Educational Note

TEN REASONS TO UPGRADE YOUR MIL-STD-461 TEST CAPABILITIES

Products:

- ► R&S®ESW EMI Test Receiver
- ► R&S®RTO Oscilloscopes
- ► R&S®RTP Oscilloscopes
- ► R&S®SMB100B RF Signal Generator
- ► R&S®BBA130 Broadband Amplifiers
- ► R&S®AdVISE Software
- ► R&S®ELEKTRA Software

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Contents

OVERVIEW

With the ongoing modernization and technology insertions in the defense industry, the military has been able to take advantage of rapidly evolving commercial technologies and field these technologies within the armed forces. These technologies include computer chips, electronic interfaces, RF and microwave technologies, and even complete commercial wireless communication standards like WiFi and cellular technologies.

Since the 1990's and the new age of information, consumer technologies have also adopted stricter EMC standards that include both emissions and immunity (susceptibility) standards. These have become compulsory to enter the worldwide market. Device compatibility and the real-world electromagnetic environment continue to evolve in commercial EMC requirements.

While MIL-STD-EMC will continue to have requirements that differ and go beyond commercial standards in many areas, the ongoing evolution of the MIL-STD-461 standard has adopted some commercial EMC practices, when these have proven to be best for the industry. These examples include the deferral of EMI measurement receivers to the ongoing evolution with the ANSI C-63.2 standards and the adoption of the new indirect lightning and electrostatic discharge (ESD) testing that have roots in the IEC 61000 series immunity standards. The changes also include self-verification requirements like those from SAE AIR6236 that put more onus on test verification procedures on an ongoing basis for the lab.

With the release of MIL-STD-461G in 2015, the culmination of advances in test equipment and test methodologies offer new opportunities for test labs in terms of test coverage, test throughput, and more. These improvements include improvements in modern receivers defined by ANSI-C63.4 (and subsequently CISPR 16-1-1); reductions in human error through automation; and enhancements and new requirements to fulfill susceptibility testing.

With faster computational speeds, high fidelity, and more automation to reduce human error, these evolutions provide a foundation for the ten reasons we believe the time is right to upgrade your test lab to support MIL-STD-461G. This application note presents 10 areas of test that have been impacted by substantial modernization in test equipment and methodologies.

Modern Receiver Performance

Initially, compliant receivers were based on swept-tuned spectrum analyzer architectures. Front-end measurement hardware (e.g., mixers, filters) included high-performance analog technologies capable of meeting stringent test standards: precise intermediate frequency (IF) bandwidths; amplitude accuracy of at least ±2 dB; wide dynamic range; and specific detector types (e.g., peak, quasi-peak, average; MIL-STD testing uses only the peak detector). Frequency coverage includes a range of relevant fundamentals as well as harmonics as high as the fifth. With these specialized capabilities, a compliant EMI receiver typically costs more than a spectrum or signal analyzer that covers the same frequency range.

With an FFT-based Time Domain Scan (TDS), the R&S®ESW captures and weights disturbance spectra in virtually no time (Figure 1). The instrument's real-time spectrum analysis capability with spectrogram display permits a detailed analysis of disturbance signals and their history. The R&S®ESW meets the most stringent requirements for certification measurements in line with CISPR, EN, MIL-STD-461, DO-160 and FCC.

Figure 1. The R&S®ESW has outstanding RF characteristics, including high dynamic range and measurement accuracy.

Reason 1: Reduce measurement time without affecting accuracy

Performing time-domain scan (TDS) with an FFT receiver can reduce measurement times by a factor of up to 45. Fortunately, these exceptionally fast measurements do not affect the accuracy of the highly sensitive receivers needed to perform compliant measurements. Working in concert, the built-in analog and digital technologies deliver accuracies that meet or exceed the requirements of the relevant test standards.

Table 1 provides a comparison across five commonly measured spans. The time advantages are especially large when measuring wide spans with narrower resolution bandwidths (e.g., 10 kHz, 100 kHz), which require long dwell times (or settling times) when implemented with analog filters.

