An Update on MIL-STD-461F

by Ken Javor

As you read this, MIL-STD-461F has either been released or soon will be. If you have worked with MIL-STD-461E, MIL-STD-461F will look familiar. Changes are evolutionary quality improvements, not major changes as when MIL-STD-461C and MIL-STD-462 were largely set aside and replaced with very nearly brand new standards MIL-STD-461D and MIL-STD-462D. This article provides a quick overview of what is new in MIL-STD-461F.

Interchangeable Modular Equipment

Paragraph 4.2.7 deals with interchangeable modular equipment, and is new in MIL-STD-461F. This new paragraph clarifies that equipment which is made up of line replaceable modules (LRM) must be requalified if an LRM is replaced by a new or different model, even if it is a form, fit and function replacement.

Prohibition of Use of Shielded Power Leads

The wording in section 4.3.8.6 ("Construction and arrangement of EUT cables") is a little more definitive than in -461E, stating that shielded power conductors may not be used unless the platform on which the equipment is to be installed shields the power bus from point-of-origin to the load. There have been problems with equipment manufacturers asking for and receiving shielded power leads from the point-of-distribution (typically a breaker box) to the load, but with the power bus from the breaker box back to the generator being unshielded.

Of course the fundamental rule is that test wiring simulate the intended installation. With a partially shielded power bus, the equipment manufacturer can claim that he gets a shielded feed on the platform while the integrator sees an unshielded main bus. MIL-STD-461E 4.3.8.6 wording was not conclusive on this subject:

"Electrical cable assemblies shall simulate actual installation and usage. Shielded cables or shielded leads (including power leads and wire grounds) within cables shall be used only if they have been specified in installation requirements."

This problem is alleviated in MIL-STD-461F, which states in plain language precisely the above quotation, but then adds, "Input (primary) power leads, returns, and wire grounds shall not be shielded."

Computer Controlled Instrumentation

Paragraph 4.3.10.2 has a title change from "Computer-controlled receivers" in MIL-STD-461E to "Computer-controlled instrumentation" in MIL-STD-461F. This change simply recognizes the fact that more than emissions tests are automated these days. The new portion of the paragraph is basically software quality assurance:

"If commercial software is being used then, as a minimum, the manufacturer, model and revision of the software needs to be provided. If the software is developed in-house, then documentation needs to be included that describes the methodology being used for the control of the test instrumentation and how the software revisions are handled."

Emission Scanning Changes

Table II, "Bandwidth and measurement time," which underwent only a minor revision from -461D to -461E, is modified to provide an alternative faster sweep speed with multiple sweeps in "max hold" mode as a better technique for catching low duty cycle transient type events.

The idea here is that, rather than one relatively slow scan according to the parameters of Table II, the spectrum analyzer or EMI receiver is allowed to scan using the minimum dwell time possible, which is the multiplicative inverse of the measurement bandwidth (note measurement bandwidths have *not* changed). Such high speed sweeps will be over in milliseconds (see below) so the idea is to sweep continuously in max hold mode for a period of time equal to or greater than the time that would have been spent sweeping per Table II.

If a low duty cycle broadband signal is present, rather than catching one or two frequency components with the old technique, the new technique may find several components, building a better spectral signature. This can be very helpful in identifying possible problems whereas a few isolated spikes might not get the same attention.

A table similar to Table 1 with more detail is included in the rationale appendix for Table II.

Frequency Range Hz	Bandwidth Hz	Band sweep time (sec)	Band sweep time per Table II (sec)	# fast sweeps required
30 – 1000	10	20	30	1.5
1 k – 10 k	100	1.8	2.7	1.5
10 k – 150 k	1000	0.28	4.2	15
0.15 – 30 M	10 k	0.6	90	150
30 M – 1 G	100 k	0.194	290	1500
above 1 G	1 M	2 ms/GHz	30 s/ GHz	15,000

Table 1: Sweep times per scan using new technique

Susceptibility Scanning Changes

Above 1 GHz, the Table III step size has been increased, resulting in a much faster RS103 test in that frequency range. Susceptibility scans have undergone revisions in both "E" and "F" in an effort to make the testing more realistic. Step sizes have decreased from revisions D to E, and from E to F, reflecting no history of sharply tuned susceptibilities outside of intrinsically tuned circuits, such as radio receivers.

