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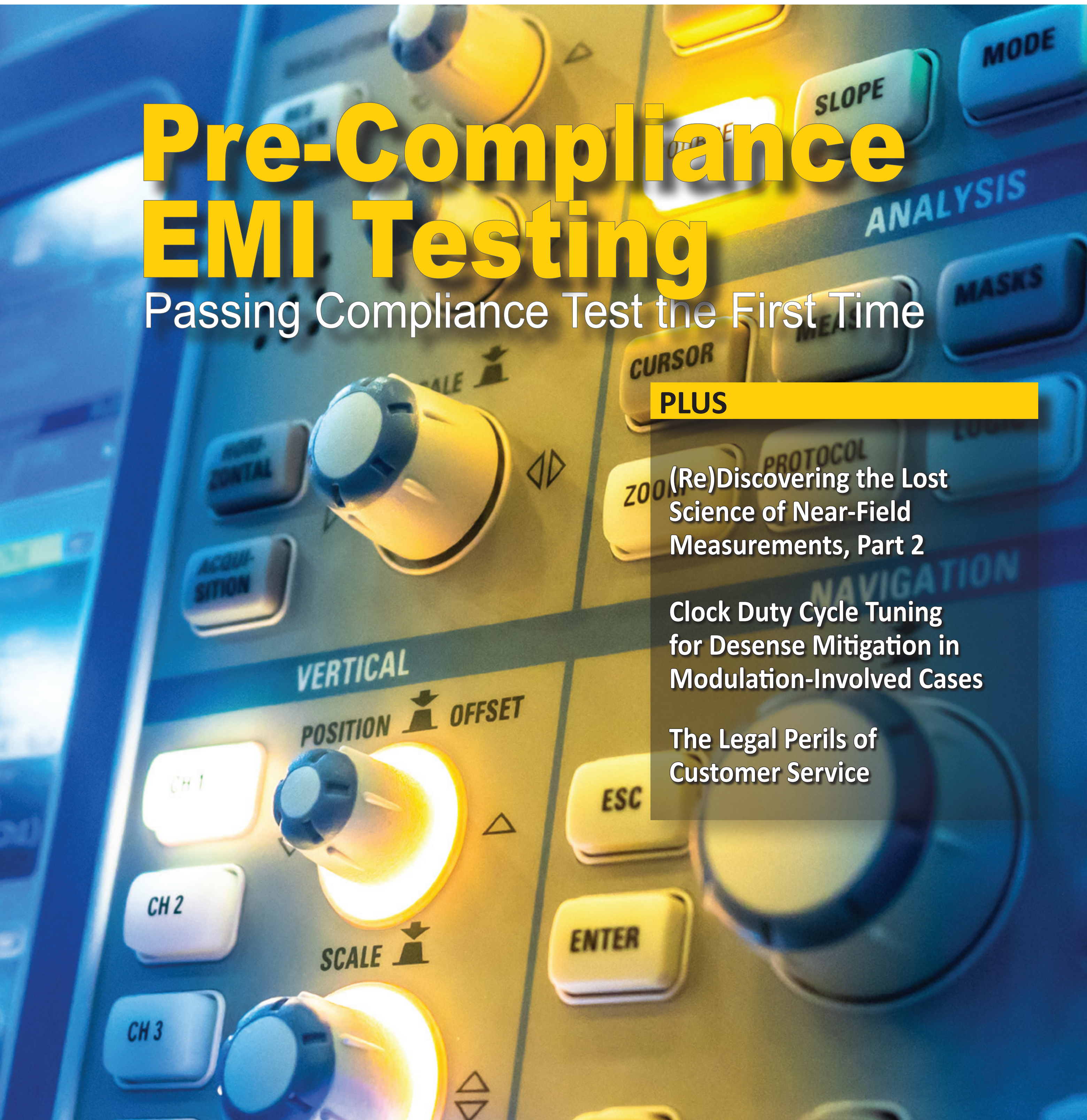

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Volume 15 | Number 8

U.S. House Proposes Removal of Private Use Land Restrictions for Amateur Radio

Members of the U.S. House of Representatives have reintroduced legislation that would remove certain private land use restrictions that apply to the installation or use of amateur radio antennas.

According to a posting on the ARRL website, the legislation, H.R. 4006, also known as the "Amateur Radio Emergency Preparedness Act," is intended to support the ability of amateur radio operators to install "reasonable" antennas and antenna structures on property or land that they own or control.

Congressman Bill Johnson (OH), one of the sponsors of the proposed legislation, noted that passage of the bill would help "remove barriers to disaster and emergency communications and training," as well as "promote education in STEM subjects related to critically needed wireless technology."

The bill is backed by the ARRL, the National Association for Amateur Radio.

New Thermal Management Process Could Double Life-Span of EV Batteries

An Israeli company is pioneering the development and use of a battery system for electric vehicles (EVs) that can offer both increased safety and extended battery life.

According to a posting on the yahoo!finance website, the company, Carrar, has developed a two-phase battery thermal management solution that minimizes the risk of thermal runaway, thereby significantly increasing battery safety. At the same time, by optimizing the operating temperature range of the battery, the company's innovative thermal management technology can help to double the effective battery life, thereby reducing the environmental impact of battery waste.

Carrar has recently announced a partnership with Rochling Automotive, a German-based supplier of customized plastic solutions, to develop a fully-sealed module for EV batteries that incorporates both Carrar's advanced thermal management technology and Rochling's lightweight plastic solutions.

FDA Releases Final Guidance on Pre-Market Submissions for Medical Device Software Functions

The U.S. Food and Drug Administration (FDA) has published a final version of its Guidance on the recommended documentation on software functions in medical devices to be included in premarket submissions for FDA review.

The Guidance, "Content of Premarket Submissions for Device Software Functions," is intended to cover a variety of software-driven functions available in today's advanced medical devices, including firmware, software accessories, and software-only functions, such as functions intended to be operated on commercial OTS computing platforms. The Guidance does not apply to automated manufacturing or quality system software.

According to the Guidance, specific areas of software functionality that should be documented in premarket submissions include:

- Software description
- Risk management file
- Software requirement specifications
- System and software architecture design
- Software design specifications
- Software development, configuration management, and maintenance practices
- Software testing as part of verification and validation
- Software version history
- Unresolved software anomalies

The updated Final Guidance supersedes the original version of the Guidance issued in May 2005.

As a reminder, Guidance documents issued by the FDA are intended only to represent the current thinking of the agency and are not binding on either the FDA or the public.

EU Moves Toward Regulation of AI

The draft law restricts use of artifical intelligence in the European Union

In a major regulatory development, the European Parliament has passed a draft law that would place restrictions on the use of artificial intelligence (AI) in the European Union (EU).

According to an article posted on the website of the *New York Times*, the Parliament has voted to adopt a revised version of a Proposal from the EU Commission that would help to ensure that AI technologies and systems are "safe, transparent, traceable, non-discriminatory, and environmentally friendly." The final version of the draft A.I. Act passed by Parliament will now be negotiated between the Parliament, the Commission, and the Council of the European Union, with a final agreement expected to be reached by year's end.

The Parliament's revision of the Commission's Proposal includes bans on "intrusive and discriminatory uses of AI systems," including certain biometric identification systems, the scraping of biometric data from social media to create facial recognition databases, and biometric categorization systems using sensitive characteristics, such as gender, race, ethnicity, religion, or political orientation.

Policymakers in other countries have also initiated discussions on potential steps to control the use and control of AI technologies. But the actions by the EU represent the most significant advancement of potential AI regulatory controls to date.

PRE-COMPLIANCE EMI TESTING

Passing Compliance Tests the First Time

Paul Denisowski is an applications engineer at Rohde & Schwarz where he specializes in interference hunting, direction finding, and mobile network testing. He has over 20 years of experience in test and measurement.

By Paul Denisowski

Most electrical and electronic devices must be tested by third-party labs to ensure that they comply with the relevant conducted and radiated emissions standards. The failure rate in compliance tests is often high, requiring costly and time-consuming redesign. With pre-compliance testing of electromagnetic interference (EMI) as part of the design process, manufacturers can identify problems early in the product cycle. Pre-compliance testing makes it easier to modify the design and electromagnetic properties of a product and increases the probability of passing compliance tests the first time.

Devices must be tested to show that they comply with the requirements of various standards, such as CISPR or MIL-STD. These standards are specified by the responsible regulatory authority, such as the Commission of the European Union (EU) or the Federal Communications Commission (FCC) in the U.S. The required compliance tests must be passed before a device can be put on the market.

Compliance testing is usually performed by a certified third-party test lab or test house. They have specialized equipment, special facilities (such as anechoic chambers), and trained testing personnel, all of which make compliance testing expensive. Testing fees can reach thousands or even tens of thousands of dollars (U.S.) per attempt.

Unfortunately, failing compliance tests is a common occurrence. Depending on the type of testing and the standards involved, the failure rate can be in the range of 70 to 90 percent. If a single part of the test is failed, the entire test is considered unsuccessful, and the device manufacturer must schedule a new test. Any necessary product redesign or remediation must be performed before retesting, and this requires additional time and money.

EMC TESTING BECOMES PART OF THE DESIGN PROCESS

Formal compliance testing only yields "pass-fail" results and does not provide much insight into the causes of the failure. Pre-compliance testing, on the other hand, can be stopped at any time and the reasons for issues can be thoroughly analyzed, tested, and debugged.

Figure 1 illustrates the electromagnetic compatibility (EMC) testing process. EMI debugging and analysis should be incorporated into the design process itself. If initial measurements do not reveal any serious issues, the equipment under test (EUT) moves into pre-compliance testing. The pre-compliance tests should come as close as possible to the associated compliance tests. If an EUT fails any of these pre-compliance tests, it goes back to the design and debugging phase for modification. Once pre-compliance tests have

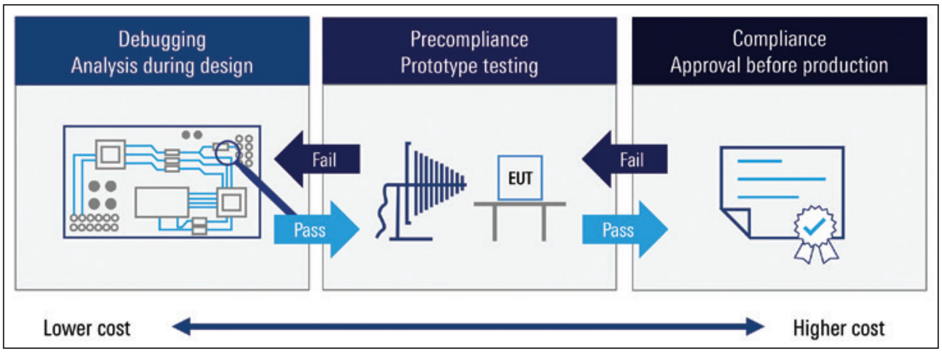

Figure 1: The EMC testing process (Source: Rohde & Schwarz)

been successfully passed, the EUT then moves to full compliance testing at a lab or test house. Successfully passing the required compliance tests results in formal certification, allowing the device to be marketed.

Test Location and Site

Formal compliance tests require specific test environments and specific test setups. For assessing conducted EMI, the required equipment and environment are quite simple. In addition to the test instruments and accessories, the test engineer needs only a simple ground plane and a non-conductive table. Therefore, conducted pre-compliance tests are often almost identical to full compliance tests.

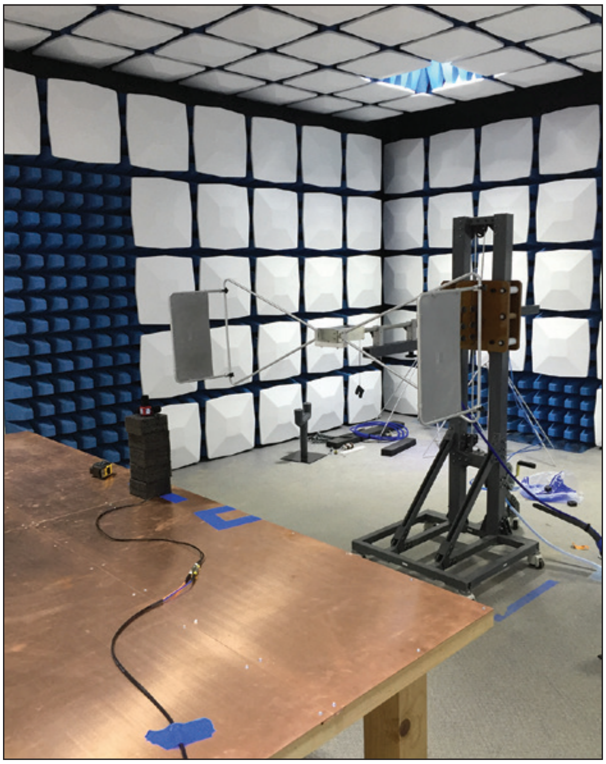

Figure 2: For radiated pre-compliance tests the distance between EUT and antenna is relevant for determining proper limits. (Source: Rohde & Schwarz)

On the other hand, radiated EMI compliance testing generally requires a shielded chamber or a suitable open-air test site. Due to the size, cost, and complexity of configuring these types of facilities, most radiated pre-compliance tests cannot precisely duplicate the compliance test environment.

As a result, modifications are often made when performing radiated pre-compliance tests, such as adding margins to the measurement results. For example, a smaller chamber leads to higher emissions than in the final compliance test as the distance between the antenna and EUT is smaller. In this case, emission limits must be raised to take the stronger signals into account. Going from a typical compliance distance of ten meters to a typical pre-compliance distance of three meters, as shown in Figure 2, might require approximately 10 dB higher emission limits.

TEST INSTRUMENTS: EMI RECEIVERS AND SPECTRUM ANALYZERS

There are two main categories of test instruments used for pre-compliance testing. Spectrum analyzers and EMI receivers are most commonly used to measure emission limits, whereas oscilloscopes are primarily used for debugging and troubleshooting.

EMI receivers and spectrum analyzers (Figure 3) are frequency-domain instruments. They measure and

Figure 3: EMI receivers and spectrum analyzers are typical test instruments for pre-compliance tests. (Source: Rohde & Schwarz)

display power as a function of frequency. Frequency domain analysis is essential for EMI testing since conducted or radiated power levels are measured over a range of frequencies defined by a standard. Spectrum analyzers and EMI receivers use automated routines that step through or scan the frequency range of interest. This functionality is either a built-in feature of the instrument or implemented by software.

Limit Lines

A "passing" result occurs when all measured values fall below a defined power-versus-frequency limit line. These maximum power values can either be configured directly on or loaded into the test instrument.

Detector types

Detectors determine how measurements during an interval are combined into a single measurement point. In Figure 4, you see the measurement of a pulsed signal. The results were calculated for each signal interval using different detector types. The average detector simply yields the average value over each interval. The peak detector selects the maximum value in each interval. Quasi-peak detectors were originally developed to better indicate the subjective annoyance level experienced by a listener hearing impulsive interference to an AM radio station. Quasi-peak or CISPR detectors are now generally used to measure the interference of a signal using a type of charging and discharging behavior. The effect of different detector types is shown in Figure 4.