Frequency band	Resolution bandwidth	Analog sweep rate	Time	FFT mode dwell time	Time	Speed improvement
150 kHz to 30 MHz	10 kHz	1.5 s/MHz	45 s	1 s	~1 s	~45x
30 MHz to 200 MHz	100 kHz	0.15 s/MHz	25.5 s	150 ms	~1 s	~25.5x
200 MHz to 1 GHz	100 kHz	0.15 s/MHz	120 s	150 ms	~4 s	~30x
1 GHz to 18 GHz	1 MHz	15 s/GHz	255 s	15 ms	9.5 s	~27x
18 GHz to 40 GHz	1 MHz	15 s/GHz	330 s	15 ms	15 s	~22x

Table 1. Considering the typical range of required tests and spans, TDS provides a tremendous cumulative advantage in measurement time over the course of a day or week

To further emphasize the benefits of modern receivers, one must also consider product family standards that might have notch or guard band requirements for radiated emissions testing. Figure 2 is an example of a product family standard that requires up to a 25 dB notch at 2.3 GHz. The only way to achieve an acceptable noise floor margin at those frequencies would be to reduce the resolution bandwidth and analog sweep rate accordingly to achieve a reduced noise floor. In these cases where the spans can be hundreds of megahertz, the speed improvements can be several orders of magnitude faster saving hours and even days of test time.

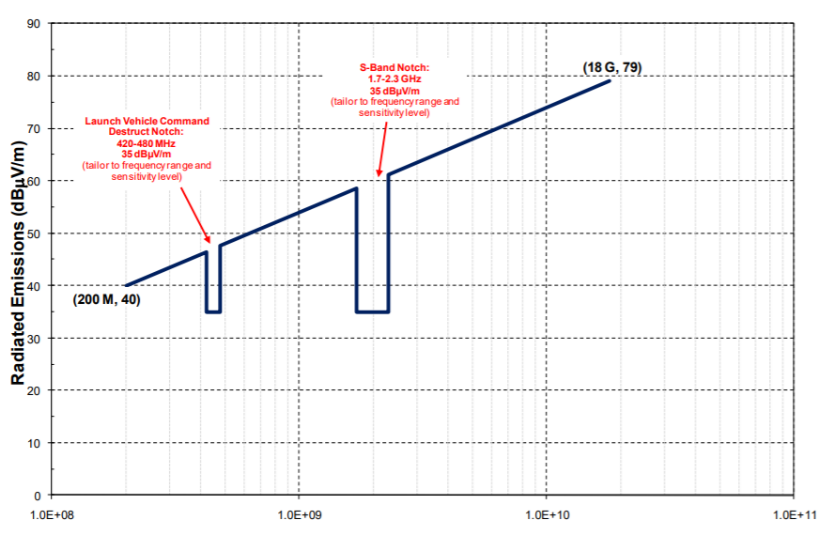

Figure 2.5-19. Radiated Emissions Electric Field Limit with Suggested Notches

Figure 2 Example of radiated emissions notch testing required for product family testing (source GSFC-STD-7000A)

Reason 2: FFT mode improves reproducibility and offers real time diagnostics

If the equipment-under-test (EUT) produces a "fail" result, FFT mode and real-time spectrum analysis can help you determine why. FFT mode enhances the ability to capture intermittent signals in two ways: it provides very good frequency resolution, and it delivers very fast spectrum updates.

The architecture of the FFT receiver also supports real-time spectrum analysis, which is a truly revolutionary tool for diagnosing EMI problems. When using measurement spans at or below the specified real-time bandwidth (e.g., 80 MHz), the analyzer provides gap-free acquisition and analysis of the incoming signals. This helps reveal “signals under signals” and can resolve pulses of extremely short duration.

A variety of display options make it easier to view and interpret real-time spectra. One of the most useful types is the spectrogram, which shows continuously scrolling frequency spectra versus time, with color-coding used to indicate relative amplitude (Figure 3, lower trace).

