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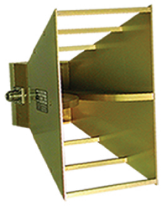

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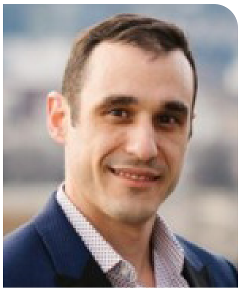
He is the author of the third edition of the 1,157-page book Electromagnetic Compatibility, Methods, Analysis, Circuits, and Measurement published by CRC press in 2017, as well as numerous papers of a practical nature.



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Zachariah Peterson received multiple degrees in physics from Southern Oregon University and Portland State University, and he received his MBA from Adams State University. In 2011, he began teaching at Portland State University while working towards his Ph.D. in Applied Physics. His research work originally focused on topics in random lasers, electromagnetics in random materials, metal oxide semiconductors, sensors, and select topics in laser physics; he has also published over a dozen peer reviewed papers and proceedings. Following his time in academia, he began working in the PCB industry as a designer and technical content creator. As a designer, his experience focuses on high-speed digital systems and RF systems for commercial and mil-aero applications. His company also produces technical content for major CAD vendors and consults on technology strategies for these clients. In total, he has produced over 2,000 technical articles on PCB design, manufacturing, simulation, modeling, and analysis. Most recently, he began working as CTO of Thintronics, an innovative PCB materials startup focusing on high-speed, high-density systems.

He is a member of IEEE Photonics Society, IEEE Electronics Packaging Society, American Physical Society, and the Printed Circuit Engineering Association (PCEA). He previously served as a voting member on the INCITS Quantum Computing Technical Advisory Committee working on technical standards for quantum computing and quantum electronics. He now sits on the IEEE P3186 Working Group focused on Port Interface Representing Photonic Signals Using SPICE-class Circuit Simulators.

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Tom Braxton has worked in the EMC industry since 1981, with experience at Lucent Technologies / AT&T Bell Laboratories, Shure Incorporated, and as an independent consultant.

Tom is an IEEE Life Senior Member, a past EMC Society Director at Large, and is the author of EMC-awareness articles for online and print publications. He chairs Technical Committee TC1 on EMC Management and was General Chair of the 2005 IEEE International EMC Symposium and Vice-Chair in 1994, both in Chicago. He is also the Vice-Chair and Program Chair of the EMC Society Chicago Chapter.

An iNARTE-Certified EMC Engineer and an iNARTE-Certified ESD Engineer, Tom holds a BSEET from Purdue University, an MSEE from the Illinois Institute of Technology, and Amateur Radio license WB9VRW.

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EDITORIAL

Zachariah Peterson
Owner, Northwest Engineering Solutions LLC

There are two areas of electronics design, production, and test that can be quite challenging, especially where high-reliability electronic systems are concerned. The first area is compliance with standards, in which a design is created with an eye towards important electrical and mechanical performance metrics. The other important area is testing against performance and reliability standards, demanding specialized equipment and experience to gather and interpret results for mission-critical systems. Military and aerospace systems have long set the standard for high reliability in mechanical and environmental integrity, electrical performance, power quality and electromagnetic compatibility (EMC).

These two areas of design and production are like black magic for some designers, but engineers can work towards success with access to the right resources. This issue of Interference Technology focuses in these areas and aims to bring the most important mil-aero design and testing knowledge to engineers. Interference Technology is one of the few publications that compiles critical standards and design information for military and aerospace systems while remaining heavily interdisciplinary, serving systems engineers, test engineers, PCB designers, component designers, and EMC professionals.

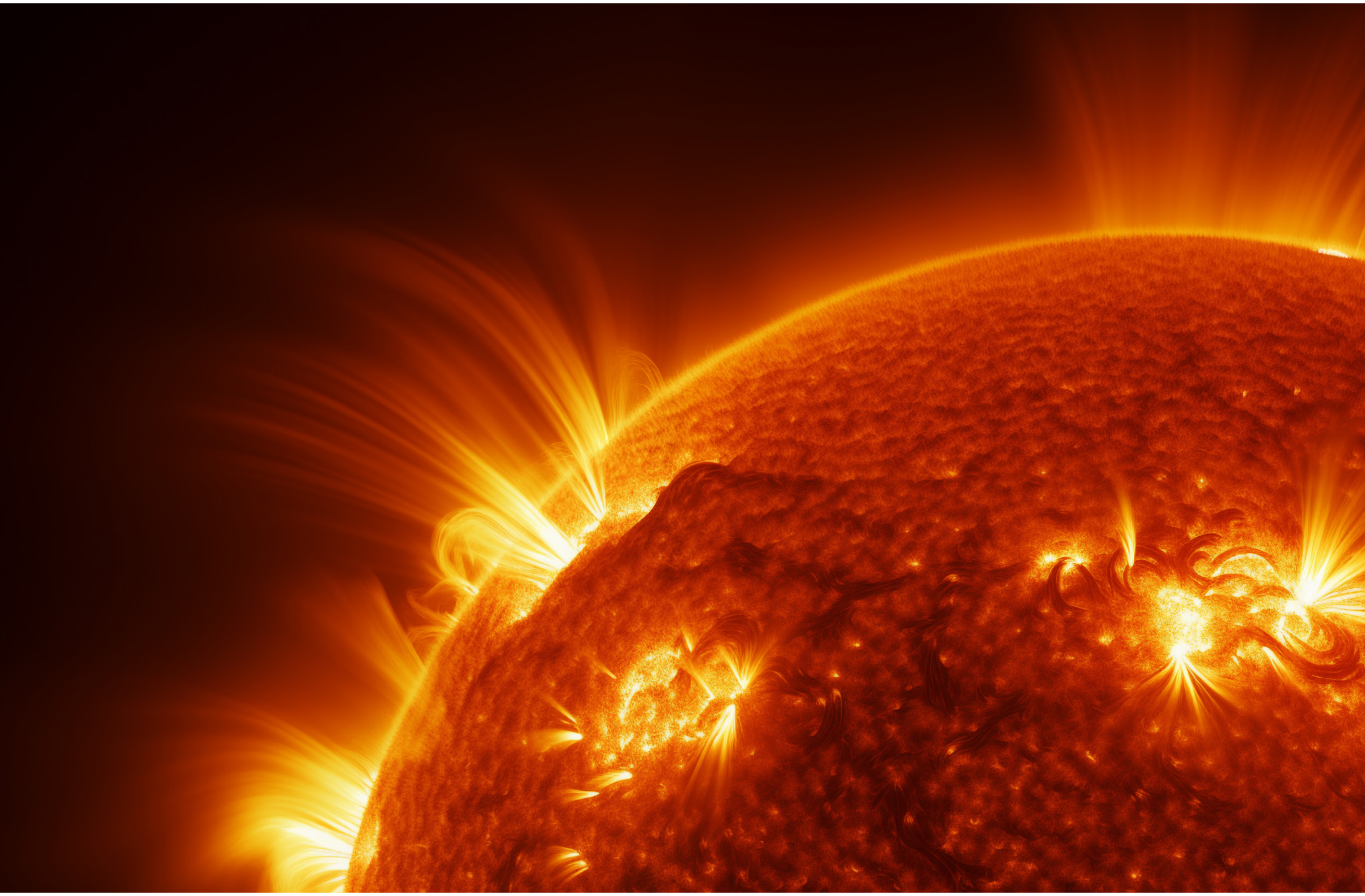
In this issue, we delve into various critical topics that are shaping the future of military and aerospace systems. You'll find an insightful article on space weather and its impact on electronic systems, a comprehensive discussion on the simultaneous operations (SIMOPS) of radio systems due to antenna-to-antenna coupling on aircraft, an in-depth review of MIL-STD 188-125-1A covering quality measures and testing requirements for HEMP protection, and an exploration of CubeSats and their growing role in space missions.