Measurements made with a peak detector are much faster than those made with a quasi-peak detector, usually by at least several orders of magnitude. Additionally, peak detector results are always higher than quasi-peak results. If an EUT passes pre-compliance testing using the faster peak detector, it will also pass the slower tests with a quasi-peak detector. For this reason, the peak detector is more common in pre-compliance testing and the quasi-peak detector is more common in compliance testing

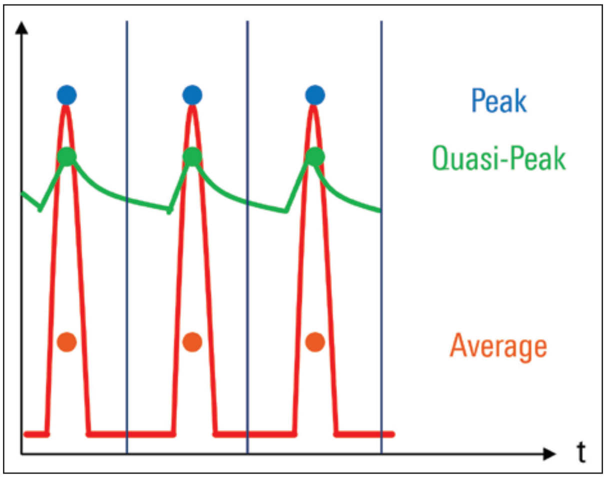

Figure 4: Common detector types (Source: Rohde & Schwarz)

In EMI testing, the input signal is neither known nor controllable. Therefore, it is possible that out-of-band or "off-screen" signals could overload the test instrument's first mixer and cause compression or distortion, leading to invalid or misleading measurement results.

Spectrograms

In addition, EMI pre-compliance tests often use spectrograms. A spectrogram is a plot of power versus frequency versus time. In order to display these three quantities in only two dimensions, signal power or intensity is mapped to the visible color spectrum, with red indicating maximum power and purple or violet indicating minimum power. The most recent measurements appear in the top line of the display and then "flow" downwards.

Spectrograms are useful because they show how signals change over time and over a range of frequencies. This enables easy identification of time-varying signal behavior such as drifting or frequency hopping. Spectrograms also make it easy to see small signals in the presence of larger signals. Most spectrum analyzers and EMI receivers have spectrograms as a standard feature, and spectrograms are also common for oscilloscopes when displaying frequency-domain information in so-called FFT (fast Fourier transform) mode.

Preselection

In EMI testing, the input signal is neither known nor controllable. Therefore, it is possible that out-of-band or "off-screen" signals could overload the test instrument's first mixer and cause compression or distortion, leading to invalid or misleading measurement results.

Preselection protects the first mixer. It is implemented as a switchable bank of filters that allows an EMI receiver to select only the frequencies of interest. The particular filter is chosen automatically by the receiver based on the configured input frequency. Many EMI standards require that the "measuring instrument" have preselection, and this is why compliance testing is performed with EMI receivers rather than with spectrum analyzers. Many spectrum analyzers also have a feature called preselection, but this is usually a high-pass filtering based on YIG technology and not a switchable filter bank.

Time Domain Scan

The classic measuring method of EMI receivers is the stepped frequency scan with a small resolution bandwidth. It is a highly accurate but slow method, especially for applications with wide spectral ranges such as radiated emissions measurements.

Modern EMI receivers support time domain scans by splitting the measurement range into large spectrum blocks. The instrument digitizes and processes each of them by using FFT. Time domain scan provides a significant speed improvement over the stepped scan without sacrificing accuracy. Time domain scan has been approved for usage in most types of compliance testing and also can save significant time during pre-compliance testing.

Test Instruments: Oscilloscopes

Oscilloscopes are primarily time domain measurements. They are a valuable measuring tool for locating, debugging, or remediating sources of non-complying emissions. Many modern oscilloscopes also support frequency domain measurements. In addition, modern oscilloscopes generally have a wide bandwidth. Oscilloscopes can be used to examine both conducted and radiated signals.

One potential drawback of using oscilloscopes for pre-compliance testing is that they usually do not natively support limit lines, although limit lines and other EMI-related features can be implemented in external software.

Fast Fourier Transform (FFT)

Some oscilloscopes can be used to display and analyze frequency domain data by performing FFT on acquired time domain data. This is helpful for pre-compliance testing as they display time and frequency domain data simultaneously. Users can correlate events

in one domain with events in another domain. This is extremely helpful when debugging EMI issues, especially if the oscilloscopes are equipped with a frequency domain trigger. This trigger occurs when a frequency mask or region is violated, as shown in Figure 5. Once the oscilloscope has been triggered by this frequency-domain event, the related time-domain event can be analyzed to determine the root cause of this violation.

Wide bandwidth and the ability to correlate time and frequency domain data make oscilloscopes very valuable for debugging issues discovered during pre-compliance testing. Features such as spectrograms and limit lines can be supported by all three instruments. EMI receivers additionally offer preselection and time domain scans. EMI receivers are used for full compliance testing and using them for pre-compliance tests leads to a closer correlation with compliance test results.

ACCESSORIES USED FOR PRE-COMPLIANCE TESTING

In addition, there are a number of different tools and accessories which are necessary for precompliance measurements.

LISN

A line impedance stabilization network (LISN) is used in conducted emissions testing. One of the main functions of a LISN is to provide a stable impedance on the AC mains line end of the EUT's power cord. Since power outlet impedance can vary widely, a LISN ensures consistent, repeatable results regardless of where the test is conducted. In addition, it blocks any RF signals present on the AC mains from entering the EUT via the EUT's power cord. This ensures that any measured emissions are coming from the EUT rather than being conducted in from the AC mains network.

Antennas

Radiated compliance testing is always done in the so-called far field, with the antenna placed several meters from the EUT.

Because of the wide frequency ranges required by most radiated testing standards, typically 1 GHz or more, a broadband antenna or a combination of antennas is needed to efficiently cover the entire frequency range. Some common examples are log-periodic antennas or biconical antennas.

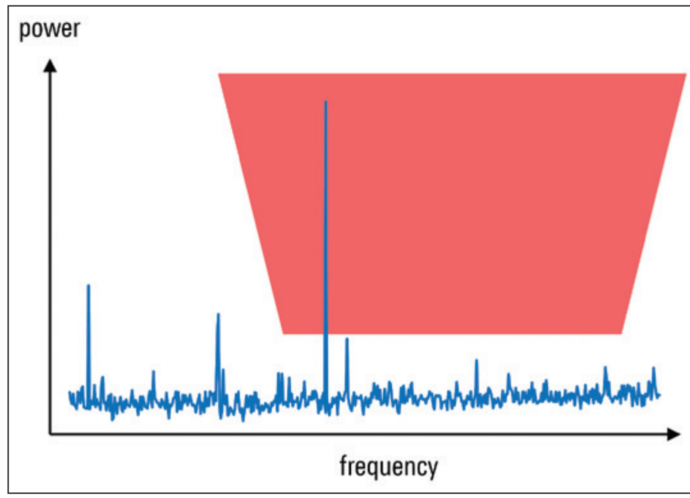

Figure 5: A frequency mask trigger can be used to help identify the cause of this violation in the time domain. (Source: Rohde & Schwarz)

Figure 6: Typical near-field probes used in pre-compliance testing (Source: Rohde &Schwarz)

The same types of antennas can be used in both compliance and pre-compliance tests but recall that the distances between the antenna and EUT are often shorter in pre-compliance testing, requiring modifications to the radiated limit lines.

However, with regard to troubleshooting or debugging the causes of emissions, these types of antennas are not appropriate. They are too large and too bulky to provide precise information about which part or component of the EUT is generating non-compliant emissions.

Near-Field Probes for EMI Debugging

Near-field probes are the appropriate tools for use in close physical proximity to the source of an emission. As a practical matter, the near field in EMI debugging is of the order of a few centimeters. Because of their small size and the ability to physically position them close to the source, near-field probes have high spatial resolution. They allow users to precisely locate the source of an emission, for example, a pin of a chip or a trace on a printed circuit board. On the other hand, near-field probes only support relative measurements. They can be used to find sources of emissions but cannot be used to measure accurate power levels for the purpose of verifying limits.

Software

Specialized software is commonly used in pre-compliance testing, most often for scripting or automating tests. The software communicates with or controls multiple instruments and accessories via a single user interface. It can also easily incorporate antenna factors, cable loss, etc. into the measurement results. It also collects and displays the measured data with advanced options, such as customized limit lines. This provides higher speed and better repeatability than manual operation, allowing rapid and accurate pre-compliance testing to be performed even by users who are relatively new to pre-compliance testing.

SUMMARY

Pre-compliance testing saves time and money by discovering potential issues early in the design cycle. Using the proper tools and techniques during pre-compliance testing greatly increases the chance of passing full compliance tests the first time.

(RE)DISCOVERING THE LOST SCIENCE OF NEAR-FIELD MEASUREMENTS, PART 2

Understanding Radiated Emissions Measurements Made at One-Meter Separation:
It's Not What You've Been Led to Believe

Ken Javor is a Senior Contributor to *In Compliance Magazine* and has worked in the EMC industry for over 40 years. Javor is an industry representative to the Tri-Service Working Groups that maintain MIL-STD-464 and MIL-STD-461. He can be reached at ken.javor@emccompliance.com.

By Ken Javor

This is the second part of our article "(Re)Discovering the Lost Science of Near Field Measurements." Part 1 of the article (see *In Compliance Magazine*, July 2023) explained what near and far field measurements entail, and that one-meter measurements are very much near field. This second part picks up where Part 1 left off, and explains the evolution of the earlier 12" and present-day one-meter separation measurements, considerations in antenna selection, and the difference between antenna-induced and field strength limits, and the evolution from one to the other.

NEAR AND FAR FIELD LIMIT DERIVATION

It is instructive to compare and contrast how the limits in standards such as CISPR 22/32 were determined, vs. those in MIL-I-6181. Limit derivation for standards like CISPR 22/32 comes directly from specifications on the quality of radio services.[14]

Figure 4 is an example excerpted from Reference 14. Such specifications state that a certain quality of baseband signal results when a specified level of broadcast signal is received. From this level, an EMI limit may be counted down using the signal-to-noise ratio required to get the specified baseband quality. Thus, it is completely natural to specify limits protecting such services in terms of field intensity, especially when the compliance measurement is made in the far field (or nearly so).

But the limits in MIL-I-6181B were not determined that way at all, and the success criterion for vehicle EMC is also not so determined. NADC-EL-5515 describes how the MIL-I-6181B limits were obtained, and this limit-setting exercise also determined the test method:

> *"These limits were decided upon as a result of tests made on a BC-384Q receiver installed in a shielded room. A 24-inch lead-in and a 12-foot straight wire antenna outside the shielded room were used to simulate an aircraft set-up. Various types of radio interference sources such as d-c motors, poorly shielded dynamotor cables, an adjustable output ignition source, etc., were installed at a distance of one foot from the lead-in. At those frequencies where interference sources happened to produce an interference signal which was slightly above the background of the BC-348Q, a measurement was made with an AN/PRM-1 in conjunction with its rod antenna. The rod was located one foot from the noise source, and the resultant measurement was taken as an approximation of the desired radio interference limit."*

Table 5-6. Typical Received Field Strengths – VHF/UHF Radio Services

Service (MHz)	Band No.	Field Strength (dBμV/m)	Comment
Public Safety			
30-54	1	31	Service Grade
136-174	5	37	Service Grade
420-470	9	39	Service Grade
Broadcast FM			
88-108	3	70-74	Principal City
		60	City, Business or Factory Area
		34	Rural Area
Civil Aeronautical			
108-136	4	12-16	FAA Squelch Setting
216-420	7/8	20	FAA Squelch Setting

Figure 4: Published expected signal levels for various broadcast radio services (from Reference 14)

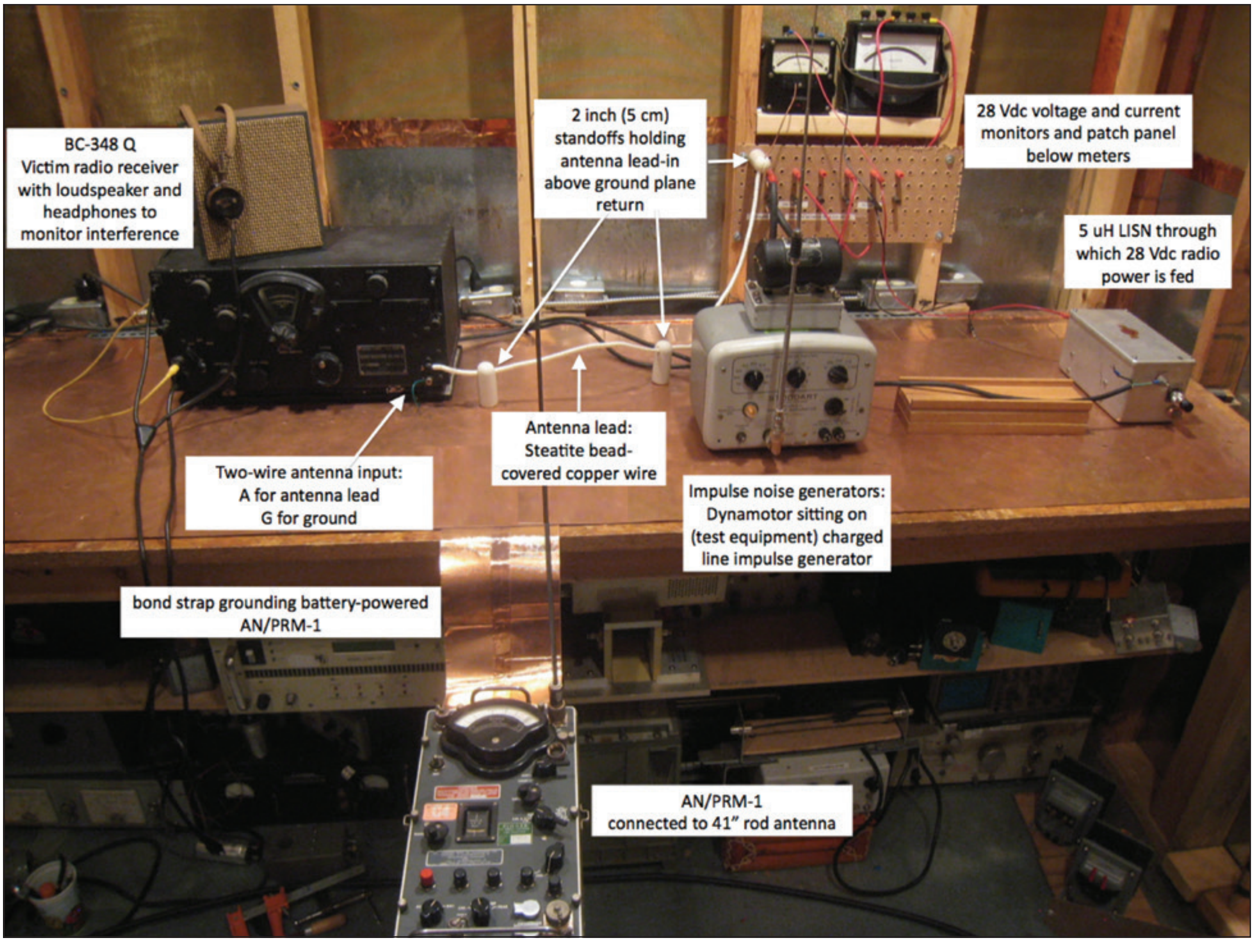

Figure 5: Reenactment of MIL-I-6181B radiated emission limit setting procedure in the EMC Compliance screened test chamber