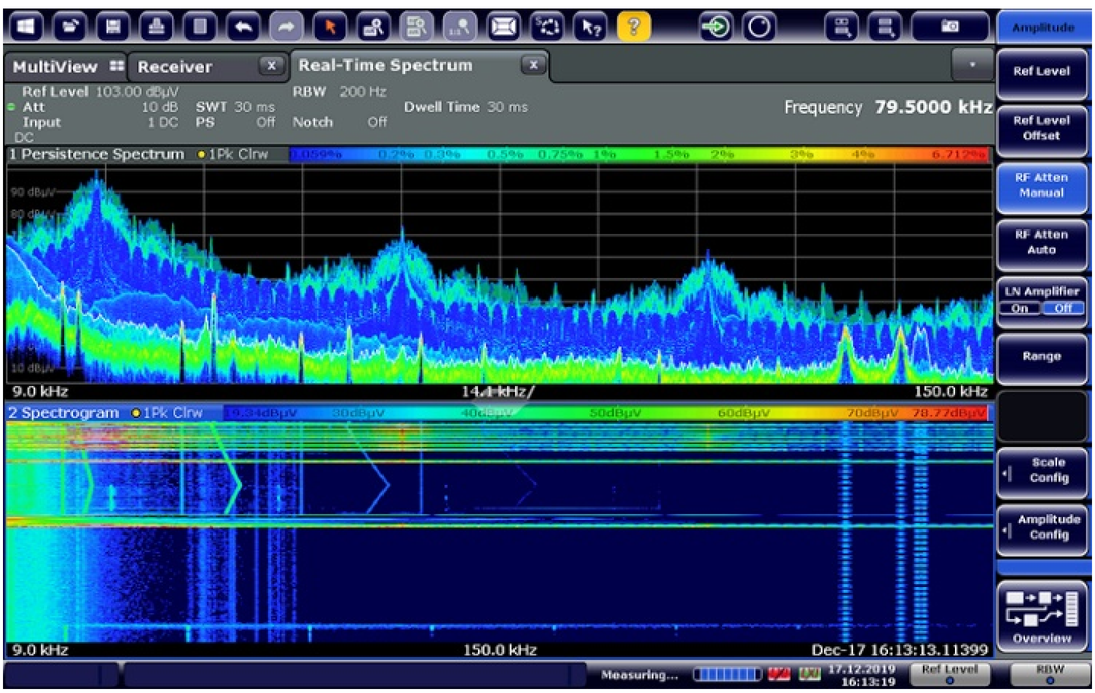

Figure 3. Displays such as the persistence spectrum (upper trace) and the spectrogram (lower trace) provide informative views of real-time signal behavior.

Two important notes are worth mentioning. *The bad news*: this highly informative mode cannot be used to perform standards-compliant measurements; an EMI receiver compliant with the stringent dynamic-range requirements of CISPR 16-1-1 is still required. *The good news*: Excellent for EMI debugging - the real-time spectrum analysis is a highly effective way to troubleshoot and diagnose problems related to conducted and radiated emissions.

These capabilities offer tremendous advantages in lab efficiency and throughput. While those benefits alone may be reason enough to consider upgrading your lab to the full extent of MIL-STD-461G, we have compiled a longer list.

Reason 3: Preselection reduces the opportunity for invalid results

Because EMI receivers are used to characterize unknown signals, additional filtering is needed to ensure accurate measurement results. Special-purpose filters called preselectors suppress signals above or below each measurement band, preventing out-of-band energy from reaching the first mixer stage within the receiver. These filters are most effectively implemented as a switchable bank—low-pass, band-pass or high-pass—that addresses specific frequency ranges.

Preselection is one of the key differences between test receivers and spectrum analyzers. In an EMI test receiver, the additional filtering ensures the accuracy and selectivity needed to be compliant with EMC standards. These are implemented most effectively as a switchable bank of filters:

- Low-pass: below 150 kHz
- Bandpass: 150 kHz to 2 MHz; 2 to 8 MHz; 8 to 25 MHz; 25 to 80 MHz; 80 to 200 MHz; 200 to 500 MHz; 500 to 1,000 MHz
- High-pass: above 1 GHz

Figure 4. Without preselection (green trace), incoming signals may overload the receiver front-end. Preselection (yellow trace) helps prevent bad data and ensure valid measurement results.

Failure to protect the mixer in a spectrum-measuring instrument can easily lead to inaccurate measurement results in two main ways: the first is overload or compression of the mixer due one or more to high power signals and the second is the creation of spurious mixing products. Both of these can, and frequently are, caused by signals that are outside of our span or current measurement range. The most effective solution to this problem is preselection, which is typically implemented as a switchable filter bank. Proper implementation of preselection reduces both the number and level of undesired mixer inputs, which in turn reduces overload and spurious mixing products. Preselection is essential for almost all types of EMI testing. Aside from the obvious advantage of using preselection to measure unknown and uncontrolled signals, preselection is also required by the CISPR 16-1 group of standards, and this is particularly true when making accurate and compliant measurements of pulsed signals with a low pulse repetition frequency.

