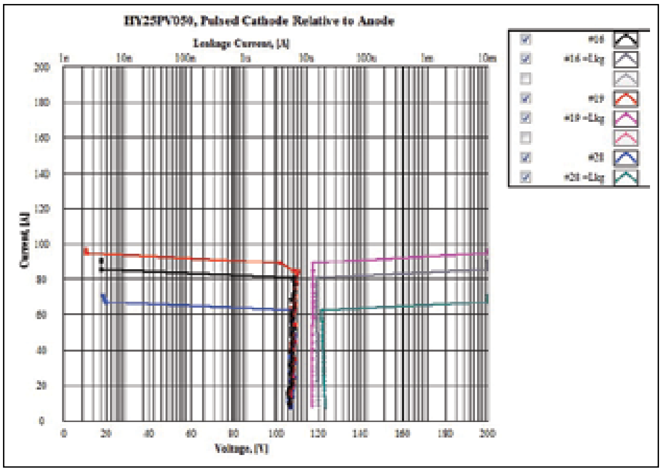


Figure 20: Sample Set #2, dynamic IV and leakage current

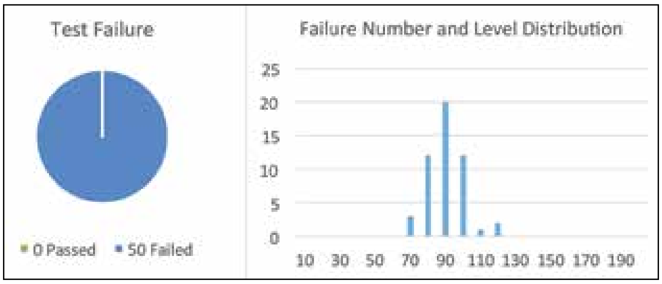


Figure 21: Sample Set #2, failure rate @ high current TLP test

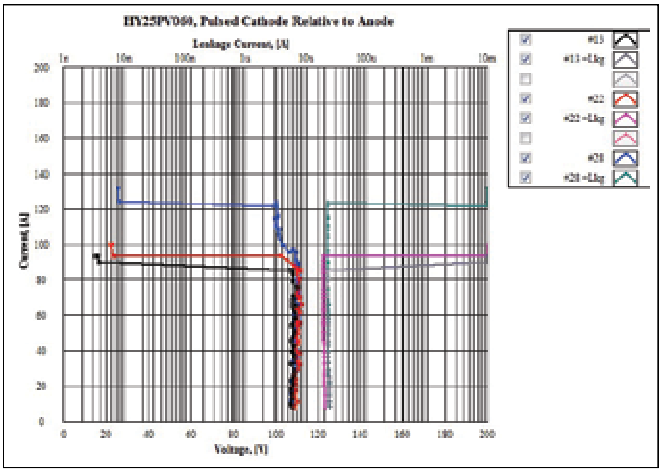


Figure 22: Sample Set #1, dynamic IV and leakage current@ high current TLP test

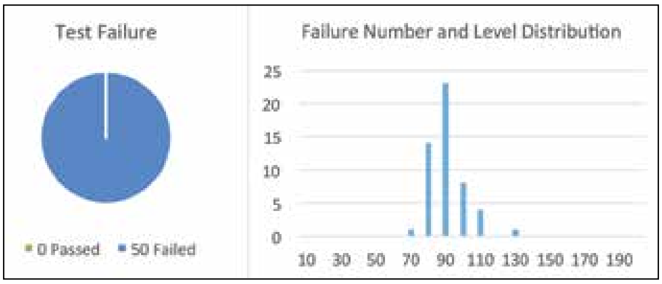


Figure 23: Sample Set #1, failure rate @ high current TLP test

Sample Set #5

Out of the 80 devices we tested in Sample Set #5, no failure occurred. The dynamic IV and leakage current curves for three samples are shown in Figure 12. The dynamic IV curve is read from the Y-axis to the bottom of the X-axis, and the leakage current from the Y-axis to the top of the X-axis. Note that the top of the X-axis is logarithmic due to the dramatic change in leakage current once a device fails to a short circuit.

Sample Set #3

The next best performers were the devices in Sample Set #3, which had only one diode fail out of one hundred units; failure occurring near the last few test pulse levels. The dynamic IV and leakage current curves are shown in Figure 14. Once the diode failed to a short, the resulting leakage current was at the compliance limit of the SMU, and is not an indicator of the diode condition.

Sample Set #6

Sample Set #6 had eleven failures out of eighty diodes tested. The minimum, maximum, and average pulse current for each of them are listed in Figure 25, and the dynamic IV and leakage current curves, for three of the failed diodes, are shown in Figure 16.

Sample Set #4

Sample Set #4 had 18 devices fail out of 100 tested. The dynamic IV and leakage current curves, for three of the failed diodes, are shown in Figure 18.

Sample Set #2

All of the diodes in Sample Set #2 failed. The minimum, maximum, and average pulse current for each of them are listed in Figure 25, and the dynamic IV and leakage current curves, for three of the failed diodes, are shown in Figure 20.

Sample Set #1

All of the diodes in Sample Set #1 failed. The minimum, maximum, and average pulse current for each of them are listed in Figure 25, and the dynamic IV and leakage current curves, for three of the failed diodes, are shown in Figure 22.

CONCLUSION

Of the diodes tested, only those in Sample Set #5 did not have failure up to 200 Amp or 10 kV of the eighty diodes tested. The next best performer was Sample Set #3, which only had only one failure, and that particular diode failed near the last few test pulses (100 diodes tested). Sample Set #6 had ten diodes fail out of eighty tested, and the Sample Set #4 had eighteen diodes fail out of one hundred tested. The worst performers were those in Sample Sets #1 and #2, where all diodes failed (all diodes tested failed for both models).

The chart shown in Figure 25 depicts the minimum, maximum, and average pulse current at failure for the diodes that failed.

It has been suggested that it is not necessarily the diode design type that determines if the diode is more or less susceptible to ESD stress, but instead a result of quality control of the manufacturing. For example, the process may be as follows: a diode as the 15SQ100 (tested data is now shown herein) is being checked in quality control after manufacturing. Its reverse breakdown voltage is checked. If it does not pass 100V, but passes 50V, it is re-labeled as a 15SQ050 model. This may not guarantee that the 15SQ50 model is a higher quality 050 design, and may instead be a poor quality 100 design relegated to the 050 model line. Here, the problem is that the diode may not hold 100V reverse voltage due to a local defect. The local defect will concentrate the current during ESD into a very small area and cause the diode locally to melt. Thus, the robustness of such a diode is much worse than a diode that passes the 100V reverse voltage, which may indicate that it does have few, and less severe local defects.

According to our customers (solar solution providers), our findings on the diode failure rate, through TLP test methodology, correlates to their field return failure rate. Therefore, we recommend that TLP testing be performed for all solar PV module diodes. In addition, it may be in the best interest of both solar PV module and diode manufacturers to investigate the quality control of the diodes selected, yielding a more reliable design for field use.

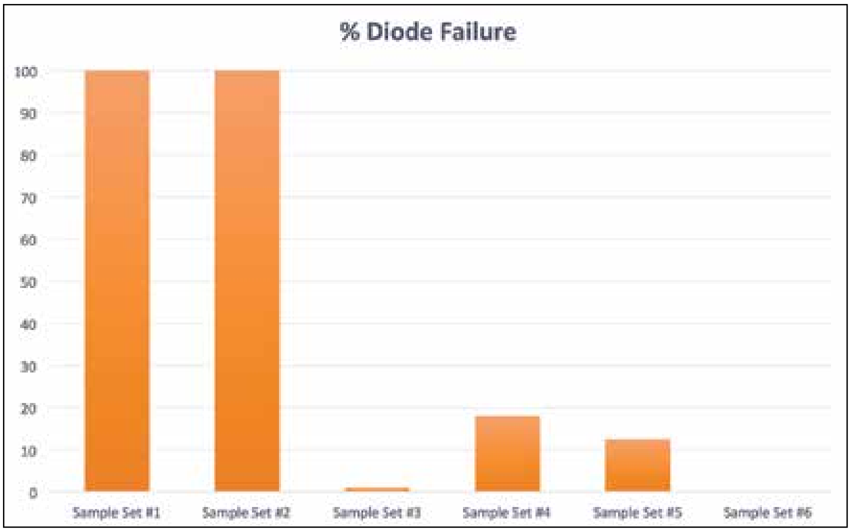


Figure 24: Diode failure rate comparison

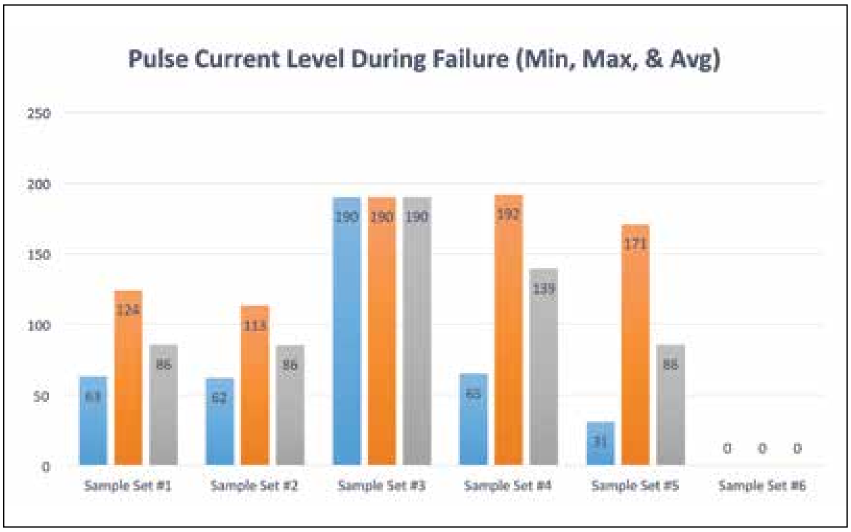


Figure 25: Minimum, maximum and average pulse current during failure for all tested diodes

REFERENCE

1. International PV Module Quality Assurance Forum, Task Force 4 (www.pvqat.org), Dec. 5-7, 2011.

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Advances in Data Transmission Speeds for RJ45 Jack Connectors

Traditional Connectors and Their Application Throughout the Industry are Changing for the Better

BY BRETT D. ROBINSON AND MICHAEL RESSO

For many decades, RJ45 jack connectors have been used for low-cost, high volume applications throughout industrial, commercial, military and medical fields. The registered jack (RJ) is a standardized physical network interface for connecting telecommunications or data equipment to a service provided by a local exchange carrier or long distance carrier. It was introduced by the Bell System under a 1976 order by the Federal Communications Commission (FCC) that ended the use of protective couplers provided exclusively by the telephone company. The modular jack was then chosen as the main candidate for ISDN systems.

Historically, the biggest design problem for RJ45 jacks was to solve crosstalk coupled from adjacent lines. The problem (at least at lower frequency rates) was solved simply by isolation techniques within the connector, or split pair wiring of the Category Cable itself. Newly designed (Femto dielectric) flex core material incorporates a unique strip-line technology that allows data transmission paths to be differentially paired. This allows data packets to be easily driven over a copper line at ranges from 125 MHz all the way up to 20.0GHz.

The RJ45 jack has played a critical role in data transfer, from an integrated circuit (IC) all the way through to the receiver end. However, commercial and military applications require higher data rates, pushing RJ 45 signal rise times and clock speeds faster than any time in history.

Compliance requirements for radiated and conducted emissions now require broader measurement bandwidths. New bandwidth requirements now range from 10kHz ~ 26.5GHz, depending on whether the device is intended for use in military applications (MIL-STD-461), avionics (RTCA-DO-160), medical devices (IEEE802.11/IEC 60601) or commercial electronics (FCC part 15 and the EU's EMC Directive 2004/108/EC). Since the transmission speeds going through an RJ45 jack have approached the effective radiating length of **λ/4** (frequency in wavelength, GHz), its radiated emission characteristics become a primary point of interest for issues involving electromagnetic compatibility (EMC) and electromagnetic interference (EMI).

CROSSTALK

Crosstalk is usually described in the context of culprit versus victim. In high-current, low-impedance circuits, crosstalk is a direct result of mutual inductance between current loops of the connector and cable wiring/shielding practices. Further, crosstalk from mutual capacitance, associated with high-voltage and high-impedance networks, is usually negligible.

However, in the case of the standard RJ45 jack (especially in high-density connectors), the culprit and victim relationships are in very close proximity to each other, which raises mutual inductance and thus the susceptibility to crosstalk. The signal and return arrangement of a standard RJ45 jack causes two current loops to overlap. So, some amount of crosstalk will be experienced on all lines, and the mutual inductance and crosstalk from line to line becomes even greater. In a transmission line, impedance matching is necessary to minimize RF reflections and to allow the connector to deliver the amplitude signal required to maximize power at the load. The effect is a maximum amount of signal being transmitted and a minimum amount of data being reflected back as loss.

To simplify this last statement, the strip-line flex technology within RJ45 jacks in use today creates an extremely low impedance path, creating an insertion loss/isolation greater than 52.78dBm. This virtually eliminates the possibility for crosstalk within the connector and creates an edge-coupled line surrounded by a ground plane, reducing stray voltage and current expenditures. This can be expressed as:

Voltage **V** = 5Vrms
Impedance **Z** = 0.13180747 Ohms
thus Power Level **L** = 52.78dBm

This advantage is not directly due to differentially-paired signal lines. Rather, this design approach minimizes electronic crosstalk and electromagnetic interference. This results in both noise emission and noise acceptance, so it can achieve a constant, known characteristic impedance. Normally, single-ended signals in other types of RJ45 jacks are resistant to interference only when the lines are balanced and terminated by a differential amplifier of some type, wire-wound magnetics or a balun.

CROSSTALK ANALYSIS USING S-PARAMETERS

As a foundation for understanding how to characterize a linear passive physical layer device such as an RJ-45 jack, a brief discussion of multiport measurements is in order. The four port device shown in Figure 1 is an example of what a real-world structure might look like if we had two adjacent printed circuit board (PCB) traces operating in a single-ended fashion. Let's assume that these two traces are located within relatively close proximity to each other on a backplane, and that some small amount of coupling might be present. Since this example involves two separate single-ended lines, this coupling creates an undesirable effect we call crosstalk.

The matrix on the left side of Figure 1 shows the 16 single-ended s-parameters that are associated with these two lines. The matrix on the right shows the 16 single-ended time domain parameters associated with these two lines. Each parameter on the left can be mapped directly into its corresponding parameter on the right through an inverse fast fourier transform (IFFT). Likewise, the right-hand parameters can be mapped into the left-hand parameters by a fast fourier transform (FFT).

If these two traces were routed close together as a differential pair, then the coupling would be a desirable effect and it would enable good common mode rejection that provides EMI benefits.

Once the single-ended s-parameters have been measured, it is desirable to transform these to balanced s-parameters to characterize differential devices. This mathematical transformation is possible because a special condition exists when the device under test is a linear and passive structure. Linear passive structures include PCB traces, backplanes, cables, connectors, IC packages and other interconnects. Utilizing linear superposition theory, all of the elements in the single-ended s-parameter matrix on the left are processed and mapped into the differential s-parameter matrix on the right. Much insight into the performance of the differential device can be achieved through the study of this differential s-parameter matrix, including EMI susceptibility and EMI emissions.

Interpreting the large amount of data in the 16-element differential s-parameter matrix is not trivial, so it is helpful to analyze one quadrant at a time. The first quadrant in the upper left of Figure 2 (page 144) is defined as the four parameters describing the differential stimulus and differential response characteristics of the device under test. This is the actual mode of operation for most high-speed differential interconnects, so it is typically the most useful quadrant that is analyzed first. It includes input differential return loss (SDD11), forward differential insertion loss (SDD21), output differential return loss (SDD22) and reverse differential insertion loss (SDD12).

Note the format of the parameter notation SXYab, where S stands for scattering parameter (or S-Parameter), X is the response mode (differential or common), Y is the stimulus mode (differential or common), A is the output port and B

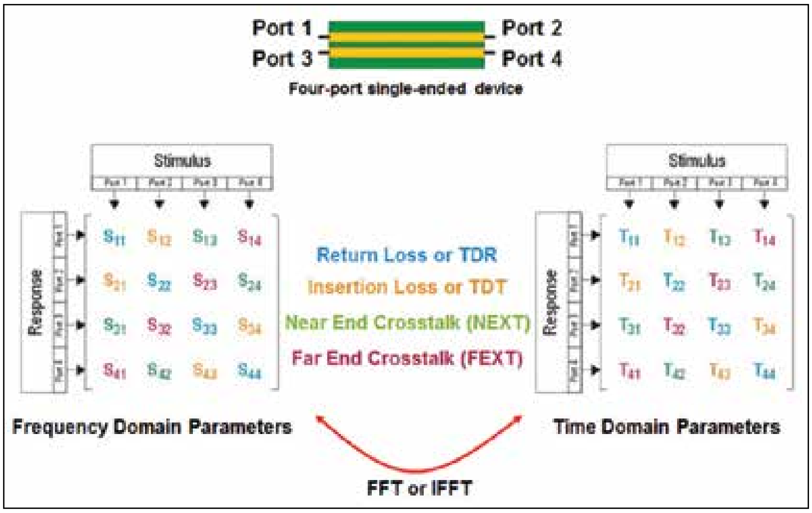


Figure 1

is the input port. This is typical nomenclature for frequency domain scattering parameters. The matrix representing the 16 time domain parameters will have similar notation, except the "S" will be replaced by a "T" (i.e. TDD11).
The fourth quadrant is located in the lower right and describes the performance characteristics of the common signal propagating through the device under test. If the device is designed properly, there should be minimal mode conversion, and the fourth quadrant data will be of little concern. However, if any mode conversion is present due to design flaws, then the fourth quadrant will describe how this common signal behaves.

The second and third quadrants are located in the upper right and lower left of Figure 3, respectively. These are also referred to as the mixed mode quadrants. This is because they fully characterize any mode conversion occurring in the device under test, whether it is common-to-differential conversion (EMI susceptibility) or differential-to-common conversion (EMI radiation). Understanding the magnitude and location of mode conversion is very helpful when trying to optimize the design of interconnects for gigabit data throughput.

Differential pairs mentioned earlier in this article technically include: 1) twisted-pair cables, shielded twisted-pair cables, and twin-ax; and 2) strip-line differential pair routing techniques onto "specialized" flex circuit boards.

Generally, a receiving device located at the end of any cable/harness connection reads the difference between the two signals. Since the receiver ignores the wires› voltages with respect to ground, small changes in the ground potential between the transmitter and receiver do not affect the receiver›s ability to detect the signal.

EMI/RFI interference tends to affect both TX and RX wires together. Because the data packet information is sent in the form of bit rates, utilizing differently paired wires, the technique improves the resistance to electromagnetic noise ratio compared with use of only one wire and an un-paired reference (ground). What is then needed is a high speed RJ45 jack which can be used for analog data, as well as digital data signaling, just as in any other Ethernet shield over twisted pair.

DESIGNING THE RJ45 FOR HIGH SPEED DATA TRANSFER

A genuine high speed RJ45 jack and its corresponding interconnection system must have a well-designed base platform from which to start. To begin, it should utilize properly plated copper conductors to ensure a path of least resistance, thus lowering the induced currents and voltages expended dramatically. Utilizing the patent pending flex material, along with differentially paired strip-line components allows for higher transmission data rates the standard ceramic capacitors, inductors, or resistors soldered onto some form of FR4 flex material.

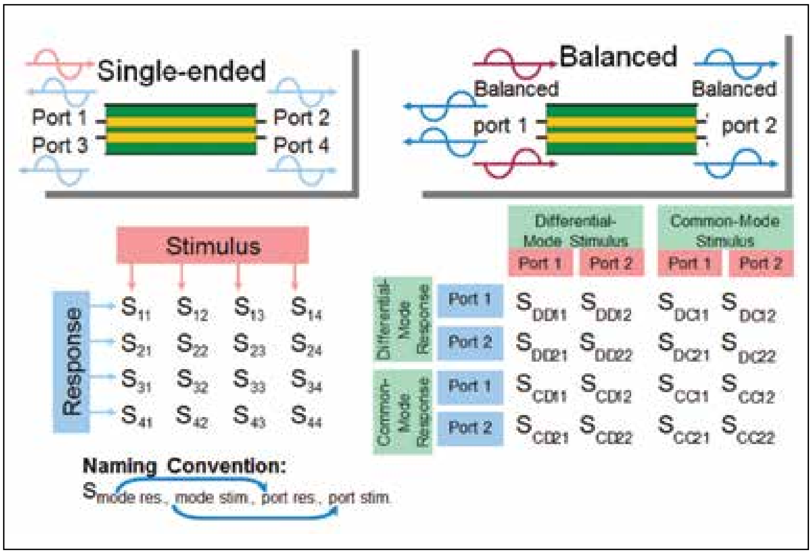


Figure 2

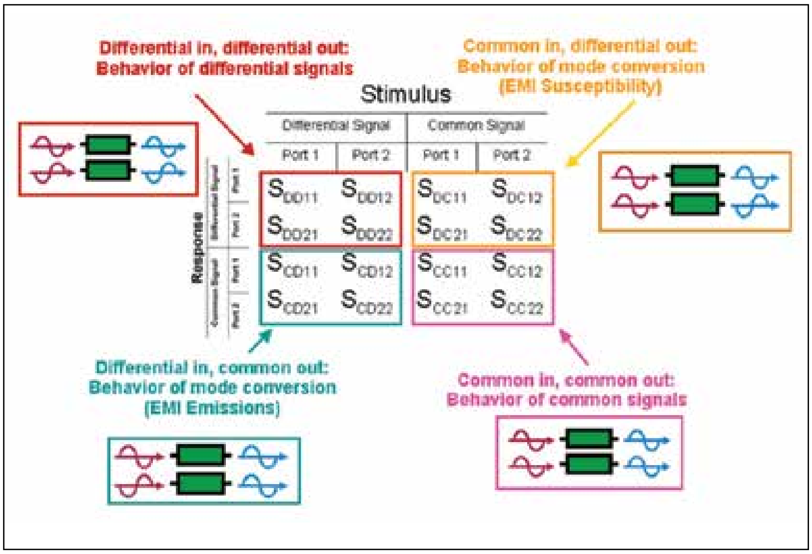


Figure 3

Many RJ45 Jack connectors produced today simply provide magnetically balanced, single-ended lines, in combination with common mode capacitive circuits. However, at much higher frequencies, this can diminish their transmission data rate capabilities. By implementing low pass, femto-dielectric constant materials, the strip-line flex circuit can be balanced differentially to provide the much needed insertion loss/isolation requirements.