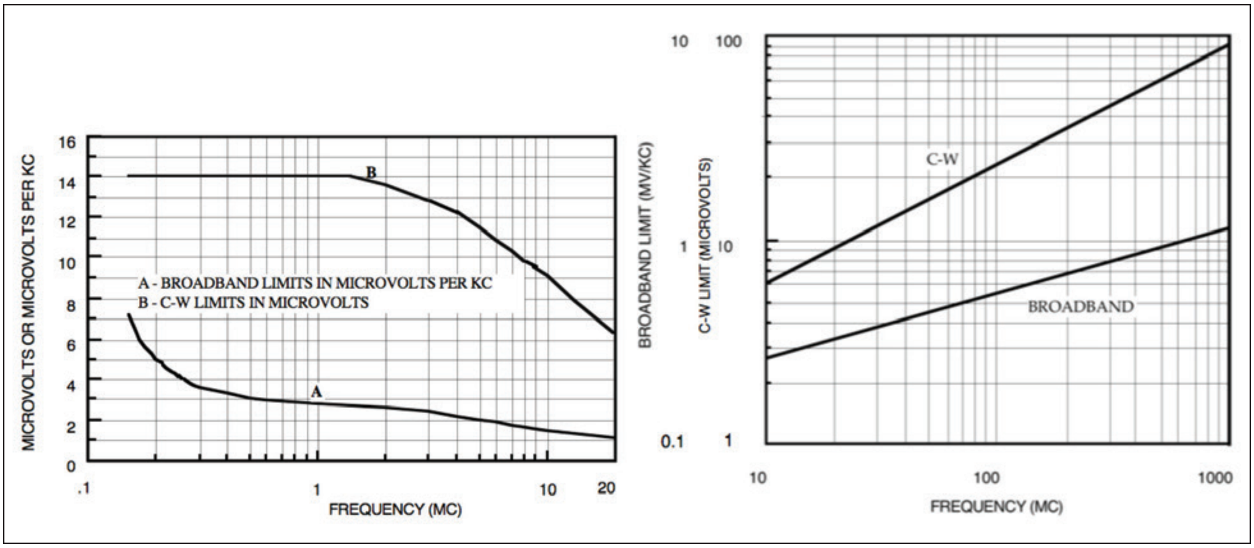

Figure 6: Figure 6a (41" rod) and Figure 6b (resonant dipole) antenna-induced radiated emission limits from NADC-EL-5515

Figure 5 is a recreation of the described limit setting measurement, based on the above passage. Two key points immediately suggest the vast difference from the CISPR 22/32 limit derivation. The first is this is entirely empirical, as opposed to using established specifications as a benchmark. The second is that the measurement distance is extremely near field, and the limits are in terms of the induced noise in the victims – no field intensities involved. When noise above the background is detected from the speaker connected to the radio's audio output, the measured level at the AN/PRM-1 is recorded. The AN/PRM-1-meter displays microvolts and decibels above a microvolt. There is no antenna factor involved here. This is termed an *antenna-induced* limit and is a key concept that has been largely lost but is every bit as pertinent today as it was in 1953. Figure 6 shows MIL-I-6181B antenna-induced radiated emission limits.

Rigorously, "antenna-induced" means the theoretical open-circuit voltage that would appear at the antenna terminals with an electric field impinging upon it. Losses associated with any circuitry necessary to adapt from that open-circuit potential to a signal that can be piped down a transmission line must be accounted for. So, with the 41" rod antenna used as in Figure 5, there is no data reduction necessary: the receiver meter reading (plus any attenuation selected) is the reading to be compared to the limit.

But above 30 MHz, where half-wave dipoles are employed, balun losses must be factored in, and NADC-EL-5515 explains how to do that. In the days of antenna-induced limits, the loss associated with a matching network was termed the antenna factor. But unlike modern practice, the antenna-induced antenna factor is a unit-less loss factor (dB), whereas the modern antenna factor, being the inverse of antenna effective height, has units of meter^{-1}, or dB per meter.

Of course, any cable losses must be accounted for as well, just as in a field intensity measurement. The concept of an antenna-induced limit may seem foreign, but there is a close modern example with which an EMC engineer should be familiar. Radiated emission measurements such as those described above are designed to force good EMC design at the equipment level, so that at system or platform integration, there are no ugly surprises resulting in delays or costly modifications at the last minute. The "proof of the pudding" is verification that all platform antenna-connected receivers can operate interference-free.

With such receivers often being tunable over thousands of channels, it is impractical to tune to and check each frequency. Instead, standards such as MIL-STD-464 mandate a "spectrum analyzer noise floor survey."[15] The transmission line connecting the receiver's antenna is disconnected from the receiver, and instead attached to a spectrum analyzer or EMI receiver, which is set to sweep over the entire tunable range of the receiver, or multiple sub-bands if that is necessary. Signals appearing above the substituted receiver's noise floor or some other level are then checked to see if they actually cause interference.

This is almost an antenna-induced measurement. The pass/fail criterion is a dBuV or more likely dBm level based on the particular receiver's performance specification. A similar example may be found in the C & D revisions of MIL-STD-464, where antenna-induced measurements at a distance of one meter from Army ground vehicles are made using not EMI test antennas as in MIL-STD-461, but rather antennas representative of those next to which the ground vehicle might be parked (typically whips). The whips are connected to a spectrum analyzer, and the limit is again in terms of the rf potential or power at the connected spectrum analyzer.

The reader should be able to appreciate the high degree of similarity between these modern measurements and those described in NADC-EL-5515. The only difference is that the noise floor measurement is referenced to the receiver's antenna input, so the matching of the antenna to the transmission line and any line losses are part of the answer and for which separate accounting is unnecessary.

One other important facet of antenna-induced limits and the passages from NADC-EL-5515 is worth mentioning here. NADC-EL-5515 went to some length to explain the selection of antennas used for MIL-I-6181B 12" measurements. They were supposed to simulate the coupling to platform antenna-connected conductors (open-wire transmission lines). If one looks at antennas used beyond the biconical frequency range in vehicle EMI testing today, one finds horns and log-periodic arrays. The simulation of platform antennas for a good quality radiated emission test uses antennas with dipole-like patterns, because such are either used on platforms, or in the case of high gain platform antennas, noise sources are typically in the back or at most side lobes of such, and thus are coupling via a low gain mechanism.

It is the author's belief that biconical antennas such as the Compliance Design collection shown in Figure 7 would serve admirably. Even if antenna-induced limits were not invoked, it is the author's opinion that such antennas are superior to what is used today above 200 MHz. With an antenna-induced limit, one could compare the output of the Figure 7 antennas to what would be required at a platform-level spectrum analyzer survey. Even without an antenna-induced limit, given the similarity between the EMI test and platform-installed antennas, one could do the comparison to get a much better prognostication of the actual EMC "proof-of-the-pudding" test results.

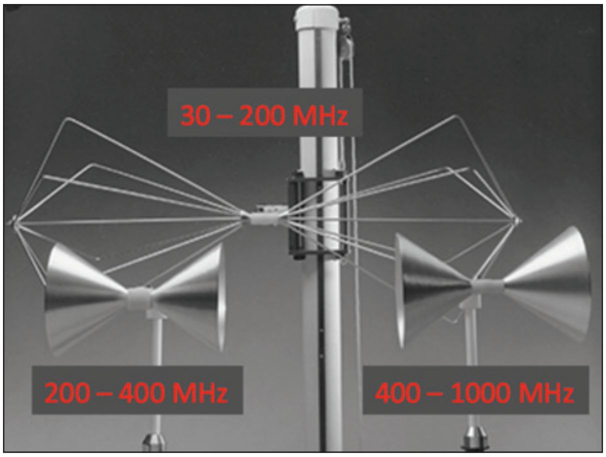

Figure 7: Compliance Design biconical antennas covering 30 MHz to 1 GHz (no longer manufactured). Frequency ranges shown are approximate. Smaller biconicals have identical elements, but different baluns. Photo courtesy of Glen Dash Foundation.

Future installments of "(Re)Discovering the Lost Science of Near-Field Measurements" will discuss both theoretical and practical problems arising from the misapplication of field intensity and far-field concepts to near-field phenomena

THE SWITCH FROM ANTENNA-INDUCED TO FIELD INTENSITY EMI LIMITS

MIL-I-6181B instituted antenna-induced limits measured at 12" from the test sample and attached cables. NADC-EL-5515 explains why, and that MIL-I-6181B also prohibited the future procurement of receivers requiring the unshielded high-impedance lead-ins. This means the stringent limits applied at 12" from the test sample were a grandfather clause, protecting the current inventory of high input impedance installed radios until such time as they had all been replaced by more modern receivers designed to work with 50 Ω coaxial transmission lines. In the words of NADC-EL-5515:

> *"(MIL-I-6181B) requires that all equipment used with antennas be designed for use with a shielded antenna lead. If and when the unshielded antenna lead is completely eliminated from use in aircraft, a review of present methods and limits in the frequency range 0.15 to 20 mc will be required."*

With the prohibition of the unshielded transmission line, the radiated emission problem is greatly ameliorated. Instead of what amounts to a crosstalk control, coupling is now to an antenna, and antennas are mounted externally and are further removed from most noise sources than the transmission line between the antenna and the antenna-connected receiver.

When the Tri-Service Committee convened circa 1966 to fashion MIL-STD-461/2/3 out of the various Service and platform-unique EMI specifications, they apparently deemed it time to abandon the 12" grandfather clause. Army and Navy EMI specifications of the time were already making some radiated emission measurements at distances greater than one foot, and the one-meter separation that resulted may have been nothing more than a "metricized" average of the Army (5' minimum), Navy (3') and Air Force (1') separations.[16, 17, 18, 19] MIL-STD-462 (1967) required the present one-meter separation between the test sample and the antenna.[20] With an antenna as the radiated emission victim, as opposed to a transmission line, it might have seemed natural to transition to a field strength type control. Whatever the reason, the move to a one-meter separation was accompanied by a shift to a field intensity limit, and the consequent need for the kinds of antenna factors we use today. Thus, SAE ARP-958 was published in 1968; one year after MIL-STD-462 was released.

For the record, it should be noted that forerunners to RTCA/DO-160 included antenna-induced radiated emission controls.[21, 22] RTCA/DO-160 was first released in 1975, and by that time field intensity limits had superseded antenna-induced, as described. Automotive radiated emission practice was always field intensity control but that did not begin until the 1970s.

Future installments of "(Re)Discovering the Lost Science of Near-Field Measurements" will discuss both theoretical and practical problems arising from the misapplication of field intensity and far-field concepts to near-field phenomena.

ENDNOTES

14. CBEMA Report – CBEMA/ESC5/77/29 – "Limits and Methods of Measurement of Electromagnetic Emanations from Electronic Data Processing and Office Equipment," 20 May 1977.
15. MIL-STD-464 and newer, Electromagnetic Environmental Effects Requirements for Systems, 1997 - present.
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17. MIL-I-16910A(SHIPS), Interference Measurement, Radio, Methods, and Limits, 14 Kilocycles to 1000 Megacycles, 30 August 1954.

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19. The late Steve Caine was the chairman of the Tri-Service Working Group that revised MIL-STD-461C (1986) and MIL-STD-462 (1967) into MIL-STD-461D and MIL-STD-462D in the 1989 – 1993-time frame. He introduced the committee to the public at the 1989 IEEE EMC Symposium in Denver, saying that as he was the last surviving member of the original committee that fashioned MIL-STD-461/2/3 back in the '60s, it fell on him to lead the effort to clean up the mess they had made of it. When he was asked at another time about how some of the MIL-STD-461 limits and -462 test methods came about back in the '60s, he sighed and said, "Well, there was a lot of horse-trading going on back then."

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CLOCK DUTY CYCLE TUNING FOR DESENSE MITIGATION IN MODULATION-INVOLVED CASES

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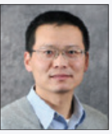

By Shengxuan Xia, Jun Fan, and Chulsoon Hwang

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INTRODUCTION

Radio frequency (RF) antenna desensitization problems, also known as desense, have drawn more attention in recent years. Due to the trend that modern electronic devices are designed to be more compact, equipped with more functions, and working under higher speed, unwanted noise sources and the coupling to the victim RF antennas will occur more frequently. There are many mechanisms that desense can happen on the RF antennas such as direct coupling [1][2], modulation [3], intermodulation [4][5], etc.

The most common cases are the direct coupling to the victim antennas. When there exist certain noise sources radiating frequency components within the receiving band, the antenna may pick up the noise when the sources have efficient coupling paths to it. Because the working frequency ranges of the antennas are known, it has been extensively studied to avoid unwanted noise coupled to the antenna from nearby modules. Typical mitigation solutions include shielding, absorbers, and even rotating the orientation [1]. The reciprocity-based theorem is used as a framework to model the direct coupling problem [6]. Based on the framework, several methods have been proposed such as equivalent dipole moment extraction for noise source modeling [7][8] or using Huygens box [9].

Desense problems with modulation involved are more difficult to identify. The radiating transmitting signals can be as high as 23 dBm, and a significant amount of TX power can be easily coupled to nearby modules and components. Owing to the nonlinearity of the components, coupled TX signals modulated with low-frequency baseband signals generate new frequency components and then interfere with the RX band. The low- frequency baseband signals, which are typically ignored for the desense issues, can be troublemakers in such a situation. There exists little study on the relationship between the baseband signal spectrum and desense.

In this paper, a new direction for desense mitigation is proposed. Without modifying the hardware design, desense can be suppressed by engineering the spectrum distribution through tuning the noise clock duty cycle. The understandings of modulation caused desense and the clock spectrum distribution versus duty cycle are explained. Then the real cellphone measurements validated the feasibility of desense mitigation by the tuning of duty cycle.