Reason 4: Extend intentional radiator testing up to 500 GHz

Emerging technologies in applications such as radar systems and wireless communications (e.g., 5G) continue to reach higher into the gigahertz range. When assessing intentional radiators, most EMI standards mandate measurements of not just the fundamental but also its harmonics. For example, the U.S. Federal Communications Commission (FCC) requires measurements up to the fifth harmonic when testing radiated spurious emissions (RSE).

As another example, commercial LTE/4G/5G specifications require the ability to measure up to the second harmonic when testing RSE. This is relevant to MIL-STD-capable test labs because every branch of the U.S. military has announced plans to adopt and use commercial 5G technology. When a commercial 5G device is repurposed or modified for purpose in a defense application, it still must meet the FCC requirements. In existing aerospace and defense applications, interferers are already being measured at 110 GHz and higher.

RSE tests are typically performed with a spectrum analyzer; however, most have a top-end frequency of 40 to 44 GHz. One viable solution is the use of harmonic mixers that translate higher frequencies downward to be within the measurement range of a receiver or analyzer. R&S offers solutions that enable measurements up to 500 GHz. With the R&S®ESW EMI test receiver, this is implemented using Option ESW-B21, LO/IF ports for external mixers, and a variety of R&S harmonic mixers (models FS-Zxx).

With their double-diode design, the mixers operate without any additional biasing. Frequency-dependent conversion loss is calibrated over the entire frequency range, and the associated conversion-loss table can be loaded directly into the analyzer, simplifying mixer configuration.

Figure 5 The R&S®ESW EMI test receiver uses Option ESW-B21, LO/IF ports for external mixers, to enable a variety of R&S harmonic mixers

Automation Reduces Human Error

Reason 5: Ensure reliable collection, evaluation and documentation of measurement results

In a busy test lab, one crucial key to success is the ability to get the measurement right the first time. Because many of the required procedures have become very complex, manual testing increases the likelihood of human error for even the most experienced engineers and technicians. Automated testing based on the relevant standards helps enable reliable collection, evaluation and documentation of measurement results. For example, predefined settings and templates ensure adherence to the required methods.

R&S®ELEKTRA controls complete EMC systems and automates measurements of EUTs being certified for emissions and immunity (EMI and EMS, respectively). The software simplifies configuration of test systems and test descriptions in accordance with common standards. It also speeds up test execution and simplifies the generation of comprehensive test reports (Figure 6).