Frequency Range	-461E step size	-461F step size	Relative sweep time F vs. E
30 Hz – 1 MHz	5%	5%	Same
1 – 30 MHz	1%	1%	Same
30 M – 1 GHz	0.5%	0.5%	Same
1 - 8 GHz	0.1%	0.25%	40% (250% faster)
above 8 GHz	0.05%	0.25%	20% (500% faster)

Table 2: Comparison of -461E & F susceptibility sweep times

CE101

CE101 is now applicable for equipment used on surface ships.

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Suggested Tailoring of CE101 and CE102

The appendix discusses that CE101 and CE102 for high current loads on 400 cycle power may require tailoring of both limit and test method, and suggests an approach that makes both the limit and test set-up more realistic. The essence of the suggestion is that the 5 uH LISN used in older military EMI standards and presently in RTCA/DO-160 for commercial avionics EMI qualification is a better model of a high current, low impedance electrical bus on most platforms. The 5 uH LISN has less voltage drop at 400 cycles, and the suggested limit scales the low frequency CE101 limit according to primary power load current. Because the 5 uH LISN impedance is not defined below 150 kHz, the suggested tailoring extends CE101 (audio frequency current control) to 150 kHz and CE102 (rf potential control) begins at 150 kHz instead of the present breakpoint of 10 kHz between these two requirements.

CS106, A New Requirement

MIL-STD-461F includes a Navy ships-only "CS106" requirement that is superficially similar to the obsolete MIL-STD-461A/B/C CS06. The only significant difference is no requirement to synchronize spikes to the ac power-line. The imposed spike is 5 us wide and 400 Volts amplitude. Your venerable but no longer obsolete CS06 spike generator may now be brought out from retirement, dusted off and put back into productive service again.

(A caution to owners of the Solar Electronics Model 8282-1: its opposite polarity "tail" does not technically meet the requirement of MIL-STD-461F Figure CS106-1. Solar Electronics is planning a new spike generator to support the new CS106 requirement. It would likely be acceptable to use the Model 8282-1, but if there were a susceptibility there might be some question as to whether the out-of-tolerance "tail" might have contributed to the problem.)

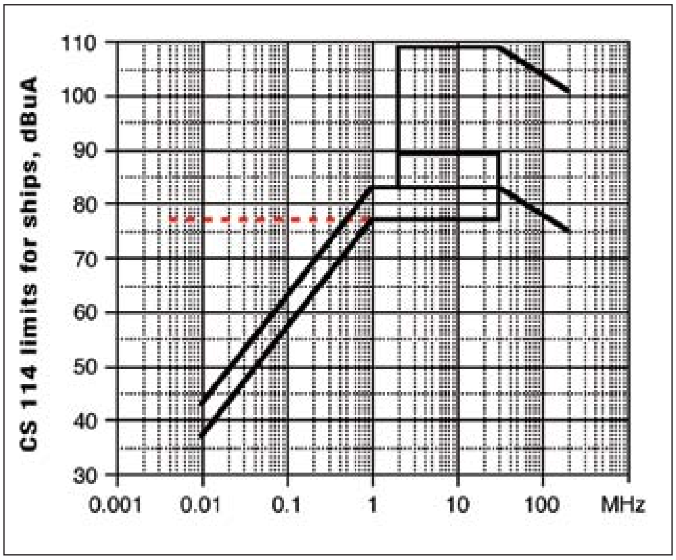

Figure 1: CS114 limits for Navy ships of all kinds (black) and extension of limit for power inputs (red dashed)