MODULATION INVOLVED DESENSE ISSUES

Brief Introduction to the Modulation Caused Desense

For frequency divide duplex (FDD) working mode RF antennas, the transmitting frequencies are usually not far away from the receiving frequency range. As Figure 1(a) on page 26 shows, using LTE band 5 as an example, the transmitting channels have a 45 MHz difference to the receiving channels. Modulation-caused desense can happen under two conditions: 1) There exist baseband signal spectral components around 45 MHz; 2) There is sufficient nonlinearity to mix the TX and the baseband signals. Then the baseband signals will be up-converted into the RX range and interfere with the channel. Previous study has well identified this modulation mechanism happened in a practical phone design [3].

As Figure 1(b) shows, the TX signals radiated from the antenna can be picked up by the nearby digital microphone (Dmic) circuit. Due to the nonlinearity of the Dmic component, the coupled TX signals can modulate with the clock signals on the mic, thus, new unwanted high-frequency signals at the RX range will be created after the mixing. Eventually, the modulated RX noise will couple back to the victim antenna and degrade the sensitivity. Notice that although the Dmic clock's fundamental frequency is 2.4 MHz, its harmonics can occur near 45 MHz.

Therefore, the interfering signals come from the intermodulation between TX and its harmonics of the Dmic clock.

Clock Spectrum vs Duty Cycle

A clock can be reasonably treated as a trapezoidal wave with a certain rise/fall time and duty cycle as Figure 2(a) shows. The waveform can be expressed in the Fourier series as [10]:

$$x(t) = c_0 + \sum_{n=1}^{\infty} 2c_n \cos(n\omega_0 t + \theta_n) \quad \text{(Eq. 1)}$$

Where $x(t)$ is the time domain waveform of the trapezoidal wave, $c0$ is the DC component, and c_n is double-sided spectrum amplitude of the n^{th} order harmonic. Applying Fourier transform, the magnitudes of the single-sided Fourier coefficients (exclude DC) of the clock harmonics can be expressed as:

$$c_n^+ = 2c_n = 2A\frac{T_d}{T}\left|\frac{\sin\left(\frac{n\pi T_d}{T}\right)}{\frac{n\pi T_d}{T}}\right|\left|\frac{\sin\left(\frac{n\pi t_{r/f}}{T}\right)}{\frac{n\pi t_{r/f}}{T}}\right| \quad \text{(Eq. 2)}$$

where c_n^+ is the single-sided Fourier coefficient for nth order harmonic, A is the amplitude of voltage level for digital "HIGH", T_d is the on-time pulse width, T is the period, $t_{r/f}$ is the rise/fall time. It is well known that the duty cycle is usually close to 50%, and the trapezoidal wave will only have odd order harmonics to be dominant while all even harmonics are practically negligible. However, this is not valid for higher order harmonics.

Assuming the rise/fall time, period, and the voltage amplitude are all fixed and only the duty cycle changes, the Fourier coefficients, $Y(n)$, become

$$Y(n) = (T_d/T)\left|\sin(n\pi T_d/T)/(n\pi T_d/T)\right| \quad \text{(Eq. 3)}$$

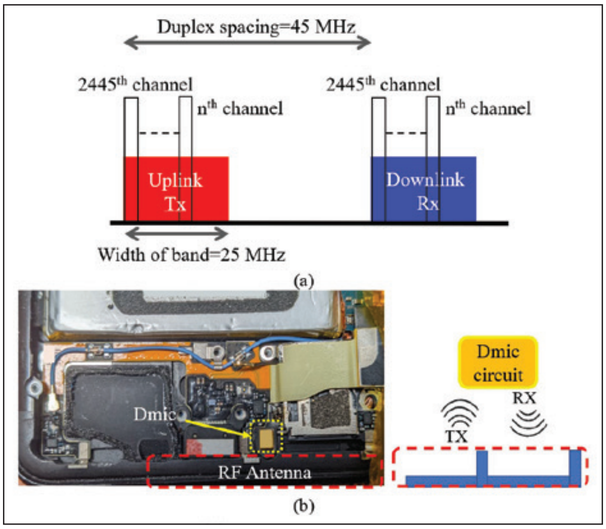

Figure 1: Modulation caused desense mechanism: (a) FDD mode working band (b5); (b) round-trip coupling of TX and modulated clock signals.

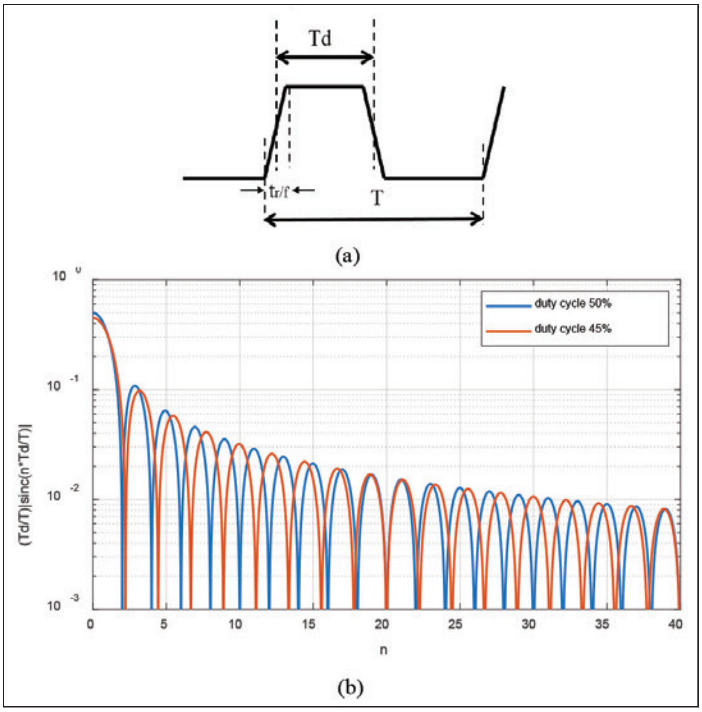

Figure 2: Trapezoidal wave and the sinc function for different duty cycles: (a) Explanations of trapezoidal wave; (b) sinc function over harmonic orders.

which is only related to the duty cycle. Figure 2(b) shows the coefficients for different duty cycles. For example, for 50% duty cycle case, $Y(n)$ is zero when n = 10 (even order) and non-zero when n = 9 (odd order). However, when the duty cycle is not ideal, for example 45% case, $Y(n = 9) << Y(n = 10)$. In this case, even order component is much greater than odd order component. It is worth mentioning that, from Figure 2(b), that the dominance between odd and even order harmonics alternates as the frequencies increase.

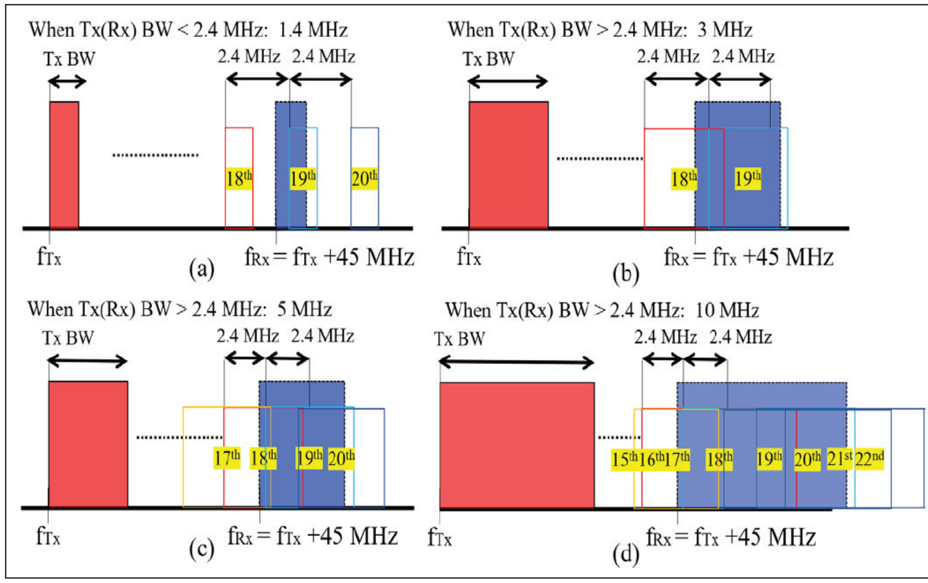

Figure 3: Interfering clock harmonic orders for different TX bandwidth: (a) 1.4MHz; (b) 3MHz; (c) 5MHz; (d) 10MHz.

Interfering Clock Harmonics for Different TX Bandwidth

The clock harmonics are narrow-band signals, but the TX signals are wide-band. The up-converted sideband noise due to the modulation will be wideband, and the bandwidth of each modulated harmonic will be equal to that of TX. The simplest case is shown in Figure 3(a) when the TX bandwidth is smaller than the fundamental frequency of the Dmic clock. Only partial power of the 19th order of the harmonic will interfere with the receiving band. When it comes to the cases with wider TX bandwidth, the 19th order harmonic will always interfere with the RX band while more and more adjacent harmonics will be involved as the TX/RX bandwidth increases. As. Figure 3(b), 3(c), and 3(d) demonstrate, when TX/RX bandwidth is 3 MHz, 18th and 19th harmonics will partially contribute to the total received power, known as received signal strength indicator (RSSI), within the RX range. While when TX/RX bandwidth is 5 MHz, 17th ~20th harmonics will interfere with the RSSI and when TX/RX bandwidth is 10 MHz, the 15th ~22nd harmonics contribute to RSSI. As mentioned in Section II Part A, regardless of channels selected to transmit and receive, the duplex spacing always keeps the same. But when the TX bandwidth becomes wider (indicated as the red blocks), the modulated harmonics will also be wider. Then more harmonics will fall into the receiving band (indicated as the blue blocks). Also, each order will have a different contribution weight to the RSSI.

As Figure 4 shows, the measured wideband TX signal occupies a 1.4 MHz bandwidth and the RF power will be dominant within the frequency range of [f_{TX}, $fTX + Bandwidth_{TX/RX}$], in this example $Bandwidth_{TX/RX}$ = 1.4 MHz. Furthermore, only part of the modulated 19th harmonic will interfere with the receiving range as Figure 3(a) shows, so the accordingly considered frequency range is marked in Figure 4(a) shadowed range. Then the unwanted power at the nth order harmonic can be expressed as [11]:

$$P\left(n,\frac{T_d}{T}\right)=\alpha\cdot c_n^+\left(n,\frac{T_d}{T}\right)\cdot 2\int_{f=f_1(n)}^{f=f_2(n)} S_{xx}(f)df \quad \text{(Eq. 4)}$$

where T_d/T is the duty cycle, $f_1(n)$ and $f_2(n)$ are the lower and upper boundaries of nth order harmonic for considered frequency range within [f_{TX}, $fTX + Bandwidth_{TX/RX}$], $S_{xx}(f)$ is the spectral density of the TX signal. The coefficient α is a constant representing the round-trip EM coupling efficiency and the mixing conversion loss between TX and clock harmonics. In other words, the integrated total TX power within the given frequency band will be firstly coupled from the antenna to the Dmic, then modulated with clock harmonics, and eventually couple back to the antenna. Unless the coupling path and the nonlinearity of the Dmic change, α remains unchanged. Also, because the duplex spacing is much smaller than the carrier frequencies, the frequency dependency of α can be neglected.

Furthermore, the wideband TX signal is not a continuous spectrum but is composed of thousands of narrowband tones with 1 KHz interval between adjacent tones if zoomed in to a small span as Figure 4(b) shows. When the resolution bandwidth (RBW) is much smaller than 1 KHz, the integral in (4) can be simplified as a summation:

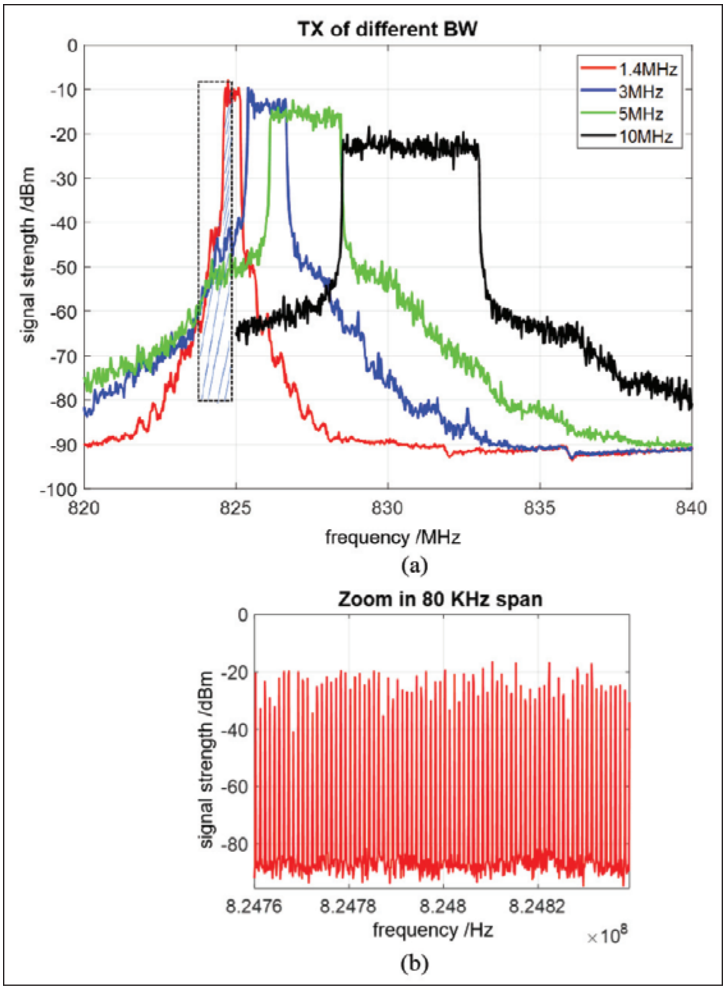

Figure 4: TX spectrum and the interfering RF power: (a) TX signals (different bandwidth settings) (b) zoomed in spectrum of TX (10MHz case).

$$P\left(n,\frac{T_d}{T}\right)=\alpha\cdot c_n^+\left(n,\frac{T_d}{T}\right)\cdot\sum_{m=m_1}^{m=m_2} P_{measured}(m) \quad \text{(Eq. 5)}$$

where $P_{measured}$ is the measured curve in the spectrum analyzer. m_1 and m_2 satisfy $f(m_1) = f_1$ and $f(m_2) = f_2$ is the recorded frequency axis data. As it can be observed in Figure 4(a), the spectrum distributions over frequencies of the TX are roughly flat within the working bandwidth. Therefore, if the total radiation TX power is known, (5) can be further simplified as:

$$P\left(n,\frac{T_d}{T}\right)\approx\alpha\cdot c_n^+\left(n,\frac{T_d}{T}\right)\cdot P_{TX}\cdot w(n) \quad \text{(Eq. 6)}$$

$$w(n) = \frac{|f_2(n) - f_1(n)|}{Bandwidth_{TX/RX}} \quad \text{(Eq. 7)}$$

$$RSSI\left(\frac{T_d}{T}\right) = P_{RX}\left(\frac{T_d}{T}\right) = \sum_n P\left(n, \frac{T_d}{T}\right) \quad \text{(Eq. 8)}$$

where P_{TX} is the total power of TX, $w(n)$ is the weighting coefficients to represent the ratio of the involved power to the total power for n^{th} order harmonic.