COMMON STRIP-LINE DESIGN MODELS

Generally speaking, strip-line transmission lines are fully contained within a substrate, sandwiched between two chassis ground planes. In this implementation, it was performed by closely surrounding the strip-line circuit in a 360 degree manner with chassis ground, as shown in the strip-line cross section model depicted in Figure 4.

(It is important to note that special low loss dielectric flexible materials must be used for the strip-line flex development, especially since the dielectric material chosen will directly affect transmission line impedance.)

THE INTUITIVE EXPLANATION

There is an old physics truism that everyone seems to have forgotten when designing electronic circuitry and cables, that is, that electrons tend to flow down the path of least resistance.

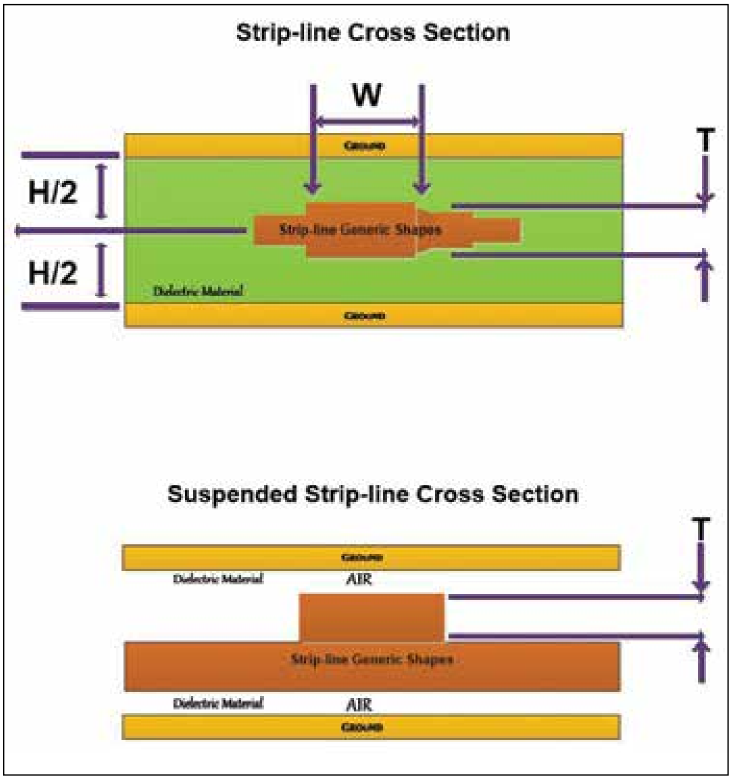


Figure 4

When a conductor (in our case a plated copper wire) is filled with a voltage "charge" and then an external "potential" is applied across it, electrons distribute themselves across the length of the conductor. This forces all of the electrons to lose energy in all directions simultaneously across the conductor's path. This same physics can be applied to multiple conductors that parallel to the current flow, the only difference being the different rates proportional to the conductivity of each conductor's base material. (See Figure 5)

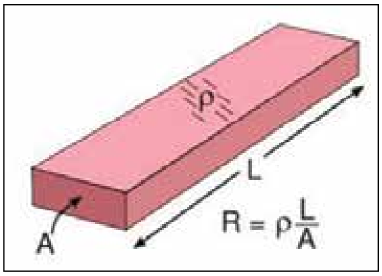


Figure 5

The biggest RJ45 jack design problem was to solve crosstalk coupled from adjacent lines and in the cable components themselves. The basic problem associated with coupled noise or crosstalk is that it increases as the signals for these components have higher and higher data transmission speeds. The historic approach was to just increase spacing between the lines or to add-in ferrites (also known as magnetics) to create needed signal isolation needed, but that alone does not protect the remaining transmission lines in the RJ45 jack from picking up unwanted noise within the jack itself.

However, the application of strip-line flex design techniques provide the important signal and data transmission advantages over conventional design approaches. Strip-line flex design works by incorporating a conductor sandwiched by dielectric material between a pair of ground planes. Traditionally, strip-line was usually made by etching circuitry onto a ceramic/copper substrate that had a ground plane on each opposite face, in order to achieve two opposing ground planes. Today, strip-line design techniques typically use "soft-board" flex technology.

Strip-line design is a transverse electromagnetic (TEM) transmission line media, just like coax, which means that it is non-dispersive. Further, strip-line filter and coupler lines, via shape and spacing, always offer better bandwidth than their counterparts using micro-strip or magnetics since, unlike other methods, the roll-off of strip-line is quite symmetrical. Another advantage of strip-line is the superior isolation between adjacent traces can be achieved with a "picket-fence" of grounds surrounding each transmit and receive line, keeping them spaced at less than 1/4 wavelength apart from each other.

S-Parameter Terms

TDD = Time domain differential

SDD = Frequency (signal) domain differential

RLCG = R=Ohms/m, L= H/m inductance, C = F/m capacitance, G = S/m conductance
S-parameters measurements are taken in magnitude and angle, because both the magnitude and phase of the input signal (angle) are changed by the network being measured.

(This is why they are sometimes referred to as complex scattering parameters).

The four S-parameters mentioned here actually contain eight separate numbers: the real and imaginary parts (or the modulus and the phase angle) of each of the four complex scattering parameters.

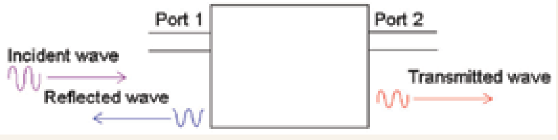
How much gain (or loss) you get is usually more important than how much the signal has been phase shifted.

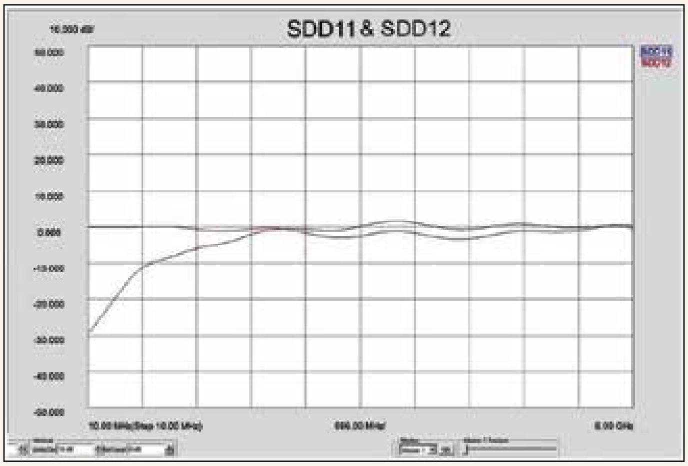
S-parameters depend upon the network and the characteristic impedances of the source and load used to measure it, plus the frequency measured at (kHz, MHz, GHz).

S_{11} = b1 / a1, S_{12} = b1 / a2, S_{21} = b2 / a1, S_{22} = b2 / a2

The transmitted and the reflected wave will have changes in amplitude and phase from the incident wave. Generally, the transmitted and the reflected wave will be at the same frequency as the incident wave.

S- Parameter data for the RJ45 jack, along with its mated twin-ax cables

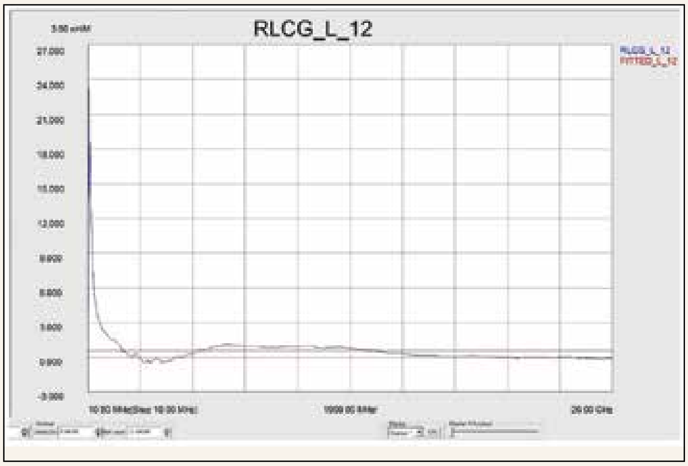




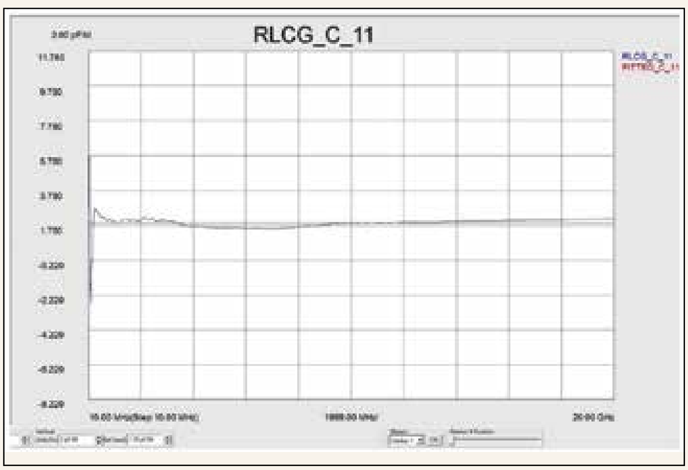
Test Data #1—Measured from 10 MHz to 6GHz (Note: SDD11 & 12 frequency domain RJ45 jack was de-imbedded from test fixture.)

Test Data #2—Measured from 10 MHz to 11GHz (Note: SDD11, 12, 21 frequency domain RJ45 jack was de-imbedded from test fixture.)

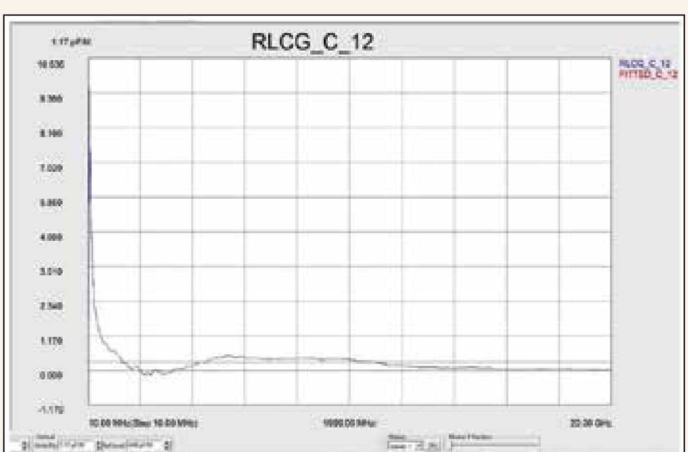
Test Data #3—RLCG cable measurement S-11 (inductance of the cable)



Test Data #4—RLCG 30 meter twin-ax cable measured from 10 MHz to 20GHz (S11 and S12—inductance of the cable)



Test Data #5—RLCG 30 meter twin-ax cable measured from 10 MHz to 20GHz (S11—capacitance of the cable)



Test Data #6—RLCG 30 meter twin-ax cable measured from 10 MHz to 20GHz (S12—capacitance of the cable)

COMPARABLE ENERGY USE

Power saving tests were performed in real-time using a DC ammeter and BERT tester as a source. We took a traditional RJ45 jack with ferrites, measured its contribution to a known data transmission circuit, and compared the mA readings with those contributed by a high-speed data RJ45 jack featuring strip-line flex design. The traditional, magnetically-loaded RJ45 added 0.212mA to the PCB's overall power consumption, compared with just 0.031mA for the high-speed RJ45 jack. This represents a power savings of 0.181ma with the high-speed jack.

CONCLUSION

An RJ45 jack with integrated strip-line flex is backward compatible with older connector systems, so that upgrading or refurbishing of legacy data systems becomes much more affordable. In addition, the strip-line flex design allows for greater power savings compared with conventional connectors and PCBs. Strip-line flex technology integrated into the RJ45 jack allows the connector to be same size and format as original connector while enhancing the connector's ability to perform throughput at higher data rates, without the need for magnetics. This approach also leaves more room on the PCB for additional components, since fewer components are required for higher speeds and signal integrity isolation.

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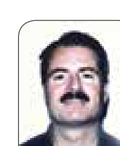

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Africa Wireless and Telecom Compliance

BY MARK MAYNARD

Telecom/Wireless

"If you want to go fast, go alone. If you want to go further, go together."

African Proverb

Comprised of over fifty countries, Africa represents a largely untapped market, as more countries are seeking to modernize and expand their economies. China has been leading the way for international trading partners that are joining forces with African countries to build large-scale infrastructure projects such as dams, clean water supplies, power supply generating plants, and upgraded telecommunications systems, which will help to raise the standard of living and access to modern communications and information technology equipment (ITE) technologies that will drive the growth of local businesses.

International companies wanting to enter these markets will want to perform formal risk analysis, to make sure the potential benefits are greater than the possible risks for each country in this continent. There are still countries in Africa with active civil conflict or border disputes with their regional neighbors, and a few have U.S. trade embargoes in place that prevent the importation of products from U.S. companies. Some countries are further along the path to becoming politically stable and ensuring financial stability for their citizens than others, so it would be wise to be selective in choosing the markets that make the most sense for each company, based on their products and size of the potential customer base.

The U.S. Central Intelligence Agency (CIA) World Factbook website,[1] referenced at the end of this article, is a useful tool for examining the various economic, political, societal, and infrastructure attributes that can be very valuable in assessing potential markets. In fact, this public domain site is the source for data in this article concerning the economies and infrastructure of these African countries, as well as the maps and flag images. A lot of companies also find it very useful to hire a consultant that has current knowledge of the laws, requirements, and restraints on the importation and sales of electronic products in this region, as well as finding compliance lab partners to assist with the formal product submittal test reports and submittal process.

There are a few countries that have well-developed programs at government agencies to handle the approval and certification of products, such as South Africa and Egypt. But most are less developed, and carry a higher level of uncertainty, as political unrest and civil disturbances can cause interruptions and delays in the process when governments are turned over or agencies abolished and reformed. The majority of less developed countries only have requirements for wireless and telecom approvals, so that helps to lessen the complexity of obtaining product approvals for most of the smaller market countries.

In this article, we look at the thirty largest countries in Africa, in terms of population.

Please note that you should not rely exclusively on the information presented here. This article is only intended to identify the major regulatory agencies for electronic and electrical product regulatory product approvals for the countries covered here, and to provide an overview of the specific compliance requirements for each country. Also, changes to the specific certification criteria and programs are common, as are updates to the international test standards utilized by most agencies. Only the official standards and laws for each country should be referenced when preparing product submittals.

If you don't have expertise on the laws and trade requirements for these countries within your own company, then you should procure the services of experienced regulatory compliance and legal consultants to prepare and submit these applications for product approvals, to protect the company from possible legal problems or the confiscation of your imported products.

NIGERIA

With over 177 million inhabitants, Nigeria is by far the most populated country in Africa, and has the highest global GDP-PPP ranking of an African country (21st in the world). Their economy is still heavily dependent on petroleum, which makes up 95 percent of their exports. A civilian government has been in place since 1999, but it has been marked by mismanagement, corruption, and occasional voting irregularities, and the country still has internal issues with ethnic and religious disputes among different groups. Nigeria is ranked tenth globally for the number of cell phones, and ninth globally for the number of Internet users.

Nigeria has two agencies for which product approvals must be obtained. Certifications from both agencies are required to import and sell products in this country.

The first is the Nigerian Communications Commission (NCC), which holds the authority for certification requirements for telecom and wireless products. EU R&TTE Directive compliance reports and CE Declarations of Conformity (DoCs) are accepted as proof of compliance. Product test samples are not required, but NCC does require a local company representatives and regulatory marking of the certified products. The NCC website is available in English (www.ncc.gov.ng), and it provides information on the categorized telecom and wireless technologies that include common wireless radio products and telecom terminal equipment (TTE). Certificates have no expiration date, but must be updated if the approved product is modified.

The second Nigerian agency is the Standards Organization of Nigeria-Conformity Assessment Program (SONCAP). This agency is concerned with the actual test standards that are utilized in the compliance testing of the product. Their English-language website (www.son.gov.ng) has more information on the required standards and application requirements.

ETHIOPIA

Ethiopia is the second most populous African country with almost 100 million residents. Since 2007, the country has experienced a period of relative peace and stability. Agriculture products and gold make up the bulk of Ethiopia's economy, which has a worldwide GDP-PPP country ranking of 73. They are ranked 47th globally in the number of cell phones, and 116nd globally in the number of Internet users.

The Ministry of Communication and Information Technology (MCIT) has authority over the certification requirements for telecom and wireless products. FCC grants and test reports, or EU R&TTE Directive compliance reports and CE DoCs are accepted as proof of compliance. Product test samples, local representatives, and regulatory marking of the product are not required for this country. The MCIT website is available in English (www.mcit.gov.et), and it provides information on the categorized telecom and wireless technologies that include common wireless radio and TTE. Certificates have no expiration date, but must be updated if the product is changed.

EGYPT

Following the lead of Tunisian opposition groups, Egypt's citizens had their own "Arab Spring" demonstrations and labor strikes, which led to the departure of their president, and the forming of a new parliament and presidential elections in 2012. However, by the next year there were periodic outbreaks of violence, resulting in a military takeover and the appointment of an interim president. 2014 saw the approval of a new constitution, and new elections that selected a new president, with new legislative elections expected by the end of 2015. These moves are expected to help stabilize the Egyptian economy.

Crude oil and petroleum products are still Egypt's leading export product, helping the country to rank 24th globally in terms of GDP-PPP. With 86 million residents, Egypt is third most populated African country and the 16th most populated country in the world, making it an attractive market for consumer electronics products. Egypt ranks 16th globally in the number of cellular phones, and 20th globally in the number of Internet users.

The National Telecommunication Regulatory Authority (NRTA) of Egypt is the wireless, telecom, and ITE certification agency, setting the compliance criteria for EMC, health and safety, wireless, and telecom attributes. The NRTA accepts EU R&TTE Directive compliance reports as proof of compliance.

The NRTA does not require a local representative, and test samples are required only for telecom products. Certificates do not expire, but remember that if any critical components in product are ever changed, the modified product must be submitted for evaluation and approval by the agency. The NRTA has an English-language website (www.tra.gov.eg/english) with more information on their allocated frequency spectrum and type approvals.

DEMOCRATIC REPUBLIC OF THE CONGO

The Democratic Republic of the Congo (DRC) has experienced internal strife and violence for many decades, with elections marred by irregularities. This country of 77 million, the fourth largest in Africa, has a GDP-PPP ranking of 105 worldwide, with exports that include diamonds, copper, gold, cobalt, wood products, crude oil, and coffee. The DRC is ranked 52nd globally for the number of cell phones, and 129th globally for Internet users.

There are U.S. Government prohibitions in place targeted at specified individuals and organizations associated with former regimes and violent groups, or others that pose a substantial risk of violence, which could disrupt stability of the DRC government and people.[2] A thorough review of the listing of these targeted individuals and organizations is highly recommended before engaging in any commercial or business transactions. That list can be found on the U.S. OFAC Specially Designated Nationals List webpage. [3]

Sanctions include restrictions on certain "dual-use" technologies, that is, devices that have both military and non-military applications. Information to determine if a particular product will necessitate an export license from the U.S. Department of Commerce can be found by verifying the Export Control Classification Number (ECCN) for the product against the Commerce Control List (CCL) found in the Bureau of Industry and Security section of the Department of Commerce website.[4]

The Société Congolaise des Postes et Télécommunications (SCPT), or the Congolese Post and Telecommunications Agency, is the telecom authority for the DRC for both wireless and telecom devices. They accept either FCC test reports and grants, or EU R&TTE Directive compliance reports, as proof of compliance. Test samples and product regulatory marks are not required, but an authorized local representative for the manufacturer or importer of the product located in-country is required. Certificates issued by the MPC are valid for ten years, assuming the product remains unchanged. They have a French-language website (www.scpt.cd) with a limited amount of information.

TANZANIA

Tanzania held its first democratic elections in 1995, albeit with some irregularities observed in voting. By 2010 two leading political parties had succeeded in reducing electoral issues, leading to a more stable society and economy. With Africa's fifth largest population of over 51 million, Tanzania has a GDP-PPP worldwide rank of 84, with exports of gold, agriculture products, and some manufacturing. Tanzania is ranked 39th globally in the number of cell phones, and 109th globally in the number of Internet users.

The Tanzania Communications Regulatory Authority (TCRA) is the telecom authority for this country. Either an EU R&TTE Directive compliance reports and CE DoCs, or an FCC grant and test report, are accepted as proof of compliance for the importation and sale of products. The TCRA does not ask for product samples, nor do they require a local representative. The TCRA website is in English (www.tcra.go.tz), and allows access to the agency policies, legislation, regulations, and licensing information for telecom and wireless products requiring certification and approvals. Certificates do not have an expiration date, assuming that there are no modifications to an approved product.

SOUTH AFRICA

In 1994, over four decades of apartheid came to an end in South Africa with the first multi-racial elections. South

Africa has struggled to make progress in eliminating disparities in housing, education, and health care, but they are making steady progress. This country is a growing market, and it is often included as one of the BRICS market countries (Brazil, Russia, India, China South Korea, and South Africa). South Africa is also the first country that companies will seek to enter as part of expansion into Africa. It is the 6th most populated African country, with almost 54 million residents, and is currently ranked 31st worldwide for GDP-PPP, the second-highest ranking among all African nations. Major export commodities are gold, diamonds, platinum, other metals and minerals, machinery and equipment. Africa is ranked 19th globally in the number of cell phones, and 52nd globally in the number of Internet users.

The Independent Communications Authority of South Africa (ICASA) is the regulator for communications, broadcasting and postal services, and responsible for TTE and wireless product certification programs. ICASA requires a local representative and regulatory product markings, but they do not require product samples. Either FCC grants and test reports or EU R&TTE test reports and CE DoCs are accepted by the ICASA as proof of compliance. ICASA certificates have no expiration date, and only requires updating if the product is modified. The agency website is in English (www.icasa.org.za), which provides more information on their publications, regulations, and certification programs.