Just as technological advances have created new design challenges in consumer and commercial products, the approach in mil-aero systems is made more complex due to strict reliability and performance requirements on equipment deployed in the field. As standards evolve and new testing techniques are developed, we will continue to bring readers these important insights so that engineers can stay at the cutting edge.

As always, we editors welcome your feedback and invite you to submit your own article to be included in a future issue.

SPACE WEATHER – PREDICTING EMC EFFECTS OF SOLAR STORMS

Tom Braxton
iNARTE-Certified EMC Engineer and an iNARTE-Certified ESD Engineer



When we think about weather, we know what it is. We feel it, worry about it, and talk about the heat, the moisture, the wind. Weather is dynamic, though mostly predictable because we can measure its conditions.

We also know that the atmosphere involves large scale electrical activity. Cloud masses move above and below each other, generating enormous static-electricity levels. Lightning happens and becomes the source of atmospheric electromagnetic interference (EMI). We know it in its most frequent form as crackling on an AM radio.

Beyond the earth we can also think about outer space having weather. The sun is a roiling ball of explosive gas generating bursts of energy through its own atmosphere. Though we don't think of a ball of gas as having a surface, what we see is the photosphere that gives the sun its shape. Its atmosphere and movement give the sun seasons and storms that discharge at levels dwarfing the earth's most violent lightning strike. Those discharges also cause EMI, but at levels millions of times higher than those on earth.

Teams of space-weather forecasters in various locations serve the National Oceanic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA), and their contractors, all of which comprise the Space Weather Prediction Center (SWPC). Monitoring the sun, they watch for surface solar flares and coronal mass ejections (CMEs), which take form beneath the photosphere and have been described as billion-ton bubbles of magnetized plasma that spray toward earth in a solar storm.

Solar storms can be bad news. The sun launches a tsunami of energy, and if that energy wave washes over the earth, it can disrupt or damage electronic and power networks. In 1859, astronomer Richard Carrington saw a bright flash on the sun's surface. Later, the aurora borealis, or northern lights, appeared with strange intensity at lower latitudes. Telegraph systems began chattering randomly or stopped working. This crippling wave of EMI became known as the "Carrington event," and potential recurrences remain a concern for space-weather forecasters.

A high-level solar storm rising to a Carrington event could cause widespread disruption. The power grid's thousands of miles of wire would act as receiving antennas and propagate an electrical surge that would cascade through the entire network.

EMI protection can be in a form as simple as a conductive shield to protect electronics, like that of a device's metal enclosure. Fortunately for us, the earth magnetic field acts as a shield deflecting most cosmic EMI. But no shield is 100% effective, and neither is the earth's magnetic field. A big enough CME could surge through the power grid, the telecom network, and cause problems for orbiting satellites outside the magnetic field's protection.

Sunspots are dark areas in the sun of intense magnetic, or B-field, energy that usually precede a solar storm. Appearing in eleven-year, 200-year, and longer cycles, space-weather forecasters watch their growth and movement, much as meteorologists watch for low-pressure areas that portend a coming storm.

The SWPC forecasters base their solar-storm warning predictions on data from a series of tools, such as helioviewer systems that process real-time images of the sun's surface. In addition, there are satellites circling the sun in fixed orbits between the earth and the sun providing solar-event and CME detection: the Deep Space Climate Observatory (DSCOVR); the Global Geospace Science (GGS, or Wind, referring to its detection of the solar wind); the Advanced Composition Explorer (ACE); and the Solar and Heliosphreric Observatory (SOHO). If SOHO or one of its companion satellites detects a burst, SWPC has time to alert power and network oper-

ators that a solar storm is on the way.

The satellites and their instruments employ receivers detecting the 10.7 cm band of frequencies, around 2800 MHz, emitted by the sun. This “F10.7” signal allows more precise determination of the activity in the sun’s interior where the magnetic field poles originate. F10.7 signals are collected at SWPC locations and compared with data from other satellite feeds.

We think about weather here on earth and rely on meteorologists to detect dangerous conditions as they develop. It’s also good to know that someone is thinking about the weather way out there. Dr. Katie Kosak, a contractor with a.i. solutions, a space-weather contract company, is among the forecasters working with Dr. Kenneth Schatten, a developer of the models that describe the sun’s magnetic fields. She works closely with the mission analysis team in the NASA Launch Services Program., where solar-storm EMI is of keen interest. Missions bound for space must anticipate EMI and provide sufficient shielding and other mitigation steps since circuit and wireless EMI disruptions can be catastrophic. “The helioviewer tool provides visual images in real time of significant solar events, like CMEs,” Dr. Kosak explained. “If a CME appears to be generating a solar storm, there is typically a lag between 16 hours and several days before the storm reaches earth. That gives us time to closely monitor data from SOHO, giving us the resolution needed to alert users who may be at risk.”

Sunspots come in positive and negative magnetic pairs and are indicators of solar activity. But they are blunt instruments. They are not able to tell, for instance, when a solar storm might occur, though the size and movement of sunspots can suggest its likelihood. Just as forecast precision has increased in meteorology, precision has increased in the prediction of space weather. Mission plans that involve a working spacecraft need to know if, when, and where a solar storm is likely to occur.

The level of energy in a solar storm is enough to travel ninety-three million miles to penetrate the earth’s magnetic field. After a severe CME, there is also enough energy after penetrating the magnetic field and disrupt or damage the web of electronics modern society depends upon.

Solar physicists have studied the sun’s behavior with increasing precision for decades. They know, for instance, that sunspot activity, which may presage a solar flare or CME, follows a cycle of roughly eleven years. They also have crafted a model of the sun’s magnetic flux, resulting in the Schatten Index that aids in longer-term prediction of the sun’s magnetic-field behavior.

A dynamo uses rotating magnets to create an electric field, which we employ on a large scale to provide electric power. The solar dynamo generates immense magnetic fields through a dynamo process in the sun’s interior. Complex magnetic fields are created, which, when large enough, can create huge flares on the sun’s surface. They can be compared to the familiar discharges of a lightning strike, but at levels millions of times greater. The plasma resulting from a major flare or a CME becomes the billion-ton plasma bubble described earlier.

Those bursts give off huge surges of electromagnetic energy that is so extremely broadband that it consists of radiation not only in the familiar electromagnetic spectrum, but also the ionizing radiation of X-rays and beyond. The solar-dynamo model describes how this vast potential develops. “There is still a lot we don’t understand about the sources in the sun creating the magnetic field causing the enormous arcs that make up solar flares,” Dr. Kosak said. “The dynamo model explains its mechanism, but there’s still much we need to learn.” Those practicing in different corners of science look for patterns in the natural world to anticipate what is likely to happen in the future. Geologists have learned that tectonic plates are constantly in motion at barely perceptible speeds, but the force of their motion will eventually bring about earthquakes. Physicians have learned that if pulse rate and blood pressure exceed expected bounds, a cardiac event is probable. Their ability to plan for a likely event has been built on the cumulative growth of knowledge in their art, made possible by the increased sophistication and accuracy of their instruments.