As the RSSI caused by TX & harmonics modulation is related to specific order(s) of the harmonics, and each harmonic has a different contribution weight to the desense level, RSSI will be determined by the summation of all the involved harmonics' power multiply by their weights. When the amplitudes of several adjacent harmonics can be tuned according to (2), there may exist an optimal option to have the RSSI minimized.

TX/RX bandwidth	*1.4 MHz*	*3 MHz*	*5 MHz*	*10 MHz*
$w(n)$	$w(19) = \frac{0.8}{1.4}$	$w(18) = \frac{1.2}{3}$ $w(19) = \frac{2.4}{3}$	$w(17) = \frac{0.8}{5}$ $w(18) = \frac{3.2}{5}$ $w(19) = \frac{4.4}{5}$ $w(20) = \frac{2}{5}$	$w(15) = \frac{1}{10}, w(16) = \frac{3.4}{10}$ $w(17) = \frac{5.8}{10}, w(18) = \frac{8.2}{10}$ $w(19) = \frac{9.4}{10}, w(20) = \frac{7}{10}$ $w(21) = \frac{4.6}{10}, w(22) = \frac{2.2}{10}$

Table 1: Weighting coefficients for involved harmonics

When it comes to wider TX bandwidth cases, the spectrum in the RX range will be more complicated because of the overlapping of the modulated harmonics.

DESENSE MITIGATION MEASUREMENT VALIDATIONS

According to the derivations in (4)~(8), the interfering RF power is a function of the duty cycle. Tuning the duty cycle will result in varying c_n^+ and thus varying RSSI. To validate the feasibility of desense mitigation, two measurements were conducted. Considering practical limitation that the Dmic inside the phone cannot modify the clock duty cycle, a separate Dmic module was used and powered up by an adjustable external signal generator. The Dmic module was placed nearby the cellphone RF antenna to maintain the coupling path as Figure 5 shows. The Dmic was provided with the clock signal and DC bias from a function generator (Agilent 81150A). In this setup, the round-trip coupling and the up-conversion due to nonlinearity still exist to mimic the same mechanism as Figure 1(b).

Duplexer-based Cellphone RFI Test

To better observe the RX spectrum changes as a function of the duty cycle, an LTE band 5 supported duplexer was used to enable access to the received spectrum. While maintaining the placement of the cellphone and the Dmic module, the wirings were changed as shown in Figure 6(a). Figure 6(b) depicts the wiring diagram and the RF signal paths. The high-power phone TX signals first went through the "TX" port to the "ANT" port of the duplexer and then injected into the RF antenna system (tuning circuits + physical antenna). The radiated TX signals were coupled to the Dmic and modulated with the clock harmonics. Then the modulated sideband is radiated back and picked up by the antenna. Eventually, the picked RX sideband signals went through the "ANT" port to the "RX" port of the duplexer and got measured by the spectrum analyzer (amplified before going into the instrument).

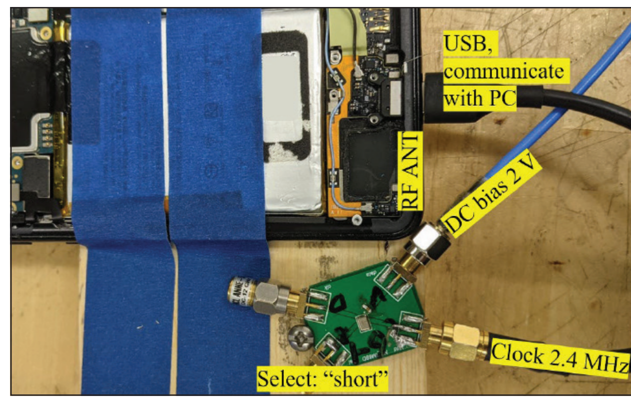

Figure 5: Cellphone RFI setup for TX & clock modulation caused desense

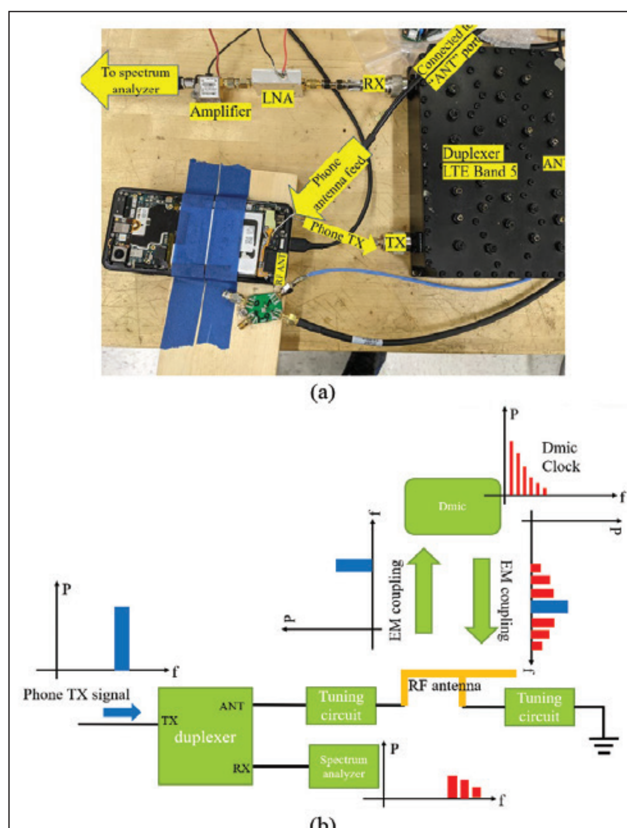

Figure 6: Duplexer-based RFI test setup: (a) actual setup; (b) wiring diagram and signal flow paths

The measured results are shown in Figure 7 for the case that the TX bandwidth is 1.4MHz. As discussed in Section II Part C, the interfering frequency range of the 19th harmonic is marked as the transparent red region. By changing the clock duty cycle, more than 10dB difference can be seen in the marked range.

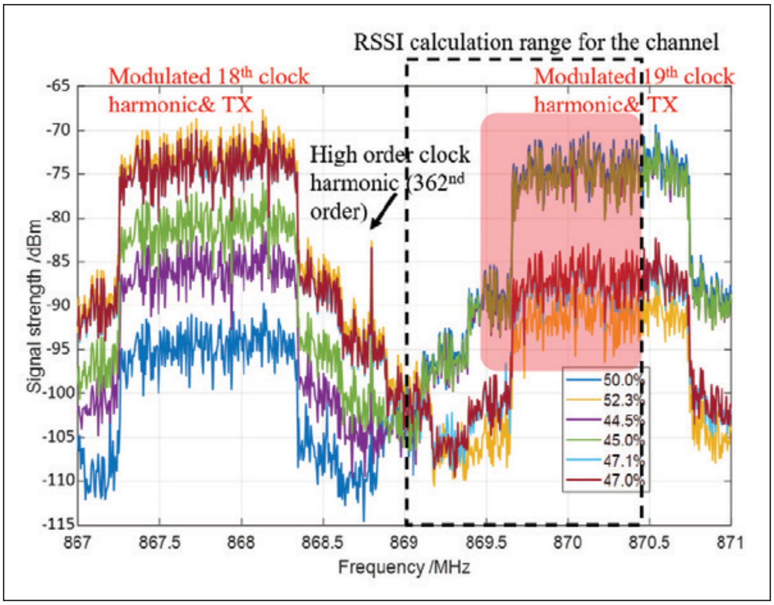

Figure 7: Duplexer-based RFI test results

Measured RSSI in Real Phones

When it comes to wider TX bandwidth cases, the spectrum in the RX range will be more complicated because of the overlapping of the modulated harmonics. Thus, measuring the spectrums for wider TX cases becomes unnecessary. Therefore, direct RSSI tests can help to find out the optimal duty cycle setting for desense mitigation for all TX/RX bandwidth settings. There is a commercial tool installed on a PC that can control and communicate with the phone under test. Real-time RSSI can be directly recorded on the PC. Measurements were done for 3 different TX bandwidth settings and a sweeping of duty cycle from 46% to 54% with the resolution of 0.1% (finest resolution of the signal generator). Equation-based RSSI change predictions will be given by (7).

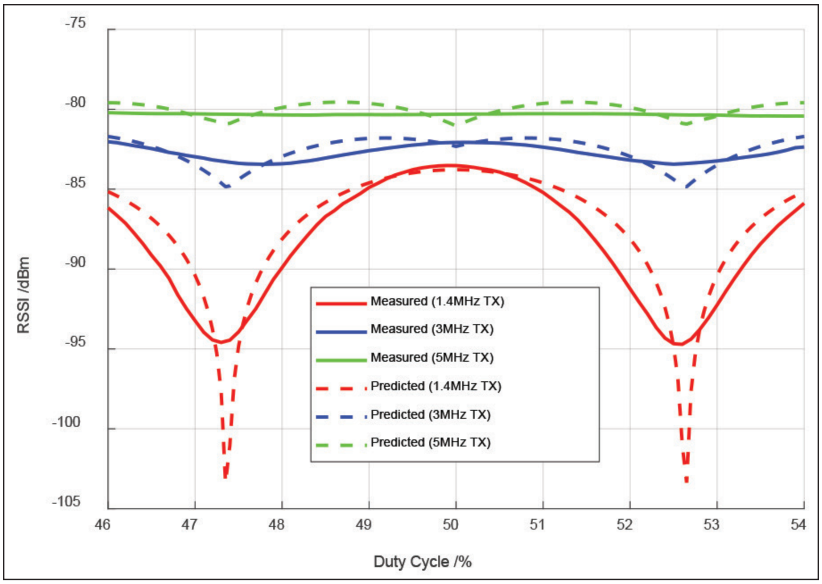

Figure 8: Direct RSSI test results

The trends of desense level, as shown in Figure 8, changed for different bandwidths are well captured. The smaller bandwidth, the higher suppression on desense can be achieved using this clock-duty tuning method. Ideally, if the modulated clock harmonics are the only noise sources, and the duty cycle can be tuned with 0.05% resolution as the dashed red curve shows, desense can be mitigated by 20 dB (47.35% or 52.65%) for the 1.4 MHz bandwidth case. However, due to the existence of other small noises and the limitation of the signal generator's finest tuning capability, a 10 dB mitigation is the best improvement. For the 5 MHz bandwidth case, the actual measurement won't be able to resolve such a small difference of 1.5 dB.

CONCLUSIONS

This paper demonstrates a comprehensive understanding of how the modulated harmonics will undermine the receiving sensitivity in an FDD mode RF system. Based on the understandings, a new direction that changing the spectrum envelope by tuning the noise source clock duty cycle is proposed to mitigate desense for the first time. Equation-based estimations have been derived and well validated with the real product measurements. When the interfering clock signals do not require a strict duty cycle to function properly, this tuning method can be used to suppress desense without any modifications on the layout design. Therefore, in the future, the modulation-involved desense problems can be solved in a new applicable method for engineers.

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THE LEGAL PERILS OF CUSTOMER SERVICE

How to Help You and Your Customer

A manufacturer's duties are very broad and encompass many different layers of the chain of production. In addition, some of these duties extend to those in the chain of distribution, namely, distributors, dealers, retailers, and service personnel.

Here are some of the types of customer service advice that can create the most significant risks:

- Pre-sale advice by the manufacturers of the finished product (original equipment manufacturer, or OEM) to an end customer who wants help in deciding what product to buy and how to use it safely and correctly.
- Pre-sale advice from the customer service personnel of a component parts supplier to an OEM or a higher tier supplier who wants to know what component to buy and how to use it or install it correctly.
- Post-sale advice from customer service personnel to customers as to how to use the product safely. This could help the customer with assembly or installation, or to help solve a specific problem.
- Post-sale investigations after a customer has suffered an incident or a "near miss." The incidents could involve the product not operating properly or damage to the product or other property, injury, and death.

Kenneth Ross is a Senior Contributor to *In Compliance Magazine*, and a former partner and now Of Counsel to Bowman and Brooke LLP. He provides legal and practical advice to manufacturers and other product sellers in all areas of product safety, regulatory compliance, and product liability prevention, including risk assessment, design, warnings and instructions, safety management, litigation management, post-sale duties, recalls, dealing with the CPSC, contracts and document management. Ross can be reached at 952-210-2212 or at kenrossesq@gmail.com. Ken's other articles can be accessed at https://incompliancemag.com/author/kennethross.

By Kenneth Ross

- Post-sale advice to customers about a recall, repair, or some other corrective action undertaken to fix a safety issue involving the product.

This article will discuss the legal responsibilities of different entities in the supply chain and offer practical advice on how to meet those responsibilities.

PRE-SALE LAW

Rarely are totally new products manufactured that don't evolve from earlier products made by that OEM or another OEM. Therefore, there is lots of information that has been developed or should have been developed that will inform an OEM about the safety and quality of a predecessor product, how consumers use similar products, and what kinds of problems consumers have when using the product.

Any manufacturer of a finished product or a component part needs to consider this information, especially on prior product designs, and how the products have been used and misused in the past. Is this information available, adequate, misleading, incomplete, overstated, or understated? Does the manufacturer need to search their databases to find such information received from consumers or talk to dealers and retailers about problems earlier consumers have had or almost had? And are competitors of similar products having the same or other problems?

Some of this information can be found in the various U.S. Consumer Product Safety Commission (CPSC) incident databases or by simple internet searches using keywords for the finished product or component. There are also legal databases that keep track of some lawsuits and settlements or verdicts involving those products. Also, some trade associations or standards groups might be willing to inform you about product problems, incidents, and lawsuits involving that category of products.

Gathering all the information that is readily available will be helpful in identifying problems or potential problems that need to be considered by the manufacturer as they design a new product or redesign an earlier version of the product. This information then can be considered during the manufacturer's risk assessment.

If the manufacturer misses pertinent information from consumers or elsewhere that might have changed the product's design, warnings, instructions, or marketing literature, they could be liable for selling a defective product and their conduct might be deemed "negligent." With some of this information available, the manufacturer has an opportunity to better anticipate potential problems so that they can take steps to mitigate the risk.

While a lot of this information should be obtained by the design engineers, it is true that much of this information could be obtained by customer service personnel of the manufacturer, the dealer, or the retailer. So someone needs to search for it as it will not get to the design engineers unless someone in customer service believes that it is pertinent to future designs or to fixing a product in the field.

POST-SALE LAW

It is after the sale of the product, whether a finished product or a component product, where customer service is most important. The customer service personnel are the eyes and ears of the manufacturer. Now there are questions, issues, and problems being raised by dealers, retailers, and customers that relate to products that were just sold.

The law is very broad in this area and the consequences of doing a poor job of identifying and analyzing post-sale risks are very significant. In most jurisdictions in the U.S., manufacturing, designing, and selling safe products does not totally satisfy a product manufacturer's legal duties. U.S. courts have held that manufacturers have a duty to warn product users when they learn of risks in their product after sale, even if the product was not defective when sold.