KENYA

Having a history of strong-man rule and periodic violence in the past several decades, Kenya instituted a new constitution by referendum in 2010 that put in place additional checks and balances, reducing the power of the president, and creating counties within the country to decentralize the power formerly held by the central government. The 7th most populated African country, with over 45 million residents, Kenya is currently ranked at 75th worldwide for GDP-PPP, with major export commodities of agricultural products, petroleum, seafood and cement. Kenya is ranked 33rd globally in the number of cell phones, and 57th globally in the number of Internet users.

The Communications Authority of Kenya (CAK) is the government agency for TTE and wireless product certifications. CAK requires a local representative and product samples, but they do not require regulatory product markings. Either FCC grants and test reports or EU R&TTE test reports and CE DoCs are accepted as proof of compliance by this agency. CAK certificates have no expiration date, and certification is granted in two stages. First a provisional "Type 1" approval is issued, followed by the final approval certification. The agency website is in English (http://ca.go.ke), which provides more information on their publications, statutes and regulations.

ALGERIA

Algeria is Morocco's neighbor to the East and, along with the other northern coastal African countries, was involved in the "Arab Spring" populist movement. Since 2011, Algeria has experienced some moderate political reforms, including more open parliamentary elections, and the removal of some of the "state of emergency" restrictions that had been in place for over twenty years. There is still occasional internal violence from marginalized groups, but there is hope that the constitution will be revised to allow for more inclusion and representation for all of the country's citizens.

Algeria is the 8th most populated African country, with over 38 million people, and is ranked 34th in the world in terms of GDP-PPP, due largely to the country's oil reserves, which make up 97 percent of their exports. Algeria ranks 48th globally in the number of Internet users, and 32nd globally in the number of cell phones.

The telecom government agency in Algeria is the L'Autorité de Régulation de la Poste et des Télécommunications (ARPT), or Authority for the Regulation of Posts & Telecommunications. FCC grants and test reports, or EU R&TTE Directive compliance reports and CE DoCs are accepted as proof of compliance. Keep in mind that ARPT can bar devices that could conflict with emergency or official-use frequencies, or TTE products that could harm their telephone network infrastructure. Product test samples and regulatory marking of the product are required, as well as a requirement to have an in-country local representative.

The ARPT website is available in either French or Arabic (www.arpt.dz). Google Translate (translate.google.com) is handy for unofficial translations of the information provided on this website, which provides information on the categorized telecom and wireless technologies that include common wireless radio and TTE products. Certificates are valid for two years, and these must be updated if the product is changed during this period. If the product will continue to be sold after this time, it should be re-submitted for a new certificate for an additional two years, and this process should be repeated for as long as the product is imported and sold in this country.

UGANDA

Uganda is the ninth most populated African country, with over 37 million residents, and has enjoyed relative stability since 1986. The constitution was reformed in 2005, which eliminated a ban on multi-party politics and elections. This country has a GDP-PPP rank of 96 worldwide, exporting mainly seafood and agricultural products. Uganda has a global ranking of 58th in the number of cell phones, and ranks 64th globally in the number of Internet users.

Uganda's telecom agency is the Uganda Communications Commission (UCC), which defines the certification requirements for wired TTE and wireless technology products. The UCC accepts both EU R&TTE Directive compliance reports and FCC test reports and grants as proof of compliance. This agency does not require a local representative, test samples, or UCC product marks. Certificates do not expire, but must be updated if any critical components in product are changed. The UCC has an English-language website (www.ucc.co.ug) with more information on their programs and publications.

SUDAN

The 10th most populous country in Africa, Sudan has experienced years of civil unrest and war, with violent armed groups in virtual control of large parts of the country. Because of ongoing activities by groups deemed terrorist by the U.S. Government, there have been trade restrictions in place since 1997. The Sudan sanctions program imposed by the U.S. is one of the most comprehensive currently in place, and deals with a multitude of issues that pose a potential threat to the national security, foreign policy and economy of the U.S. The full text of the current sanctions can be obtained at the U.S. OFAC website.[5] Except for humanitarian aid, U.S. companies and citizens are legally barred from most trading or business activities involving Sudan.

THE TEN LARGEST MARKET COUNTRIES

We have now traversed through the ten largest market countries in Africa, from Nigeria to Sudan. While some countries are just beginning their path towards developing their economies and markets, others will provide special opportunities for the companies that do their research and find their own groups of customers. These citizens have seen the benefits that come from access to modern communications and ITE technologies that their Western neighbors enjoy, and for those businesses that can see the prospects for long term growth, many new markets are ready to present themselves.

MOROCCO

The people of Morocco were part of the Arab Spring pro-democracy movement that started in 2011, and have experienced some moderate reforms within their country that were granted by the ruling monarchy. They have been working towards opening up their markets, and their location as the closest African country to Europe is helping this effort. This country of over 32 million people has the 11th largest population in Africa. Morocco's GDP-PPP is ranked 57th in the world, ranks 28th in the number of Internet users, and 31st in the number of cell phones, showing that it has one of the most tech-savvy populations in this region.

The Agence Nationale de Réglementation des Telecommunications (ANRT), or the National Agency for the Regulation of Telecommunications, is the telecom authority of Morocco. They accept either the EU R&TTE Directive compliance reports and CE DOC, or the FCC grant and test reports, as proof of compliance for the importation of electronic products. ANRT defines the requirements for wireless and telecom products, and reserves the right to review or reject any application that might interfere with protected frequencies, such as those for emergency or military uses, or products that might cause degradation to their telephone telecommunications infrastructure. Typically, they do not ask for product samples as part of the approval process; however, a local representative is required in-country.

There is an English-language version of the ANRT website available (www.anrt.net.ma/en), although the official languages are Arabic and Tamazight, and French is the unofficial language of commerce and diplomacy. This website allows access to the regulations and application procedures for telecom and wireless products requiring certification and approvals, such as Bluetooth, Wi-Fi, cellular and satellite phones, and telephone terminal equipment (TTE). Certificates are normally valid for ten years, but they do require an update submittal any time the product is substantially changed.

GHANA

After a period of military rule, this country has held multiparty elections since 1992. Ghana has a GDP-PPP rank of 80, exporting oil, gold, cocoa, minerals, and agricultural products. With a population of 26 million. They have a global ranking of 42 in the number of cell phones, and 91 in Internet users.

Ghana's telecom agency is the National Communications Authority (NCA), and they define the certification requirements for wired TTE and wireless technology products. The NCA accepts both EU R&TTE Directive compliance reports and FCC test reports and grants as proof of compliance. This agency does not require a local representative, test samples, or NCA product marks. Certificates do not expire, but must be updated if any critical components in product are changed. The NCA has an English-language website (www.nca.org.gh) with more information on their legal framework, licensing, and other projects.

MOZAMBIQUE

Mozambique became independent in 1975, after almost 500 years as a colony of Portugal. In 1990 a new constitution brought democratic elections and helped to open up their economy. This country of 25 million has a GDP-PPP rank of 127, exporting aluminum, seafood, agricultural products, timber, and generated electricity. They rank 91st in the number of cell phones, and 111th in the number of Internet users.

Instituto Nacional das Comunicações de Moçambique (INCM), or the National Institute of Communications for Mozambique, is the telecom agency for this country. FCC grants and test reports or EU R&TTE Directive compliance reports and CE DOC are accepted as proof of compliance for wireless and TTE products. INCM does not require product test samples or regulatory marking of the product, but they do require an in-country authorized local representative. The INCM website is in Portuguese (www.incm.gov.mz), which is their official language. Certificates do not expire, as long as there are no changes to the product's critical components.

MADAGASCAR

Madagascar has held free presidential and national assembly elections since 1992, with some political instability arising over a contested election in 2001. This island nation of almost 24 million is currently ranked at 120th for GDP-PPP, with exports of agricultural products, seafood, minerals, and petroleum products. They are ranked 89th in the number of cell phones, and 124th in the number of Internet users.

The L'Autorite de Regulation des Technologies de Communication (ARTEC), or the Regulatory Authority for Communications Technologies, is the government agency for telecom TTE and wireless product certifications. ARTEC requires a local representative as well as product samples, but they do not require regulatory label marks. Either FCC grants and test reports or EU R&TTE test reports and CE DOCs are accepted as proof of compliance by this agency. ARTEC certificates have no expiry date, as long as the product is not modified from the approved design. The ARTEC website is in their official French language (www.artec.mg), which provides more information on the regulations and certification requirements.

CAMEROON

Cameroon has had a constitutional federal government since 1972, and have been a stable country. The have a GDP-PPP ranking of 96, with the majority of their exports being oil and petroleum products, lumber, cocoa beans, aluminum, coffee, and cotton. They have almost 24 million inhabitants, making them the 15th most populated country in Africa, and are ranked 64th in the number of cell phones, and 104th in the number of Internet users.

Agence de Régulation des Télécommunications (ART), or the Regulatory Agency for Telecommunications, is the telecom authority of Cameroon. Either the EU R&TTE Directive compliance reports and CE DOC, or the FCC grant and test reports, are accepted as proof of compliance for the importation and sell of products. They do not ask for product samples when submitting an application for approval; however, a local representative is required. There is an English-language version of the ART website available www.art.cm), although French is the official language. This website allows access to the regulatory activities and publications for telecom and wireless products requiring certification and approvals. Certificates are valid for five years, and should be renewed if the approved product will continue to be sold in Cameroon after this time period.

COTE D'IVOIRE (IVORY COAST)

Since 1999 this country has been the scene of multiple military coups and political instability. In fact, thousands of UN peacekeeping forces have been deployed throughout the country since 2011, helping to support the new president in rebuilding the infrastructure and economy, so they can manage their own security once the peacekeepers are gone. Cote d'Ivoire's 23 million residents have a GDP-PPP ranked at 92, and rank 49th in the number of cell phones, and 101st in the number of Internet users.

Cote d'Ivoire has specific U.S. government sanctions in place that are targeted at individuals and organizations associated with former regimes and violent groups, or those that present a significant threat of violent acts, which could disrupt the peace and stability for the residents and government. [6] A full listing of the specific individuals and organizations can be found on the OFAC Specially Designated Nationals List webpage. [7]

These sanctions prohibit the trade or sell of certain dual-use technologies, which are products that perform either military or non-military applications. To determine if a product will require an U.S. Department of Commerce export license, first determine the Export Control Classification Number (ECCN) for the product, and then access the Commerce Control List (CCL) posted in the Bureau of Industry and Security section of the Department of Commerce website. [8] The ECCN is an alpha-numeric code that designates the product and specifies the licensing requirements. For example, for an ECCN code of "3A001," "3" would place it in the "electronics" category, and the "A" would place it in the "systems, equipment, and components" group, and "001" would give the specific type within that group.

Autorité de Régulation des Télécommunications/TIC de Côte d'Ivoire (ARTCI), or the Authority for Regulations of Telecommunications and ITE of the Ivory Coast, is the telecom agency for this country that certifies TTE and wireless products. This agency requires an in-country authorized representative as well as product samples, but they do not require agency product marks. Either FCC grants and test reports, or EU R&TTE test reports and CE DOCs are accepted as proof of compliance. ARTCI certificates are valid for five years, as long as the product is unchanged. ARTCI has an English-language version of their website (www.atci.ci) with more information on the program requirements and agency activities, although the official language of this country is French.

ANGOLA

Angola had twenty-five years on internal violence and conflict prior to 2002, which are estimated to have caused up to 1.5 million deaths and the displacement of 4 million people. A new constitution was instituted in 2010, with democratic elections following in 2012, as the country works to rebuild their infrastructure and society. This country of almost 20 million has a GDP-PPP rank of 65, with major export commodities of oil and petroleum products, diamonds, seafood, and agricultural products. Angola has a global ranking of 80 in the number of cell phones, and 112th in Internet users.

The Instituto Angolano das Comunicações (INACOM), or the Angola Institute of Communications, is the government agency for telecom TTE and wireless product certifications. INACOM does not require a local representative or product samples, and they accept FCC or CE product label regulatory marks. Either FCC grants and test reports or EU R&TTE test reports and CE DOCs are accepted as proof of compliance by this agency. INACOM certificates do not have an expiry date, as long as the product is not modified from the approved design. The INACOM website is in their official language of Portuguese (www.inacom.gov.ao), which provides more information on the regulations and certification requirements.

BURKINA FASO

After two decades of military takeovers during the 1970s and 1980s, Burkina Faso has held multiparty elections since the beginning of the 1990s. There are few natural resources in this country of almost 19 million, with a GDP-PPP is ranking is 124, with exports of gold and agriculture products. They rank 79th in the world for the number of cell phones, and 140th in the number of Internet users.

The Autorité de Régulation des Communications Électroniques (ARCE), or Regulatory Authority for Electronic Communications, is the government agency for telecom and wireless product certifications. ARCE does not require product samples or their own regulatory mark on the product, but they do require a local representative in-country. Either FCC grants and test reports or EU R&TTE test reports and CE DOCs are accepted as proof of compliance. ARCE certificates do not have an expiry date, and resubmittals are not required as long as the approved product is not modified. This agency has a French-language website (www.arcep.bf) which provides more information on their programs and certification requirements.

NIGER

This country has experienced decades of political and civil unrest, with military coups and counter-coups, resulting in a very poor country with a GDP-PPP rank of 147. With a population of over 18 million, their economy is dependent on uranium and agriculture exports. Niger is ranked 107th in the number of cell phones, and 151st in the number of Internet users.

The L'Autorité de Régulation des Télécommunications et de la Poste (ARTP), or Authority for Regulation of Telecom and Posts is the telecom certification agency for Niger, for wired and wireless products. The ARTP accepts both EU R&TTE

Directive compliance reports and FCC test reports and grants as proof of compliance. The ARTP does not require a local representative, test samples, or product marks. Certificates do not expire, but must be updated if any critical components in product are changed. The ARTP has a French-language website (www.armniger.org) with more information on their allocated frequency spectrum and approvals requirements.

MALAWI

Malawi became a democracy in 1994, and has experienced two decades of relative stability, but with some political issues and government mismanagement. They have the 20th largest population of the African countries, with over 18 million residents. Their GDP-PPP is ranking is 152, with an economy heavily dependent on agriculture. Malawi is ranked 117th in the number of cell phones, and 107th in the number of Internet users.

The Malawi Communications Regulatory Authority (MACRA) is the agency for telecom and wireless product certifications. MACRA requires a local representative, but does not require product samples. The FCC or CE label marks can be used on the product, instead of a special MACRA marking. Either FCC grants and test reports or EU R&TTE test reports and CE DOCs are accepted as proof of compliance. MACRA certificates don't expire, as long as the product remains unchanged. This agency has an English-language website (www.macra.org.mw) which provides more information on the agency policies, regulations, and publications.

MALI

Mali became a democracy in 1991, and experienced two decades of relative stability until internal conflict resulted in a military coup in 2012. An international military coalition intervened in 2013 to quell tensions, and a democratic presidential election was held in mid-2013. The current government is working to rebuild their infrastructure, modernize their utilities, and grow their economy. Their GDP-PPP is ranking is 131 with a population of over 16 million, and their economy is dependent on gold mining and agriculture exports. Mali is ranked 59th in the number of cell phones, and 132nd in the number of Internet users.

The Autorité Malienne de Régulation des Télécommunications/TIC es Postes (AMRTP), or Regulatory Authority for Telecom, ITE, and Posts, is the government agency for telecom and wireless product certifications. This is a voluntary requirement, which some companies obtain for marketing reasons, such as government agencies in Mali giving preference to products that have obtained this approval. AMRTP requires product samples to be submitted with the application, and also requires a local representative, but they do not require their own regulatory mark on the product. Either FCC grants and test reports or EU R&TTE test reports and CE DOCs are accepted as proof of compliance. AMRTP certificates are valid for five years, as long as the product remains unchanged. This agency has a French-language website (www.amrtp-mali.org) which provides more information on the program and certification requirements.

ZAMBIA

For the past decade Zambia has enjoyed political stability, with open democratic elections. This nation of 15 million has a GDP-PPP rank of 100th, with exports of metals, minerals, generated electricity, and agricultural products. They rank 76th in the world for the number of cell phones, and 103rd in the number of Internet users.

The Zambia Information and Communications Technology Authority (ZICTA) is the regulatory agency for telecom and wireless product certifications. ZICTA does not require product samples or their own regulatory mark on the product, but they do require a local representative in-country. Either FCC grants and test reports or EU R&TTE test reports and CE DOCs are accepted as proof of compliance. ZICTA certificates do not have an expiry date, and resubmittals are not required as long as the approved product is not modified. This agency has an English-language website (www.zicta.zm) which provides more information on their regulations and agency guidelines.

ZIMBABWE

This country has experienced a long history of rule by despots, widespread violence, and rigged elections. Zimbabwe has 14 million residents, a GDP-PPP ranked at 132, and export commodities that include platinum, cotton, tobacco, gold, ferroalloys, textiles and clothing. They rank 69th in the number of cell phones, and 82nd in the number of Internet users.

Zimbabwe has U.S. government sanctions in place for targeted individuals and organizations associated with the current regimes and those that are undermining democratic processes. [9] A full listing of the specific individuals and organizations can be found on the OFAC Specially Designated Nationals List webpage. [3]

These sanctions prohibit the trade or sell of certain dual-use technologies, which are products that perform either military or non-military applications. To determine if a product will require an U.S. Department of Commerce export license, first determine the Export Control Classification Number

(ECCN) for the product, and then access the Commerce Control List (CCL) posted in the Bureau of Industry and Security section of the Department of Commerce website. [8]

The Postal and Telecommunications Regulatory Authority of Zimbabwe (POTRAZ) is the telecom agency for this country that certifies TTE and wireless products. This agency does not require an authorized representative, product samples, or agency product marks. Either FCC grants and test reports, or EU R&TTE test reports and CE DOCs are accepted as proof of compliance. POTRAZ certificates do not expire, as long as the product is unchanged. The agency has an English-language website (www.potraz.gov.zw) with more information on the program requirements and agency activities.

SENEGAL

Senegal is one of the most stable democracies in Africa, and has a GDP-PPP ranking of 119, exporting agricultural products, petroleum products, and phosphates. They have almost 14 million inhabitants, and are ranked 73rd in the number of cell phones, and 74th in the number of Internet users.

L'Autorité de Régulation des Télécommunications et des Postes (ARTP), or the Authority for Regulation of Telecommunications and Posts, is the telecom authority of Senegal. Either the EU R&TTE Directive compliance reports and CE DOC, or the FCC grant and test reports, are accepted as proof of compliance for the importation and sell of products. The agency reserves the right to review any application that might interfere with protected frequencies or products that could cause harm to their telephone network. They do not ask for product samples when submitting an application for approval; however, a local representative is required.

Autorité de Régulation des Télécommunications et des Postes

There is an English-language version of the ARTP website available (www.artpsenegal.net), although the official language is French. This website allows access to the regulatory activities and publications for telecom and wireless products requiring certification and approvals. Certificates do not have an expiry date, but they do require an update submittal any time the product is substantially changed.

RWANDA

Rwanda experienced a horrific civil war and genocide in the 1990s. They held their first post-genocide presidential and legislative elections in 2003. This 25th most populated African country of 12 million residents is rebuilding their infrastructure and economy, and have has a GDP-PPP rank of 144, with their major export commodities of coffee, tea, hides, and tin ore. They rank 104th in the number of cell phones, and 115th in the number of Internet users.

The Rwanda Utilities Regulatory Authority (RURA) is the telecom agency for this country. FCC grants and test reports, or EU R&TTE Directive compliance reports and CE DOC are accepted as proof of compliance for wireless and TTE products. RURA does not require product test samples, local representative, or regulatory marking of the product. The RURA website is available in English (www.rura.gov.rw). Certificates are valid for five years, and these are required be updated if the product is changed during this period. If the product will continue to be sold after this time, it should be re-submitted for a new certificate for an additional five years.

GUINEA REPUBLIC

The Guinea Republic is a fledgling democracy that only had their first free and open election in 2010, and have a population of close to 12 million. They have has a GDP-PPP rank of 150, and possess the world's largest reserves of both high-grade iron ore and bauxite, and also export gold, diamonds, and agricultural products. They rank 115th in the number of cell phones, and 157th in the number of Internet users.

The Autorité de Régularisation des Postes et Télécommunications (ARPT), or Authority for Regulation of Posts and Telecommunications, is the telecom agency for this country. FCC grants and test reports, or EU R&TTE Directive compliance reports and CE DOC are accepted as proof of compliance for wireless and TTE products. Product test samples and regulatory marking of the product are required, as well as a requirement to have an in-country local representative. The ARPT website is available in French (www.arpt.gov.gn). Certificates are valid for five years, and these are required be updated if the product is changed during this period. If the product will continue to be sold after this time, it should be re-submitted for a new certificate for an additional five years.

Autorité de Régulation des Postes et Télécommunications

CHAD (REPUBLIC OF TCHAD)

This country has experienced decades of internal conflict, but since 2008 has settled into a period of peace and stability. Chad is heavily dependent on oil revenues, accounting for around 60 percent of their exports, with agricultural products making up most of the rest, and has a GDP-PPP rank of 126. They have over 11 million inhabitants, and are ranked 119th in the number of cell phones, and 141st in the number of Internet users.

The L'Office Tchadien de Régulation des Télécommunications (OTRT), or the Chad Office of Telecom Regulation, is the government agency for telecom TTE and wireless product certifications. OTRT requires both product samples and a local representative, but they do not require regulatory product markings. Either FCC grants and test reports or EU R&TTE test reports and CE DOCs are accepted as proof of compliance. OTRT certificates are valid for five years, as long as the product is not modified from the approved design. OTRT has a French-language website (www.otrt.td/fr) which provides more information on the regulations and certification requirements.

TUNISIA

The beginnings of the Arab Spring movement started in Tunis, the capital of Tunisia, in December 2010. What started as protests had escalated to rioting by January 2011, which led to a national unity government being formed. A new constitution was ratified in January 2014, and Parliamentary and presidential elections for a permanent government were held at the end of 2014.

There have been some recent isolated violent attacks, but the new government is eager to unite the country and build up the economy in this country with almost 11 million residents. Tunisia is ranked 77th in the world, in terms of GDP-PPP, ranks 88th in the number of Internet users, and 68th in the number of cell phones, with both technologies being credited with helping the success of the Arab Spring citizen movement that reformed their government.