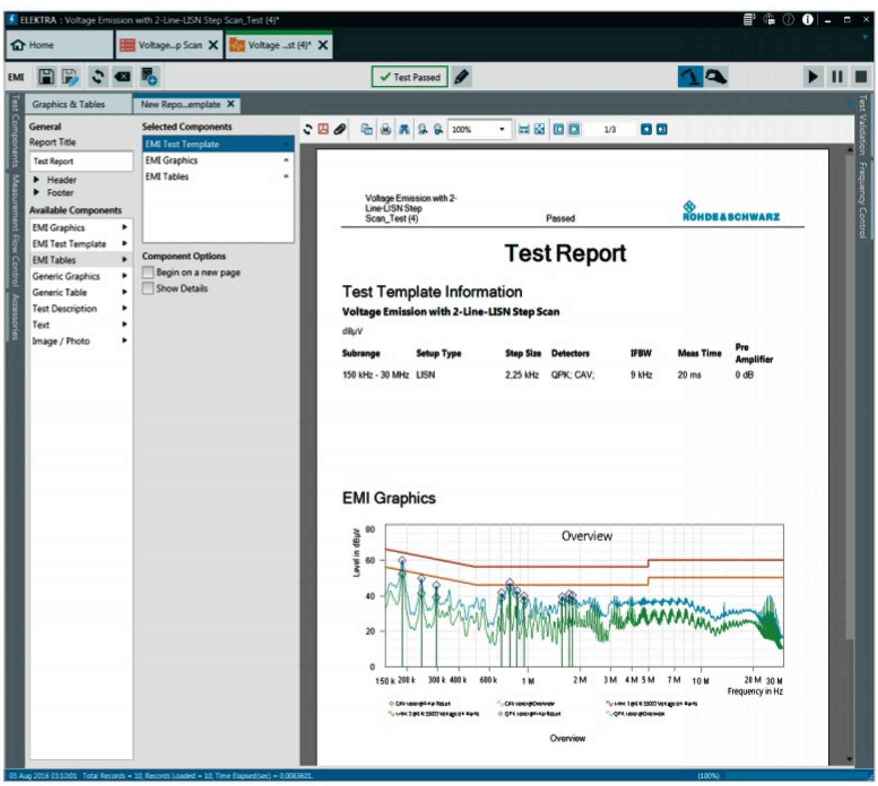

Figure 6. The R&S®ELECTRA software makes it easy to create reports for tests such as this measurement of disturbance voltage.

The software ensures efficient operation through its sleek, modern user interface. The UI offers an all-on-one-page design that provides access to all required settings and selections without the need to navigate through multiple windows. To improve test efficiency, the software includes keyword search plus the ability to tag and pin favorite items onto the dashboard for instant access.

Reason 6: Modern receivers simplify setup and reduce access to compliant parameters

The capabilities built into the latest EMI test receivers do even more to reduce the potential for human error. One key example: calculation of sweep time versus the number of measurement points. This must be done manually when using a typical spectrum analyzer. In contrast, instruments such as the R&S®ESW EMI test receiver allow the user to select values taken directly from Table II of MIL-STD-461G, ensuring the configuration of compliant measurement settings (Figure 7).