Case law requires manufacturers or product suppliers, in certain instances, to provide post-sale warnings or possibly to recall or repair their products. In analyzing possible post-sale liability, it is important that manufacturers and product suppliers be aware of the factors that may trigger a post-sale duty under common law. In addition, manufacturers and product suppliers need to be familiar with post-sale duties imposed on them by U.S. government agencies and, if the product is sold outside the U.S., by foreign government agencies.

Armed with this knowledge, they can establish procedures to identify and quantify the existence of risks and implement appropriate post-sale remedial measures to prevent or limit their post-sale exposure.

The law concerning post-sale duties is based on negligence. And it is clear that the product does not have to be defective when it was sold. One description of the law is as follows:

> *"One engaged in the business of selling or otherwise distributing products is subject to liability for harm to persons or property caused by the seller's failure to provide a warning after the time of sale or distribution of a product if a reasonable person in the seller's position would provide such a warning."* Restatement 3rd of Torts (Products Liability), American Law Institute.

And the "reasonableness" of the seller is based on these four factors:

1. The seller knows or reasonably should know that the product poses a substantial risk of harm to persons or property; and
2. Those to whom a warning might be provided can be identified and can reasonably be assumed to be unaware of the risk of harm; and
3. A warning can be effectively communicated to and acted on by those to whom a warning might be provided; and
4. The risk of harm is sufficiently great to justify the burden of providing a warning.

Thus, a jury could hold a manufacturer liable for violating its post-sale duties if these four factors are proven.

Customer service personnel will be aware of and provide information to the company that they receive after sale that could help the seller conclude that the product poses a substantial risk of harm to persons or property. And if they don't have this information or didn't provide it to the relevant people in the organization, then the manufacturer could be considered negligent.

On this point, the law says that the general duty of reasonable care may require manufacturers to investigate when reasonable grounds exist for the seller to suspect that a previously unknown risk exists. However, to put some restrictions on this broad duty, the law says that "constantly monitoring product performance in the field is usually too burdensome" and not doing so will not support a claim of violating a post-sale duty.

Despite this language, plaintiffs have tried to use the law to impose a broader duty on product suppliers to establish systems to obtain information from the field. The failure of a manufacturer to set up a system to gather post-sale information and then claim a lack of knowledge may appear unreasonable to a jury, especially when this information could be obtained with little effort and expense.

In addition to receiving calls from customers and dealers, the growth of the Internet and social media has made it even easier to find post-sale information and easier for manufacturers to receive this information from those who want to communicate with them about it. However, much of this information will be unverified, and possibly overstated, inaccurate, or incomplete. Consequently, manufacturers must decide how to follow up and when to investigate such reports to determine the facts and to minimize avoidable problems that these reports identify.

Being aware of all information—good and bad, true and untrue, complete and incomplete—can be helpful if a company can identify and verify the important information, adequately evaluate and document it, and take any warranted corrective actions.

PRE-SALE SAFETY SYSTEMS AND CUSTOMER SERVICE

Obtaining necessary information before the design and sale of the product is an essential part of any manufacturer's product safety management program. Those designing new products, along with the product safety professionals, need to identify the information they need to meet their responsibility to sell a compliant and reasonably safe product. It is going to differ depending on the product, prior experience with similar products made by the manufacturer or others or with safety-critical components, the existence of any standards or regulations that apply to the product, and the occurrence of any incidents, claims, or litigation that pertain to the product or any of its components.

Some of this information is not easy to obtain. And trying to confirm its accuracy and interpret what it means can be difficult. But any diligent manufacturer must try their best to get what information they need or be prepared to explain later why this information isn't important or difficult to obtain.

Customer service personnel can be helpful or harmful in this phase of development. I worked for a component supplier who asked me to interview their customer service personnel about the advice they gave during the sales process. OEMs would call them and ask for a recommendation on which of their components to buy. The customer service personnel didn't know when to give a recommendation and when not to.

Many times, the OEM could not tell the component supplier where the component would be used and the temperatures, pressures, and contaminants to which the component would be subjected. In that case, they weren't sure what component and what size would be appropriate. But they wanted to be helpful and didn't want to jeopardize a sale. I thought it was acceptable to give such advice if they clearly documented what the OEM told them about how the component would be used and told the OEM that their recommendation is based on this information. So, if the information is incorrect or changes later, then the recommendation is not valid. In any case, it should be clear that the final decision is the OEM's and not the component part supplier.

Some component part suppliers tell their customer service personnel that they aren't allowed to give advice even if the OEM knows exactly how they are going to use the component. They want the OEM to rely on the catalogs and other marketing literature to select the correct component. This seems a little too protective and the component part supplier should want to be sure that the OEM purchases the correct component and installs it correctly.

Many times, the component part supplier will know or should know that the component is incorrect for a particular use. However, they don't want to miss out on a sale. When the component doesn't work correctly and litigation ensues, both parties will blame each other, and it is very difficult to figure out who was at fault. Documenting the sales process by customer service personnel can help to understand the history of what was said by different parties.

POST-SALE CUSTOMER SERVICE

When we think of customer service, we usually think of questions and contacts by customers to the OEM's or seller's customer service personnel after sale of the finished product. This is the most important function for customer service and the one that can most impact safety and liability.

Things come up after sale that may indicate a potential or real current or future safety issue, a reporting responsibility to the CPSC, and a possible corrective action or recall with products in the field. What is written or not written, what is investigated or not investigated, and what information is obtained can have a huge impact on future safety actions and help or hurt in the defense of litigation.

After advising companies on product safety efforts over many years, I can say that most companies have customer service programs that could be improved, some significantly. And the lack of good customer service procedures and documentation makes the job of analyzing future safety risks much more difficult. This can result in more accidents, more risk of being fined for late reporting by the CPSC, and more difficulty in defending claims and lawsuits.

One of the main deficiencies in customer service efforts is a reluctance to get sufficient information from a customer or a person who was injured. It is a real dilemma. Customer service views their job as helping the customer, not giving them the third degree to determine what or who caused the accident and injury. However, trying to figure out what happened and what caused it is key to determining how to respond to the customer and what, if anything, needs to be done with products already sold.

Don Mays, in an article in ADK's 2023 Product Safety and Recall Directory, said the following about questions to ask when an injury or damage occurs:

> *"Say, for example, a consumer calls a company and claims that the company's product caught fire. Did the product actually catch fire, or did it almost catch fire? Were there visible flames or was it just smoke or did the product get very hot? Were the flames contained in the product itself, or did they escape the product? Was anyone or anything burned? If someone was burned, did they seek professional medical treatment for the burn or did they self-treat?*
>
> *"If professional medical treatment was sought, was the treatment in a clinic or a hospital emergency room? Were they admitted to the hospital? Was there a diagnosis citing the severity of the injury ... first-, second-, or third-degree burn, for example? Can they provide any documentation or a photo or video evidence of the problem? And should the agent ask for the customer to return the product for further examination by the companies' engineers?"*

An additional problem is deciding what to do about a customer that is clearly exaggerating their injury or describing an accident scenario that is implausible. Challenging a customer's story is very awkward and tricky, given the goal of trying to appease a customer and resolve their problem.

It is hard to ask a mad or grieving customer or parent these questions. But it is imperative to get this information to decide what to do with this contact. Should it be escalated for follow-up by the safety group, or should an investigator contact the customer and do a more professional and comprehensive investigation?

For any matter reported to the CPSC, the agency will want this information so that they can evaluate whether and when a matter should have been reported and what kind of corrective action may be appropriate. In addition, the CPSC may do their own in-depth investigation in which the injured party may also misstate what happened and minimize any mistakes they made in using the product.

GUIDELINES FOR CUSTOMER SERVICE

Every customer service group needs to establish policies and procedures that are appropriate for their product, their risk, their field experience, the type of questions coming from consumers, and the answers that the consumer expects to receive. They are also based on factors such as the experience of the customer service personnel, the customer service scripts that are created and how closely these personnel must stick to the script, how many calls are received monthly and how many of them involve injuries. Also, relevant to consider is the quality and quantity of product safety professionals at the company and their expertise with the products.

There are a number of "best practices" identified by various documents that a company can refer to in setting up a customer service function. These are contained in various standards that talk about product safety, product recalls, and complaint handling. ISO 10002 is an extensive standard that just focuses on complaint-handling procedures. Its title is *"Quality management — Customer satisfaction — Guidelines for complaints handling in organizations."* It has sections on guiding principles, complaints-handling network, planning, design, and development of a complaint-handling system, operation of the process, and maintenance and improvement of the complaint-handling process. Also see ISO 10377 which focuses on product safety and ISO 10393 which deals with recalls.

I have some suggestions from my legal perspective that you should consider. These may or may not be contained in these standards.

- It is acceptable to say that you are sorry that the incident or problem occurred, but don't admit liability unless the company has decided to try to compensate the customer for such an incident.
- Don't discuss other similar problems or incidents that have been reported to the company. However, tell the caller that the company really wants to know what happened and why so that it can try to reduce the chance of incidents similar to theirs happening again.

- Document what the consumer says but make it clear that they are the ones who are saying it. Don't say things to the consumer that make it look like you agree that the product caused the incident and is unsafe.
- If what they tell you sounds implausible, don't tell them that. But ask more questions in a non-judgmental way to try to clarify what really happened and why.
- Develop a list of trigger words which, if used by the customer or dealer, will cause the contact to be escalated to someone higher up in customer service or to someone in the product safety department.
- Don't offer to the consumer any opinions or conclusions as to what you think happened and why unless you are confident that the company will agree with what you say.
- Don't promise to tell them the results of your investigation. But if they insist, tell them that you will have someone report back to them. This should be in writing.
- If someone has been injured, find out exactly what happened prior to the accident. This involves the injured and anyone else who was nearby. Find out about the environment, time of day, weather, lighting, etc. Get detailed information on what happened to the injured and what they did about it – seek medical assistance, where, and what kind of treatment. If they say there was a fire or explosion, don't just take their word for it. Ask more questions as to exactly what happened and what they saw.
- If the caller is willing, do a Facetime, Zoom, or Teams call so you can see them, and they can see you and they can show you the product and show you exactly how they used the product and what happened. Record the call if they agree to it.
- Find out where the product is now. If appropriate, ask if a company person can come see it or if the customer would be willing to send it back for inspection.
- Properly categorize and route the complaint. After your initial investigation is complete, categorize it according to its level of risk and potential for future incidents. Forward the investigation, consumer data, and product data to the proper department in the company.
- Develop monthly reports that clearly show the number of calls, the reasons for the calls, any incidents or near misses, and why they may have occurred, and route the reports to upper management and the Law Department. If you have a product safety committee, also send the reports to committee members and periodically discuss the results of these contacts and investigations with them.
- Select customer service personnel who can ask good questions, ask appropriate follow-up questions, and who can document the answers properly. Train these personnel and other company personnel who may be in contact with customers or suppliers about information gathering and escalation procedures.
- Train dealers about these procedures if customers are likely to contact dealers about safety problems.
- Ask retailers whether they are doing their own investigation and the circumstances in which they request that the customer contact the manufacturer. Inform retailers what kinds of customer contacts should be routed to the manufacturer and how to route them.

CONCLUSION

Every company's complaint-handling process is going to be different. However, the standards and guidelines mentioned in this article are ideas that should be considered when establishing a program. Every company should develop a program that is adequate for their purposes and one that they feel comfortable defending if it is under attack by the CPSC or a plaintiff's attorney.

Whatever you do, someone will argue that you should have done more. The goal of any program is to find out what is helpful to manufacturers and consumers and what might be considered reasonable by a jury. Do the best you can do, document the process, continually evaluate whether it is serving your needs, and improve it if necessary. Whatever you do, you always want to look like you are diligent in learning about safety issues and doing whatever is necessary to solve them and preventing them from occurring again in the future.

RETURN-CURRENT DISTRIBUTION IN A PCB MICROSTRIP LINE CONFIGURATION

Part 1: Solid Reference Plane

By Bogdan Adamczyk and Scott Mee

This is the first article of a two-article series devoted to the return current distribution in a 2-layer FR-4 PCB microstrip line configuration with a solid reference plane. This topic was discussed in [1], where the analytical results for a solid reference plane were presented. In this article, we compare these analytical results to the CST Studio simulation results. Simulation results closely follow the analytical results and give an insight into the details of the return current distribution. In Part 2, we will discuss the return current distribution in the reference plane containing numerous via anti-pads (cutouts).


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Scott Mee is a co-founder and owner at E3 Compliance which specializes in EMC & SIPI design, simulation, pre-compliance testing and diagnostics. He has published and presented numerous articles and papers on EMC. He is an iNARTE certified EMC Engineer and Master EMC Design Engineer. Scott participates in the industrial collaboration with GVSU at the EMC Center.

1. RELEVANT BACKGROUND

In [2], the return path of high-frequency current was discussed for a two-layer PCB configuration shown in Figure 1.

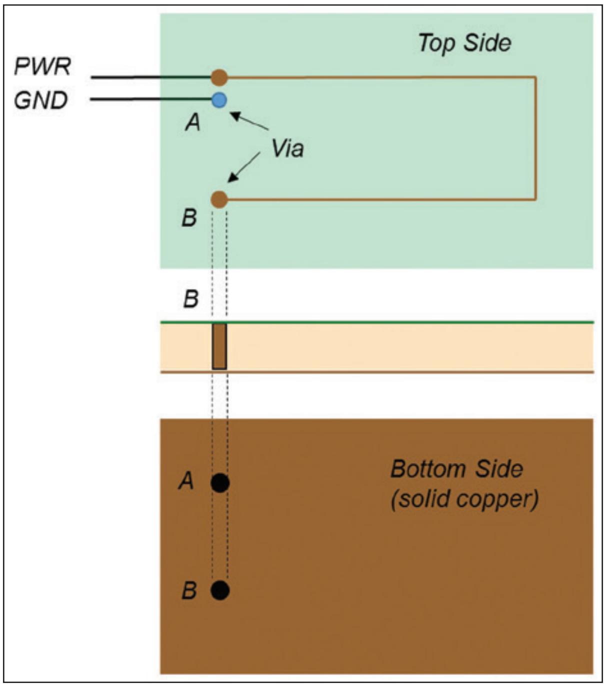

Figure 1: Two-layer PCB with a solid reference plane

At points *A* and *B*, vias connect the top trace to the ground (reference) plane. The forward current flows on the top trace as shown in Figure 2.

Upon reaching the point *B* the current travels to the reference plane and returns to the source (*A*). Current returns to the source through the path of *least impedance*. At high frequencies, the return current takes the path of least inductance, which is directly underneath the forward current trace, because this represents the smallest loop area (smallest inductance).