The Centre d'Etudes et de Recherche des Télécommunications (CERT), or Research and Studies Telecommunications Center is the government agency for telecom and wireless product certifications, for scoped wireless and telecom technologies. CERT requires product samples to be submitted, and also requires an authorized local representative; they do not, however, require product label markings. Both FCC grants and test reports, and EU R&TTE test reports and CE DOCs are accepted as proof of compliance. CERT certificates are valid for three years, as long as the product is not modified. If any critical components in product are changed, the updated product must go through a resubmittal process, with the understanding that the changed product cannot be imported until a new approval has been granted. CERT has a French-language website (www.cert.nat.tn) which provides more information on standards, testing, and product certification.

SOMALIA

Somalia has experienced internal and external conflict for many decades, but now has a democratically-elected government, and is in the process of rebuilding the country's infrastructure and economy. Somalia has 10 million people, and their GDP-PPP is ranked at 169, with exports of agriculture products, charcoal, and scrap metal.

Unlike Sudan, Somalia is not currently subject to a wide-ranging U.S. sanctions program. However, there are prohibitions in place targeted at specified individuals and organizations associated with former regimes, as well as those groups that have committed violence, or pose a substantial risk of violence, with the intention of disrupting the peace and stability of the people and government of Somalia. [10] A complete listing of these targeted individuals and organizations can be found on the OFAC Specially Designated Nationals List webpage. [7]

These sanctions include restrictions on certain dual-use technologies, that is, devices that have both military and non-military applications. Information on determining if a specific commodity will require an export license from the U.S. Department of Commerce, can be found by first determining the Export Control Classification Number (ECCN) for the product, and then by accessing the Commerce Control List (CCL) found in the Bureau of Industry and Security section of the Department of Commerce website. [8]

The Ministry of Posts and Communications (MPC) is the telecom authority for Somalia, for both wireless and TTE products. They accept either FCC test reports and grants, or EU R&TTE Directive compliance reports, as proof of compliance. Test samples and product regulatory marks are not required, but an authorized local representative for the manufacturer or importer of the product located in-country. Certificates issued by the MPC do not have an expiry date and remain valid if the product is unchanged. They have an English-language website (www.mopc.somaligov.net) with a limited amount of information.

BURUNDI

Burundi experienced ethnic violence from 1993 to 2005 that resulted in the deaths of over 200,000 people, with hundreds of thousands more being displaced and becoming refugees. A new constitution and elected government were implemented in 2005, but there are still many economic and political issues to resolve. Closing out our list as the 30th most populated African country with 10 million inhabitants, they have a GDP-PPP is ranking of 162, and an economy based on agriculture products. They rank 140th in the world for the number of cell phones, and 143rd in the number of Internet users.

The L'Agence de Régulation et de Contrôle des Télécommunications, (ARCT), or the Regulatory Board of Telecommunications and Control, is the government agency for telecom and wireless product certifications. ARCT does not require product samples or their own regulatory mark on the product, but they do require a local representative in-country. Either FCC grants and test reports or EU R&TTE test reports and CE DOCs are accepted as proof of compliance. ARCT certificates do not have an expiry date, and resubmittals are not required as long as the approved product is not modified. This agency has a French-language website (www.arct.gov.bi) which provides more information on their regulations and requirements.

CONCLUSION

We have now traveled through the next twenty largest market countries in Africa, from Morocco with the 11th largest population, to Burundi with the 30th largest. While some countries are just beginning their path towards developing their economies and markets, others will provide special opportunities for the companies that do their research and find their own groups of customers. These citizens have seen the benefits that come from access to modern communications and ITE technologies that their Western neighbors enjoy, and for those businesses that can see the prospects for long term growth, many new markets are ready to present themselves.

It is important to keep in mind that the information contained in this article can become stale at a fast rate, so make sure to utilize your professional contacts and network to stay current on the latest requirements and compliance developments. One professional organization that can be a very reliable source is the Institute of Electrical and Electronics Engineers (IEEE), which has over thirty different sub-groups, including the EMC Society, the Product Safety Engineering Society, and the Consumer Electronics Society.

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CPSC Mandates Safety Programs for Manufacturers and Retailers

The History Behind the CPSC's Action

BY KENNETH ROSS

Since its inception, the U.S. Consumer Product Safety Commission (CPSC) has encouraged companies to implement active product safety management programs. Since 2010, however, the CPSC has made this a bit more official. Requirements for the establishment of safety compliance programs have appeared in a final rule of factors to be considered for civil penalties, in a number of consent decrees and settlement agreements for civil penalties, in letters from the CPSC where they decided not to seek civil penalties, and finally in a proposed interpretive rule.

This article will examine the CPSC's previous guidance on safety programs, describe the new requirements and proposed rules and discuss what they might mean for product manufacturers.

PRIOR GUIDANCE ON SAFETY PROGRAMS

The CPSC first published the *Handbook for Manufacturing Safer Consumer Products* in the 1970s, shortly after the agency was created. The last edition of this handbook came out in 2006 and discusses product safety policies, organization, and training as well as all aspects of design, manufacturing, quality, corrective actions, etc. In other words, it discusses safety procedures that it believes are appropriate for any company making consumer products in all aspects of design, production, sales, and post-sale.

The CPSC first published the Handbook for Manufacturing Safer Consumer Products *in the 1970s, shortly after the agency was created.*

At the beginning of the handbook, it says:

> *"Manufacturers must assure the safety of consumer products. This is achieved through the design, production and distribution of the products they manufacture. It is best accomplished by a comprehensive systems approach to product safety, which includes every step from the creation of a product design to the ultimate use of the product by the consumer. The basic concepts for a comprehensive systems approach for the design, production and distribution of consumer products are discussed in this Handbook."*

In addition, the CPSC's Recall Handbook, in existence for many years but updated in March 2012, has had sections on the appointment of a Recall Coordinator, development of a company recall policy and plan, and extensive suggestions for the creation and retention of records to support a recall.

The safety processes advocated in these handbooks are just suggestions and not legal requirements. In addition, they are similar to those procedures employed by companies who have a well-functioning safety effort. So, there is nothing particularly onerous here that a company shouldn't already be doing.

NEW REQUIREMENTS FOR SAFETY COMPLIANCE PROGRAMS

Recently, however, new requirements for safety compliance programs have been inserted by the CPSC into various documents.

Factors to Consider for Civil Penalties

First, on March 31, 2010, the CPSC published in the *Federal Register* a final rule of factors that its staff is expected to consider when deciding whether to seek civil penalties. The rule (16 CFR §1119.4(b)(1)) clearly states that product safety programs are one of the factors to be considered by the staff in assessing civil penalties:

> *"The Commission may consider, when a safety/compliance program and/or system as established is relevant to a violation, whether a person had at the time of the violation a reasonable and effective program or system for collecting and analyzing information related to safety issues. Examples of such information would include incident reports, lawsuits, warranty claims, and safety-related issues related to repairs or returns. The Commission may also consider whether a person conducted adequate and relevant premarket and production testing of the product at issue; had a program in place for continued compliance with all relevant mandatory and voluntary safety standards; and other factors as the Commission deems appropriate. The burden to present clear, reliable, relevant, and sufficient evidence of such program, system, or testing rests on the person seeking consideration of this factor."*

In addition, the Commissioners released a statement dated March 10, 2010 concerning these new factors that said in part:

> *"The safety/compliance program factor takes into account the extent to which a person (including an importer of goods) has sound, effective programs/systems in place to ensure that the products he makes, sells or distributes are safe. Having effective safety programs dramatically lessens the likelihood that a person will have to worry about the application of this civil penalty rule. Any good program will make sure that there is continuing compliance with all relevant mandatory and voluntary safety standards. This is not the same as saying if one's product meets all mandatory and voluntary standards that the Commission will not seek a civil penalty in appropriate cases. The Commission expects companies to follow all mandatory and voluntary safety standards as a matter of course."*

Daiso Consent Decree

At the same time that the new civil penalty factors were being finalized, the establishment of a product safety management program was included for the first time in a consent decree for civil penalties. In a March 4, 2010 agreement, Daiso Holding, a U.S. subsidiary of a Japanese company, agreed to pay a little more than $2 million in fines for violating various laws and regulations concerning the sale of toys and children's products.

The consent decree required Daiso to hire a product safety coordinator approved by the CPSC to do, in part, the following:

- Create a comprehensive product safety program
- Conduct a product audit to determine which of Defendants' merchandise requires testing and certification of compliance with the FHSA, the CPSA, and any other Act enforced by the CPSC
- Establish and implement an effective and reasonable product safety testing program in compliance with the FHSA, the CPSA, and any other Act enforced by the CPSC
- Create guidance manuals for managers and employees on how to comply with product safety requirements
- Establish procedures to conduct product recalls
- Establish systems to investigate all reports of consumer incidents, property damage, injuries, warranty claims, insurance claims and court complaints regarding products under the jurisdiction of the CPSC that Defendants imported into the United States

The consent decree contains many more specific requirements, and also includes the following monitoring requirements:

> *"At the end of the first year of the monitoring period and at the end of any 180-day extension of the monitoring period under this paragraph, the Coordinator shall provide a written report to the Office of Compliance. If the Coordinator certifies Defendants are in compliance as described in this paragraph, the monitoring period will end. If the Coordinator cannot certify that Defendants meet each of the compliance requirements listed below, the monitoring period shall continue for an additional 180 days, at the end of which the Coordinator shall provide an updated written report to the Office of Compliance."*

Daiso retained an independent consultant to certify compliance, and the CPSC sent its staff to Daiso facilities to audit compliance. Daiso passed and the monitoring was ultimately discontinued.

Safety Requirements in Civil Penalty Settlement Agreements

The CPSC did nothing further to impose safety requirements until they were inserted into civil penalty settlement agreements starting in February 2013. In the first such agreement, Kolcraft agreed to pay a $400,000 civil penalty. In addition, they agreed to the following language:

"Kolcraft shall maintain and enforce a system of internal controls and procedures designed to ensure that: (i) information required to be disclosed by Kolcraft to the Commission is recorded, processed and reported in accordance with applicable law; (ii) all reporting made to the Commission is timely, truthful, complete and accurate; and (iii) prompt disclosure is made to Kolcraft's management of any significant deficiencies or material weaknesses in the design or operation of such internal controls that are reasonably likely to adversely affect in any material respect Kolcraft's ability to record, process and report to the Commission in accordance with applicable law.

"Upon request of Staff, Kolcraft shall provide written documentation of such improvements, processes, and controls, including, but not limited to, the effective dates of such improvements, processes, and controls. Kolcraft shall cooperate fully and truthfully with Staff and shall make available all information, materials, and personnel deemed necessary by Staff to evaluate Kolcraft's compliance with the terms of the Agreement.

"Kolcraft shall implement and maintain a compliance program designed to ensure compliance with the safety statutes and regulations enforced by the CPSC that, at a minimum, contains the following elements (i) written standards and policies; (ii) a mechanism for confidential employee reporting of compliance-related questions or concerns to either a compliance officer or to another senior manager with authority to act as necessary; (iii) effective communication of company compliance-related policies and procedures to all employees through training programs or otherwise; (iv) senior manager responsibility for compliance; (v) board oversight of compliance (if applicable); and (vi) retention of all compliance-related records for at least five (5) years and availability of such records to CPSC upon request."

Then, Chairman Tenenbaum and Commissioner Adler issued a joint statement in connection with this agreement, stating their concern that Kolcraft had had a dozen recalls since 1989 and that some further action was required. They said:

"The failure of a company to have an effective means of detecting and addressing serious or continuous safety issues with its products is contrary to the expectations of consumers and is unacceptable to this Commission. While we certainly understand that even the most responsible companies can make mistakes, the failure of a company to have in place an effective compliance program and internal controls is irresponsible. Thus, going forward, we expect those 2companies that lack an effective compliance program and internal controls to voluntarily adopt them. If not, we will insist that they do so."

The Commissioners also made it clear in their statement that having an adequate safety program does not let a company off the hook for failing to report a safety problem in a timely manner.

Then, in May 2013, Williams-Sonoma agreed to pay $987,500 in civil penalties for failing to report a safety problem to the CPSC in a timely manner. The three paragraphs from the Kolcraft opinion quoted above were also inserted in the Williams-Sonoma agreement. In addition, Commissioner Nord submitted a statement on the Williams-Sonoma agreement that questioned the piecemeal creation of a mandate for such programs through enforcement. Commissioner Adler responded to Commissioner Nord's concern and signaled his views on the future use of such safety requirements. He said, in part:

"Far from viewing this settlement as punishment, I view it as the Commission and the company mutually agreeing to a set of reasonable measures designed to lead to safer products and fewer recalls in the future. Indeed, I suspect that the reason that companies agree to such language is their sense that any conscientious, responsible firm should follow such procedures in their approach to compliance. And to the extent that their past practices might have fallen short of these goals, they are eager to demonstrate that their future approach will be one of strict adherence to such provisions…

"…The fact that the Commission has sought similar language in the two settlements says little at this point about whether there has been a shift in agency policy in the future. Even if it did, there is nothing improper about implementing the policy in individual case settlements. That said, I do not rule out asking for such clauses in future non-civil penalty settlement agreements nor do I rule out future expansions of the Commission's voluntary recall policies."

Since May 2013, every settlement agreement for civil penalties has had some compliance requirements. Based on this history, it is virtually certain that future settlement agreements will also contain some type of requirement for the establishment of more robust safety compliance programs. However, it is still an open question as to how compliance will be audited and monitored, and when the CPSC will require that additional processes and procedures be established. In addition, it is unknown what the CPSC would do if a firm failed to fully comply with these requirements.

Or, let's say the firm complies and then is charged again with late reporting. Will their new safety programs reduce the likelihood of penalties or reduce the amount of penalties? This is a concept that has already been adopted by the Department of Justice in connection with the Federal Sentencing Guidelines for Organizations. The establishment of a compliance program is taken into account when deciding whether to defer prosecution or the amount of penalties to seek.

SAFETY REQUIREMENTS IN OTHER AGREEMENTS

As signaled by then Commissioner Adler in his statement above, even if the CPSC decides not to seek civil penalties, it might ask companies to set up more robust programs. In September 2013, I received a letter from the CPSC saying that a decision not to proceed with a civil penalty would be conditional upon the firm agreeing to take a variety of corrective measures similar to those in the above settlement agreements.

I have heard from other lawyers that they have also seen such requests in letters of this type. However, one recent letter used the word "encourage" rather than "required" concerning such programs. And some of these letters make it clear that the manufacturer still has a duty to report new information, and that they can again be subject to civil penalties for late reporting or for failing to report.

SAFETY REQUIREMENTS IN CORRECTIVE ACTION PLANS

The last CPSC action concerning compliance programs is contained in a Notice of Proposed Rulemaking published in the November 21, 2013 *Federal Register*. This rule deals with voluntary recall notices, but also allows the CPSC to mandate compliance programs as part of corrective action plans (CAPs). The requirements for safety programs are the same as those in the civil penalty settlement agreements described above.

This proposed interpretative rule also provides that the corrective action, including an agreement to establish a safety program, is legally binding. Therefore, if this rule is approved, the CPSC would be able to legally enforce the compliance program if a company fails to comply.

It is unclear how the CPSC will be able to evaluate the procedures and controls of the manufacturer or product seller and determine whether they are insufficient or ineffectual. Who will do it? When will they have time to do it? What is the basis of their determination? Will the recall be postponed until this analysis is done?

The comment period for this Notice of Proposed Rulemaking ended in February 2014. As of this writing, we are waiting to see what the CPSC Commissioners and staff decide to do.

CONCLUSION

It is certainly possible for a company that has a robust safety program to fail to notify the CPSC of certain potentially reportable information because it does not believe that there is a product defect or substantial product hazard. Indeed, reasonable minds may differ in such matters. However, the open question is whether the CPSC is justified in imposing new procedures on a manufacturer that may already have sufficient safety programs in place. It will be interesting to see whether, going forward, companies that have good safety programs are able to keep these provisions out of future agreements, and whether such programs will enable them to escape all civil penalties or negotiate lower civil penalties.

In the meantime, product manufacturers should consider all of these requirements and evaluate their own programs. They should also consider the new ISO standard (ISO 10377) that sets forth some "best practices" in safety management, as well as other studies and reports on what is an effective product safety management program. (See articles in www.productliabilityprevention.com discussing the new ISO standard and other product safety management best practices.)

Most companies don't do a good enough job in monitoring product safety issues and incidents, especially when they are selling their products globally. Therefore, it would be prudent for every company to pull their safety program out of the file cabinet and review it with a fresh eye.

The responsible course of action is to be proactive about complying with these requirements before a safety problem arises. Dealing with such issues after the fact only increases the risk of their becoming a much bigger problem, both for your products and for your company.

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Failing Product Safety Testing in the 21st Century

BY STEVE WILLIAMS AND UWE MEYER

Product Safety

Even though safety is second nature to electrical product designers, testing laboratories still see their share of products failing safety testing. This is often due to circumstances that could have been prevented through simple yet effective safety measures. This article will provide a technical overview of areas of concern in regards to product design, testing and documentation.

OFF TO A GREAT START… OR IS IT?

After the product design is complete and the entire organization is in anticipation of a new, hot product hitting the market, there remains a question of product safety approval process. Naturally, the designers considered safety features so the laboratory can run the sample through and issue the certificate in time for the official product launch. In the ideal world, that is.

First, the laboratory might have other products in queue, so waiting till the product is complete before contacting a test lab is not a good idea. The equipment needed for testing might not be available right away. Second, even if technicians begin testing right away, it is possible that they find non-conformances that could delay the product from getting to market on time.

THE DEVIL IS IN THE DESIGN DETAILS

It is always a good idea to review basic safety requirements applicable to the product in the works. This reduces the chance of overlooking a minor technical detail that may turn into a costly mistake if the design team needs to make physical changes to the product during the safety approval process. While the safety standards will have many different features, the tricky ones are listed below.

Ground Is King

The laboratory will examine the ground path according to the applicable standard and look at such factors as the capacity of current-carrying parts in the ground path, reliability and prevention against accidental loosening. Remember to use the wire of the correct color. Ground is sacred in many standards as it will shunt the fault current away from a user in the event of a fault.

Watch Your Spacings

Spacings are the separations between circuits at different voltage levels and different circuits and user-accessible parts. The laboratory will check the creepage and clearance as required by the standard (refer to the Reference Guide to Terms and Basic Requirements at the end of the article).

Proper layout of the printed circuit board (PCB) is critical. Today, automated programs allow a PCB designer to input design rules. A good practice is to define all nodes on the schematic by the circuit type (primary, Safety Extra Low Voltage (SELV), ground, etc.) and then set design rules based on the standard used to evaluate the product. Designers must be careful on the tolerance. A well-designed PCB will often fail because the design allowed for under etching, which can cause a failure by as small a distance as one micron. A tight tolerance on the low dimension is recommended.

Regarding spacings, the other area to watch is next to the enclosure. Engineers need to ensure that component devices, such as a switch mode power supply, are mounted on standoffs tall enough to ensure proper clearance. They need to watch for sneak paths from the PCB in contact with a plastic enclosure through a seam. This is a valid creepage path and products often fail because many designers ignore the seam. The last thing an engineer wants to do is reduce a PCB size.

Enclosures Keep Fires In and Fingers Out

The enclosure prevents users from coming into contact with hazardous electrical or mechanical parts. It also prevents an internal product fire from spreading to the surrounding environment. That is why enclosures are evaluated for proper materials, openings and strength and suitability for the purpose. The openings in an enclosure must be examined for both accessibility and their ability to contain fire, and polymeric materials of construction must be of the type with a suitable flame retardancy rating.

There are a few major traps to watch out for. Plastic has flame ratings according to its thickness. If the enclosure for the product is thinner than the approved thickness for a flame rating, this presents a problem.
Also, plastics are approved in various colors. Make sure the color of the enclosure, as selected typically by the marketing department, is covered under the plastics' approvals.

Additionally, the lab will put the enclosure through a series of abuse tests to make sure it can withstand long-term usage. Engineers are well advised to review the standard against which the product will be evaluated for details on these mechanical tests.

The Fine Art of Specmanship

Specmanship is the practice of assigning ratings, not tolerances, to a product based on the worst-case tolerances of parts inside the end product. Following are a few examples.

- The power supply is rated 100-240VAC but its specs say 86 to 264V. Often, a manufacturer will rate the product 86-264V. For the heating test, this means the laboratory will test at 90% of 86V (77.4V) and 106% of 264 (280V) There will most likely be failures. Additionally, many components in the device are rated only 250V and, strictly speaking, cannot be used in a product rated as high a 264V.
- A component inside is good to a 5,000-meter altitude so the manufacturer rates the product as suitable for use at 5,000 meters. In the laboratory, the assumption is that the product is good to 2,000 meters. If the product is rated higher than 2,000 meters, the spacings values change dramatically, a consideration sometimes missed by designers.

Shopping for the Right Components

Designers must pay attention to safety-critical components. It is always better to choose pre-approved components. They will still need to be tested in the end product but the safety mark on them goes a long way. Custom made parts without approval could add weeks and extra cost to the safety approval process. The laboratory will have to evaluate the component and will need information that a designer may not have and a vendor may not want to provide. While a custom part allows engineers to add some great features, they need to check early in the design stage if its use will have an impact on the safety process.

Meters testing: **The lab staff are determining the energy levels available from a standard switch mode power supply with the goal of ensuring that the power available is limited to safe levels in accordance with the standard.**

AVOID THE TEST TRAPS

Below is a set of traps that manufacturers can fall into and end up with test failures.

- **Hipot:** Engineers need to check the trimming of through hole components on the power supply. They also must make sure the standoffs for the power supply are tall enough. It is a good idea to check any possible arc paths and be prepared to add insulators.
- **Leakage current caused by EMI fixes** (see hipot as well): Designers must be careful about adding too many capacitors to pass EMC tests. They are the reason they have a leakage current. A proper balance is always required.
- **Ground continuity:** There are two main traps. The first happens when carrying product ground through a PCB. If this is done, a 1000A test is conducted and most traces are not designed for this test. The other trap is painted metal surfaces. Designers need to either employ masking techniques or utilize paint biting washers for any screws.
- **Heating:** A lack of airflow is always the culprit in heating test failures. Ensuring there is enough airflow will keep the components from exceeding the allowable temperature limits.
- **Batteries:** Lithium batteries will need approval to IEC 62133. Even user-replaceable AA batteries will need this approval, so it pays off to select approved batteries.