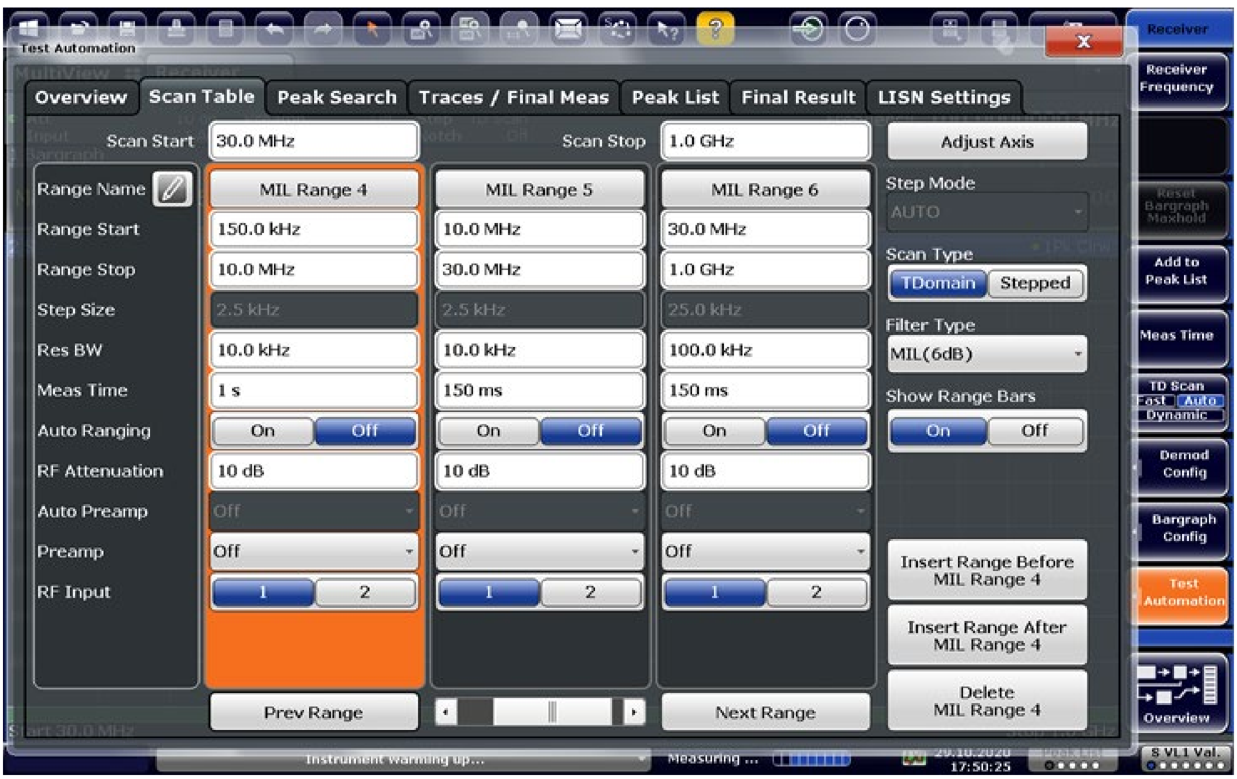

Figure 7. Modern EMI receivers simplify setup and reduce access to compliant parameters. In this example, measurement time is the only user-accessible variable.

Reason 7: Visual and audio inspection software captures 100% of occurrences

Video and audio inspection software captures 100 percent of all occurrences. This overcomes human inattention, ensures reproducible results, and simplifies test documentation. For example, R&S®AdVISE visual inspection software automates the process of visually monitoring the EUT during a test sequence (Figure 8). The software analyzes video in real time using "regions of interest." It can monitor up to 32 regions at 30 frames per second, applying automatic error recognition to identify faulty tests. A typical application is EMS testing with R&S®EMC32 and R&S®ELEKTRA test software. In addition to EMC testing, R&S®AdVISE lends itself to many other applications.

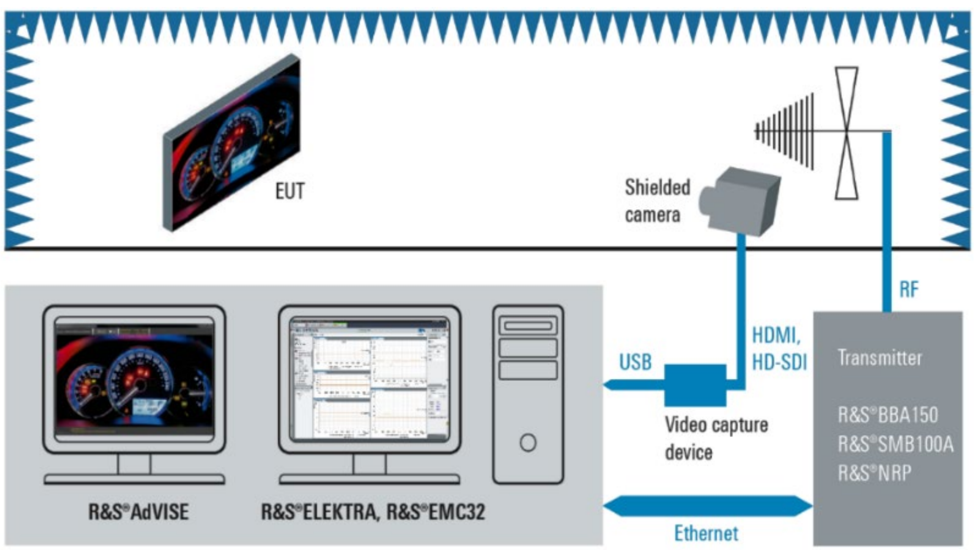

Figure 8. R&S®AdVISE can run independently or under the control of system software such as R&S®ELEKTRA or R&S®EMC32.

Enhance Your Susceptibility Testing

Reason 8: Reduce complexity and avoid excessive power in CS114 conducted testing

In MIL-STD-461G, section CS114 is a test for conducted susceptibility via direct injection of electrical current into the EUT. Also called bulk cable injection or bulk current injection, BCI is used to verify the ability of the EUT to withstand RF signals coupled onto any associated cabling.

The most commonly used test setups are quite complex, involving a signal generator, an external amplifier, two measurement receivers, and a variety of test accessories. The test process includes separate setups for calibration and verification.

The use of an RF signal generator with high output power (e.g., 2 watts) may eliminate the need for the external amplifier when testing versus four of the five required test curves. The R&S®SMB100B RF signal generator is all about performance and versatility in a small footprint (Figure 9). Available frequency ranges span 8 kHz to 1, 3 or 6 GHz. Outstanding spectral purity and high output power combined with comprehensive functionality and simple operation are some of its most impressive features.