The purpose of this requirement is, however, entirely different than when CS06 was developed and required in MIL-STD-826 and MIL-STD-461 A/B/C. CS106 has little to do with electrical power quality, except modeling coupling from power bus transients to signal lines within an equipment enclosure. It is now a special purpose cross-talk test limited to Navy procurements, particularly submarines, which requested and justified it, as follows (from the rationale appendix):

> *"The Navy submarine community has found the obsolete CS06 of MIL-STD-461 (through revision C) requirement to be an effective method to minimize risk of transient related equipment and subsystem susceptibility. This type of transient susceptibility test has been successful in early identification of transient related EMI problems in naval equipment and subsystems. The Navy has found good correlation between transient related shipboard EMI problems, including longevity, degraded performance and premature failures, and CS106 susceptibilities."*

Most of the problems uncovered by the heritage CS06 requirement were not with the power input circuitry, but rather with other circuits which were affected by cross-talk between power and signal wiring within the test sample. Whereas other Services found that meeting CS115 and CS116 provided the necessary hardness against this type of coupled EMI, for Navy submarines these requirements are felt to be overkill. While other platforms route power and signal cables in close proximity and in perhaps poorly shielded configurations, it is Navy ship practice to segregate power and signal cables and install them in high permeability conduit when required. (Navy ships practice is detailed in the Handbook of Electromagnetic Shielding Practices, S9407-AB-HBK-010.)

Therefore, the driving reasons for CS115 and CS116 do not really exist for submarine platforms, and the only problem from transients is coupling within the equipment chassis. A long time ago, it was considered good EMC design practice to provide a separate electrical power connector with EMI filtering immediately adjacent in a shielded EMI "doghouse" configuration. This design completely protected the equipment from noise incoming through the power bus.

But today it is often the case that power and signals come into the same connector, and further that a ribbon cable attachment is made to that connector. Under these conditions, any noise that was on the power bus can couple over easily to unshielded signals on the ribbon cable, and the segregation and shielding that was effective in long runs through the ship is bypassed within the equipment enclosure.

The heritage CS06 requirement is all that is necessary to check for cross-talk within the test sample, is a much less stringent requirement than CS115 and CS116, and is quicker to perform. Now it should be clear why deletion of the synchronization requirement is the major difference between heritage CS06 and MIL-STD-461F CS106. The cross-talk aspect will be unaffected by the absolute level of the 400

Volt spike relative to the ac waveform; the cross-talk will be proportional to the time derivative of the spike, and that value will swamp the coupling from the power waveform itself over the short distance of parallel runs within the equipment. Or, in the more laconic style of the rationale appendix, "…the argument provided for re-establishing a CS106 type transient was based on crosstalk issues which have no relationship to phase position."

CS109

CS109 is now only applicable for surface ship equipments that have an operating frequency of 100 kHz or less and have the sensitivity to read a signal at or below 1 µV.

CS114

For Navy ships and submarines, there is a low frequency add-on to this requirement that models common mode noise generated by new power systems. The add-on is a level of 77 dBuA from 4 kHz to 1 MHz. This is shown in Figure 1 as the dashed red extension to the various Navy ship CS114 requirements. The reason for this new add-on is new dc power systems used on ships. A multi-kilovolt dc potential comes from an electromechanical generator, but there are many lower levels of dc power that are derived from the original high potential bus by solid-state dc-to-dc conversions which in turn generate these large amounts of common mode noise.

Note that the extension only applies to complete power cables, not signal bundles. Figure CS114-2 has extended the allowable insertion loss curves from 10 kHz down to 4 kHz in order to make this measurement. The extended curves should bracket the performance of injection clamps that meet the curve above 10 kHz.

CS115

CS115 is only applicable for submarine and surface ship procurements when specified by the Procuring Activity. This change dovetails with the addition of CS106.