NO REQUIREMENT IS TOO MINOR

One of the most common issues that delays any laboratory from completing a product safety review is the lack of labels and a manual. Documentation and labeling are an integral part of the safety standards but they are often overlooked, with the design getting all the attention. Typical labeling and manual requirements for generic electronic equipment are listed below.

Safety-related documentation accompanying an electric product must contain the following items:

- Technical specifications, instructions for use, name and address of the manufacturer or supplier for technical assistance and an explanation of warning symbols;
- Equipment ratings such as supply voltage, frequency, power, current and environmental conditions under which the equipment can operate;
- Equipment installation instructions, including those required for assembly, mounting, protective earthing, ventilation and similar actions;
- Equipment operation instructions, such as use of operating controls, interconnection to accessories, replacement of consumables and cleaning;
- Equipment maintenance instructions, including identification of a specific battery type, fuse types and parts that need to be supplied by the manufacturer or his agent.

The equipment must feature the following markings:

- Manufacturer's name, trademark and model number
- Equipment ratings (supply voltage, frequency, power/ current and IP)
- Fuse marking (current rating and type) according to IEC 60127 (e.g., 250 V F 2.0 A)
- Equipment protected throughout by double or reinforced insulation must be marked as such.
- Warning markings
- Safety instructions must be available in the language of the country of installation.
- Other markings, which may include:
  - Short duty cycles and mains voltage adjustment
  - Power outlets in the operator accessible area must be marked with the maximum load allowed, voltage and current
  - Fusing, if operator replaceable, must be marked with the rated current, voltage and characteristic. If it is in the service area, then a cross reference is acceptable: F1, F2, etc., with a replacement information in the service instructions; e.g., = 250V 3A. The following fuse characteristic markings should be used:
    - FF = very fast acting
    - F = fast acting (fast blow)
    - M = medium acting
    - TT = time lag
    - T = time lag (slow blow)

REFERENCE GUIDE TO TERMS AND BASIC REQUIREMENTS

This section contains the most commonly used terms and basic requirements for product safety as well as guidance to help designers implement them.

Hazardous Voltages

When it comes to hazardous voltages, follow these ranges: >30 V r.m.s. or >42.2 V peak or >60 V d.c., according to IEC 60950-1, and >33 V r.m.s. or >46.7 V peak or 70 V d.c. respectively, per IEC 61010-1.

Enclosure flame ratings

When selecting materials for enclosures, remember the following requirements:

- For movable equipment having a mass of < 18 kg, use 94V-1 or the test of clause A2;
- For movable equipment having a mass of > 18 kg and all stationary equipment, use 94-5V or the test of clause A1;
- For decorative parts outside the fire enclosure, 94-HB is acceptable.

Electric Shock Protection

Protection against electric shock relies on three measures: a connection to protective earth; double insulation between hazardous parts and the operator; and supply by SELV. However, this last measure is not defined in EN 61010-x.

Insulation Types

An electric device can incorporate one or more of the following five insulation types:

1. While insufficient for safe electrical separation, operational insulation is nevertheless needed for the correct operation of equipment and is applied between line and neutral

***Blender testing:* Even today, testing laboratories still see their share of electric products failing safety testing. Pictured is a simple test that often leads to failures as the lab staff are running the product through normal use and then check if they can access the moving blades with the test finger. Simple yet effective safety measures help ensure the product's compliance and timely release to market.**

and in SELV circuits. There is no thickness specified for operational insulation. Dielectric is dependent on the working voltage and spacings are the same as for basic insulation. Abnormal short circuits or dielectric testing is allowed to show compliance.

2. Applied between primary circuits and earthed parts, basic insulation supplies a basic level of insulation against shock. There is no thickness specified for basic insulation. Dielectric between primary and earth is 1500Vrms or 2121dc for compliance with EN 60950. Dielectric between primary and earth is 1350Vrms or 1900Vdc for compliance with EN 61010.
3. When combined with basic insulation, supplementary insulation creates a double insulation for protection against electric shock. Independent insulation is applied to basic insulation to ensure protection against electric shock if basic insulation fails. The specified thickness is 0.4 mm when it is combined with basic insulation. Transformers must have two thin layers where one layer passes dielectric for supplemental insulation, or three thin layers where any two pass the required dielectric.

   Supplementary insulation is applied between primary circuits and SELV. Dielectric is 1500Vrms or 2121Vdc for a working voltage of 250Vrms for compliance with EN60950. Dielectric is 1350Vrms or 1900Vdc for a working voltage of 300Vrms or dc for compliance with EN61010.
4. Double insulation is comprised of basic and supplementary insulation. Its main application is between primary hazardous voltage and SELV circuits. Dielectric for 250Vrms working voltage between primary and SELV is 1500Vrms (basic) + 1500Vrms (supp.) = 3000Vrms or 4242Vdc for compliance with EN60950. Dielectric for 300Vrms or dc working voltage between primary and SELV is 2300Vrms or 3250V dc for compliance with EN 61010.
5. Reinforced insulation is a single insulation that provides protection against electric shock equal to that of double insulation. It is usually a thin sheet material used in transformers and comprised of at least two layers, where either layer passes the dielectric for reinforced insulation. Its minimum thickness must be 0.4 mm and its main application is between hazardous voltage circuits and SELV circuits. Dielectric between primary hazardous voltages and SELV for a working voltage of 250Vrms is 3000Vrms or 4242Vdc. Dielectric for 300Vrms or dc working voltage between primary and SELV is 2300V rms or 3250 dc for compliance with EN61010.

Understanding the Insulation System

Keeping in mind that, for various types of insulation, designers need to build an insulation system in an electric device. Any insulation system must include the elements described below:

1. Creepage distance over solid insulation. It is the shortest distance between two conductive parts, measured through air.
2. Clearance through air. It is the shortest path between two conductive parts measured along the surface of the equipment.
3. Solid insulation material. There are no requirements for the thickness of material but it has to undergo a dielectric strength test.

Varying Electrical Protection Based on Equipment Class

The type of insulation used to protect a device will depend on its classification. Protection against electric shock in Class I equipment is achieved with both the basic insulation and a reliable earth connection to the metal parts that may assume hazardous voltage if the basic insulation fails.

To render Class II equipment safe, designers do not need to have a connection to the earth, but the unearthed metal parts are isolated by reinforced insulation from hazardous voltages. Class II equipment must be marked with symbol 5172 from IEC Publication 417, and the mark must be visible on the outside of the product in the operator accessible area.

Class III equipment is the type of equipment where protection against electric shock relies upon a supply from SELV circuits and in which hazardous voltages are not generated.

PLAYING IT SAFE

When it comes to safety of electric devices, it pays to spend extra time on shock and burn protection. Consideration of the technical factors discussed above will ensure a great degree of confidence in the outcome of the regulatory compliance process, and significantly increase the odds of the product passing the tests and getting to market on time and on budget.

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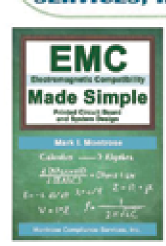

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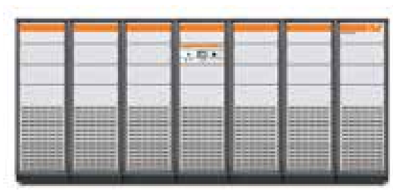

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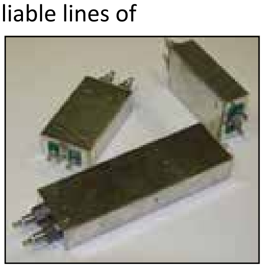

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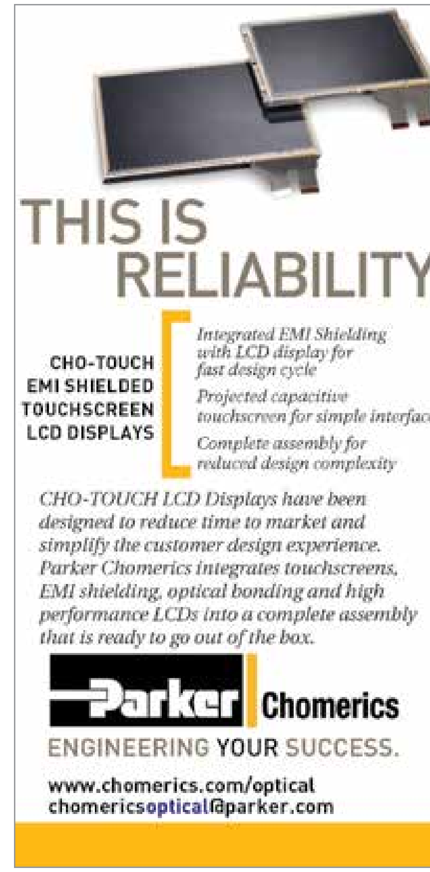

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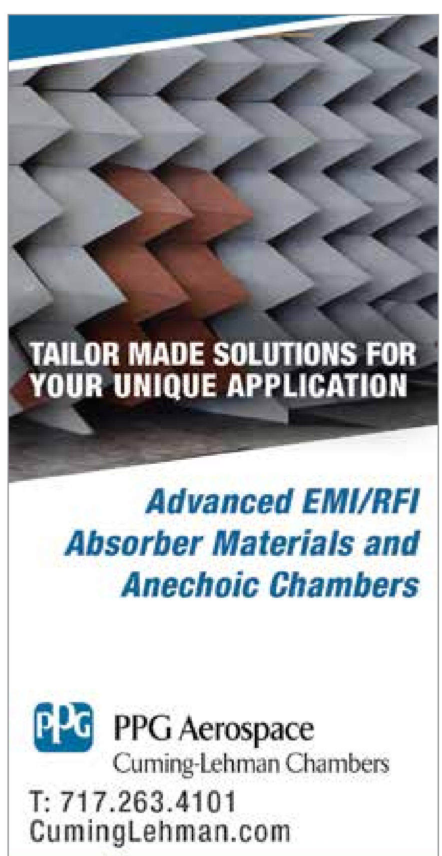

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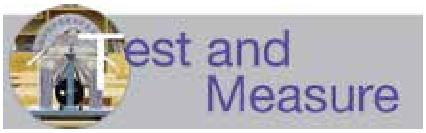
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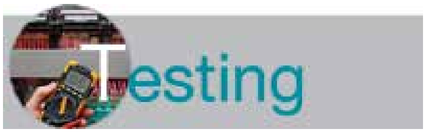
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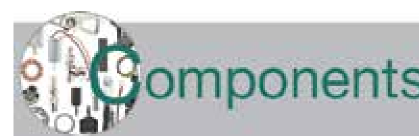

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A.H. Systems, Inc.

AR RF/Microwave Instrumentation

ARC Technical Resources, Inc.

Avalon Equipment Corporation Rentals

Electronic Instrument Associates

EM TEST United States of America

Excalibur Engineering Inc.

Fischer Custom Communications, Inc.

HAEFELY HIPOTRONICS

IFI

Keysight Technologies Inc.

Liberty Labs, Inc.

MILMEGA

NSI-MI Technologies

Calibration & Repair

(continued)

Pearson Electronics, Inc.
Ross Engineering Corp.
Sanwood Environmental Chambers Co., Ltd
Schwarzbeck Mess-Elektronik OHG
Solar Electronics Co.
TDK RF Solutions
TESEO SpA
Teseq Inc.
Trescal
VEROCH - Testing Equipment USA

Codes, Standards & Regulations

A2LA
American National Standards Institute
DG Technologies
Eisner Safety Consultants
Enerdoor
Go Global Compliance Inc.
Grund Technical Solutions, LLC
InfoSight Corporation
Laboratory Accreditation Bureau (L-A-B)
Phoenix Technical Group
RM Regulatory & Export Compliance, LLC
UL Knowledge Solutions

Consulting

Cleanroom / Static Control

Advanced ESD Services +
Bennett and Bennett
BestESD Technical Services
Bystat
OnFILTER
Protective Industrial Polymers

EMC Consulting

ACS - Atlanta, GA
André Consulting, Inc.
Atlas Compliance & Engineering
BestESD Technical Services
Cherry Clough Consultants Ltd
CKC Laboratories - Bothell, WA
CKC Laboratories - Brea, CA
CKC Laboratories - Fremont, CA
CKC Laboratories, Inc. - Mariposa, CA
Compliance & More Inc.
Compliance inSight Consulting Inc.
CSIA, LLC
D. C. Smith Consultants
D.L.S. Electronic Systems, Inc. - EMC Testing
D.L.S. Electronic Systems, Inc. - Military and Aerospace Testing
D.L.S. Electronic Systems, Inc. - Wireless Compliance Testing
Dayton T. Brown, Inc.
DG Technologies
DNB Engineering, Inc.
Don HEIRMAN Consultants
EMC Instrument & Solution
Enerdoor
ESDEMC Technology LLC
F2 Labs - Damascus, MD
F2 Labs - Middlefield, OH
G&M Compliance, Inc.
Go Global Compliance Inc.
Grund Technical Solutions, LLC
Henry Ott Consultants
Hoolihan EMC Consulting
International Certification Services, Inc.
Jastech EMC Consulting LLC
JDM LABS LLC
Kimmel Gerke Associates Ltd.
Kitagawa Industries America, Inc.
LS Research
Montrose Compliance Services
Northwest EMC, Inc. - Texas
Northwest EMC, Inc. - Oregon
NTS - Boxborough, MA
NTS - Fullerton, CA
NTS - Plano, TX
NTS - Rockford, IL
NTS - Silicon Valley Fremont & Newark, CA
NTS - Tinton Falls, NJ
OnFILTER
Panashield LLC
Remcom
RM Regulatory & Export Compliance, LLC
RTF Compliance
SIEMIC
SILENT Solutions LLC
Southwest Research Institute
Spectrum EMC Consulting, LLC
Test Site Services Inc.
TÜV Rheinland of North America - Newtown, CT
TÜV Rheinland of North America - Pleasanton, CA
TÜV Rheinland of North America - Santa Clara, CA
TÜV Rheinland of North America - Webster, NY
TÜV Rheinland of North America - Youngsville, NC
Wave Scientific Ltd
WEMS Electronics
Wyatt Technical Services LLC

ESD Consulting

BestESD Technical Services
CKC Laboratories - Bothell, WA
CKC Laboratories - Brea, CA
CKC Laboratories - Fremont, CA
Conductive Containers Inc.
ESDEMC Technology LLC
F2 Labs - Damascus, MD
F2 Labs - Middlefield, OH
OnFILTER
SILENT Solutions LLC

Government Regulations

BMSI (Korea) Regulatory Consulting

Atlas Compliance & Engineering
Compliance & More Inc.
D.L.S. Electronic Systems, Inc. - Wireless Compliance Testing
Go Global Compliance Inc.
NTS - Silicon Valley Fremont & Newark, CA
RM Regulatory & Export Compliance, LLC
RTF Compliance

EU (Europe) Regulatory Consulting

ACEMA
André Consulting, Inc.
Atlas Compliance & Engineering
CKC Laboratories - Fremont, CA
CKC Laboratories, Inc. - Mariposa, CA
Compliance & More Inc.
Compliance inSight Consulting Inc.
Compliance Worldwide, Inc.

D.L.S. Electronic Systems, Inc. - EMC Testing

D.L.S. Electronic Systems, Inc. - Environmental Testing

D.L.S. Electronic Systems, Inc. - Product Safety

Eisner Safety Consultants

F2 Labs - Damascus, MD

F2 Labs - Middlefield, OH

Go Global Compliance Inc.

International Certification Services, Inc.

Kimmel Gerke Associates Ltd.

Montrose Compliance Services

NTS - Rockford, IL

NTS - Silicon Valley Fremont & Newark, CA

RM Regulatory & Export Compliance, LLC

RTF Compliance

TÜV Rheinland of North America - Newtown, CT

TÜV Rheinland of North America - Pleasanton, CA

TÜV Rheinland of North America - Santa Clara, CA

TÜV Rheinland of North America - Webster, NY

TÜV Rheinland of North America - Youngsville, NC

Wyatt Technical Services LLC

FCC (U.S) Regulatory Consulting

André Consulting, Inc.

Atlas Compliance & Engineering

CKC Laboratories, Inc. - Mariposa, CA

Compliance & More Inc.

Compliance Worldwide, Inc.

D.L.S. Electronic Systems, Inc. - EMC Testing

D.L.S. Electronic Systems, Inc. - Wireless Compliance Testing

F2 Labs - Damascus, MD

F2 Labs - Middlefield, OH

Go Global Compliance Inc.

International Certification Services, Inc.

Kimmel Gerke Associates Ltd.

Montrose Compliance Services

NTS - Silicon Valley Fremont & Newark, CA

RM Regulatory & Export Compliance, LLC

RTF Compliance

TÜV Rheinland of North America - Newtown, CT

TÜV Rheinland of North America - Pleasanton, CA

TÜV Rheinland of North America - Santa Clara, CA

TÜV Rheinland of North America - Webster, NY

TÜV Rheinland of North America - Youngsville, NC

GOST (Russia) Regulatory Consulting

Compliance & More Inc.

Go Global Compliance Inc.

NTS - Fullerton, CA

NTS - Plano, TX

NTS - Silicon Valley Fremont & Newark, CA

RM Regulatory & Export Compliance, LLC

RTF Compliance

VCCI Consulting

Atlas Compliance & Engineering

CKC Laboratories, Inc. - Mariposa, CA

Compliance & More Inc.

D.L.S. Electronic Systems, Inc. - EMC Testing

RM Regulatory & Export Compliance, LLC

Lightning Protection

André Consulting, Inc.

D. C. Smith Consultants

D.L.S. Electronic Systems, Inc. - EMC Testing

D.L.S. Electronic Systems, Inc. - Military and Aerospace Testing

Dexmet Corporation

NexTek, Inc.

NTS - Boxborough, MA

NTS - Fullerton, CA

NTS - Pittsfield, MA

NTS - Plano, TX

NTS - Silicon Valley Fremont & Newark, CA

UL Knowledge Solutions

Medical Device

André Consulting, Inc.

CKC Laboratories - Bothell, WA

CKC Laboratories - Brea, CA

CKC Laboratories - Fremont, CA

D. C. Smith Consultants

D.L.S. Electronic Systems, Inc. - EMC Testing

D.L.S. Electronic Systems, Inc. - Product Safety

Darryl Ray EMC Consultants LLC

Eisner Safety Consultants

F2 Labs - Damascus, MD

F2 Labs - Middlefield, OH

G&M Compliance, Inc.

Kimmel Gerke Associates Ltd.

Montrose Compliance Services

NTS - Boxborough, MA

NTS - Fullerton, CA

NTS - Plano, TX

NTS - Silicon Valley Fremont & Newark, CA

O'Brien Compliance Management

Orbis Compliance LLC

Product Safety Consulting

Test Site Services Inc.

TÜV Rheinland of North America - Newtown, CT

TÜV Rheinland of North America - Pleasanton, CA

TÜV Rheinland of North America - Santa Clara, CA

TÜV Rheinland of North America - Webster, NY

TÜV Rheinland of North America - Youngsville, NC

TÜV SÜD America Inc. - Headquarters Peabody, MA

TÜV SÜD America - Alpharetta, GA

TÜV SÜD America - Auburn Hills, MI

TÜV SÜD America - Fremont, CA

TÜV SÜD America - Holland, MI

TÜV SÜD America - New Brighton, MN

TÜV SÜD America - Portland, OR

TÜV SÜD America - Plymouth, MI

TÜV SÜD America - Rancho Bernardo, CA

TÜV SÜD America - San Diego, CA

TÜV SÜD America - Tampa, FL

TÜV SÜD Canada - Gormley, ON

TÜV SÜD Canada - Newmarket, ON

UL Knowledge Solutions

Product Safety Consulting

ACS - Atlanta, GA

CASE Forensics

Compliance & More Inc.

Compliance inSight Consulting Inc.

CSIA, LLC

D.L.S. Electronic Systems, Inc. - Environmental Testing

D.L.S. Electronic Systems, Inc. - Product Safety

Eisner Safety Consultants

Evans Regulatory Certification Consulting

F2 Labs - Damascus, MD

F2 Labs - Middlefield, OH

G&M Compliance, Inc.

Go Global Compliance Inc.

InfoSight Corporation

Intertek

Kelmac Group

Lewis Bass International Engineering Services

Montrose Compliance Services

NTS - Boxborough, MA

NTS - Fullerton, CA

NTS - Plano, TX

NTS - Silicon Valley Fremont & Newark, CA

O'Brien Compliance Management

Orbis Compliance LLC

Product EHS Consulting LLC

Product Safety Consulting

RM Regulatory & Export Compliance, LLC

Test Site Services Inc.

TJS Technical Services Inc.

TÜV Rheinland of North America - Newtown, CT

TÜV Rheinland of North America - Pleasanton, CA

TÜV Rheinland of North America - Santa Clara, CA

TÜV Rheinland of North America - Webster, NY

TÜV Rheinland of North America - Youngsville, NC

TÜV SÜD America Inc. - Headquarters Peabody, MA

TÜV SÜD America - Alpharetta, GA

TÜV SÜD America - Auburn Hills, MI

TÜV SÜD America - Fremont, CA

TÜV SÜD America - Holland, MI

TÜV SÜD America - New Brighton, MN

TÜV SÜD America - Portland, OR

TÜV SÜD America - Plymouth, MI

TÜV SÜD America - Rancho Bernardo, CA

TÜV SÜD America - San Diego, CA

TÜV SÜD America - Tampa, FL

TÜV SÜD Canada - Gormley, ON

TÜV SÜD Canada - Newmarket, ON

UL Knowledge Solutions

VDE Americas

VEROCH - Testing Equipment USA

Quality

ACS - Marietta, GA

Eisner Safety Consultants

Globe Composite Solutions

InfoSight Corporation

RM Regulatory & Export Compliance, LLC

Spectrum EMC Consulting, LLC

TÜV SÜD America Inc. - Headquarters Peabody, MA

TÜV SÜD America - Alpharetta, GA

TÜV SÜD America - Auburn Hills, MI

TÜV SÜD America - Fremont, CA

TÜV SÜD America - Holland, MI

TÜV SÜD America - New Brighton, MN

TÜV SÜD America - Portland, OR

TÜV SÜD America - Plymouth, MI

TÜV SÜD America - Rancho Bernardo, CA

TÜV SÜD America - San Diego, CA

TÜV SÜD America - Tampa, FL

TÜV SÜD Canada - Gormley, ON

TÜV SÜD Canada - Newmarket, ON

UL Knowledge Solutions

Telecom

CKC Laboratories - Fremont, CA

CSIA, LLC

CV. DIMULTI

D. C. Smith Consultants

D.L.S. Electronic Systems, Inc. - Wireless Compliance Testing

F2 Labs - Middlefield, OH

FPX, LLC

Go Global Compliance Inc.

