WHY IS MIL-STD 461 AN IMPORTANT COTS FEATURE FOR OUR MILITARY?

Commercial Off-The-Shelf (COTS) has been the driving force for government portable, desktop, and rack mount computer procurement for over a decade. However, when these portables are purchased for the Department of Defense (DoD), COTS sometimes is not enough. In the military world, these computers must coexist with all other equipment, including powerful radio, radar, and microwave transmitters as well as highly sensitive receivers. Depending on their use, many of these COTS computers must be upgraded to meet more rigorous military needs.

For the DoD, specifying a computer's electromagnetic interference (EMI) and its electromagnetic compatibility (EMC) is an important judge on how well the computer will operate within many "noisy" environments. MIL-STD 461 documents the EMI requirements for a wide range of applications, from trucks to ships to aircraft to fixed installations, not to mention the different requirements within an application (e.g., above deck and below deck on a Navy ship). There is also a trend to tailor the requirements to particular applications. Although the most modest EMC requirements are not much different from COTS commercial requirements, most applications are decidedly harsh.

The Evolution of MIL-STD 461

The military's concern for EMI began with the installation of the first radio in a vehicle before World War I. However, since the application of radio technology and understanding its effects seem to parallel each other, it wasn't until 1934 that the US Army Signal Corps published its first EMI standard: SCL-49, "Electrical Shielding and Radio Power Supply in Vehicles." This document "protected" radio receivers by requiring vehicle operations to not "disturb" radio reception through shielding the ignition system, regulator, and generator.

From this simple beginning, military EMI evolved and changed as the complexity of the systems increased, frequencies jumped, and the threat from EMP (electromagnetic pulses) were documented and quantified. As the specifications evolved, each branch of the service defined requirements specifically for their departments or platforms. This forced manufacturers to comply with significantly different specifications for each branch as well as different specifications for specific programs within each branch.

As a result, the DoD formed a working group to consolidate and replace approximately 20 requirements into the initial MIL-STD 461 (the requirements), MIL-STD 462 (the measurement methodology), and MIL-STD 463 (definitions and acronyms) that were published in 1967. As with any general standard, especially the initial standard, revisions were required resulting in MIL-STD 461A being issued in August 1968. Although mandated, many programs made revisions and exceptions to the standard (even as 461 went from revision A to C). In 1993, the Tri-Service EMC Committee issued an updated MIL-STD 461 and MIL-STD 462, revision D. MIL-STD 463 was dropped and its definitions referenced to the American National Standards Institute (ANSI) C63.14 "Standard Dictionary for Technologies of Electromagnetic Compatibility (EMC), Electromagnetic Pulse (EMP) and Electrostatic Discharge (ESD)". In 1999, 461 and 462 were combined, requirements updated and published in the currently enforced standard: MIL-STD 461E.

Applying MIL-STD 461E

MIL-STD 461E is a set of EMC requirements, intended to serve a wide range of applications, from trucks to ships to aircraft to fixed installations. It specifically provides the opportunity to tailor the requirements for each application (e.g., above deck or below deck on a Navy ship) without having to issue exceptions to the standard. Although the more modest sections are not much different from the common IEC and FCC commercial requirements, most sections are decidedly harsh.

Table 1 is adapted from the MIL-STD 461E standard and identifies the emissions and susceptibility requirements. Each test is defined using the following syntax:

C = Conducted	CExxx = Conducted emissions test
R = Radiated	RExxx = Radiated emissions test
E = Emission	CSxxx = ? Conducted susceptibility test
S = Susceptibility	RSxxx = Radiated susceptibility test

The table also summarizes how the tests apply to computers with the text lifted and edited directly from the applicability sections of the standard. Major changes from revision D are also shown and summ ari zed.