CS116

Whereas there were previously two CS116 limits, there is now just one, the more stringent of the two, which peaks at 10 Amps. This change reflects a concern that the 5 Amp limit was not stringent enough except perhaps under atypical conditions of very high platform-provided shielding. CS116 now has a limited applicability for equipment on submarines. The requirement applies only to cabling that exits the pressure hull.

RE101

If the equipment exceeds the limit at the 7 cm distance, a requirement has been added to increase the measurement distance until the emission falls within the specified limit and to record the emissions and the measurement distance.

Another change is mainly of historical interest. Since 1967, the RE01/RE101 loop probe design has remained the same, and in MIL-STD-461 (1967) was said to be based on the Stoddart Aircraft Radio Company AT-205/URM-6 loop design. The RE01/RE101 loop probe design for the past forty years has been 36 turns of 7-41 Litz wire (seven strands of AWG 41 magnet wire) wrapped on a 5.25" diameter coil, with an electrostatic shield surrounding the windings. Solar Electronics submitted a Standardization Document Improvement Proposal in 2007 that amounted to removing the requirement to use 7-41 Litz wire. The Solar Electronics Model 7334-1 uses 36 turns of AWG 30 wire instead.

Investigation of the Solar proposal revealed that there might have been a mistake in the original release of MIL-STD-461 back in 1967. In the NAVSIPS 93134 Technical Manual for Radio Interference Measuring Set AN/URM-106, dated 13 March 1958, in paragraph 2.6.b on page 2-15 the AT-205/URM-6 loop is described: "The loop is a solenoid winding 5 ¼ inches in diameter, consisting of 36 turns of No. 31 Formvar wire." Formvar was an early synthetic magnet wire insulating material. It is mentioned in the third edition of the "Reference Data for Radio Engineers" handbook, published in 1949.

Pictures of the original AT-205/URM-6 loop and the present day Solar Electronics 7334-1 probe are shown in Figures 2 and 3. Figure 2 shows the original with balanced twinaxial output as well as a later model with coaxial output. The modern Solar version uses a bnc output. Construction details of the Stoddart and Solar probes are visibly similar.

RE102

There are several changes here. A universal change is in the use of the 41" rod antenna, used below 30 MHz. Since MIL-STD-462 Notice 2 was released on 1 May 1970, there has been a requirement to ground the rod antenna counterpoise to the ground plane. This has caused problems with measurement accuracy above 10 MHz. Under MIL-STD-461F the counterpoise is floated just as under the original MIL-STD-462 released in 1968.

Figure 2: Stoddart AT-205/URM-6 balanced loop and Stoddart 90114-3, same but with coaxial output (Museum of EMC Antiquities)

Figure 3: Solar Electronics Model 7334-1 modern day version of AT-205/URM-6 (courtesy of Electronic Product Testing)

In addition, Figure RE102-6 is revised to show the antenna lowered so that the center point of the 41" rod element is 120 cm above the test chamber floor. Further, this figure shows that the coaxial cable emanating from the rod antenna base is carried directly to the floor and grounded there, with a ferrite bead installed between the rod base and the floor ground point. The ferrite bead should have between 20 – 30 Ohms impedance at 20 MHz. (A bead that works in this application is the Ferrishield B1642.) Test facilities whose EMI chamber floors have been covered with tile or poured concrete will have to bore through the nonconductive coating to provide the required bond point. If this is impractical, the rationale appendix for this section states:

"For shielded enclosures that do not have an available point for bonding the coaxial cable from the matching network to the floor directly beneath the counterpoise, a low inductance copper sheet should be installed from the nearest access point on the floor to the counterpoise location."

Lastly, if you own a rod antenna whose coax output connector shell is isolated from the case, you must defeat that isolation and ground it to the case. That isolation is necessary at the mains frequency and its harmonics, but over the frequency range of RE102 the connector shell needs to be grounded.