Nolato Silikonteknik AB

NTS - Boxborough, MA

NTS - Fullerton, CA

NTS - Plano, TX

NTS - Silicon Valley Fremont & Newark, CA

Orbis Compliance LLC

UL Knowledge Solutions

Tempest

D. C. Smith Consultants

Dayton T. Brown, Inc.

Kimmel Gerke Associates Ltd.

Transient

André Consulting, Inc.

BestESD Technical Services

F2 Labs - Middlefield, OH

Grund Technical Solutions, LLC

NexTek, Inc.

SILENT Solutions LLC

Design

André Consulting, Inc.

Conductive Containers Inc.

CST AG

CST of America

D. C. Smith Consultants

DG Technologies

EMS-PLUS

Globe Composite Solutions

Jastech EMC Consulting LLC

LS Research

Montrose Compliance Services

NTS - Baltimore, MD

NTS - Boxborough, MA

NTS - Chicago, IL
NTS - Detroit, MI
NTS - Europe
NTS - Fullerton, CA
NTS - Pittsfield, MA
NTS - Plano, TX
NTS - Rockford, IL
NTS - Santa Clarita, CA
NTS - Silicon Valley Fremont & Newark, CA
NTS - Tempe, AZ
SILENT Solutions LLC
UL Knowledge Solutions
VEROCH - Testing Equipment USA
Videon Central, Inc.
Washington Laboratories
WEMS Electronics
Wyatt Technical Services LLC

Other

Conductive Painting Services

Nolato Silikonteknik AB
VTI Vacuum Technologies, Inc.

Relocation Services

Sirco Machinery Company Ltd.

Shielded Enclosure Design

3Gmetalworx Inc.
Conductive Containers Inc.
Dexmet Corporation
Leader Tech Inc.
Magnetic Shield Corporation
Panashield LLC
Raymond EMC Enclosures Ltd.
VTI Vacuum Technologies, Inc.

Site Survey Services

Dayton T. Brown, Inc.
Electronic Instrument Associates
F2 Labs - Damascus, MD
F2 Labs - Middlefield, OH
Spectrum EMC Consulting, LLC
Wave Scientific Ltd

Rentals

See Test Equipment Rentals

Shielding

Architectural Shielding Products

ETS-Lindgren
Leader Tech Inc.
MAJR Products
Metal Textiles Corporation

Fingerstock

3Gmetalworx Inc.
Laird
Leader Tech Inc.
Metal Textiles Corporation
Parker Chomerics
Schlegel Electronic Materials
Tech-Etch

Shielded Air Filters

Alco Technologies, Inc.
Ja-Bar Silicone Corp
Leader Tech Inc.
MAJR Products
P &P Technology Ltd
Parker Chomerics
Spira Manufacturing Corporation
Tech-Etch

Shielded Cable Assemblies & Harnesses

Alco Technologies, Inc.
Leader Tech Inc.
Magnetic Shield Corporation
MAJR Products
York EMC Services Ltd.

Shielded Coatings

ARC Technologies, Inc.
Leader Tech Inc.
Parker Chomerics
Polyonics
VTI Vacuum Technologies, Inc.

Shielded Compounds

Ja-Bar Silicone Corp
Leader Tech Inc.
Parker Chomerics

Shielded Conduit

Electri-Flex Company
Leader Tech Inc.
Magnetic Shield Corporation

Shielded Connectors

Alco Technologies, Inc.
Gemini Electronic Components, Inc.
Isodyne Inc.
Leader Tech Inc.
Metal Textiles Corporation
METZ CONNECT USA
Spira Manufacturing Corporation
Tech-Etch

Shielded Enclosures

3Gmetalworx Inc.
Comply Tek, Inc.
Comtest Engineering Inc.
ETS-Lindgren
Leader Tech Inc.
Lionheart Northwest
Magnetic Shield Corporation
The MuShield Company Inc.
Panashield LLC
PPG Aerospace Cuming-Lehman Chambers

Shielded Enclosures

(continued)

Raymond EMC Enclosures Ltd.

Select Fabricators, Inc.
VTI Vacuum Technologies, Inc.

Shielded Tubing

Electri-Flex Company
Leader Tech Inc.
Magnetic Shield Corporation

Shielded Wire & Cable

Alco Technologies, Inc.
Dexmet Corporation
Isodyne Inc.
Leader Tech Inc.
Magnetic Shield Corporation
Metal Textiles Corporation
METZ CONNECT USA

Shielding Gaskets

3Gmetalworx Inc.
Alco Technologies, Inc.
Ja-Bar Silicone Corp
Kitagawa Industries America, Inc.
Laird
Leader Tech Inc.
MAJR Products
Metal Textiles Corporation
Nolato Silikonteknik AB
P &P Technology Ltd
Parker Chomerics
SAS Industries, Inc.
Schlegel Electronic Materials
Spira Manufacturing Corporation
Tech-Etch
VTI Vacuum Technologies, Inc.
W. L. Gore & Associates, Inc.

Shielding Materials

EMI / RFI Shielding Materials

Alco Technologies, Inc.
Bal Seal Engineering
Dexmet Corporation
Fabritech, Inc.
Fair-Rite Products Corp.
Isodyne Inc.
Ja-Bar Silicone Corp
Kitagawa Industries America, Inc.
Laird
Leader Tech Inc.
MAJR Products
Metal Textiles Corporation
P &P Technology Ltd
Panashield LLC
Polyonics
PPG Aerospace Cuming-Lehman Chambers
Schlegel Electronic Materials
Spira Manufacturing Corporation
Swift Textile Metalizing LLC
VTI Vacuum Technologies, Inc.
W. L. Gore & Associates, Inc.

Magnetic Field Shielding Materials

3Gmetalworx Inc.
Dexmet Corporation
Leader Tech Inc.
MAJR Products
The MuShield Company Inc.
PPG Aerospace Cuming-Lehman Chambers

Shielding, Board-Level

3Gmetalworx Inc.
Conductive Containers Inc.
Faspro Technologies
Laird
Leader Tech Inc.
MAJR Products

EMC Simulation Software

Altair Engineering Inc. - FEKO
ANSYS Inc.
CST AG
CST of America

Delcross Technologies
Electro Magnetic Applications, Inc. (EMA)
EMS-PLUS
Hilo-Test
LS Research
Moss Bay EDA
Remcom
Rohde & Schwarz, Inc.
TechDream, Inc.
TESEO SpA
Wave Computation Technologies, Inc.

ESD / Static Control Software

ACL Staticide Inc.
Desco Industries Inc.
Monroe Electronics

Lab Control Software

AR RF/Microwave Instrumentation
TESEO SpA

Product Safety Software

AR RF/Microwave Instrumentation
O'Brien Compliance Management
OnRule
Saf-T-Gard International, Inc.

Signal Integrity & EMC Analysis Software

AFJ INSTRUMENTS Srl
Altair Engineering Inc. - FEKO
CST AG
CST of America
Delcross Technologies
Remcom
Rohde & Schwarz, Inc.
TDK RF Solutions

Wireless Propagation Software

Altair Engineering Inc. - FEKO
Delcross Technologies
Remcom

Static Control

Air Ionizers

Simco-Ion

Clothing & Accessories

ESD Garments

TECH WEAR, Inc.

Footwear

Amstat Industries, Inc.
Lubrizol Engineered Polymers
Saf-T-Gard International, Inc.

Wrist Straps

Amstat Industries, Inc.
Lubrizol Engineered Polymers
Saf-T-Gard International, Inc.

Containers

Conductive Containers Inc.
Lubrizol Engineered Polymers

ESD Tape

Conductive Containers Inc.
Leader Tech Inc.
Polyonics

Flooring

Carpet

Ground Zero
Protective Industrial Polymers
StaticStop ESD Flooring

Floor Coatings

ACL Staticide Inc.
Arizona Polymer Flooring
Ground Zero
Protective Industrial Polymers

StaticStop ESD Flooring

Mats

StaticStop ESD Flooring

Tiles

Ground Zero
StaticStop ESD Flooring

Packaging

Conductive Containers Inc.
CST AG
CST of America
Lubrizol Engineered Polymers

Simulators

EMP Simulators

CST AG
CST of America
Fischer Custom Communications, Inc.
Grund Technical Solutions, LLC

ESD Simulators

Comply Tek, Inc.
CST AG
CST of America
EM TEST United States of America
ESDEMC Technology LLC
Hilo-Test
Kikusui America Inc.
TechDream, Inc.

Lightning Simulators

Comply Tek, Inc.
CST AG
CST of America
EM TEST United States of America

Transient Detectors & Suppressors

Fischer Custom Communications, Inc.
NexTek, Inc.

Workstations

ACL Staticide Inc.
Conductive Containers Inc.
HEMCO Corporation
Lubrizol Engineered Polymers

Test and Measure

Accelerometers

Clark Testing

Amplifiers

Amplifier Modules

AMETEK Compliance Test Solutions
AR RF/Microwave Instrumentation
Empower RF Systems
IFI
MILMEGA
OPHIR RF
Prana
TREK, Inc.

Low Power Amplifiers

A.H. Systems, Inc.
AMETEK Compliance Test Solutions
AR RF/Microwave Instrumentation
IFI
MILMEGA
TREK, Inc.

Microwave Amplifiers

AMETEK Compliance Test Solutions
Applied Systems Engineering, Inc.
AR RF/Microwave Instrumentation
Empower RF Systems
Giga-tronics Incorporated
HV TECHNOLOGIES, Inc.
IFI
MILMEGA
OPHIR RF
Prana
Wave Scientific Ltd

Power Amplifiers

AE Techron, Inc.
AMETEK Compliance Test Solutions
AR RF/Microwave Instrumentation
Associated Power Technologies
CPI, Inc.
Empower RF Systems
HV TECHNOLOGIES, Inc.
IFI
Laplace Instruments
Lionheart Northwest
MILMEGA
OPHIR RF
Prana
Rohde & Schwarz, Inc.
TechDream, Inc.
TESEO SpA
TREK, Inc.

RF Amplifiers

A.H. Systems, Inc.
AMETEK Compliance Test Solutions
AR RF/Microwave Instrumentation
Avalon Equipment Corporation Rentals
CPI, Inc.
Empower RF Systems

EMSource
Frankonia GmbH
HV TECHNOLOGIES, Inc.
IFI
Laplace Instruments
MILMEGA
OPHIR RF
Prana
Reliant EMC LLC
US Microwave Laboratories
Wave Scientific Ltd

Solid State Amplifiers

AMETEK Compliance Test Solutions
AR RF/Microwave Instrumentation
Comply Tek, Inc.
CPI, Inc.
Empower RF Systems
IFI
MILMEGA
OPHIR RF
Prana
TREK, Inc.

Traveling Wave Tube Amplifiers

AR RF/Microwave Instrumentation
Avalon Equipment Corporation Rentals
Comply Tek, Inc.
CPI, Inc.
Hilo-Test
IFI
OPHIR RF

Analyzers

EMI/EMC, Spectrum Analyzers

AFJ INSTRUMENTS Srl
Cobham (formerly Aeroflex)
Electro Rent Corporation
Electronic Instrument Associates
EMC Instrument & Solution
EMSource
Excalibur Engineering Inc.
Kaltman Creations LLC
Keysight Technologies Inc.
Laplace Instruments
Narda Safety Test Solutions GmbH
Reliant EMC LLC
Rigol Technologies
Rohde & Schwarz, Inc.
Signal Hound

Flicker Analyzers

EM TEST United States of America
HV TECHNOLOGIES, Inc.
Kikusui America Inc.
Lionheart Northwest
Teseq Inc.
York EMC Services Ltd.

Harmonics Analyzers

EM TEST United States of America
HV TECHNOLOGIES, Inc.
Kikusui America Inc.
Laplace Instruments
Teseq Inc.
York EMC Services Ltd.

Network Analyzers

AFJ INSTRUMENTS Srl
Cobham (formerly Aeroflex)
Electro Rent Corporation
Excalibur Engineering Inc.
Keysight Technologies Inc.
LS Research

Power Quality Analyzers

Electro Rent Corporation
Excalibur Engineering Inc.
Lionheart Northwest

Audio & Video

Audio Systems

Audivo GmbH
Videon Central, Inc.

CCTV

Audivo GmbH
TDK RF Solutions
TESEO SpA
Videon Central, Inc.

Automatic Test Sets

AFJ INSTRUMENTS Srl
ARC Technical Resources, Inc.
EM TEST United States of America
IFI
MILMEGA

Avionics Test Equipment

AE Techron, Inc.
AMETEK Compliance Test Solutions
Cobham (formerly Aeroflex)
EM TEST United States of America
HV TECHNOLOGIES, Inc.
IFI
MILMEGA
Pickering Interfaces

Burn-in Test Equipment

OPHIR RF
Sanwood Environmental Chambers Co., Ltd

Data Acquisition Monitoring Systems

Degree Controls, Inc.
DG Technologies
NSI-MI Technologies

Fiber-Optic Systems

DG Technologies
Excalibur Engineering Inc.
HV TECHNOLOGIES, Inc.
Michigan Scientific Corp.
MITEQ Inc.
Ross Engineering Corp.
TESEO SpA

Flow Meters

Advanced Test Equipment Rentals
VEROCH - Testing Equipment USA

Generators

Arbitrary Waveform Generators

AE Techron, Inc.
AMETEK Compliance Test Solutions
Applied Physical Electronics, L.C. (APELC)
EM TEST United States of America
Hilo-Test
Keysight Technologies Inc.
Teseq Inc.
York EMC Services Ltd.

EMP Generator

EMSource
HV TECHNOLOGIES, Inc.

ESD Generators

AMETEK Compliance Test Solutions
ARC Technical Resources, Inc.
EM TEST United States of America
EMSource
Grund Technical Solutions, LLC
HAEFELY HIPOTRONICS
HV TECHNOLOGIES, Inc.
Reliant EMC LLC
Teseq Inc.

Fast/Transient Burst Generators

AE Techron, Inc.
AMETEK Compliance Test Solutions
ARC Technical Resources, Inc.
Comply Tek, Inc.
EMSource
HAEFELY HIPOTRONICS
Hilo-Test
HV TECHNOLOGIES, Inc.
Reliant EMC LLC
Teseq Inc.

Impulse Generators

AFJ INSTRUMENTS Srl
AMETEK Compliance Test Solutions
Applied EM Technology
Applied Physical Electronics, L.C. (APELC)
EM TEST United States of America
EMSource
Grund Technical Solutions, LLC
HAEFELY HIPOTRONICS
Hilo-Test
HV TECHNOLOGIES, Inc.
Solar Electronics Co.
Teseq Inc.

Interference Generators

AMETEK Compliance Test Solutions
EM TEST United States of America
IFI
MILMEGA
Teseq Inc.

Lightning Generators

ARC Technical Resources, Inc.
Avalon Equipment Corporation Rentals
EM TEST United States of America
HAEFELY HIPOTRONICS
HV TECHNOLOGIES, Inc.
Solar Electronics Co.

Signal Generators

AFJ INSTRUMENTS Srl
Applied EM Technology
Cobham (formerly Aeroflex)
Electro Rent Corporation
Excalibur Engineering Inc.
Frankonia GmbH

Generators

Signal Generators

(continued)

Giga-tronics Incorporated
Keysight Technologies Inc.
Kikusui America Inc.
Laplace Instruments
Reliant EMC LLC
Teseq Inc.
York EMC Services Ltd.

Surge Transient Generators

ARC Technical Resources, Inc.
Avalon Equipment Corporation Rentals
EM TEST United States of America
HAEFELY HIPOTRONICS
Hilo-Test
HV TECHNOLOGIES, Inc.
Solar Electronics Co.
TechDream, Inc.
Teseq Inc.
Thermo Fisher Scientific

Meters

Field Strength Meters

AR RF/Microwave Instrumentation
Monroe Electronics
Narda STS, USA
TREK, Inc.

Gaussmeters

PCE Instruments

Magnetic Field Meters

AR RF/Microwave Instrumentation

Megohmmeters

ACL Staticide Inc.
Amstat Industries, Inc.
Chroma Systems Solutions, Inc.
Monroe Electronics
Ross Engineering Corp.

Radiation Hazard Meters

AR RF/Microwave Instrumentation
EMC Test Design, LLC

RF Power Meters

AR RF/Microwave Instrumentation
Cobham (formerly Aeroflex)
Electro Rent Corporation
Frankonia GmbH
Giga-tronics Incorporated
Keysight Technologies Inc.
OPHIR RF

Static Charge Meters

ACL Staticide Inc.
Monroe Electronics
TREK, Inc.

Static Decay Meters

Monroe Electronics
TREK, Inc.

Monitors

Current Monitors

Grund Technical Solutions, LLC
Pearson Electronics, Inc.

EMI Test Monitors

DG Technologies
OnFILTER

ESD Monitors

Monroe Electronics

Ionizer Balance Monitors

Monroe Electronics
TREK, Inc.

Static Voltage Monitors

Michigan Scientific Corp.
TREK, Inc.

Oscilloscopes & Transient Recorders

Avalon Equipment Corporation Rentals
Electro Rent Corporation
Keysight Technologies Inc.
Lionheart Northwest
Rohde & Schwarz, Inc.
Teledyne LeCroy

Probes

Current / Magnetic Field Probes

A.H. Systems, Inc.
AR RF/Microwave Instrumentation
Fischer Custom Communications, Inc.
Pearson Electronics, Inc.
Prana
Solar Electronics Co.

Electric Field Probes

AR RF/Microwave Instrumentation
EMC Test Design, LLC
Enerdoor
Narda STS, USA
TREK, Inc.

Voltage Probes

EM TEST United States of America
Fischer Custom Communications, Inc.
Hilo-Test
Laplace Instruments
OnFILTER
Ross Engineering Corp.
Solar Electronics Co.

Receivers

EMI / EMC Receivers

AFJ INSTRUMENTS Srl
AR RF/Microwave Instrumentation
Comply Tek, Inc.
EMSource
Excalibur Engineering Inc.
GAUSS INSTRUMENTS GmbH
HV TECHNOLOGIES, Inc.
Keysight Technologies Inc.
Laplace Instruments
MITEQ Inc.
Reliant EMC LLC
Rohde & Schwarz, Inc.
Schwarzbeck Mess-Elektronik OHG
TechDream, Inc.

RF Receivers

AFJ INSTRUMENTS Srl
Narda STS, USA
NSI-MI Technologies

RF Leak Detectors

AR RF/Microwave Instrumentation

Safety Test Equipment

Advanced Test Equipment Rentals
AEMC Instruments
AR RF/Microwave Instrumentation
Chroma Systems Solutions, Inc.
E. D. & D., Inc.
EMC Test Design, LLC
HAEFELY HIPOTRONICS
Kikusui America Inc.
MPB measuring instruments
O'Brien Compliance Management
Product Safety Consulting
Sanwood Environmental Chambers Co., Ltd
VEROCH - Testing Equipment USA

SAR Testing Equipment

ART-MAN

Shock & Vibration Testing Shakers

Globe Composite Solutions
Sanwood Environmental Chambers Co., Ltd
Thermotron

Susceptibility Test Instruments

AMETEK Compliance Test Solutions
ARC Technical Resources, Inc.
DG Technologies
EM TEST United States of America
EMC Test Design, LLC
ESDEMC Technology LLC
Grund Technical Solutions, LLC
IFI
Laplace Instruments
MILMEGA
OPHIR RF
TDK RF Solutions

TechDream, Inc.
Teseq Inc.

Telecom Test Equipment

Advanced Test Equipment Rentals
AE Techron, Inc.
AMETEK Compliance Test Solutions
Avalon Equipment Corporation Rentals
Cobham (formerly Aeroflex)
CSIA, LLC
Electro Rent Corporation
EM TEST United States of America
EMSCAN
Fischer Custom Communications, Inc.
HAEFELY HIPOTRONICS
IFI
MILMEGA
Pickering Interfaces
TechDream, Inc.

Test Equipment Rentals

Advanced Test Equipment Rentals
AMETEK Compliance Test Solutions
AR RF/Microwave Instrumentation
Avalon Equipment Corporation Rentals
Barth Electronics, Inc.
CSZ Testing
Electro Rent Corporation
EM TEST United States of America
ESDEMC Technology LLC
Excalibur Engineering Inc.
Grund Technical Solutions, LLC
IFI
Lionheart Northwest
Michigan Scientific Corp.
MILMEGA
TechDream, Inc.
TestWorld Inc.
Transient Specialists, Inc.
VEROCH - Testing Equipment USA

Testers

Current Leakage Testers

Associated Research, Inc.
Barth Electronics, Inc.
Chroma Systems Solutions, Inc.
ESDEMC Technology LLC
Kikusui America Inc.
Ross Engineering Corp.
Slaughter Company, Inc.

Dielectric Strength Testers

Associated Research, Inc.
Chroma Systems Solutions, Inc.
EM TEST United States of America
Slaughter Company, Inc.

Electrical Safety Testers

Associated Research, Inc.
Chroma Systems Solutions, Inc.
Kikusui America Inc.
O'Brien Compliance Management
Saf-T-Gard International, Inc.
Slaughter Company, Inc.

EMC Testers

AE Techron, Inc.
AMETEK Compliance Test Solutions
Detectus AB
DG Technologies
EM TEST United States of America
EMC PARTNER AG
EMC Test Design, LLC
EMSCAN
EMSource
ESDEMC Technology LLC
Grund Technical Solutions, LLC
HAEFELY HIPOTRONICS
IFI

Testers

EMC Testers

(continued)

Langer EMV-Technik GmbH
MILMEGA
OPHIR RF
Rohde & Schwarz, Inc.
Teseq Inc.

Ground Bond Testers

Associated Research, Inc.
Chroma Systems Solutions, Inc.
Slaughter Company, Inc.

Ground Resistance Testers

Associated Research, Inc.
Atlas Foundation Company
Slaughter Company, Inc.