Requirement	Application	Frequency Range	Description	Changes From MIL-STD 461E
Conducted Emissions				
CE101	Power & Interconnecting Leads	30Hz - 10kHz		No longer applicable to shipboard equip.
CE102	Power & Interconnecting Leads	10kHz - 10MHz		
CE106	Antenna Terminals	10kHz - 40GHz		
Conducted Susceptibility				
CS101		30Hz - 150kHz	The requirement is applicable to power input leads that obtain power from other sources not part of the computer including those that are rechargeable. There is no requirement on power output leads. This test ensures that performance is not degraded from the ripple voltages associated with generators, airborne, ship-borne, and vehicle-borne power sources.	Applicability and limits extended to 150kHz
CS103	Antenna Port , Intermodulation	15kHz - 10GHz	Not applicable to laptop, portable, or rack computers. (Applies only to receivers, transceivers, amplifiers, and the like.)	
CS104	Antenna Port , Signal Rejection	30Hz - 20GHz	Not applicable to laptop, portable, or rack computers. (Applies only to receivers, transceivers, amplifiers, and the like.)	
CS105	Antenna Port , Cross modulation	30Hz - 20GHz	Not applicable to laptop, portable, or rack computers. (Applies only to receivers, transceivers, amplifiers, and the like, which extract information from the amplitude modulation of a carrier.)	
CS109	Structure current	60Hz - 100kHz	Not applicable to computers unless it is directly attached to very sensitive equipment (sensitive to 1µV or better) such as tuned receivers operating over the frequency range of the test.	Measurement procedures revised
CS114	Bulk Cable Injection	10kHz - 200MHz	The requirements are applicable to all electrical cables interfacing	Limits reduced to 200MHz

			with the computer. It simulates currents that may be developed on the platform cabling from electromagnetic fields generated by antenna transmissions both on and off the platform.	
CS115	Bulk Cable Injection, Impulse Excitation	Transients - 2nS x 30nS	The requirements are applicable to all electrical cables interfacing with the computer. It simulates the fast rise and fall time transients that may be present due to platform switching operations and external transients such as lightning and electromagnetic pulses.	Applicability revised
CS116	Damped Sinusoid Transients - I/O & Power Cables	10kHz - 100MHz	The requirements are applicable to all electrical cables interfacing with the computer. It simulates electrical current and voltage waveforms occurring in platforms from excitation of natural resonance. In contrast to fast transients of CS115, this test uses dampened sine waveforms to simulate the occurrence on platforms resulting from lightning, electromagnetic pulses, and the electrical switching phenomena of the platform.	Measurement procedures & applicability revised
Radiated Emissions				
RE101	Magnetic Field	30Hz - 100kHz	This is applicable to computers and is intended prim ari ly to control magnetic fields for applications where other equipment is sensitive to magnetic induction at lower frequencies. The most common example is a tuned receiver. (RS101 is a complementary requirement imposed on equipment to ensure compatibility with the anticipated magnetic fields.)	50cm requirement deleted; limits more stringent
RE102	Electric Field	10kHz - 18GHz	The requirements are applicable to electric field emissions from the computer and associated cables. The intent is to protect sensitive receivers from interference radiated from the computer and coupled through the antennas associated with the receiver (many receivers have sensitivities on the order of one microvolt).	Limits revised for subm ari ne equipment
RE103	Antenna Spurious & Harmonic Outputs	10kHz - 40GHz	Not applicable to computers, laptops, and notebooks.	
Radiated Susceptibility				
RS101	Magnetic Field	30Hz - 100kHz	This requirement is applicable to computers and ensures that performance is not degraded	Limits revised for Navy applications; Added Helmholtz

			when subjected to low frequency magnetic fields.	coil test
RS103	Electric Field	2MHz - 40GHz		Added use of mode-tuned reverberation chambers above 200MHz
RS105	Electromagnetic Pulse Field Transient		This requirement is prim ari ly intended for computers that could be subject to the fast rise time, free-field, transient environment of an electromagnetic pulse (EMP). It applies only to those computer equipments and enclosures that are directly exposed to the incident field outside of the platform structure, or for equipment inside poorly shielded or unshielded platforms. This requirement is applicable only for EUT enclosures (electrical interface cabling should be protected in shielded conduit). Potential equipment responses due to cable coupling are controlled under CS116.	Limits revised for consistency with IEC Standards

Table 1: MIL-STD 461E Test Requirements Adapted From The Standard

It is important to remember that MIL-STD 461E doesn't directly cover a number of commercial EMI situations, including lightning and ESD. Thus, a number of related requirements are added to the list -- some from commercial standards and some from DEFSTAN (UK) or STANAG (NATO) requirements.