In addition to that global change, there are changes to specific Navy limits and applicability. Equipment slated for use on Navy ASW aircraft now need qualification from 10 kHz to 18 GHz. Other Navy aircraft require RE102 qualification from 2 MHz to 18 GHz. In Figure RE102-1, equipment slated for use below the decks of Navy surface ships get a 20 dB relaxation from the previous -461E limit which was the same for topside or below decks.

RE103

The requirement is now met if the harmonics do not exceed the applicable RE102 limit.

RS101

RS101 for submarine procurements now applies only to equipment and subsystems that have an operating frequency of 100 kHz or less and have the sensitivity to read a signal at or below 1 µV.

RS103

This first change is a bit of a sleeper in that it is contained in one short sentence in paragraph 5.20.3.4.d.1.c. "Ensure that the E-field sensor is indicating the field from the fundamental frequency and not from the harmonics." MIL-STD-461F for the first time ever imposes a requirement that the radiated signal be demonstrated to be higher in amplitude than its harmonics.

When using wide-band field intensity sensors, there has always been a problem that if the harmonics of a signal come through higher than the fundamental, the probe senses the harmonic. This problem is most prevalent using the biconical antenna below 80 MHz, but can also be a problem using multi-band traveling wave tube amplifiers. Regardless of what your electric field probe sensor is reading out, your 137 cm tip-to-tip length biconical fed with 3 kW or less is not generating 200 V/m below about 70 MHz. In fact, it would take around 30 kW to generate 200 V/m at one meter distance with that antenna at the low end, a power level you don't have and which, if applied, would melt the balun.

Although MIL-STD-461 does not prescribe antennas for RS103, leaving the choice to the test facility, the appendix explains that from 30 – 80 MHz one option for improving radiated signal purity is the use of extended element biconicals. The extended biconical is more efficient than the standard 137 cm tip-to-tip biconical at frequencies below 80 MHz. In turn, this means the amplifier driving the antenna is not driven as hard, which reduces harmonic output. There is no problem using the extended biconical in horizontal polarization, but it is difficult to use vertically due to its length. A parallel plate antenna of the correct dimensions may be used to 80 MHz if the dimensions of the test sample allow it; or a transmission line radiator may be employed that generates the required field in both polarizations.

Under MIL-STD-461E (but not -461D), there was a special requirement for RS103 at the tuned frequency of a radio receiver. That is, if the test sample happened to be a radio, there was a requirement for testing at the tuned frequency. Under MIL-STD-461D, the radio was exempt from testing at the tuned frequency. The basis for the exemption was the idea that the source of any RS103-level field is outside the platform, therefore it impinges more strongly on the antenna than on the receiver itself, and that the antenna of course being a better pickup than the radio, there was no point in exposing the radio to a lesser field than what was impinging on the antenna.

This was logical, but in the Tri-Service Working Group (TSWG) meetings leading up to the -461E revision, a receiver manufacturer recounted the following. In an equipment rack on a large aircraft, two radios were sitting side-by-side. One radio was tuned such that its LO or another frequency it generated (but not a transmit frequency) was at the tuned frequency of the adjacent radio receiver. The level of emissions was high enough to cause RFI to the receiver, and it was box-to-box. Based on that interaction, the TSWG imposed an RS103 limit at the tuned frequency of a receiver that was 20 dB higher than the RE102 limit. The idea being that if two equipments are adjacent, the field will be higher than at one meter, plus you have to allow significant tolerance for anything having to do with an RE102 measurement.

Under MIL-STD-461F, Air Force and Army procurements go back to no RS103 limit at the tuned frequency, but Navy surface ships and submarines have to meet the full requirement with no relaxation at the tuned frequency. The justification for this is that the Navy is using more and more transmitters within the ship that can be in direct proximity to a victim receiver.

The RS103 frequency range for equipment procured for Navy aircraft is 100 MHz to 18 GHz. So NAVAIR procurements don't have to worry about the signal purity issue with the biconical. There is still the issue with multi-octave TWT amplifiers, but this can be solved with filters, if need be. ☐

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