Solar physicists’ understanding of the sun’s electromagnetic behavior and the tools they use to quantify that behavior have also grown in precision, allowing them to characterize the effect EMI from a solar flare or CME may have. Like meteorologists using doppler radar to predict severe thunderstorms and tornadoes, solar-weather forecasters’ use of the detection capabilities of SOHO, DSCOVR, Wind, ACE, and helioviewers allows them time to warn network operators and ground-based satellite controllers of an incoming solar storm. Another Carrington event and its vast EMI effects could disable Global Positioning System (GPS), communication satellites, and the wired network we all rely on.

EMC began as a technically primitive discipline in the early days of wireless more than a century ago. Our understanding of its importance in communication, commerce, transportation, and public safety has made us appreciate the ubiquity of interfering signals. Our understanding of the measures required to minimize EMI’s harmful effects has grown as well. We know now that EMI can originate anywhere – from annoying distant lightning to the explosive interior furnace of the sun.

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SIMULTANEOUS OPERATIONS (SIMOPS) OF RADIO SYSTEMS DUE TO ANTENNA TO ANTENNA COUPLING ON AN AIRCRAFT

David A. Weston
EMC Consulting Inc.

Although specifically dealing with aircraft systems, the methods described in this article are applicable for other platforms where a number of antennas are in close proximity. The number of antennas in use and in close proximity on mission specific aircraft are as many as 22 on a small search and rescue aircraft.

ANALYSIS METHODS

The methods of coupling analysis include electromagnetic analysis programs, measurements on a 1/10th scale aircraft, a full-scale mockup of a part of the aircraft fuselage and wing, as an example, and provisionally mounting antennas on the actual aircraft. All these methods mean that the analysis can be performed before installation of antennas on the aircraft and thus the location of antennas can be modified, or mitigation techniques employed if a coupling problem exists. All of the analysis techniques have advantages and disadvantages. For example, the antennas and antenna drive element would be too small on the 1/10th scale model at 93.75MHz and test equipment for 93.7GHZ would almost certainly not be available. Ideally the electromagnetic analysis programs alone would be good enough. However, in two articles, reference 1 and 2, and in an upcoming paper comparing the accuracy of the four methods, we see that that is not true.

The 1/10th scale model is shown in *Figure 1* and the FEKO program model of the aircraft in *Figure 2*.

Figure 1: 1/10th scale model

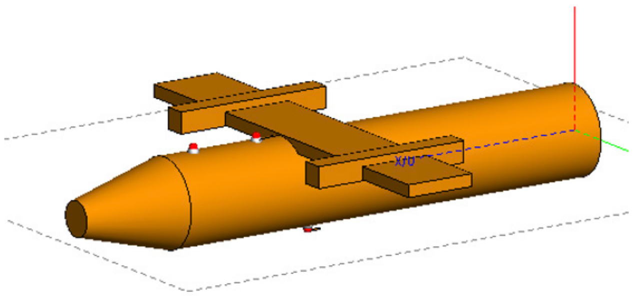

Figure 2: FEKO model

In-Band Coupling

For transmitter receiver pairs that are in band (i.e., transmitter and receiver frequency the same) a simultaneous operations (SIMOPS) red case (non SIMOPS possibility) is obvious. A possibility for acceptable in-band performance at low frequency may be achieved with an in-band cancellation circuit shown in *reference 3*.

Out of Band Coupling

Most antennas do not function as an effective filter and pass "out of band" frequencies with often little attenuation. When a high-level source of electromagnetic radiation is close to an antenna, and the receiver does not contain a band pass filter at the input, then the signal present at the input of the receiver can result in cross modulation (where the interferer modulates the intentional signal). Also, when the transmitter frequency is close to the receiver IF bandwidth or the edges of the receiver bandwidth.

With high input levels desensitization/compression of the receiver can occur, which means the gain of the receiver reduces. Alternatively, the high RF level can be demodulated by a semiconductor in the receiver resulting in a dc level which can effectively saturate the front end. High input levels can result in a spurious response in the receiver which may be in band. If the induced power is too high, a voltage or current can be applied to an input semiconductor, resulting in breakdown or overheating and stressing. To reduce high levels, a series of band pass, band stop, high pass, and low pass filters have been designed and built from 30MHz to 9.375GHz, described in *references 4* and *5*.

Passive Intermodulation

A source of in band interference is Passive intermodulation (PIM). Intermodulation products are generated when two or more signals mix in a structure with nonlinear junctions or ferrous metal. When these intermodulation products fall in band for a co-located receiver, a SIMOPS red case may exist.

Passive Intermodulation may occur in any metal structure in proximity to a receiving antenna, such as the antenna structure, railings, towers, or other metallic surfaces. *Reference 4* describes PIM in more detail. One common source of a nonlinear junction is either a loose joint or oxidization of metal. A structure that includes ferrous materials (which has a nonlinear magnetic hysteresis) or carbon fiber (which has a nonlinear resistivity) may also exhibit PIM, and this is, perhaps surprisingly, an order of magnitude higher than the joint generated PIM.

On the aircraft, the ferrous material is typically in the landing gear, flap rods/tracks, and door handles, with the landing gear, flap rods/track the most likely source. *Figure 3* shows an example of the incident and PIM fields.

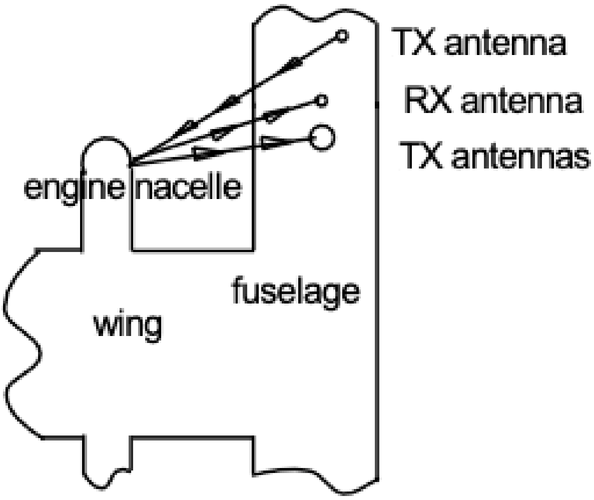

Figure 3

Some of the sources of PIM which have been experienced are:

- Poor alignment of parts
- Moving structures which are not adequately bonded
- Insufficient or incomplete cleaning of parts
- Contaminated plating bath
- Poor plating adhesion
- Dissimilar metals in direct contact
- Plating non uniformly applied and on insufficient thickness (high resistance)
- Material which has not been in the plating bath long enough (high resistance)
- Oxidization

Luckily the reradiated PIM level is usually at a low level.

Another source of in-band noise may be the broad band noise from a high-power transmitter which is in band.

In-Band Coupling Analysis Sheet (example)
An example of an in-band coupling sheet is provided in *table 1* with some of these coupled levels being a clear possibility for a red case of SIMOPS.