Hipot Testers

Applied Physical Electronics, L.C. (APELC)
Associated Research, Inc.
Chroma Systems Solutions, Inc.
Electro Rent Corporation
Kikusui America Inc.
Ross Engineering Corp.
Slaughter Company, Inc.

Thermocouples

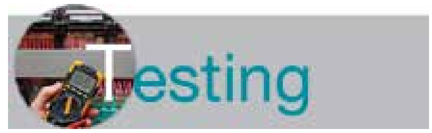
Applied Physical Electronics, L.C. (APELC)
VEROCH - Testing Equipment USA

Used & Refurbished Test Equipment

AR RF/Microwave Instrumentation
Avalon Equipment Corporation Rentals
Electro Rent Corporation

Vibration Controllers

Excalibur Engineering Inc.
Globe Composite Solutions
Thermotron



Accredited Registrar

CKC Laboratories - Bothell, WA
CKC Laboratories - Brea, CA
Excalibur Engineering Inc.
Green Mountain Electromagnetics, Inc.
Laboratory Accreditation Bureau (L-A-B)
LS Research
Northwest EMC, Inc. - California
Northwest EMC, Inc. - Minnesota
Northwest EMC, Inc. - Oregon
Northwest EMC, Inc. - Texas
Northwest EMC Inc.- Washington
QAI Laboratories
TÜV SÜD America Inc. - Headquarters Peabody, MA
TÜV SÜD America - Alpharetta, GA
TÜV SÜD America - Auburn Hills, MI
TÜV SÜD America - Fremont, CA
TÜV SÜD America - Holland, MI
TÜV SÜD America - New Brighton, MN
TÜV SÜD America - Portland, OR
TÜV SÜD America - Plymouth, MI
TÜV SÜD America - Rancho Bernardo, CA
TÜV SÜD America - San Diego, CA
TÜV SÜD America - Tampa, FL
TÜV SÜD Canada - Gormley, ON
TÜV SÜD Canada - Newmarket, ON

CE Competent Body

CKC Laboratories - Bothell, WA
CKC Laboratories - Brea, CA
CKC Laboratories - Fremont, CA
D.L.S. Electronic Systems, Inc. - EMC Testing
D.L.S. Electronic Systems, Inc. - Environmental Testing
Elite Electronic Engineering
QAI Laboratories
UL - Consumer Technology - Fremont Center of Excellence
UL - India
UL - Italy
UL - Japan Inc. (Yokawa EMC Laboratory)
UL - Japan, Inc. (Ise Head Office)
UL - Japan, Inc. (Shonan EMC Laboratory)
UL - Japan, Inc. (Yamakita)
UL - Korea Ltd.
UL - New Zealand
UL - Novi, MI
UL - Research Triangle Park, NC
UL - UK (Ashwood Park)
UL - UK (Kingsland Park)
UL LLC
Washington Laboratories

CE Notified Body

American Certification Body
CKC Laboratories - Bothell, WA
CKC Laboratories - Brea, CA
CKC Laboratories - Fremont, CA
CKC Laboratories, Inc. - Mariposa, CA
Clark Testing
Compatible Electronics, Inc.
CSIA, LLC
Elite Electronic Engineering
Northwest EMC, Inc. - California
Northwest EMC, Inc. - Minnesota
Northwest EMC, Inc. - Oregon
Northwest EMC, Inc. - Texas
Northwest EMC Inc.- Washington
QAI Laboratories
SIEMIC
TESEO SpA
Test Site Services Inc.
TÜV Rheinland of North America - Newtown, CT
TÜV Rheinland of North America - Pleasanton, CA
TÜV Rheinland of North America - Santa Clara, CA
TÜV Rheinland of North America - Webster, NY
TÜV Rheinland of North America - Youngsville, NC
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TÜV SÜD America - Portland, OR
TÜV SÜD America - Plymouth, MI
TÜV SÜD America - Rancho Bernardo, CA

TÜV SÜD America - San Diego, CA
TÜV SÜD America - Tampa, FL
TÜV SÜD Canada - Gormley, ON
TÜV SÜD Canada - Newmarket, ON
UL - Consumer Technology - Fremont Center of Excellence
UL - Italy
UL - Japan Inc. (Yokawa EMC Laboratory)
UL - UK (Ashwood Park)
Washington Laboratories

Environmental Testing & Analysis Services

ACS - Melbourne, FL
Boeing Technology Services
Cascade TEK
CSZ Testing
D.L.S. Electronic Systems, Inc. - Environmental Testing
D.L.S. Electronic Systems, Inc. - Military and Aerospace Testing
Dayton T. Brown, Inc.
DNB Engineering, Inc.
Elite Electronic Engineering
NTS - Boxborough, MA
NTS - Fullerton, CA
NTS - Orlando, FL
NTS - Plano, TX
Professional Testing (EMI), Inc.
QAI Laboratories
Retlif Testing Laboratories
Sanwood Environmental Chambers Co., Ltd
Test Site Services Inc.
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TÜV SÜD America - New Brighton, MN
TÜV SÜD America - Portland, OR
TÜV SÜD America - Plymouth, MI
TÜV SÜD America - Rancho Bernardo, CA
TÜV SÜD America - San Diego, CA
TÜV SÜD America - Tampa, FL
TÜV SÜD Canada - Gormley, ON
TÜV SÜD Canada - Newmarket, ON
UL - Consumer Technology - Fremont Center of Excellence
UL - India
UL - Italy
UL - Japan Inc. (Yokawa EMC Laboratory)
UL - Japan, Inc. (Ise Head Office)
UL - Japan, Inc. (Shonan EMC Laboratory)
UL - Japan, Inc. (Yamakita)
UL - Korea Ltd.
UL - New Zealand
UL - Novi, MI
UL - Research Triangle Park, NC
UL - UK (Ashwood Park)
UL - UK (Kingsland Park)
UL LLC
Washington Laboratories

Homologation Services

CSIA, LLC
Go Global Compliance Inc.
Jacobs Technology
Lewis Bass International Engineering Services
MET Laboratories, Inc.
Northwest EMC, Inc. - California
Northwest EMC, Inc. - Minnesota
Northwest EMC, Inc. - Oregon
Northwest EMC, Inc. - Texas
Northwest EMC Inc.- Washington
Orbis Compliance LLC
TÜV SÜD America Inc. - Headquarters Peabody, MA
TÜV SÜD America - Alpharetta, GA
TÜV SÜD America - Auburn Hills, MI
TÜV SÜD America - Fremont, CA
TÜV SÜD America - Holland, MI
TÜV SÜD America - New Brighton, MN
TÜV SÜD America - Portland, OR
TÜV SÜD America - Plymouth, MI
TÜV SÜD America - Rancho Bernardo, CA
TÜV SÜD America - San Diego, CA
TÜV SÜD America - Tampa, FL
TÜV SÜD Canada - Gormley, ON
TÜV SÜD Canada - Newmarket, ON
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UL - Italy
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UL - Japan, Inc. (Ise Head Office)
UL - Japan, Inc. (Shonan EMC Laboratory)
UL - Japan, Inc. (Yamakita)
UL - Korea Ltd.
UL - New Zealand
UL - Novi, MI
UL - Research Triangle Park, NC
UL - UK (Ashwood Park)
UL - UK (Kingsland Park)
UL LLC

Pre-Assessments

A2LA
ACS - Boca Raton, FL
ACS - Marietta, GA
ACS - Melbourne, FL
ACS - RTP, NC
CertifiGroup Inc.
Clark Testing
Compatible Electronics, Inc.
D.L.S. Electronic Systems, Inc. - Product Safety
Eisner Safety Consultants
Elite Electronic Engineering
F2 Labs - Damascus, MD
F2 Labs - Middlefield, OH
International Certification Services, Inc.
Jastech EMC Consulting LLC
Laboratory Accreditation Bureau (L-A-B)
Lewis Bass International Engineering Services
Product Safety Consulting
SILENT Solutions LLC
Spectrum EMC Consulting, LLC
UL - Consumer Technology - Fremont Center of Excellence
UL - India
UL - Italy
UL - Japan Inc. (Yokawa EMC Laboratory)
UL - Japan, Inc. (Ise Head Office)
UL - Japan, Inc. (Shonan EMC Laboratory)
UL - Japan, Inc. (Yamakita)
UL - Korea Ltd.
UL - New Zealand
UL - Novi, MI
UL - Research Triangle Park, NC
UL - UK (Ashwood Park)
UL - UK (Kingsland Park)
UL LLC
Wyatt Technical Services LLC

Product & Component Testing Services

ACS - Atlanta, GA
ACS - Boca Raton, FL
ACS - Marietta, GA
ACS - Melbourne, FL
ACS - RTP, NC
ART-MAN
Cascade TEK
CKC Laboratories - Bothell, WA
Compliance Testing, LLC
Dayton T. Brown, Inc.
Diversified T.E.S.T. Technologies, Inc.
DNB Engineering, Inc.
Elite Electronic Engineering
F2 Labs - Damascus, MD
F2 Labs - Middlefield, OH
Green Mountain Electromagnetics, Inc.
International Certification Services, Inc.
NTS - Anaheim, CA
NTS - Baltimore, MD
NTS - Boxborough, MA
NTS - Chicago, IL
NTS - Fullerton, CA
NTS - Huntsville, AL Nuclear
NTS - Longmont, CO
NTS - Orlando, FL
NTS - Plano, TX
NTS - Silicon Valley Fremont & Newark, CA
Product Safety Consulting
Retlif Testing Laboratories
RM Regulatory & Export Compliance, LLC
Sanwood Environmental Chambers Co., Ltd
SIEMIC
Southwest Research Institute
TÜV SÜD America Inc. - Headquarters Peabody, MA
TÜV SÜD America - Alpharetta, GA
TÜV SÜD America - Auburn Hills, MI
TÜV SÜD America - Fremont, CA
TÜV SÜD America - Holland, MI
TÜV SÜD America - New Brighton, MN
TÜV SÜD America - Portland, OR
TÜV SÜD America - Plymouth, MI
TÜV SÜD America - Rancho Bernardo, CA
TÜV SÜD America - San Diego, CA
TÜV SÜD America - Tampa, FL
TÜV SÜD Canada - Gormley, ON
TÜV SÜD Canada - Newmarket, ON
UL - Consumer Technology - Fremont Center of Excellence
UL - India
UL - Italy
UL - Japan Inc. (Yokawa EMC Laboratory)
UL - Japan, Inc. (Ise Head Office)
UL - Japan, Inc. (Shonan EMC Laboratory)
UL - Japan, Inc. (Yamakita)
UL - Korea Ltd.
UL - New Zealand
UL - Novi, MI
UL - Research Triangle Park, NC
UL - UK (Ashwood Park)
UL - UK (Kingsland Park)
UL LLC

Testing Laboratories

Accelerated Stress Testing

ACS - Marietta, GA
Boeing Technology Services
Cascade TEK
Core Compliance Testing Services
CSZ Testing
D.L.S. Electronic Systems, Inc. - Environmental Testing
Dayton T. Brown, Inc.
Elite Electronic Engineering
F2 Labs - Damascus, MD
Intertek
NTS - Baltimore, MD
NTS - Boxborough, MA
NTS - Chicago, IL
NTS - Fullerton, CA
NTS - Orlando, FL
NTS - Plano, TX
NTS - Santa Clarita, CA
NTS - Tempe, AZ
NTS - Tinton Falls, NJ
Product Safety Consulting
Professional Testing (EMI), Inc.
Radiometrics Midwest Corporation
TÜV SÜD America Inc. - Headquarters Peabody, MA
TÜV SÜD America - Alpharetta, GA
TÜV SÜD America - Auburn Hills, MI
TÜV SÜD America - Fremont, CA
TÜV SÜD America - Holland, MI
TÜV SÜD America - New Brighton, MN
TÜV SÜD America - Portland, OR
TÜV SÜD America - Plymouth, MI
TÜV SÜD America - Rancho Bernardo, CA
TÜV SÜD America - San Diego, CA
TÜV SÜD America - Tampa, FL
TÜV SÜD Canada - Gormley, ON
TÜV SÜD Canada - Newmarket, ON
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UL - India
UL - Italy
UL - Japan Inc. (Yokawa EMC Laboratory)
UL - Japan, Inc. (Ise Head Office)
UL - Japan, Inc. (Shonan EMC Laboratory)
UL - Japan, Inc. (Yamakita)
UL - Korea Ltd.
UL - New Zealand
UL - Novi, MI
UL - Research Triangle Park, NC
UL - UK (Ashwood Park)
UL - UK (Kingsland Park)
UL LLC
Videon Central, Inc.

Acoustical Testing

ACS - Atlanta, GA
Boeing Technology Services
Clark Testing
Core Compliance Testing Services
D.L.S. Electronic Systems, Inc. - Product Safety
Dayton T. Brown, Inc.
DNB Engineering, Inc.
Electronic Instrument Associates
Intertek
NTS - Baltimore, MD
NTS - Boxborough, MA
NTS - Chicago, IL
NTS - Europe
NTS - Fullerton, CA
NTS - Plano, TX
NTS - Rockford, IL
NTS - Santa Clarita, CA
NTS - Silicon Valley Fremont & Newark, CA
NTS - Tinton Falls, NJ
Retlif Testing Laboratories
UL - Consumer Technology - Fremont Center of Excellence

BSMI Compliant Certification Testing

ACS - Atlanta, GA
Atlas Compliance & Engineering
CKC Laboratories - Brea, CA
CKC Laboratories - Fremont, CA
Compliance Worldwide, Inc.
Core Compliance Testing Services
D.L.S. Electronic Systems, Inc. - Wireless Compliance Testing
Elite Electronic Engineering
Northwest EMC, Inc. - California
Northwest EMC, Inc. - Minnesota
Northwest EMC, Inc. - Oregon
Northwest EMC, Inc. - Texas
Northwest EMC Inc.- Washington
NTS - Baltimore, MD
NTS - Boxborough, MA
NTS - Chicago, IL
NTS - Fullerton, CA
NTS - Plano, TX
NTS - Silicon Valley Fremont & Newark, CA
TestingPartners.com
UL - Consumer Technology - Fremont Center of Excellence
UL - India
UL - Italy
UL - Japan Inc. (Yokawa EMC Laboratory)
UL - Japan, Inc. (Ise Head Office)
UL - Japan, Inc. (Shonan EMC Laboratory)
UL - Japan, Inc. (Yamakita)
UL - Korea Ltd.
UL - New Zealand
UL - Novi, MI
UL - Research Triangle Park, NC
UL - UK (Ashwood Park)
UL - UK (Kingsland Park)
UL LLC

CB Test Report

ACS - Atlanta, GA
D.L.S. Electronic Systems, Inc. - Product Safety
Elite Electronic Engineering
Energy Assurance LLC
Intertek
NTS - Baltimore, MD
NTS - Chicago, IL
NTS - Longmont, CO
Professional Testing (EMI), Inc.
TÜV Rheinland of North America - Newtown, CT
TÜV Rheinland of North America - Pleasanton, CA
TÜV Rheinland of North America - Santa Clara, CA
TÜV Rheinland of North America - Webster, NY
TÜV Rheinland of North America - Youngsville, NC
TÜV SÜD America Inc. - Headquarters Peabody, MA
TÜV SÜD America - Alpharetta, GA
TÜV SÜD America - Auburn Hills, MI
TÜV SÜD America - Fremont, CA
TÜV SÜD America - Holland, MI
TÜV SÜD America - New Brighton, MN
TÜV SÜD America - Portland, OR
TÜV SÜD America - Plymouth, MI
TÜV SÜD America - Rancho Bernardo, CA
TÜV SÜD America - San Diego, CA
TÜV SÜD America - Tampa, FL
TÜV SÜD Canada - Gormley, ON
TÜV SÜD Canada - Newmarket, ON
UL - Consumer Technology - Fremont Center of Excellence
UL - India
UL - Italy
UL - Japan Inc. (Yokawa EMC Laboratory)
UL - Japan, Inc. (Ise Head Office)
UL - Japan, Inc. (Shonan EMC Laboratory)
UL - Japan, Inc. (Yamakita)
UL - Korea Ltd.
UL - New Zealand
UL - Novi, MI
UL - Research Triangle Park, NC
UL - UK (Ashwood Park)
UL - UK (Kingsland Park)
UL LLC

CE Marking

Abstraction Engineering Inc.
ACS - Atlanta, GA
ACS - Melbourne, FL
ACS - RTP, NC
Atlas Compliance & Engineering
CertifiGroup Inc.
CKC Laboratories - Bothell, WA
CKC Laboratories - Brea, CA
CKC Laboratories - Fremont, CA
CKC Laboratories, Inc. - Mariposa, CA
Compatible Electronics, Inc.
Compliance Worldwide, Inc.
Core Compliance Testing Services
D.L.S. Electronic Systems, Inc. - EMC Testing
D.L.S. Electronic Systems, Inc. - Environmental Testing
D.L.S. Electronic Systems, Inc. - Product Safety
D.L.S. Electronic Systems, Inc. - Wireless Compliance Testing
DNB Engineering, Inc.
Elite Electronic Engineering
Energy Assurance LLC
F2 Labs - Damascus, MD
F2 Labs - Middlefield, OH
G&M Compliance, Inc.
Global Testing Laboratories
Green Mountain Electromagnetics, Inc.
H.B. Compliance Solutions
International Certification Services, Inc.
Intertek
Lewis Bass International Engineering Services
Northwest EMC, Inc. - Minnesota
Northwest EMC, Inc. - Texas
Northwest EMC, Inc. - California
Northwest EMC, Inc. - Oregon
NTS - Baltimore, MD
NTS - Boxborough, MA
NTS - Chicago, IL
NTS - Fullerton, CA
NTS - Plano, TX
NTS - Rockford, IL
NTS - Silicon Valley Fremont & Newark, CA
NTS - Tinton Falls, NJ
Professional Testing (EMI), Inc.
Retlif Testing Laboratories
TESEO SpA
Test Site Services Inc.
TestingPartners.com
TÜV Rheinland of North America - Newtown, CT
TÜV Rheinland of North America - Pleasanton, CA
TÜV Rheinland of North America - Santa Clara, CA
TÜV Rheinland of North America - Webster, NY

Testing Laboratories

CE Marking

(continued)

TÜV Rheinland of North America - Youngsville, NC
TÜV SÜD America Inc. - Headquarters Peabody, MA
TÜV SÜD America - Alpharetta, GA
TÜV SÜD America - Auburn Hills, MI
TÜV SÜD America - Fremont, CA
TÜV SÜD America - Holland, MI
TÜV SÜD America - New Brighton, MN
TÜV SÜD America - Portland, OR
TÜV SÜD America - Plymouth, MI
TÜV SÜD America - Rancho Bernardo, CA
TÜV SÜD America - San Diego, CA
TÜV SÜD America - Tampa, FL
TÜV SÜD Canada - Gormley, ON
TÜV SÜD Canada - Newmarket, ON
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UL - India
UL - Italy
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UL - Japan, Inc. (Ise Head Office)
UL - Japan, Inc. (Shonan EMC Laboratory)
UL - Japan, Inc. (Yamakita)
UL - Korea Ltd.
UL - New Zealand
UL - Novi, MI
UL - Research Triangle Park, NC
UL - UK (Ashwood Park)
UL - UK (Kingsland Park)
UL LLC
Walshire Labs, LLC

China Compulsory Certification

ACS - Atlanta, GA
CSIA, LLC
D.L.S. Electronic Systems, Inc. - EMC Testing
D.L.S. Electronic Systems, Inc. - Product Safety
G&M Compliance, Inc.
Northwest EMC, Inc. - California
Northwest EMC, Inc. - Minnesota
Northwest EMC, Inc. - Oregon
Northwest EMC, Inc. - Texas
Northwest EMC Inc.- Washington
NTS - Baltimore, MD
NTS - Chicago, IL
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TÜV Rheinland of North America - Pleasanton, CA
TÜV Rheinland of North America - Santa Clara, CA
TÜV Rheinland of North America - Webster, NY
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TÜV SÜD America - San Diego, CA
TÜV SÜD America - Tampa, FL
TÜV SÜD Canada - Gormley, ON
TÜV SÜD Canada - Newmarket, ON

Electrical Safety Testing

Abstraction Engineering Inc.
ACS - Atlanta, GA
ACS - Melbourne, FL
Boeing Technology Services
CertifiGroup Inc.
CKC Laboratories - Fremont, CA
Coilcraft Critical Products & Services
D.L.S. Electronic Systems, Inc. - Product Safety
Dayton T. Brown, Inc.
DNB Engineering, Inc.
Elite Electronic Engineering
Energy Assurance LLC
F2 Labs - Damascus, MD
F2 Labs - Middlefield, OH
G&M Compliance, Inc.
Green Mountain Electromagnetics, Inc.
H.B. Compliance Solutions
Intertek
NTS - Anaheim, CA
NTS - Baltimore, MD
NTS - Chicago, IL
Orbis Compliance LLC
Professional Testing (EMI), Inc.
TestingPartners.com
TÜV Rheinland of North America - Newtown, CT
TÜV Rheinland of North America - Pleasanton, CA
TÜV Rheinland of North America - Santa Clara, CA
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TÜV SÜD America - Rancho Bernardo, CA
TÜV SÜD America - San Diego, CA
TÜV SÜD America - Tampa, FL
TÜV SÜD Canada - Gormley, ON
TÜV SÜD Canada - Newmarket, ON
UL LLC

EMC Testing

Abstraction Engineering Inc.
ACS - Atlanta, GA
ACS - Boca Raton, FL
ACS - Marietta, GA
ACS - Melbourne, FL
ACS - RTP, NC
AHD
APREL Inc.
AR RF/Microwave Instrumentation
ART-MAN
Atlas Compliance & Engineering
Boeing Technology Services
CKC Laboratories - Bothell, WA
CKC Laboratories - Brea, CA
CKC Laboratories - Fremont, CA
CKC Laboratories, Inc. - Mariposa, CA
Clark Testing
Compatible Electronics, Inc.
Compliance Worldwide, Inc.

Core Compliance Testing Services

CSIA, LLC

D.L.S. Electronic Systems, Inc. - EMC Testing

D.L.S. Electronic Systems, Inc. - Military and Aerospace Testing

D.L.S. Electronic Systems, Inc. - Wireless Compliance Testing

Dayton T. Brown, Inc.