Applicable sections are summ ari zed in Table 2 and cross referenced as to how and where the equipment and subsystems are intended to be installed in, on, or launched from v ari ous military platforms or installations. If the equipment or subsystem may be installed on more than one platform, the standard requires that it comply with the more stringent requirement. An "A" entry in the table indicates the requirement is applicable and must be followed; an "L" means the applicability of the requirement is limited, as specified in the appropriate requirement paragraphs of the standard; an "S" entry means the procuring activity or department must specify the applicability, limit, and verification procedures in the procurement specification. Absence of an entry means the requirement is not applicable for that application.

Equipment and Subsystems installed in, on, or launched from the following platforms or installations	CE101	CE102	CE106	CS101	CS103	CS104	CS105	CS109	CS114	CS115	CS116	RE101	RE102	RE103	RS101	RS103	RS105
		A	L	A	S	S	S		A	L	A	A	A	L	A	A	L
Subm ari nes	A	A	L	A	S	S	S	L	A	L	A	A	A	L	A	A	L
Aircraft																	
Army (including flight line)	A	A	L	A	S	S	S		A	A	A	A	A	L	A	A	L
Navy	L	A	L	A	S	S	S		A	A	A	L	A	L	L	A	L
Air Force		A	L	A	S	S	S		A	A	A		A	L		A	
Space Systems (including launch vehicles)		A	L	A	S	S	S		A	A	A		A	L		A	

Ground																	
Army		A	L	A	S	S	S		A	A	A		A	L	L	A	
Navy		A	L	A	S	S	S		A	A	A		A	L	A	A	L
Air Force		A	L	A	S	S	S		A	A	A		A	L		A	

A = Applicable; L = Limited applicability; S = Specified in procurement; Blank = not applicable
Table 2: MIL-STD 461E Application Requirement Matrix Adapted From The Standard

How stringent these requirements are enforced on laptop and other portable computers depends solely on the application and procurement office. Many DoD purchases require only commercial units; but if 461 is required, it is safe to say most COTS computers will fail without serious modifications. This is prim ari ly due to the RS103 and RE102 requirements. RS103 requires that a computer maintain normal operation when exposed to a 20V per meter field (double the IEC 61000-4-3 requirements of 3 to 10V per meter). On the emission side, RE102 requires compliance when measured at one meter, not the three - meters specified in FCC Part 15, the most common commercial standard. This distance change alone means the RE102 is nine times more restrictive than the FCC, but RE102 also has tougher limits.

In addition to these requirements, there are several tough conductive susceptibility tests -- CS101, CS114, and CS116. These require injecting radio frequencies on the power lines as well as the printer, network, USB and other data ports.

Combined, these five tests are the key to compliance with MIL-STD 461. If the product complies with these tests, it will pass the entire group of tests a notebook, handheld, laptop, or other portable computer must meet (See Table 1, Description) to be certified to MIL-STD 461.

This testing is not inexpensive. The five core tests (RS103, RE102, CS101, CS114 and CS116) will require roughly two days of lab time; the entire standard, seven to 10 days. These estimates assume there are no major redesigns.

As mentioned earlier, MIL-STD 461E doesn't directly cover a number of commercial EMI situations, including ESD. For some military projects, a number of related commercial requirements may be added to the list, such as IEC 61000-4-2 (ESD) and, occasionally, some DEFSTAN (UK) or STANAG (NATO) requirements.

Designing For MIL-STD 461 Tests

Many rugged computers fall well short of the ideal enclosure -- a welded closed box. The display, access panels, drives, keyboards, and I/O connections provide many openings and cracks that can potentially let radiation in and out. Because computer boards have densely packed layouts and run at high speeds, by their very nature, they radiate EMI. Add a plethora of antennas in the form of high-speed data connections to internal drives and external I/O ports and put these in a plastic case, and it's easy to see why a COTS laptop or notebook will need serious modifications to pass RS103 and RE102.