The effect on the receivers can best be provided by the receiver manufacturer. However, this may not be provided. Another possibility is that the input circuit of the receiver is available, in which case the effect of the level on the circuit can be modelled using a circuit model program. If neither is possible then the assumption can be made that the 15.5dBm and 18dBm levels will cause a problem.

An Example of Antenna Coupling
The aircraft has a Side Looking Airborne Radar (SLAR) antenna mounted on the sides operating at 9375MHz. Underneath the fuselage is a Maritime Search Radar also operating at 9375MHz. The antennas transmit and receive a vertically polarized wave.

Receiver and frequency (MHz)	Transmitter and frequency (MHz)	Frequency over lap	Received level (dBm)
#1 Cockpit V/UHF 30-88 18-174 225-400 400-600	#2 Cockpit HF 2-30	At 30MHz	-11
#1 Cockpit V/UHF 30-88 18-174 225-400 400-600	#3 Mission HF R&S 1.5 - 30	At 30MHz	15.5
#1 Cockpit V/UHF 30-88 18-174 225-400 400-600	#3 Mission V/HF R&S V/UHF 100-512	225-400	-13
#1 Cockpit V/UHF 30-88 18-174 225-400 400-600	#5 Cockpit VHF Comm. VHF#2 118- 137	118 - 137	18
#6 Acoustics VHF Sonobuoy VHF 136-173.5	#3 Mission V/HF R&S V/UHF 100-512	136-173.5	1.1
#6 Acoustics VHF Sonobuoy VHF 136-173.5	#5 Cockpit VHF Comm. VHF#2 136 -173.5	136-173.5	28

Table 1: In-band coupling example

A creeping wave will be generated from the SLAR antenna to the Maritime Search Radar and vice versa, but due to the high frequency the power will be at a low level. The use of a 1/10th scale model is not practical, nor is the use of one of two analysis computer programs, again because of the high frequency. Neither the SLAR antenna nor the Search Radar Antenna were available. Instead, an E plane sectional horn antenna was built and calibrated.

Figure 4 shows the gain plot of the SLAR and the sectional horn, and it can be seen that they have a good correlation.

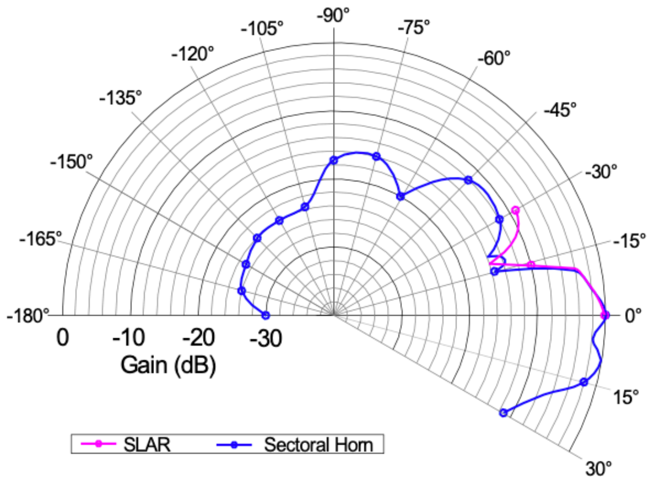

Figure 4: The SLAR antenna plot versus the sectional antenna plot

A parabolic dish antenna was used in place of the maritime search radar. It was angled 5.6 degrees in the H plane and 60 degrees in the E plane to the side of the fuselage. The sidelobe of the radar is minimum 36dB down on the main lobe, and so the sidelobe is 31-36 = -5dB. The parabolic dish gain is 28dB and at 90 degrees it is 27dB. So 27dB-28 = -1dB, and that is the gain used in the analysis.

Figure 5 shows the coupling path from the SLAR to the radar.

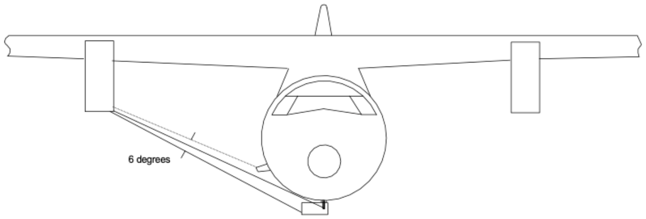

Figure 5: SLAR to radar coupling

The SLAR output power is 25,000W. The power into the sectional horn is 10W and in the analysis the power received by the parabolic dish was corrected accordingly, along with the gain correction.

A full-scale section of the fuselage, wing and nacelle were built with a copper foil covering and the horn and parabolic dish antennas were mounted at the appropriate location. The ground under the mockup was covered in absorber with high absorption at 9375MHz.

The predicted level induced into the Maritime Search Receiver is 42.3dBm.

The SLAR generates a 50nS wide pulse at a repetition rate of 50Hz. This means that the Maritime Search Radar will only see an interfering signal for a short time at a low repletion rate, and may be able to identify it and ignore this level. Because the level is so high (16W) damage to the receiver may be possible. If the SLAR generates a blanking pulse, the Maritime Search Radar may be able to use this to protect the receiver input.

CONCLUSIONS

Lack of SIMOPS between transmitters and receivers on a platform can have many causes, including in-band coupling; out of band coupling with high levels at the receiver; and PIM. The mitigation of lack of SIMOPS may be achieved by locating transmitting and receiving antennas on opposite sides of the fuselage (the higher the frequency the more effective this is); moving antennas down the aircraft to minimize reflections from structures such as engines and wings and reduce PIM; signal filters at the antenna end of the receiver cable; in-band cancellation at lower frequencies (See *reference 5*). Blanking receivers when a transmitter operates may reduce cross modulation, generation of spurious emissions, and receiver damage.

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CUBESATS:
FLYING ABOVE AND WITHIN THE FRAY

Mike Violette, P.E.
President, Washington Laboratories

All satellites are vulnerable to a wide variety of EMC and environmental effects, from launch to deployment. Of particular concern is the effects of *Coronal Mass Ejection (CME)* events. These are caused by sun activities that result in waves of cosmic rays and particles and electromagnetic energy. Significant CME events occur in sync with the "11 Year Sunspot Cycle" which, for reasons known to nature, pulse with this particular rhythm, caused by magnetic flux pushing up from the interior to the surface of Old Sol. (swrc.nasa.gov).

Sunspots are indicative of surface-sun activity and occur at periodic maxima. These cycles have been "numbered" since 1755, but have obviously been occurring in the 4.8B years or so of the solar system's existence. The approximate cycle of 11 years is fairly easy to predict with the current cycle (as of June 2024) is numbered as 24, beginning in 2008.

The sunspots (or, rather, the phenomena that causes them) creat so-called "Space Weather," so the Space Weather Prediction Center prepares a daily report on sunspot activities with a "Solar Region Summary Report."

It may be said, or interpreted, that sunspot activity is a result of some internal resonance of the Sun's complex "magnetic heartbeat." "A new solar cycle is considered to have begun when sunspot groups emerge at the higher latitudes with the magnetic polarities opposite to that of the previous cycle."[1]

Space weather has tremendous impacts on satellite and terrestrial systems. The protective blanket provided by Earth's magnetic field, provides a shield for systems and life itself. Arguable, life on this planet would be impossible if not for the magnetic field of old Gaia. This protection is provided at lower/below the ionosphere, but for GPS and other satellites operating in upper orbits, such protection doesn't exist. Thus, for those systems, satellite systems must be designed with this threat in-mind. See '***Space Weather – Predicting EMC Effects of Solar Storms***' in this issue.