DNB Engineering, Inc.

Electronics Test Centre

EMC Testing Laboratory Inc.

F2 Labs - Damascus, MD

F2 Labs - Middlefield, OH

G&M Compliance, Inc.

Global EMC Inc.

Green Mountain Electromagnetics, Inc.

H.B. Compliance Solutions

International Certification Services, Inc.

Intertek

Jacobs Technology

Jastech EMC Consulting LLC

LS Research

MET Laboratories, Inc.

National Institute for Aviation Research

Northwest EMC, Inc. - California

Northwest EMC, Inc. - Minnesota

Northwest EMC, Inc. - Oregon

Northwest EMC, Inc. - Texas

Northwest EMC Inc.- Washington

NTS - Baltimore, MD

NTS - Boxborough, MA

NTS - Chicago, IL

NTS - Europe

NTS - Fullerton, CA

NTS - Longmont, CO

NTS - Orlando, FL

NTS - Plano, TX

NTS - Rockford, IL

NTS - Silicon Valley Fremont & Newark, CA

NTS - Tempe, AZ

NTS - Tinton Falls, NJ

Parker Chomerics

Professional Testing (EMI), Inc.

Radiometrics Midwest Corporation

Retlif Testing Laboratories

SIEMIC

Southwest Research Institute

Spes Development Co

Test Site Services Inc.

TestingPartners.com

Timco Engineering, Inc.

TÜV Rheinland of North America - Newtown, CT

TÜV Rheinland of North America - Pleasanton, CA

TÜV Rheinland of North America - Santa Clara, CA

TÜV Rheinland of North America - Webster, NY

TÜV Rheinland of North America - Youngsville, NC

TÜV SÜD America Inc. - Headquarters Peabody, MA

TÜV SÜD America - Alpharetta, GA

TÜV SÜD America - Auburn Hills, MI

TÜV SÜD America - Fremont, CA

TÜV SÜD America - Holland, MI

TÜV SÜD America - New Brighton, MN

TÜV SÜD America - Portland, OR

TÜV SÜD America - Plymouth, MI

TÜV SÜD America - Rancho Bernardo, CA

TÜV SÜD America - San Diego, CA

TÜV SÜD America - Tampa, FL

TÜV SÜD Canada - Gormley, ON

TÜV SÜD Canada - Newmarket, ON

UL - Consumer Technology - Fremont Center of Excellence

UL - India

UL - Italy

UL - Japan Inc. (Yokawa EMC Laboratory)

UL - Japan, Inc. (Ise Head Office)

UL - Japan, Inc. (Shonan EMC Laboratory)

UL - Japan, Inc. (Yamakita)

UL - Korea Ltd.

UL - New Zealand

UL - Novi, MI

UL - Research Triangle Park, NC

UL - UK (Ashwood Park)

UL - UK (Kingsland Park)

UL LLC

Washington Laboratories

WEMS Electronics

Wyatt Technical Services LLC

Yazaki Testing Laboratory

Energy Efficiency Testing

ACS - Atlanta, GA

ACS - Marietta, GA

Boeing Technology Services

Energy Assurance LLC

MET Laboratories, Inc.

NTS - Baltimore, MD

NTS - Boxborough, MA

NTS - Chicago, IL

NTS - Fullerton, CA

NTS - Plano, TX

NTS - Silicon Valley Fremont & Newark, CA

Testing Laboratories

Energy Efficiency Testing

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TÜV Rheinland of North America - Newtown, CT

TÜV Rheinland of North America - Pleasanton, CA

TÜV Rheinland of North America - Santa Clara, CA

TÜV Rheinland of North America - Webster, NY

TÜV Rheinland of North America - Youngsville, NC

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TÜV SÜD America - Auburn Hills, MI

TÜV SÜD America - Fremont, CA

TÜV SÜD America - Holland, MI

TÜV SÜD America - New Brighton, MN

TÜV SÜD America - Portland, OR

TÜV SÜD America - Plymouth, MI

TÜV SÜD America - Rancho Bernardo, CA

TÜV SÜD America - San Diego, CA

TÜV SÜD America - Tampa, FL

TÜV SÜD Canada - Gormley, ON

TÜV SÜD Canada - Newmarket, ON

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UL - Japan, Inc. (Shonan EMC Laboratory)

UL - Japan, Inc. (Yamakita)

UL - Korea Ltd.

UL - New Zealand

UL - Novi, MI

UL - Research Triangle Park, NC

UL - UK (Ashwood Park)

UL - UK (Kingsland Park)

UL LLC

Environmental Simulation Testing

ACS - Marietta, GA

ACS - Melbourne, FL

Boeing Technology Services

Cascade TEK

CertifiGroup Inc.

Coilcraft Critical Products & Services

Core Compliance Testing Services

CSZ Testing

D.L.S. Electronic Systems, Inc. - Environmental Testing

D.L.S. Electronic Systems, Inc. - Military and Aerospace Testing

Dayton T. Brown, Inc.

DNB Engineering, Inc.

Energy Assurance LLC

H.B. Compliance Solutions

MET Laboratories, Inc.

NTS - Anaheim, CA

NTS - Baltimore, MD

NTS - Boxborough, MA

NTS - Chicago, IL

NTS - Detroit, MI

NTS - Europe

NTS - Fullerton, CA

NTS - Huntsville, AL Nuclear

NTS - Orlando, FL

NTS - Pittsfield, MA

NTS - Plano, TX

NTS - Rockford, IL

NTS - Santa Clarita, CA

NTS - Tempe, AZ

NTS - Tinton Falls, NJ

Professional Testing (EMI), Inc.

Retlif Testing Laboratories

Sanwood Environmental Chambers Co., Ltd

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TÜV SÜD America - Auburn Hills, MI

TÜV SÜD America - Fremont, CA

TÜV SÜD America - Holland, MI

TÜV SÜD America - New Brighton, MN

TÜV SÜD America - Portland, OR

TÜV SÜD America - Plymouth, MI

TÜV SÜD America - Rancho Bernardo, CA

TÜV SÜD America - San Diego, CA

TÜV SÜD America - Tampa, FL

TÜV SÜD Canada - Gormley, ON

TÜV SÜD Canada - Newmarket, ON

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UL - Japan, Inc. (Shonan EMC Laboratory)

UL - Japan, Inc. (Yamakita)

UL - Korea Ltd.

UL - New Zealand

UL - Novi, MI

UL - Research Triangle Park, NC

UL - UK (Ashwood Park)

UL - UK (Kingsland Park)

UL LLC

ESD Testing

ACS - Atlanta, GA

ACS - Melbourne, FL

CKC Laboratories - Bothell, WA

CKC Laboratories - Brea, CA

CKC Laboratories - Fremont, CA

Compliance Worldwide, Inc.

DNB Engineering, Inc.

ESDEMC Technology LLC

F2 Labs - Damascus, MD

F2 Labs - Middlefield, OH

H.B. Compliance Solutions

Northwest EMC, Inc. - California

Northwest EMC, Inc. - Minnesota

Northwest EMC, Inc. - Oregon

Northwest EMC, Inc. - Texas

Northwest EMC Inc.- Washington

NTS - Baltimore, MD

NTS - Chicago, IL

EuP Directive Compliance

NTS - Baltimore, MD

NTS - Chicago, IL

GOST R Certification

ACS - Atlanta, GA

G&M Compliance, Inc.

Northwest EMC, Inc. - California

Northwest EMC, Inc. - Minnesota

Northwest EMC, Inc. - Oregon

Northwest EMC, Inc. - Texas

Northwest EMC Inc.- Washington

NTS - Baltimore, MD

NTS - Chicago, IL

NTS - Silicon Valley Fremont & Newark, CA

TestingPartners.com

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TÜV SÜD America - Holland, MI

TÜV SÜD America - New Brighton, MN

TÜV SÜD America - Portland, OR

TÜV SÜD America - Plymouth, MI

TÜV SÜD America - Rancho Bernardo, CA

TÜV SÜD America - San Diego, CA

TÜV SÜD America - Tampa, FL

TÜV SÜD Canada - Gormley, ON

TÜV SÜD Canada - Newmarket, ON

UL - Consumer Technology - Fremont Center of Excellence

UL - India

UL - Italy

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UL - Japan, Inc. (Ise Head Office)

UL - Japan, Inc. (Shonan EMC Laboratory)

UL - Japan, Inc. (Yamakita)

UL - Korea Ltd.

UL - New Zealand

UL - Novi, MI

UL - Research Triangle Park, NC

UL - UK (Ashwood Park)

UL LLC

Green Energy Compliance

CertifiGroup Inc.

NTS - Baltimore, MD

NTS - Chicago, IL

TÜV Rheinland of North America - Newtown, CT

TÜV Rheinland of North America - Pleasanton, CA

TÜV Rheinland of North America - Santa Clara, CA

TÜV Rheinland of North America - Webster, NY

TÜV Rheinland of North America - Youngsville, NC

UL - Consumer Technology - Fremont Center of Excellence

UL - India

UL - Italy

UL - Japan Inc. (Yokawa EMC Laboratory)

UL - Japan, Inc. (Ise Head Office)

UL - Japan, Inc. (Shonan EMC Laboratory)

UL - Japan, Inc. (Yamakita)

UL - Korea Ltd.

UL - New Zealand

UL - Novi, MI

UL - Research Triangle Park, NC

UL - UK (Ashwood Park)

UL - UK (Kingsland Park)

UL LLC

GS Mark Certification

ACS - Atlanta, GA

NTS - Baltimore, MD

NTS - Chicago, IL

TÜV Rheinland of North America - Newtown, CT

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TÜV Rheinland of North America - Webster, NY

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TÜV SÜD America - Fremont, CA

TÜV SÜD America - Holland, MI

TÜV SÜD America - New Brighton, MN

TÜV SÜD America - Portland, OR

TÜV SÜD America - Plymouth, MI

TÜV SÜD America - Rancho Bernardo, CA

TÜV SÜD America - San Diego, CA

TÜV SÜD America - Tampa, FL

TÜV SÜD Canada - Gormley, ON

TÜV SÜD Canada - Newmarket, ON

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UL - India

UL - Italy

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UL - Japan, Inc. (Ise Head Office)

UL - Japan, Inc. (Shonan EMC Laboratory)

UL - Japan, Inc. (Yamakita)

UL - Korea Ltd.

UL - New Zealand

UL - Novi, MI

UL - Research Triangle Park, NC

UL - UK (Ashwood Park)

UL - UK (Kingsland Park)

UL LLC

Halogen Testing

NTS - Baltimore, MD

NTS - Chicago, IL

UL - UK (Kingsland Park)

Lithium-Ion Battery Testing

Boeing Technology Services

Cascade TEK

CSZ Testing

Energy Assurance LLC

MET Laboratories, Inc.

NTS - Baltimore, MD

NTS - Boxborough, MA

NTS - Chicago, IL

NTS - Detroit, MI

NTS - Fullerton, CA

NTS - Plano, TX

NTS - Santa Clarita, CA

TÜV SÜD America Inc. - Headquarters Peabody, MA

TÜV SÜD America - Alpharetta, GA

TÜV SÜD America - Auburn Hills, MI

TÜV SÜD America - Fremont, CA

TÜV SÜD America - Holland, MI

TÜV SÜD America - New Brighton, MN

TÜV SÜD America - Portland, OR

TÜV SÜD America - Plymouth, MI

TÜV SÜD America - Rancho Bernardo, CA

TÜV SÜD America - San Diego, CA

TÜV SÜD America - Tampa, FL

Testing Laboratories

Lithium-Ion Battery Testing (continued)

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TÜV SÜD Canada - Newmarket, ON
UL - Consumer Technology - Fremont Center of Excellence
UL - India
UL - Italy
UL - Japan Inc. (Yokawa EMC Laboratory)
UL - Japan, Inc. (Ise Head Office)
UL - Japan, Inc. (Shonan EMC Laboratory)
UL - Japan, Inc. (Yamakita)
UL - Korea Ltd.
UL - New Zealand
UL - Novi, MI
UL - Research Triangle Park, NC
UL - UK (Ashwood Park)
UL - UK (Kingsland Park)
UL LLC

Marine Electronics Testing

ACS - Atlanta, GA
ACS - Boca Raton, FL
ACS - Melbourne, FL
ACS - RTP, NC
Cascade TEK
CertifiGroup Inc.
Core Compliance Testing Services
D.L.S. Electronic Systems, Inc. - Military and Aerospace Testing
D.L.S. Electronic Systems, Inc. - Wireless Compliance Testing
Green Mountain Electromagnetics, Inc.
NTS - Baltimore, MD
NTS - Boxborough, MA
NTS - Chicago, IL
NTS - Fullerton, CA
NTS - Plano, TX
NTS - Silicon Valley Fremont & Newark, CA
Retlif Testing Laboratories
UL - Research Triangle Park, NC

Nationally Recognized Testing Laboratory (NRTL)

CertifiGroup Inc.
MET Laboratories, Inc.
NTS - Baltimore, MD
NTS - Chicago, IL
Product Safety Consulting
TÜV Rheinland of North America - Newtown, CT
TÜV Rheinland of North America - Pleasanton, CA
TÜV Rheinland of North America - Santa Clara, CA
TÜV Rheinland of North America - Webster, NY
TÜV Rheinland of North America - Youngsville, NC
TÜV SÜD America Inc. - Headquarters Peabody, MA
TÜV SÜD America - Alpharetta, GA
TÜV SÜD America - Auburn Hills, MI
TÜV SÜD America - Fremont, CA
TÜV SÜD America - Holland, MI
TÜV SÜD America - New Brighton, MN
TÜV SÜD America - Portland, OR
TÜV SÜD America - Plymouth, MI
TÜV SÜD America - Rancho Bernardo, CA
TÜV SÜD America - San Diego, CA
TÜV SÜD America - Tampa, FL
TÜV SÜD Canada - Gormley, ON
TÜV SÜD Canada - Newmarket, ON
UL - Consumer Technology - Fremont Center of Excellence
UL - India
UL - Italy
UL - Japan Inc. (Yokawa EMC Laboratory)
UL - Japan, Inc. (Ise Head Office)
UL - Japan, Inc. (Shonan EMC Laboratory)
UL - Japan, Inc. (Yamakita)
UL - Korea Ltd.
UL - New Zealand
UL - Novi, MI
UL - Research Triangle Park, NC
UL - UK (Ashwood Park)
UL - UK (Kingsland Park)
UL LLC

Network Equipment Building System (NEBS) Testing

International Certification Services, Inc.
NTS - Baltimore, MD
NTS - Boxborough, MA
NTS - Chicago, IL
NTS - Europe
NTS - Fullerton, CA
NTS - Plano, TX
NTS - Silicon Valley Fremont & Newark, CA
NTS - Tinton Falls, NJ
UL - Consumer Technology - Fremont Center of Excellence
UL - Research Triangle Park, NC

Product Pre-Compliance Testing

ACS - Atlanta, GA
ACS - Boca Raton, FL
ACS - Marietta, GA
ACS - Melbourne, FL
ACS - RTP, NC
ART-MAN
Atlas Compliance & Engineering
Cascade TEK
CASE Forensics
CertifiGroup Inc.
Coilcraft Critical Products & Services

Compatible Electronics, Inc.
Compliance Worldwide, Inc.
Core Compliance Testing Services
D.L.S. Electronic Systems, Inc. - EMC Testing
D.L.S. Electronic Systems, Inc. - Environmental Testing
D.L.S. Electronic Systems, Inc. - Product Safety
D.L.S. Electronic Systems, Inc. - Wireless Compliance Testing
Energy Assurance LLC
F2 Labs - Damascus, MD

F2 Labs - Middlefield, OH
G&M Compliance, Inc.
Green Mountain Electromagnetics, Inc.
H.B. Compliance Solutions
International Certification Services, Inc.
Lewis Bass International Engineering Services
Northwest EMC, Inc. - California
Northwest EMC, Inc. - Minnesota
Northwest EMC, Inc. - Oregon
Northwest EMC, Inc. - Texas
Northwest EMC Inc.- Washington
NTS - Baltimore, MD
NTS - Boxborough, MA
NTS - Chicago, IL
NTS - Detroit, MI
NTS - Europe
NTS - Fullerton, CA
NTS - Huntsville, AL Nuclear
NTS - Longmont, CO
NTS - Pittsfield, MA
NTS - Plano, TX
NTS - Rockford, IL
NTS - Santa Clarita, CA
NTS - Silicon Valley Fremont & Newark, CA
NTS - Tempe, AZ
NTS - Tinton Falls, NJ
O'Brien Compliance Management
Product Safety Consulting
Professional Testing (EMI), Inc.
Test Site Services Inc.
TestingPartners.com
TÜV Rheinland of North America - Newtown, CT
TÜV Rheinland of North America - Pleasanton, CA
TÜV Rheinland of North America - Santa Clara, CA
TÜV Rheinland of North America - Webster, NY
TÜV Rheinland of North America - Youngsville, NC
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UL - Japan, Inc. (Ise Head Office)
UL - Japan, Inc. (Shonan EMC Laboratory)
UL - Japan, Inc. (Yamakita)
UL - Korea Ltd.
UL - New Zealand
UL - Novi, MI
UL - Research Triangle Park, NC
UL - UK (Ashwood Park)
UL - UK (Kingsland Park)
UL LLC
Washington Laboratories
Wyatt Technical Services LLC

Product Safety Testing

Abstraction Engineering Inc.
ACS - Atlanta, GA
ACS - Marietta, GA
ACS - Melbourne, FL
Bharat Test House
Boeing Technology Services
Cascade TEK
CASE Forensics
CertifiGroup Inc.
Coilcraft Critical Products & Services
Compatible Electronics, Inc.
Core Compliance Testing Services
CSA Group
D.L.S. Electronic Systems, Inc. - Product Safety
Energy Assurance LLC
F2 Labs - Damascus, MD
F2 Labs - Middlefield, OH
G&M Compliance, Inc.
Green Mountain Electromagnetics, Inc.
Lewis Bass International Engineering Services
MET Laboratories, Inc.
NTS - Anaheim, CA
NTS - Baltimore, MD
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NTS - Silicon Valley Fremont & Newark, CA
NTS - Tinton Falls, NJ
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TÜV SÜD Canada - Newmarket, ON
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UL - Japan, Inc. (Shonan EMC Laboratory)
UL - Japan, Inc. (Yamakita)
UL - Korea Ltd.
UL - New Zealand
UL - Novi, MI
UL - Research Triangle Park, NC
UL - UK (Ashwood Park)
UL - UK (Kingsland Park)
UL LLC
Washington Laboratories

Radio Performance & Functionality Testing

ACS - Atlanta, GA
ACS - Boca Raton, FL
ACS - Melbourne, FL
ACS - RTP, NC
Applied Physical Electronics, L.C. (APELC)
D.L.S. Electronic Systems, Inc. - Wireless Compliance Testing
H.B. Compliance Solutions
Northwest EMC, Inc. - California
NTS - Baltimore, MD
NTS - Chicago, IL
Orbis Compliance LLC
Radiometrics Midwest Corporation

Testing Laboratories

Radio Performance & Functionality Testing

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UL - Italy

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UL - Japan, Inc. (Shonan EMC Laboratory)

UL - Japan, Inc. (Yamakita)

UL - Korea Ltd.

UL - New Zealand

UL - Novi, MI

UL - Research Triangle Park, NC

UL - UK (Ashwood Park)

UL - UK (Kingsland Park)

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Washington Laboratories

RoHS Directive Compliance

D.L.S. Electronic Systems, Inc. - Product Safety

NTS - Anaheim, CA

NTS - Baltimore, MD

NTS - Chicago, IL

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TÜV Rheinland of North America - Webster, NY

TÜV Rheinland of North America - Youngsville, NC

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TÜV SÜD America - Tampa, FL

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UL - Korea Ltd.

UL - New Zealand

UL - Novi, MI

UL - Research Triangle Park, NC

UL - UK (Ashwood Park)

UL - UK (Kingsland Park)

Shock & Vibration

ACS - Marietta, GA

ACS - Melbourne, FL

Boeing Technology Services

Cascade TEK

Clark Testing

Coilcraft Critical Products & Services

CSZ Testing

D.L.S. Electronic Systems, Inc. - Environmental Testing

DNB Engineering, Inc.

Energy Assurance LLC

Fiarex Testing Laboratory Inc.

MET Laboratories, Inc.

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NTS - Boxborough, MA

NTS - Chicago, IL

NTS - Detroit, MI

NTS - Europe

NTS - Fullerton, CA

NTS - Huntsville, AL Nuclear

NTS - Orlando, FL

NTS - Plano, TX

NTS - Santa Clarita, CA

NTS - Tinton Falls, NJ

Professional Testing (EMI), Inc.

Retlif Testing Laboratories

Sanwood Environmental Chambers Co., Ltd

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TÜV SÜD America - Holland, MI

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TÜV SÜD America - Tampa, FL

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TÜV SÜD Canada - Newmarket, ON

UL - Research Triangle Park, NC

UL LLC

WEMS Electronics

Standards Council of Canada Certification Body

ACS - Atlanta, GA

CertifiGroup Inc.

NTS - Baltimore, MD

NTS - Chicago, IL

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TÜV SÜD America - Tampa, FL

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UL - Japan, Inc. (Shonan EMC Laboratory)

UL - Japan, Inc. (Yamakita)

UL - Korea Ltd.

UL - New Zealand

UL - Novi, MI

UL - Research Triangle Park, NC

UL - UK (Ashwood Park)

UL - UK (Kingsland Park)

UL LLC

Telecommunications Testing

Cascade TEK

CKC Laboratories - Fremont, CA

CKC Laboratories, Inc. - Mariposa, CA

Clark Testing

Compliance Worldwide, Inc.

CSIA, LLC

CSZ Testing

D.L.S. Electronic Systems, Inc. - Wireless Compliance Testing

F2 Labs - Damascus, MD

F2 Labs - Middlefield, OH

Green Mountain Electromagnetics, Inc.

H.B. Compliance Solutions

MET Laboratories, Inc.

NetSPI

NTS - Baltimore, MD

NTS - Chicago, IL

NTS - Huntsville, AL Nuclear

Orbis Compliance LLC

Retlif Testing Laboratories

SIEMIC

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TÜV SÜD America - Plymouth, MI

TÜV SÜD America - Rancho Bernardo, CA

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TÜV SÜD America - Tampa, FL

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