The Continuing Saga of MIL-STD-461/462

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Background

In the 1997 issue of ITEM, I provided an overview of how the Tri-Service Committee was convened to develop the D versions of MIL-STD-461 and MIL-STD-462. Additionally, I discussed some of the more significant differences between the C and D versions. Since a book could be written on the subject, last year's article focused on the cost effects associated with testing to the D versions of the standards.

The ongoing activities of the Defense/Industry E^3 Standardization Committee (DIESC) were described, as were DoD plans to update the D version of the standards. Now a year later, the status is the same. DIESC is still meeting and there are still plans to update the standards. For this article, I will provide insights into some of the studies that were performed during the preparation of the D version of the standards, discuss possible areas to be addressed in 1998, and editorialize a bit on the role of MIL-STD-461/462 in industry.

History

For nearly two decades, MIL-STD-461/462 were the standards for EMI requirements and test methods. Although there were differences within the standards themselves as to the application of requirements, limits, and test methods, the standards as a whole comprised the basis for EMI control. Nearly all NATO countries used these standards, although some have translated requirements into their own language and implemented some modifications. Even India, Russia and former Eastern Block countries utilize MIL-STD-461 as their baseline EMC criteria. As new concepts and requirements for MIL-STD-461 and 462 were published over the years by the U.S. Department of Defense, they were adopted worldwide as many countries followed the U.S. leadership in EMC standardization.

When the Food and Drug Administration (FDA) first developed a Medical Device EMI standard in the late 1970s, its approach was to utilize MIL-STD-462 test methods and equipment in order to minimize the cost impact of testing. Many hospitals were surveyed at the time in order to establish hospital-unique limits. However, the only new test method inserted into the FDA's EMI standard[1] was the use of a Helmholtz coil for magnetic field susceptibility. This is an example of how relevant MIL-STD-461 and 462 were.

If the U.S. Department of Defense were to cancel MIL-STD-461/462 or elect not to maintain the standard through modifications for technological updates, a dilemma would be created for numerous governments. NATO EMC Standards (STANAGs) have recently been modified in order to be consistent with MIL-STD-461/462. When the U.S. DoD updates MIL-STD-461/462 again, the STANAGs will also have to be updated in order to assure harmonization and consistency.

The requirements contained in MIL-STD-461 are based upon documented or predicted EMI problems. From actual experiences, limits have been established and test methods have been developed. Unlike past standards and specifications, requirements were not driven by test equipment capabilities or manufacturers.

Members of the technical team involved in preparing the D version of the standards each had a minimum of 20 years of experience in EMI measurement and control. Most had field experience in cataloging and solving problems, and studying and developing test methodology. There was always concern for the cost-effectiveness of equipment designs and test facilities. Often, requirements were modified to accommodate the capabilities of what was considered to be standard EMI measurement equipment, and what was a reasonable design objective.

The Magical 200 V/m Limit

Site surveys performed on military ships, land-based antenna farms, and other locations have shown that the electromagnetic environment can well exceed 200 V/m. The operation of ISM equipment (as defined by Part 18 of the FCC Rules) has produced measured fields in excess of 200 V/m. When the automobile industry established its original radiated susceptibility criteria, it used 200 V/m. Today, MIL-STD-461 still utilizes 200 V/m as the maximum criteria, although MIL-STD-464 and MIL-HDBK-235 clearly show that operational environments far exceed this value. Why then, does nearly everybody use the magical 200 V/m level?

For many years, the U.S. ANS C95.1 RF radiation hazard level for personnel was set at 10 mW/m^2 from 300 kHz – 100 GHz. This, of course, was before Specific Absorption Rates (SARs) were taken into account and the frequency range was extended. Based upon reliable sources, the automobile industry felt that it was reasonable to assume that an automobile would not be driven in a field intensity which was unsafe for human exposure. (10 mW/m^2 is equal to 196 V/m in free space.)

The military, on the other hand, was concerned about the cost of power amplifiers which would be required to generate a field in excess of 200 V/m. There was concern for the test methodology of monitoring this field, including the narrow bandwidth of standard gain antennas in the microwave region. The reliability of MIL-HDBK-235 and early site surveys, which established a need for the higher fields, was of concern. (Obviously, 6 dB of uncertainty can result in a field intensity variance ranging from 100 V/m to 400 V/m.)