For CubeSats, the main issues occur when getting the devices through launch and on to deployment. This article discusses the main design issues with these devices, which take on many functions, but must follow a common form-factor and other operational/design considerations.

So, what is a CubeSat? By definition, these micro-satellites are 10X10X10 cm form-factor, hence the "cube" denomination. A CubeSat has an international standard ISO 17770:2019, which defines the requirements for physical, mechanical, electrical and operational requirements, including interface requirements between the CubeSat and the launch vehicle.

According to **Nanoavionics.com**, Cubesats are typically developed for the following uses:

- Scientific Research, including water and other resource monitoring
- Earth monitoring and Relay
- Communications
- Technology Trials, feasibility assessments
- National Security and Defense

Typical costs of CubeSat projects range from $50-100k for educational/research applications and $500K-$MM for commercial and science missions. This is compared with the hundreds of millions for development and deployment of a traditional satellited.

The low cost benefit has an upside: many satellites can be deployed and the failure of a single unit may not compromise the entire mission. The downside is that the functions and applications may be limited by the small size and ability to incorporate many functions.

ORBITAL DEFINITIONS

At CubeSat orbital altitudes, so-called Low Earth Orbit (LEO), "Space Weather" is less concern because of the lower levels of ionizing radiation is relatively low. This is important because the use of Common Off-The-Shelf (COTS) equipment keeps the price of the CubeSat device low. Use of COTS components also allows for mass production of the CubeSats. Many of the constellations that have been deployed or are planned rely on hundreds, if not thousands of these devices.

There are several orbital altitudes that are used in the vernacular of satellite deployment.

Notionally, and there are no strict boundaries, the orbital levels are described thus:

- Low Earth Orbit: <800 km above sea level (ASL)
- Medium Earth Orbit: 800-2000 km ASL
- High Earth Orbit: Less than GEO
- GEO: 35,786 km ASL
- Graveyard Orbit: Above operational orbits
- Disposal Orbit: Way out there…

Sputnik flew between 212 and 950 km ASL as the first human-made object to orbit the Earth. The highly elliptical orbit was maintained for three months before the satellite burned up in the Earth's atmosphe on January 5, 1958

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[1] SWRC.NASA.GOV

CubeSats, because of their sheer number and occupancy of LEO orbits, are required to de-orbit (disposed of in the atmosphere) after their operational lifetime. This is normally accomplished by a de-orbit burn, scuttling the craft into the upper atmosphere until the aether sets its drag on the device, slowing and eventually causing the satellite to burn up. The risk of debris reaching the Earth's surface is low, because of the small mass of the CubeSat; for the most part it is assumed that the CubeSat will be completely consumed before reaching the Earth's surface.

One aspect of CubeSat's orbital behavior is the relatively fast orbital period (i.e., transit around the globe) and hence, they are inherently non-Geo-Stationary. *Geo-Synchronous Positioning Systems* (GPS) are set in geo-synchronous or near-geo-stationary (or semi-synchronous), passing over the same point on Earth twice-daily. GPS systems (including GNSS and GLONASS) are subject to the whims of the Solar Wind; at GEO orbits, the electronics must be hardened and the materials carefully selected to withstand the bombardment of Solar emanations—typically not an issue with CubeSats (exceptions noted).

CubeSat design, as stated earlier, must survive partus and the post-partum of the launch. Notably critical the vibration and mechanical stresses of ascent and deployment.

The vibration "profile" simulates the intense forces of launch deployment, the profile most often depends on the launch vehicle being used for the mission. The vigorous (and LOUD) vibration profile only lasts a few minutes until flight is achieved, with the shaking settling down for the rest of the orbital insertion. More on that later in this article.

CUBESAT LIFETIMES

A feature/drawback of CubeSat operation, compared to traditional satellites, that may be on-orbit for many years, is the relatively short orbital lifetimes, which may be, by design, a few months to a few years.

Yet, during that time, the majority of the "things in orbit" (a technical term) are so-called "Space Debris." According to Sciencedirect.com, "It is estimated that more than 22,000 human made objects are in-orbit above the Earth." What is remarkable is that approximately 90% of the devices may be considered space junk, that is they are no longer operational (or controllable!).

A concern with the CubeSat concept is the additional future 'debris' posed by launching these new technologies is the sheer number of constellations, to wit:

- Flock > 100 devices
- Amazon > 3000
- Starlink > 4000
- Boeing > 1000

Not to mention the constellations in-orbit or planned by foreign governments. Not all actors will ascribe to the notion to de-orbit their systems after their operational lives are over (just a guess…).

NASA has released NASA-STD-8719.14 "Process for Limiting Orbital Debris" which (probably) only applies to NASA-launched devices. Private launch vehicle providers may or may not have their own requirements for "fly" on their vehicles, but permission from the government may dictate compliance to this critical aspect of flying above the planet.

MISSION SUCCESS FOR CUBESAT

NASA GSFC[2]-HDBK-8007: “Mission Success for CubeSat Missions” which was released 16 December 2019 is now up for validation in December 2024.

Under Appendix A of this document is a list of recommendations derived from the legacy General Environmental Verification Standard (GEVS) that has been part of the verification requirements evolved during the Space Shuttle program.

A tailoring of the requirements is appropriate as a “full GEVS-defined approach would be overkill for CubeSates.” GEVS is written to assume a *very low tolerance for on-orbit risk* (emphasis added). This posture is appropriate because of the high-risk assumed with the large cost of the Shuttle and the not-so-small fact that human space flight is involved.

A summary of Appendix A includes:
Section 2.3 Electrical Function Test Requirements, including electrical interface, compliance performance, limited performance, operating time, structural and mechanical performance, structural loads and other modal necessities (anything else), EMC (based on MIL-STD-461—which has subsumed into the GEVS, anyway).

EMC ISSUES FOR CUBESAT

Regarding Electromagnetic Compatibility (EMC) issues, because CubeSats operate singularly, i.e., not connected to other systems, typically) and are only connected with the launch vehicle during pre-launch checkout and ascent. For most cases the CubeSats are, ostensibly, dormant or only nominally functional until placed in orbit (as always, exceptions noted).

Card-level tests (to vendors) are called-out, notably CE101 for low frequency emissions, CS (conducted susceptibility) and Radiated Emission (RE101) for low frequency emissions (tailored). The ultimate EMC test occurs at the integrated level, that is, the thing has to be self-compatible (and that’s ‘motherhood’ or the obvious).

CubeSat integrated tests reference MIL-STD-464, which is used to assess *platform-level EMC*. The level of testing is to a function of mission. It is suggested (and this is an editorial comment)

EARTH-TO-ON-ORBIT INTERFERENCE

Once into orbit, CubeSats (and all satellites) are subject to on-orbit RF (human-made) threats, notably ground-based radars and other RF sources. A profile of the RF threats may be available (either publicly available or via classified sources, as appropriate). Knowledge of the frequency and expected field levels is critically important if the CubeSat is performing Earth observatory functions, such as sensing, radiometry or employing other passive techniques as might be used for ground imaging and quantification.