Figure 9. The R&S®SMB100B is the perfect combination of performance and capability in a compact form factor.

To further reduce complexity, R&S also offers a convenient, all-in-one solution for EMI testing (Figure 10). This compact test system supports wired EMS measurements using the BCI test method, as prescribed for testing electronic modules in vehicles. The BCI system consists of a compact R&S®SMC100A signal generator, an R&S®BBA150-AB broadband amplifier, an R&S®NRP6AN average power sensor (developed specifically for EMC applications), and the R&S®EMC32 measurement software. This test system's configuration is flexible and can accommodate other instrumentation as needed as long as the instrumentation chosen fits in the 7HU chassis.

Figure 10. The R&S®BCI Compact Test System supports wired EMS measurements using the BCI test method, as prescribed for testing electronic modules in vehicles.

Reason 9: 1GHz oscilloscopes address new verification requirements

MIL-STD-461G section CS101, *conducted susceptibility, power leads*, verifies the ability of the EUT to withstand signals coupled onto the power leads. If you still use the trusted analog oscilloscope and grease pencil, now is your opportunity to change. As mentioned previously, the self-verification requirements to SAE for MIL-STD 461G want to assure testing is done with confidence.

A modern test method can use a digital oscilloscope with high resolution FFT function, a power input isolation transformer, and floating measurements. CS101 requires extremely high voltage levels, and the use of differential voltage probes with a suitable oscilloscope enables safe measurements up to 1 kV.

A modern digital oscilloscope with frequency coverage up to 1 GHz simplifies the measurements called out in CS101. The digital oscilloscope will lend themselves to the two new tests in release 461G: lightning transients (CS117) and ESD (CS118). Specifically, CS118 includes time-domain test requirements for 1 GHz system verification of the ESD pulse measurement on the ESD current target.

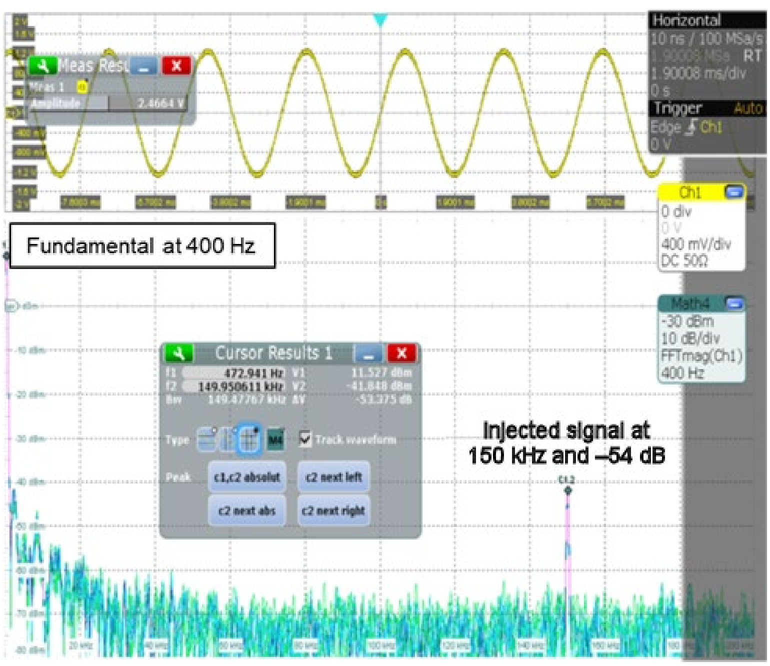

Figure 11. With the potential for 90 dB signal ratios, HD mode surpasses the performance of old scalar analyzers.

The R&S®RTO6 is engineered to deliver reliable results. High-definition (HD) mode enables easy visualization and triggering on signals with up to16 bit resolution. It can detect and display sporadic signal faults with an industry-leading update rate of up to 1 million waveforms/s. The high dynamic range and input sensitivity of 1 mV/div at full measurement bandwidth make it possible to detect even weak emissions. The powerful FFT capabilities are ideal for EMI analysis in the frequency domain thanks to their easy operation, high acquisition rate and manifold functions, such as color coding of the spectral display according to frequency of occurrence. The mask trigger in the frequency domain is ideal for detecting sporadic emission frequencies. The stop-on-violation condition halts acquisition if the spectrum violates the frequency mask. The gated FFT capability provides better insight by displaying the time and frequency domain correlation over a user-defined window.