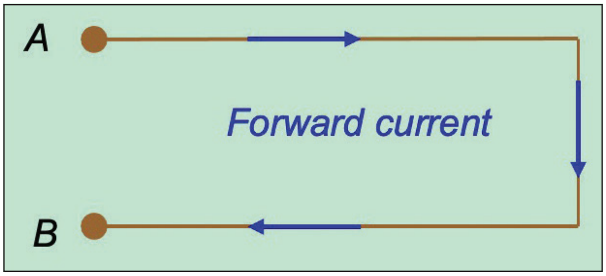

Figure 2: Forward current flow

This is shown in Figure 3 (not drawn to scale).

2. RETURN CURRENT DISTRIBUTION IN THE REFERENCE PLANE - ANALYTICAL RESULTS

The microstrip line geometry is shown in Figure 4, where the trace of width *w* is at a height *h* above a reference plane; *x* is the distance from the center of the trace.

The current distribution in the reference plane underneath the trace is described by its current density [3], *J(x)*:

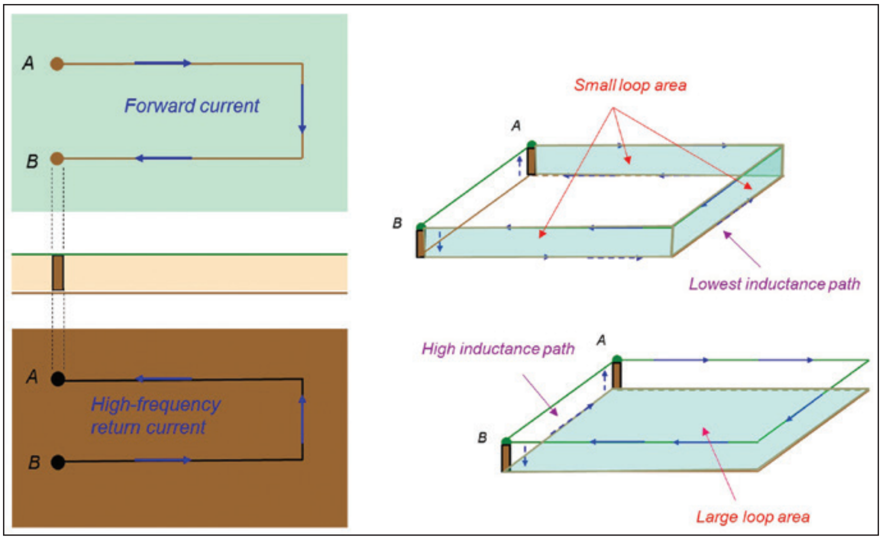

Figure 3: Path of the high-frequency return current

$$J(x) = \frac{I}{w\pi}\left[\tan^{-1}\left(\frac{2x-w}{2h}\right) - \tan^{-1}\left(\frac{2x+w}{2h}\right)\right] \qquad (1)$$

where *I* is the *total current flowing in the loop*. This formula is valid at frequencies where the resistance of the reference return plane is negligible compared to its inductive reactance. This effect will be visualized in the simulation section of this article.

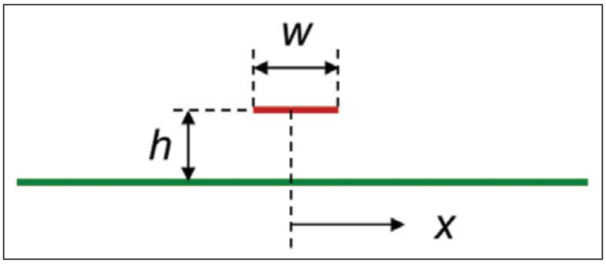

Figure 4: Microstrip line geometry

The current density underneath the center of the trace is:

$$J(0) = \frac{I}{w\pi}\left[\tan^{-1}\left(\frac{-w}{2h}\right) - \tan^{-1}\left(\frac{w}{2h}\right)\right] \qquad (2)$$

Figure 5 shows the MATLAB plot of (normalized) current density underneath a trace as a function of *x/h*.

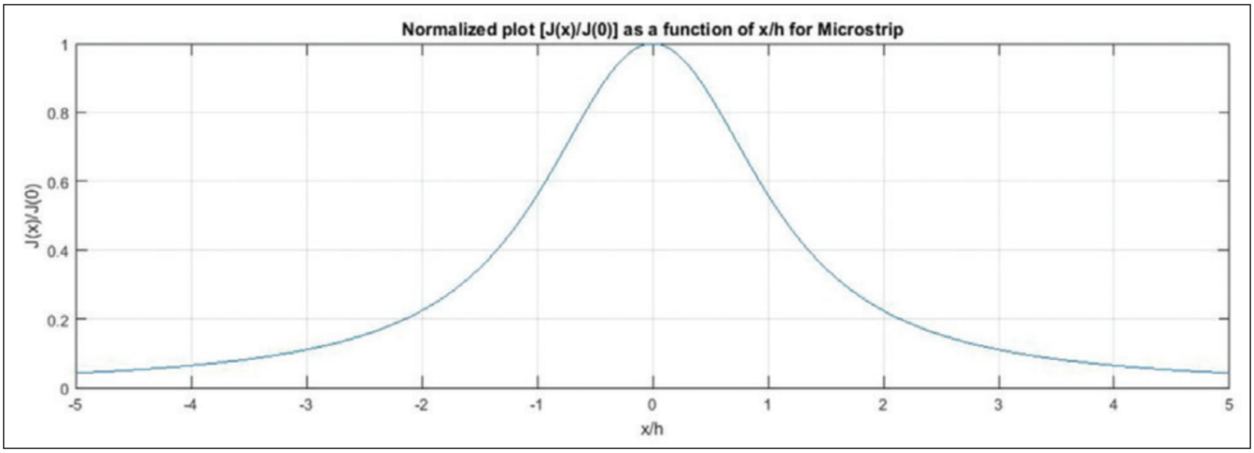

Figure 5: Current density underneath a microstrip trace

Note that most of the current tends to remain close to the area underneath the trace. As the distance from the center underneath the trace increases the current density becomes smaller.

3. RETURN CURRENT DISTRIBUTION IN THE REFERENCE PLANE – SIMULATION RESULTS

Let's verify the analytical results of the previous section through simulation. Figure 6 shows the CST Studio model of a two-layer PCB with a solid copper reference return plane and a microstrip trace on the top layer. A source signal having an impedance of 50 ohms is used to excite the model.

Figure 7 shows the return current path (forward current trace is hidden) flowing in the reference plane at different frequencies.

Observations: At 10 Hz the return current spreads wide over the reference plane, flowing both under the top trace and directly from the load port to the source port. As the frequency increases to 100 Hz, more of the return current flows under the trace (with a narrower spread), and less of it flows directly from the load port to the source port. This trend continues as the frequency increases to 1 kHz.

The results for 10 kHz and beyond show something very interesting. As the frequency increases beyond 10kHz, the return current path remains virtually unchanged, predominantly flowing beneath the forward trace. In other words, the return current path and current density no longer depend on frequency. The frequency is high enough that the resistance of the return plane is negligible compared to its inductive reactance, [3].

This phenomenon is explained in [4], as follows: "The current distribution, ..., balances two opposing forces. Were the current more tightly drawn together, it would have higher inductance (a skinny wire has more inductance than a broad, flat one). Were the current spread farther apart from the signal trace, the total loop area between the outgoing and returning signal paths would increase, raising the inductance."

Figure 8 shows the details of the PCB simulation model used to plot the current density distribution. A straight line that cuts down the middle of the longitudinal axis of the reference plane is used to obtain the simulated magnitude of the current density.

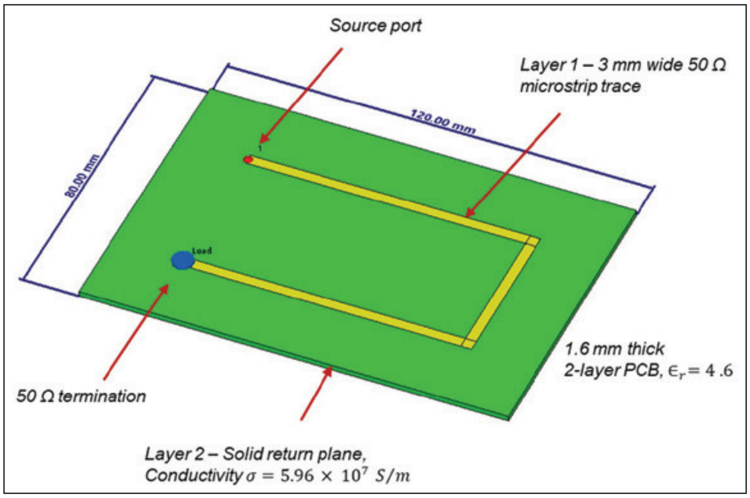

Figure 6: CST Model – Two-layer PCB with solid reference return plane

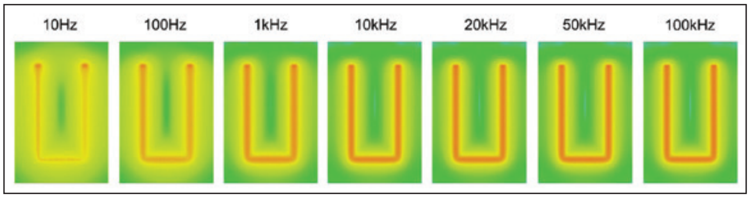

Figure 7: Return current path at different frequencies

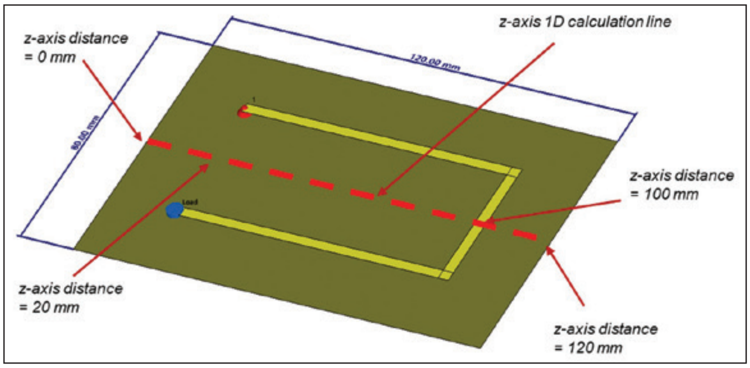

Figure 8: Board geometry and the centerline location

Normalized current distributions at different frequencies along the z-axis are shown in Figure 9.

When the frequency is above 10 kHz, the current distribution is virtually unaltered, i.e., does not depend on frequency, and predominantly remains underneath the forward trace. This is consistent with the result presented earlier in Figure 7.

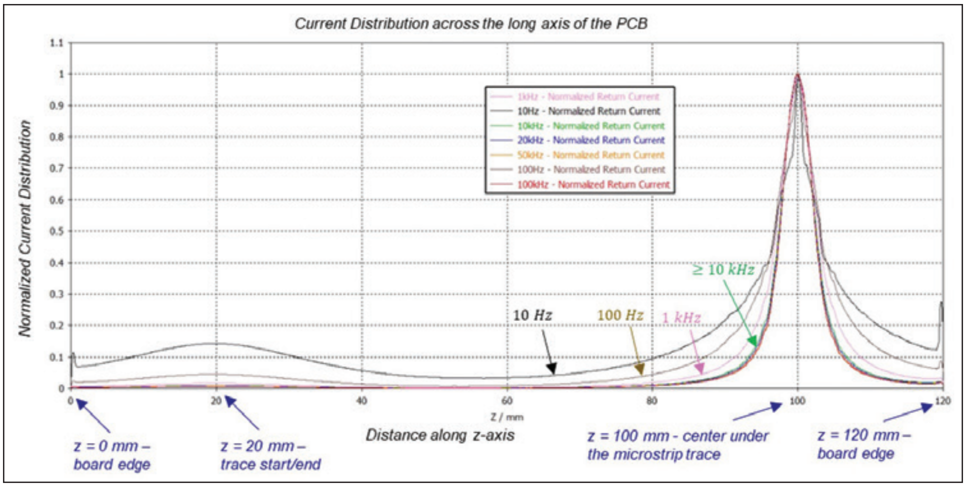

Figure 9: Normalized current distributions at different frequencies

The next article will discuss the return plane current distribution for a PCB with numerous via anti-pads (cutouts) in the reference plane, shown in Figure 10.

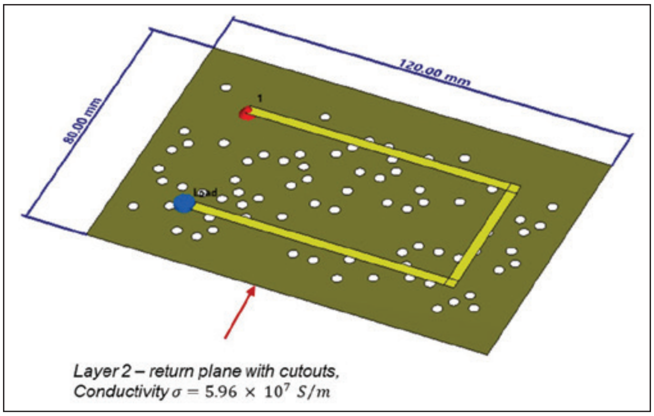

Figure 10: PCB with cutouts in the reference plane

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CAN ELECTROSTATIC DISCHARGE DESIGN PROBLEMS BE SOLVED WITH ELECTRONIC DESIGN AUTOMATION TOOLS ALONE?

Part 1: What are EDA tools good for?

By Michael Khazhinsky, Eleonora Gevinti, Krzysztof Domanski, Guido Quax, and Matthew Hogan for EOS/ESD Association, Inc.

Going back several decades, Electrostatic Discharge (ESD) design and layout checks that were done manually were laborious and time-consuming, let alone not confidently reliable. These issues have been exacerbated by more advanced technologies along with the introduction of System on Chip (SoC) with digital, analog, and RF domains interacting. Thus, the complexity of ESD design verification needed sophisticated tools to bring in efficiency.

Nowadays, Electronic Design Automation (EDA) tools are particularly good at performing a considerable number of verification tasks in a very short time for ESD robustness and efficiency at both the schematic and layout levels on a broad spectrum of aspects. They brilliantly solve the well-known past issues of error-prone manual verifications. EDA tools' flexibility allows one to employ them in every phase of the project design (from early debugging to final sign-off). They can be used directly by IC designers if a conscious usage is made. The involvement of ESD experts can be minimized during development.

The EDA checks can efficiently span a huge multitude of objects present in schematic and layout (components, circuits, nets, layers, properties) within a relatively short time. EDA tool precision can be tuned to obtain an advantageous tradeoff between accuracy and runtime. This is important to get complete verification results in time for a project design tape out.

Contemporary ESD EDA check tools can be divided into static and dynamic. The dynamic tools rely on electrical simulations of the ESD network, whereas the static tools rely on hard-coded rules predefined in runsets. Static checks are regarded as more reliable than dynamic checks for standard (general-purpose) architectures. Static checks are widely used in the industry and offered by many vendors and foundries.