The ground-based systems are typically fixed (radars, etc.), but not all may be known. For critical missions, notably for defense and national security missions, the threats may be fed into the operational commands of the satellite and, as the satellite passes over the threat, the systems may be temporarily “blanked” until the threat is over-flown. Fortunately, system planners realize that the passage of the satellite over ground is relatively fast. Often, the interference may be ignored. However, because of the very wide bandwidths inherent in radiometric and sensing functions, understanding the RF profile on-orbit is critical.

Other specification and performance targets include *RF link margin analysis*, which includes various factors such as propagation losses, fading, atmospheric absorption, coding and error-correction, antenna beam-angle, output powers and receiver sensitivity. Typically, a link margin analysis includes some overhead to compensate for the uncertainties in the data and physical performance of the RF link.

The CubeSate integrated platform tests reference MIL-STD-464, which has long been used to asses platform-level EMC. The level of testing is to be a fnction of mission and operational requirements. It is highly suggested that specifications and applicability of the testing be carefully tailored to the mission requirements. Program planners must not accept carte-blance the general requirements less an overly-exuberant end-user hold the system’s feet to the fire in case there are non-compliances that are really not critical to mission success. We have seen this in the lab numerous times and, test targets need to have the option to waive a certain level of non-compliances that may exist once the device is on the bench. This not only applies to CubeSats, but can be generally applied to nearly every program of this kind.

Finally, the Mechanical Section of 2.6.1 summarizes the most critical aspects of design and development, notably the following test protocols:

1. Bake-out (outgassing)
2. Balance (thermal balance across the devices volume)
3. Temperature and humidity
4. Thermal cycling and stresses (temperature shock, for example)

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[2] GSFC: Goddard Space Flight Center

5. Thermo-vacuum assessment
6. Contamination
7. Coatings
8. Planetary protection (in case the CubeSate is leaving Earth Orbit*)
9. End-to-end testing

*This, notably, applies to any device that may be making its way to the moon (very rare, but potentially feasible, although the energy required to escape Earth's gravity grip is significant).

The most common sets of test that we run at Washington Labs is NASA GEVS, both qualification at 10.0G and proto-flight 14.1G tests. Space-X has their own for the Falcon 9 Heavy, and others have a "soft-stow" profile (wherein the test units gets ratchet-strapped to the table while wrapped in foam – an unusual configuration).

METEOR/DEBRIS THREATS

A final note on our exploration of CubeSat discussion is the threat of natural objects (meteors) and man-made (space junk) on mission operation. Although most metors are small in size, the large velocities impart significant kinetic energies. The smallest object, whether it be mineral/rock from outer space or a missing bolt or launch ascent debris can rip through any satellite with ease.

Mission planning typically includes a loss of some percentage of the constellation due to any number of factors (electronics failure, mechanical or collisions) and the networks have, to a degree a self-healing nature.

CONCLUSION

CubeSats are here to stay, that is a given. The design and deployment of these devices requires careful planning and consideration for the environment from launch to deployment and on-orbit functionality. Resources exist and considerations for the EM/ENV environment must be assessed at an early stage to improve (maybe not assure) mission success.

MIL-STD-188-125-1A: QUALITY MEASURES AND TESTING REQUIREMENTS FOR HEMP PROTECTION

TSS USA Manufacturing

Military systems are susceptible to the destructive effects of **High-altitude Electromagnetic Pulse (HEMP)** events. To mitigate these risks, MIL-STD-188-125-1A provides guidelines for protecting electronic and communications systems of on the ground installations, as well as onboard aircraft and vessels.

The B-2 Spirit stealth bomber incorporates HEMP protection measures in its design, including shielding, grounding, and surge protection. Rigorous testing, including EMC and HPEM evaluations, is conducted to verify the aircraft's resilience to HEMP events.

Similarly, the Aegis Combat System—used on various Navy ships—undergoes extensive HEMP protection testing to ensure its electronic systems can withstand HEMP-induced electromagnetic fields while maintaining mission-critical operations.

This article outlines the quality measures and testing requirements that ensure HEMP protection is effective in an emergency and safe during everyday operation. By adhering to these standards, Department of Defense (DoD) agencies can enhance system resilience and maintain operational capabilities in the face of electromagnetic threats.

THE METRICS OF COMPLIANCE

The major areas of concern in MIL-STD-188-125 can be summarized in the following categories:

> **Shielding Effectiveness:** Proper electromagnetic shielding is essential for safeguarding electronic systems against HEMP. Effective shielding ensures that sensitive components are isolated from external electromagnetic fields. Quality measures involve evaluating the shielding materials, design, installation techniques, and verification of radio-frequency emission levels. For example, conductive gaskets, enclosures, and coatings can be tested to ensure their effectiveness in attenuating electromagnetic interference (EMI).
>
> **Grounding and Bonding:** Robust grounding and bonding practices are critical for dissipating HEMP-induced currents and preventing damaging voltage differentials. Quality measures include verifying proper grounding of components, cables, and enclosures, as well as ensuring low-impedance pathways for current flow. Testing may involve measuring ground resistance, verifying proper bonding connections, and assessing the overall integrity of the grounding system.
>
> **Surge Protection:** HEMP events can induce high-voltage surges that can cause permanent damage to electronic systems. Surge protection measures, such as surge arrestors and suppressors, help divert and dissipate excess energy. Quality measures involve evaluating the surge protection devices' response time, clamping voltage levels, and overall reliability. Testing may include subjecting the devices to surge waveforms and assessing their ability to suppress surges effectively.

Installation of **low-voltage** and **medium-voltage HEMP filters** from TSS USA Manufacturing are a proven intervention for defense systems. The specialty filters attenuate the higher-end frequencies that represent the greatest threat to electronics during surges. Both types of HEMP filters are designed and tested to conform to this guidance and integrate into compliance military-grade systems.

LABORATORY AND ON-SITE TESTING REQUIREMENTS

MIL-STD-188-125-1A details the testing methods to ensure HEMP protection in critical systems. To gain approval for DoD use, new electronics products and systems undergo a battery of engineering tests. These physical tests may occur on site or in a laboratory setting that simulates the installation site and as well as various levels of electromagnetic radiation.

Electromagnetic Compatibility (EMC) Testing: EMC testing ensures that electronic systems can operate in the presence of electromagnetic interference, including HEMP. Quality measures involve subjecting systems to radiated and conducted emissions testing to assess their immunity to external electromagnetic fields. For example, conducted susceptibility testing evaluates the system's ability to operate in the presence of conducted disturbances induced by HEMP.

High-Power Electromagnetic (HPEM) Testing: One of the main aspects of HEMP is the high-altitude burst, which emits an intense electromagnetic field. MIL-STD-188-125-1A specifies the characteristics of the HEMP waveforms—designated as designated as E1, E2, and E3—including its electric field strength, rise time, and pulse duration.

Quality measures include assessing the system's ability to withstand HPEM without experiencing catastrophic failures or functional impairments. For instance, susceptibility testing exposes the system to controlled HEMP-like waveforms to assess its vulnerability.

System-Level Testing: Comprehensive system-level testing is essential to evaluate the effectiveness of HEMP protection measures in a realistic operational environment. Quality measures involve subjecting the entire system, including its components, interconnections, and external interfaces, to simulate HEMP events. This includes shielding, grounding, bonding, filtering, and surge protection considerations. This testing ensures that the protection measures are properly integrated, coordinated, and capable of withstanding the expected electromagnetic threats.