A first step in certifying to MIL-STD 461 involves examining the board and enclosure to find the potential leaks and areas of susceptibility. The easiest place to start is with the motherboard design. The fundamental source of all EMI is time varying currents. A motherboard has many sources, from the CPU, to disk drives, to read/write to memory, to typing on the keyboard. Logic states change and produce these currents. Designers reduce these effects through the use of large ground planes, shielded cables, short trace runs from the CPU to SDRAM, and adding common mode chokes. All these design strategies reduce the possibility of inadvertently creating tiny radar transmitters and receivers within the PCB that will leave the computer vulnerable to external radiation and from becoming a broadcaster of unwanted energy. How well this is done will reduce the shielding required in the case.

Unlike a rack mount computer that is surrounded by additional shielding, a portable laptop or wearable computer relies solely on its own case to mitigate the EMI affects. The case will need to suppress the remaining emissions that are impractical in the board design, absorb and reflect any external fields, and survive the rigors of the MIL-STD 810 environmental tests. They also must be lightweight.

As such, most MIL-STD enclosures are aluminum, magnesium, or a mixed-alloy material. Gaps or seams in the enclosures around the connectors, drive openings, and keyboards allow EMI to radiate through the shield, unless the shield continuity can be preserved across these gaps. The function of an EMI gasket is to preserve continuity or current flow in the shield around these gaps. The gasket should be made of material

identical to the walls of the enclosure, making the current flow in the gasket the same as the wall and approaching the ideal design: a welded seam.

The display is another major gap where EMI can escape or affect the operation. All MIL-STD 461 tests require that the display of the information on the screen not flicker or be impaired during the test. Fortunately, there are several vendors that make a shielded glass that meet both the 461 and MIL-STD 810 requirements that can be mounted over the LED or LCD displays. Though costly, this method saves money by allowing manufacturers to use industrial COTS screens, while still complying with the stringent MIL-STD 461 standards.

The last area to address is the attached antenna or better known as printer, USB, Firewire, RS-232, and network cables. Common mode currents turn these cables into antennas that can pick up and conduct radiation through computer ports and impact the operation. This is why the RS103 susceptibility test requires all cables be connected to the unit during the test.

Manufacturers can mitigate these common mode currents by using shielded cables and adding filters into the connector ports. They can also redesign these ports to incorporate fiber optics rather than the wired cables. Fiber optic cables are immune to the external EMI fields, and, as such, could be extremely important for portable, laptop and wearable computers.

Conclusion

Since the 1990s, the US Department of Defense has stressed the need to use COTS components wherever it is possible. However, in many areas, the military standards, such as MIL-STD 461E/E, must be enforced since the computer must coexist with all other equipment including powerful transmitters and highly sensitive receivers. In many cases, the COTS computers must be upgraded to meet these more rigorous military needs. This goes beyond just EMC and includes environmental requirements such as wider temperature ranges, higher shock and vibration, ability to withstand high humidity and salt spray, while also not growing mold, fungus, and others.

It is important to remember that the MIL-STD 461E (and earlier C and D versions) is really a set of EMC requirements intended to serve a wide range of platforms from trucks to ships to aircraft to fixed installations, and many different applications (e.g., above deck and below deck on a Navy ship). Program managers also are allotted much leeway to tailor the requirements to their particular applications. Although the most modest of these EMC requirements are not much different from commercial, industrial, and medical requirements, most applications are decidedly harsh and require modifications to the COTS computers. These modifications include additional shielding and gaskets as well as metal cases.

COTS is still very relevant for MIL-SPEC computers. While more expensive, a unit that complies with both MIL-STD 461E/E and MIL-STD 810E use many COTS components to keep the price difference to a minimum, while maintaining the mil-grade, reliability, and performance needed for today's forces. This price difference between military and COTS laptop and portable computers is not as great as it used to be, so there is a reasonable chance of finding the appropriate system within the budget.

About the author:

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