Figure 12. The R&S®RTO6 is engineered to act as a sophisticated laboratory companion to solve measurement problems fast and keep you on schedule.

The Rohde & Schwarz oscilloscope probe portfolio includes specific probes for EMI debugging. The portfolio covers high voltage probes and differential probes for voltages up to 6000 V (peak) with exceptional common mode rejection ratios over a broad frequency range, as well as current probes for accurate, non-intrusive measurements of DC and AC currents in the range of 1 mA to 2000 A with a maximum bandwidth of up to 120 MHz. E and H near-field probes are available for the frequency range from 9 kHz to 3 GHz with optional preamplifier for EMI debugging.

Reason 10: Use smart broadband amplifiers when field strength and VSWR tolerance matter

Unlike commercial standards where the field is calibrated before the DUT is introduced for test, for MIL-STD susceptibility testing the field is created and measured when the DUT is under test. Couple with the use of shielded rooms without anechoic material, the interactions between large test DUT's in close proximity to the test antenna can create large back-EMF (reflections or high VSWR) at very sharp Q's. This mismatch tolerance can create damage to an otherwise unsuspecting amplifier.

When field strength and VSWR tolerance are important, “smart” broadband amplifiers can deliver more power at frequencies that have severe mismatch. For example, the R&S®BBA130 broadband amplifiers offer RF output power of up to 10 kW. These amplifiers deliver nominal output power at 6:1 VSWR, and they provide one-half output power into an open or short circuit.

Three models are available: 80 MHz to 1.0 GHz; 0.69 GHz to 3.2 GHz; and 2.5 GHz to 6.0 GHz. A modular design makes it possible to upgrade the initial configuration to higher output power and a different frequency range. During operation, the user can choose between maximum output power or greater tolerance for mismatch at the output.

The R&S®BBA130 broadband amplifiers offer a variety of settings, enabling optimal tuning of the output signal to suit specific applications. During a test, the amplifier can be adjusted for Class A or Class AB operation, and the user can choose between maximum output power or greater tolerance for mismatch at the output.

The R&S®BBA150 broadband amplifier family generates power in the frequency range from 4 kHz to 6 GHz. These compact amplifiers are ideal for amplitude, frequency, phase and pulse modulation (Figure 13). Extensive switching options for input, output and sample ports are available for different applications.

Figure 13. One of today's most advanced broadband amplifiers, the R&S®BBA150 is also reliable, ensuring high availability.

Conclusion

The military is taking advantage of rapidly evolving commercial technologies and fielding them. While MIL-STD-EMC will continue to have requirements that differ and go beyond commercial standards in many areas, the ongoing evolution of the MIL-STD-461 standard has adopted some commercial EMC practices, when these have proven to be best for the industry.

Our experts are fully involved in the relevant standards bodies. As a result, we offer a full portfolio of compliant receivers and complete solutions. With faster computational speeds, high fidelity, and more automation to reduce human error, we believe the time is right to upgrade your test lab's MIL-STD-461 test capabilities.

Ordering Information

Designation	Type	Order No.
EMI Test Receiver, 1 Hz to 44 GHz	R&S®ESW44	1328.4100.45
RF Signal Generator, 8 kHz to 6 GHz	R&S®SMBB-B106	1422.5205.02
Oscilloscope, 8 GHz	R&S®RTP-084	1320.5007.08
Oscilloscope, 6 GHz	R&S®RTO2064	1329.7002.64
Single-band Power Amplifier	R&S®BBA130	BBA130-E280
Single-band Power Amplifier	R&S®BBA150	BBA150-E200
Visual Inspection Software	R&S®AdVISE	1434.6518.02
ELEKTRA EMC Test Software	R&S®ELEKTRA	5601.0030.02
EMI Measurement Software, for Conducted and Radiated Emissions	R&S®EMC32-EB	1300.7010.02
EMI Measurement Software, for Conducted and Radiated Susceptibility	R&S®EMC32-S	1119.4638.02
EMS Measurements in Line with Automotive and Military Standards	R&S®EMC32-K1	1147.5493.02

Rohde & Schwarz

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