MIL-STD-188-125-1A also includes measures for system hardening, which involves modifying existing system components or adding protective measures to enhance their resistance to HEMP effects. This may include replacing vulnerable components, adding shielding, or incorporating surge protection devices.

DOCUMENTATION AND SUBMISSION

It is worth noting that the certification process for HEMP protection systems can be complex and may involve multiple stages of testing and evaluation.

Systems seeking certification must provide comprehensive documentation detailing the design, test results, and analysis of the system's HEMP protection features. The system, along with the supporting documentation, needs to be submitted to the appropriate certification authority or testing laboratory for review and evaluation. The certification authority will assess the system's compliance with MIL-STD-188-125-1A and issue the certification if the requirements are met.

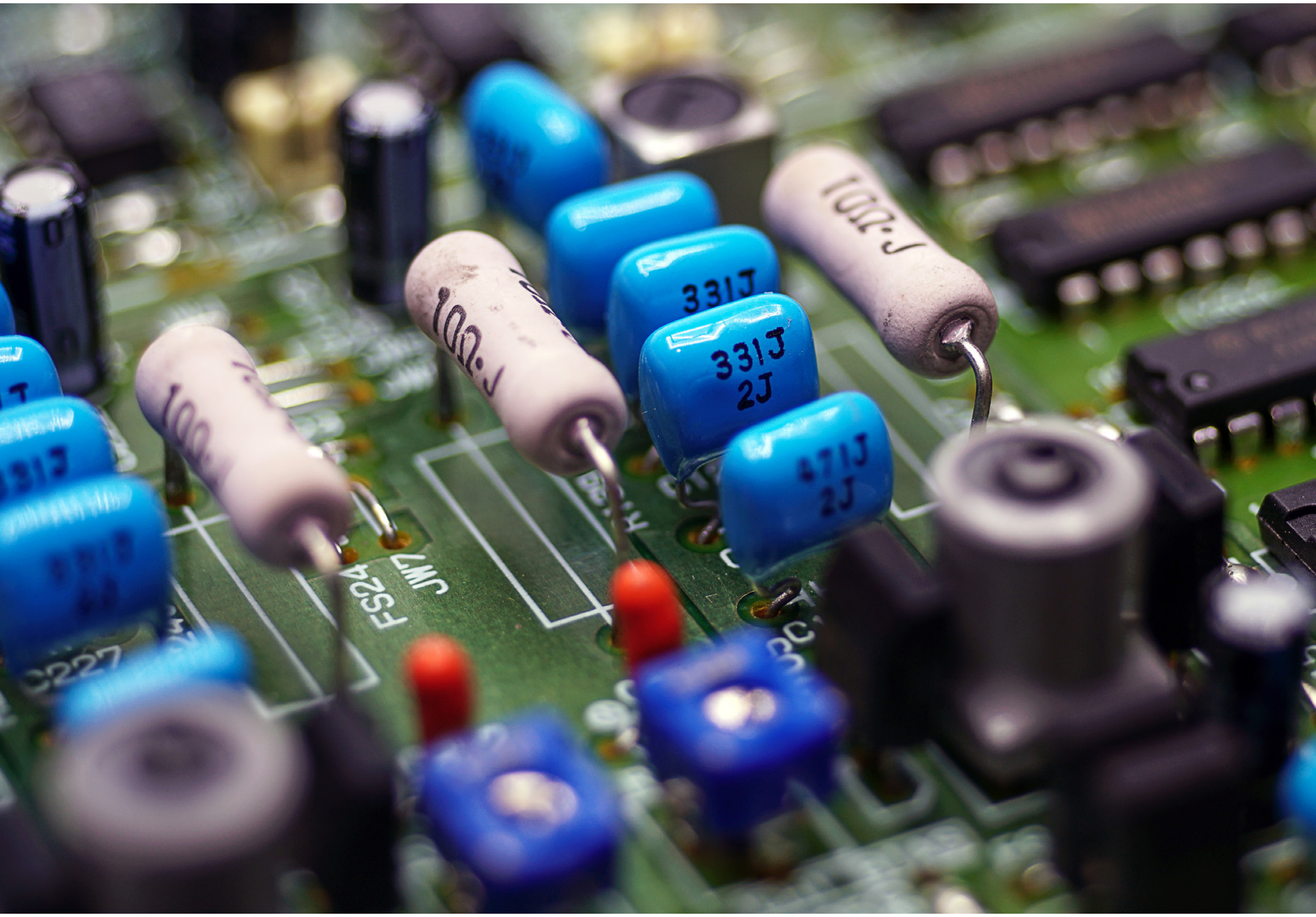
Working with experts familiar with the standard and its requirements—along with the overall process of certification—is recommended to ensure a successful certification process. TSS USA Manufacturing has been assisting DoD clients with testing and compliance for decades. **Discuss** your organization's specific compliance situation with a TSS HEMP specialist today.

For more information you can view TSS's **Vulnerability of the Grid and Beyond Webinar** here.

2024 EMC SUPPLIER GUIDE

Introduction

In this section, we provide a quick guide to some of the top suppliers in each EMC category–test equipment, components, materials, services, and more. To find a product that meets your needs for applications, frequencies, standards requirements, etc., please search these individual supplier websites for the latest information and availability. If you have trouble finding a particular product or solution, email info@interferencetechnology.com for further supplier contacts.



	COMPANY	WEBSITE	AMPLIFIERS	ANTENNAS	CABLES & CONNECTORS	CERTIFICATION	CONSULTANTS	COMPONENTS	DESIGN / SOFTWARE	EMI RECEIVERS	FILTERS / FERRITE'S	LIGHTNING & SURGE	MEDIA	SEALANTS & ADHESIVES	SHIELDING	SHIELDED ROOMS	SPECTRUM ANALYZERS	TEST EQUIPMENT	TEST EQUIPMENT RENTALS	TEST EQUIPMENT OTHER	TESTING	TESTING LABORATORIES	TRAINING SEMINARS & WORKSHOPS
A	Aaronia AG	www.aaronia.com	X	X						X							X						
	Advanced Test Equipment Corp. (ATEC)	www.atecorp.com	X	X		X				X		X			X	X	X	X	X	X	X		
	AH Systems, Inc.	www.ahsystems.com	X	X	X													X	X	X			
	Altair- US	www.altair.com					X		X														
	American Certification Body Inc.	https://acbcert.com/				X	X		X												X	X	X
	Ametek- CTS Compliance Test Solutions	www.ametek-cts.com	X	X														X		X			X
	Anritsu Company	www.anritsu.com		X													X	X		X	X		
	AR RF/Microwave Instrumentation	www.arworld.us	X	X	X				X									X	X				
B	Beehive Electronics	www.beehive-electronics.com																			X		
	Bulgin	www.bulgin.com				X																	
C	Captor Corporation (EMC Div.)	www.captorcorp.com									X												
	Coilcraft	www.coilcraft.com						X			X												
	CPI- Communications & Power Industries (USA)	www.cpii.com/emc	X																				
D	Dassault System Simulia Corp	www.3ds.com							X														
	Delta Electronics (Americas) Ltd.	www.delta-americas.com									X												
	DLS Electronic Systems, Inc.	www.dlsemc.com					X															X	
E	Electro Rent	www.electrorent.com	X							X				X			X		X				
	Elite Electronic Engineering Co.	www.elitetest.com																				X	
	EMC Live	www.emc.live																					X
	EMC Partner	www.emc-partner.com																X					
	Empower RF Systems, Inc.	www.empowerrf.com	X																X				
	EM TEST USA	www.emtest.com																X					
	Exemplar Global (iNarte)	www.exemplarglobal.org																					X
	EXODUS Advanced Communications	www.exoduscomm.com	X	X	X													X					
F	F2 Labs	www.f2labs.com				X	X														X	X	X
	Fair-Rite Products Corp.	www.fair-rite.com						X							X								
	Fischer Custom Communications	www.fischercc.com																		X			
	Frankonia Solutions	www.frankonia-solutions.com													X	X		X				X	
G	Gauss Instruments	www.gauss-instruments.com								X							X						
	Gowanda Electronics	www.gowanda.com						X															
H	Haefely	www.haefely.com							X									X			X		
	Heilind Electronics, Inc	www.heilind.com									X												
	HV TECHNOLOGIES, Inc.	www.hvtechnologies.com	X	X						X		X				X	X	X		X			