The contemporary static-check tools constitute a flow that encompasses several aspects of ESD codesign, extracting information from schematics (circuit topology) and layout (resistance/current capability of metallization). If properly executed and defined, these checks can

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Founded in 1982, EOS/ESD Association, Inc. is a not for profit, professional organization, dedicated to education and furthering the technology Electrostatic Discharge (ESD) control and prevention. EOS/ESD Association, Inc. sponsors educational programs, develops ESD control and measurement standards, holds international technical symposiums, workshops, tutorials, and fosters the exchange of technical information among its members and others.

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ensure high-quality ESD protection for projects with standardized architecture. In modern design packages, a clean output of ESD sign-off flow reassures successful ESD qualification of hardware.

EDA tools can be used as a safeguard for basic defined rules to avoid compromised ESD design mistakes. At the schematic level, the driver/receiver construction can be checked, including proper sizing, ballasting, or driver stacking. The existence and connection of primary ESD discharge paths via diodes, power, and local clamps can be reliably proven in schematics. Also, the placement and sizing of anti-parallel diode pairs between grounds can be easily checked using schematic-based topological checks. While this can still be managed manually in many cases, EDA tools help with sign-off automation. Furthermore, several advanced topologies can be detected by EDA schematic tools, e.g., vulnerable devices at signal cross domains (Figure 1).

The static-check tools executed on layouts can assess the hook-up resistance and current density for the typical ESD device in the discharge path providing advanced analysis capabilities (Figure 2). In complex ESD design cases involving large, distributed rail clamp networks, the EDA tools involving the layout can be used to simulate ESD events including the distributed metal bus resistance. These are static simulations. However, dynamic EDA checks are indispensable for special pads. A reliable dynamic checker could even be a competitive differentiator for the company.

While there are examples of commercial dynamic EDA tools, many large companies develop their own dynamic EDA tools and methods to secure competitive performance of, for example, high-speed interfaces with a tight capacitive load budget for ESD protection. Overall, one can state that the benefits of using EDA tools increase with the complexity of the ESD design.

In Part 2 of the article, we will discuss the limitations of EDA tools.

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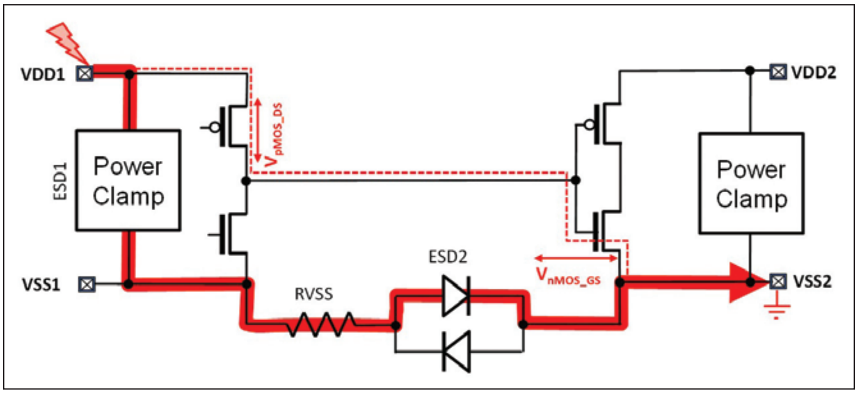


Figure 1: Typical signal cross-domain ESD issue detected using schematic-based topological EDA tool [1].

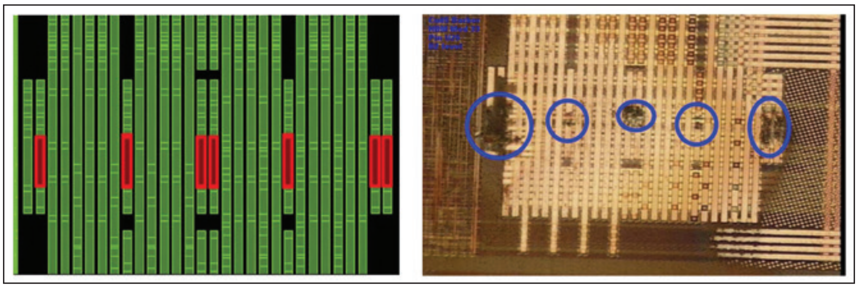
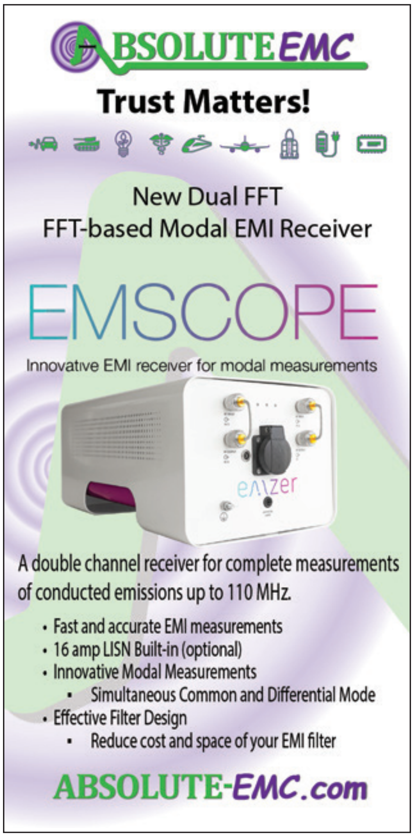
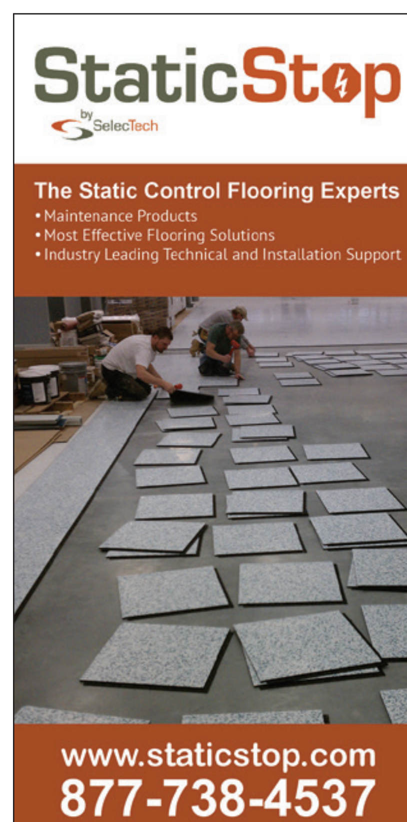


Figure 2: Screenshot of the results of the current density-based EDA tool run, showing regions of high current spots greater than the allowed maximum current densities in a metal bus (left). Optical image of a part after failure analysis, showing regions of BEOL failure matching the predicted failure regions by the current density-based EDA tool (right) [2].

PRODUCT Showcase





LOCATING THE NOISE SOURCE OF THE 10-30 MHZ "HUMP"

By Dr. Min Zhang

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Many of my clients are power electronics companies that specialize in making switched-mode power supplies and motor drives. During the conducted emission tests, one of the challenges these manufacturers face is the resonance peaks in the harmonic noise somewhere between 10 MHz and 30 MHz. Often, no amount of filtering will eradicate or attenuate the peak. This is so typical that it is worth investigating the root causes of these peaks.

WHAT CAUSED THE "HUMP"?

In Reference 1, Williams explains in great detail that the "hump" in the 20 MHz is caused by the structural resonance introduced by the test set-up. The circuit under test normally has a front-end filter which often consists of common-mode capacitors and inductance. The main power conversion stage usually utilizes magnetic components such as a transformer or inductor, which itself has parasitic capacitance. The DUT is connected to a LISN by a cable (often longer than 1 meter), so the common mode transfer function of the set-up (including the circuit, the cable, and the LISN) has a few poles and zeros, indicating multiple resonance points.

When the circuit is energized with multiple energy sources (hard-switching devices in the circuit), it will show the resonance peak in the test results. As in the 10s of MHz frequency range, it is the rise time of the switching event that determines the energy level. It is safe to conclude that the resonance peak is caused by how hard the switching event is (rise time) rather than how often it is switched (frequency).

It is also worth mentioning that in 10s of MHz, the conducted emission of a switched-mode power supply is predominantly common mode.

HOW TO LOCATE THE NOISE SOURCE

As explained earlier, a switched-mode power supply often consists of multi-stage converters, which means there could be multiple noise sources. A typical example is an AC-DC converter, where the AC to DC high-voltage (HV) stage often includes a power factor correction (PFC) circuit (buck or boost type). From the DC HV to DC low-voltage (LV) stage, the circuit can be a flyback, an LLC, a dual active bridge (DAB) or a phase-shift full bridge, depending on the power level. In this particular case, design engineers often face challenges in determining whether the resonance peak is caused by the PFC circuit, the DC-DC converter, or both.

To locate the noise source, it is essential to understand the relationship between the time domain and the frequency domain. A resonance peak observed in the frequency domain can also be observed in the time domain. Wyatt provides a demonstration of this concept in a video [2].

Here, we present a case study demonstrating how to locate the noise source in a motor drive circuit. The method is based on techniques introduced in Reference [3]. In Figure 1, we can observe a 10 MHz resonance peak in the conducted emission results. The motor drive unit comprises an AC-to-DC power converter stage (with active power factor correction), a DC-to-DC power converter stage, and a DC-to-three-phase motor drive circuit. It is crucial to identify which circuit in this product is responsible for the 10 MHz "hump."

Figure 2 illustrates the setup for locating the noise source. An RF current probe is positioned on the mains cable and connected to the 50-ohm input of an oscilloscope (channel 2 in this case). Channel 1 of the oscilloscope (also configured to be a 50-ohm input) is connected to a near-field probe. The measurement result from the RF current probe serves as a stable trigger. By moving the near-field probe to accessible parts of the system, we can compare the noise signal picked up by the near-field probe with the RF current probe signal. The noise signal picked up by the near-field probe can be in phase or anti-phase compared with the RF probe.

After zooming in on the noise signal captured by the RF current probe, we can observe the 10 MHz ringing on the oscilloscope. If the near-field probe also displays a similar ringing pattern, we can conclude that the noise source has been located. In Figure 2, it is evident that both channels exhibit a 10 MHz ringing when the near-field probe is positioned near the PFC circuit.

Once the noise source is identified, we can proceed to develop strategies for mitigating its impact. In this case, the solution involves optimizing the RC snubber circuit of the PFC circuit, which utilizes a SiC MOSFET. The high noise level experienced can be attributed to the SiC MOSFET. By implementing improvements to the RC snubber circuit, we can effectively reduce the noise generated by the PFC circuit.

REFERENCES

1. T. Williams, *EMC for Product Designers,* Fifth edition, Newnes, 2017.
2. K. Wyatt, "Switch-Mode Power Supply - Ringing Demo." https://youtu.be/dHDAuxRcReo
3. D. C. Smith, *High Frequency Measurements and Noise in Electric Circuits,* Springer, 1992.

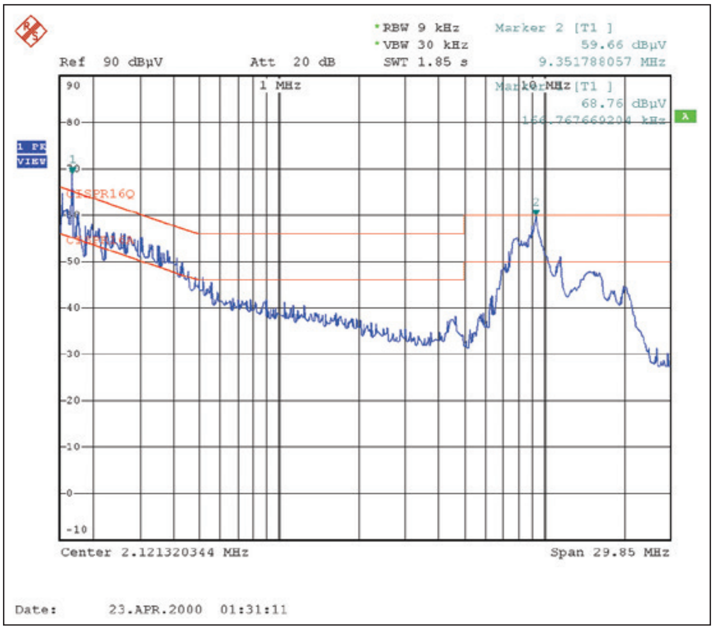

Figure 1: Conducted emission results show a 10 MHz hump

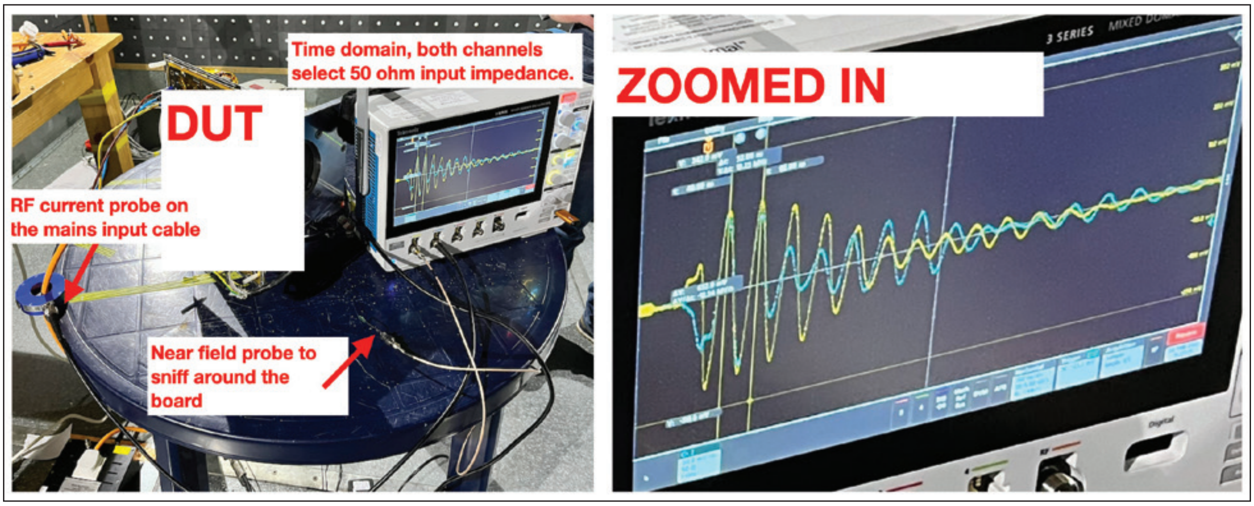

Figure 2: Locating the noise source with an RF current probe and a near-field probe

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September 4-8
EMC Europe

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The Battery Show

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2023 Minnesota EMC Event

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October 4-6
The Battery Show India

October 8-13
45th Annual Meeting and Symposium of the Antenna Measurement Techniques Association (AMTA)

November 7-9
Fundamentals of Random Vibration and Shock Testing Training

December 4-7
Military Standards 810 (MIL-STD-810) Test Training

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Introduction
Tyler Helps
NORTH AMERICA


System: modular and pluggable

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