	COMPANY	WEBSITE	AMPLIFIERS	ANTENNAS	CABLES & CONNECTORS	CERTIFICATION	CONSULTANTS	COMPONENTS	DESIGN / SOFTWARE	EMI RECEIVERS	FILTERS / FERRITE'S	LIGHTNING & SURGE	MEDIA	SEALANTS & ADHESIVES	SHIELDING	SHIELDED ROOMS	SPECTRUM ANALYZERS	TEST EQUIPMENT	TEST EQUIPMENT RENTALS	TEST EQUIPMENT OTHER	TESTING	TESTING LABORATORIES	TRAINING SEMINARS & WORKSHOPS
I	Interference Technology	www.interferencetechnology.com																					X
	Intertek	www.intertek.com																				X	
	ITG Electronics	www.itg-electronics.com									X												
K	Keysight Technologies	www.keysight.com								X							X		X	X			
	Kikusui America, Inc.	www.kikusuiamerica.com/solution/	X															X					
	Krieger Specialty Products	www.kriegerproducts.com														X							
	Kyocera AVX	www.kyocera-avx.com		X	X			X			X												
L	Laird a DuPont Business	www.laird.com									X			X	X								
	Langer EMV-Technik	www.langer-emv.de/en/index																		X			
M	Magnetic Shield Corp.	www.magnetic-shield.com													X								
	Master Bond Inc.	www.masterbond.com												X									
	MBP Srl	www.mbp.it/en/							X											X			
	Microlease	www.microlease.com	X							X							X		X				
	Montrose Compliance Services	www.montrosecompliance.com					X																
	MVG Microwave Vision Group	www.mvg-world.com		X		X					X				X	X							
N	Narda Safety Test Solutions	www.narda-sts.com	X	X						X							X			X			
	Noise Laboratory Co., Ltd.	www.noiseken.com																				X	
	NTS	www.nts.com																			X		
O	Ohmite	www.ohmite.com								X													
	Ophir RF	www.ophirrf.com	X																				
P	Parker Chomerics	www.chomerics.com													X								
	Pearson Electronics	www.pearsonelectronics.com						X															
	Polymer Science, Inc.	www.polymerscience.com												X	X								
	PPG Cuming Lehman Chambers	www.cuminglehman.com													X	X					X		
	PPG Engineering Materials	www.dexmet.com													X								
	Prana	www.prana-rd.com	X																				
	Pulse Power & Measurement	https://ppmtest.com/																		X			
Q	Quell Corporation	www.eeseal.com			X						X	X									X		
R	Radiometrics	www.radiomet.com																				X	
	R&B Laboratory, Inc.	www.rblaboratory.com																				X	
	Retlif Testing Laboratories	www.retlif.com																			X	X	X
	RECOM Power GmbH	www.recom-power.com									X										X		
	RF Consultant	www.rf-consultant.com					X																
	RIGOL Technologies	www.rigolna.com	X							X							X	X		X			

	COMPANY	WEBSITE	AMPLIFIERS	ANTENNAS	CABLES & CONNECTORS	CERTIFICATION	CONSULTANTS	COMPONENTS	DESIGN / SOFTWARE	EMI RECEIVERS	FILTERS / FERRITE'S	LIGHTNING & SURGE	MEDIA	SEALANTS & ADHESIVES	SHIELDING	SHIELDED ROOMS	SPECTRUM ANALYZERS	TEST EQUIPMENT	TEST EQUIPMENT RENTALS	TEST EQUIPMENT OTHER	TESTING	TESTING LABORATORIES	TRAINING SEMINARS & WORKSHOPS
R	R&K Company Limited	www.rk-microwave.com	X							X													
	Rohde & Schwarz GmbH & Co. KG	www.rohde-schwarz.com/de	X	X						X					X	X	X	X					
	Rohde & Schwarz USA, Inc.	www.rohde-schwarz.com	X	X						X					X	X	X	X					
S	Schaffner EMC, Inc.	www.schaffner.com						X			X										X	X	
	Schurter, Inc.	www.schurter.com			X		X	X			X												
	Schwarzbeck Mess-Elektronik	www.schwarzbeck.com		X																			
	Select Fabricators	www.select-fabricators.com													X	X							
	Siglent Technologies	www.siglentna.com																X					
	Signal Hound	www.signalhound.com						X		X							X				X		
	Spectrum Control	www.spectrumcontrol.com	X		X			X			X	X									X	X	
	Solar Electronics	www.solar-emc.com		X																			
	Spira Manufacturing Corp.	www.spira-emi.com													X								
	Standex Electronics	www.standexelectronics.com						X															
T	TDK	www.tdk.com						X			X					X				X			
	Tektronix	www.tek.com																X					
	Teledyne LeCroy	www.teledynelecroy.com																X					
	TESEQ Inc.	www.teseq.com																X					
	Test Equity	www.testequity.com	X							X							X		X				
	Thurlby Thandar (AIM-TTi)	www.aimtti.com								X							X						
	Toyotech (Toyo)	www.toyotechus.com/emc-electromagnetic-compatibility/	X	X						X							X						
	Transient Specialists	www.transientspecialists.com																	X				
	TRSRenTelCo	www.trsrentelco.com/categories/spectrum-analyzers/emc-test-equipment	X	X						X							X	X	X		X		
V	Vectawave Technology	www.vectawave.com	X																				
	V Technical Textiles / Shieldex US	www.vtechtextiles.com													X								
W	Washington Laboratories	www.wll.com				X	X		X			X									X	X	X
	Windfreak Technologies	www.windfreaktech.com																X			X		
	Würth Elektronik eiSos GmbH & Co. Kg	www.we-online.com		X	X			X	X		X	X			X								X
	Wyatt Technical Services	www.wyatt-tech.net					X																X
X	XGR Technologies	www.xgrtec.com													X								

MILITARY RELATED DOCUMENTS AND STANDARDS

The following references are not intended to be all inclusive, but rather a representation of available sources of additional information and point of contacts.

MIL-HDBK-235-1C Military Operational Electromagnetic Environment Profiles Part 1C General Guidance, 1 Oct 2010.

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