Extensive studies by EUROCAE, the Federal Aviation Administration (FAA) and others have determined that the field intensities through which aircraft must fly exceed 200 V/m near transmitting antennas. Thus, the requirements of RTCA DO-160 for radiated susceptibility have changed from the once meager 1 V/m to levels well in excess of 200 V/m over the past 10 years. Now, levels of 600 V/m or more are being considered.

The testing of equipment and subsystems to field intensities in excess of 200 V/m is still very expensive. Testing to 200 V/m could become more expensive if "measurement uncertainty" must be considered. New test methods, such as the advanced technology chamber (ATC) and mode-stirred chamber, which are gaining greater acceptance, do not require more expensive amplifiers.

However, the development of the chamber itself, which involves related software and data mapping, can be as expensive as larger amplifiers and the technology may exceed the capabilities of testing organizations that utilize simplistic techniques. With the FAA and automobile industry endorsing mode-stirred chamber applications, and with MIL-STD-464 high field intensity environments needing wider application, the magical 200 V/m limit may soon be history.

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One Size Fits All

MIL-STD-462 contains procedures primarily designed for EUTs not much larger than a bread box. This is a carryover of the old Air Force EMI standards with some modifications to include multiple bread boxes which create a subsystem. Unfortunately, a very large amount of equipment has been omitted and overlooked, especially large electronic subsystems used aboard combat ships.

During its development phase, a series of 12 different test configurations encompassing small and large subsystems, floor-mounted racks, backpacks, and a multitude of other equipments were developed for inclusion in MIL-STD-462D. However, most of these were not included in the standard. The basis for this decision was "simplicity," or the philosophy that the test procedure will describe how larger equipments will be tested. Such has been the case.

Large systems, such as torpedo launchers, radars, fire control systems, fire fighting training facilities, etc., have been tested to the requirements of MIL-STD-461 using unique and tailored test methods derived from MIL-STD-462. Compliance to the standards was required on some of these large systems and subsystems as a means to control electrical interference and its effects. The limits were utilized for a contractual basis to give the customer recourse in the event the equipment under test, for instance, completely obliterated the UHF radio spectrum or if temperature sensors failed to operate in critical circuits. With the cancellation of MIL-E-6051, which established EMC in the end environment as a criteria, the misapplication of MIL-STD-461/462 on systems and very large subsystems has proven to be quite worthwhile.

Test Requirements That Were Rejected

CE07: TIME DOMAIN TRANSIENT EMISSIONS

CE07 was a time domain transient emission criteria stemming from MIL-E-6051D and then adapted for use by the Air Force. The original intent behind this requirement was to control time domain transients beyond the bounds

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of MIL-STD-704, the criteria for aircraft power. The committee studied this test method for nearly a year and prepared an initial new draft test method dated 30 November 1990 and later a draft Revision 1 dated 1 February 1991. A study performed by R&B Enterprises (Report No. 912802, dated March 28, 1991) compared the validity of a voltage measurement versus a current measurement and recommended a current measurement.

Ultimately, this requirement was dropped from consideration since it applied to single-event transients and historical data from the field did not show very many significant aircraft EMI failures due to these transients. The decision was not unanimous since heavy current loads are switched on ships and at ground facilities which create significant time domain transients. There was a transient susceptibility requirement of 1000 V in MIL-E-16400 which addressed this issue at that time. (MIL-E-16400 has since been canceled.) However, the committee could not be persuaded to extend the requirement beyond its original aircraft application. This requirement is not likely to be resurrected in future revisions of MIL-STD-461 unless equipment failures from such events can be documented. An interesting outgrowth of the studies performed in this area was the design of a three-phase delta line impedance stabilization network (Figure 1).

POWER LINE SOURCE IMPEDANCE (PSI)

Below the cutoff frequency of the LISN and the shielded room filter, the power line source impedance in any given test laboratory or facility can vary significantly. It is dependent upon the characteristics of the power source, which could be a UPS, public utility, dedicated power, or facility power. Studies revealed that an anti-resonance occurs between the typical shielded room filter and the LISN in the 1-10 kHz frequency range. This anti-resonance would provide an impedance spike of approximately 12 dB, but measurements and experiments could not show that this impedance spike made any significant difference in the measured data when testing an EUT. However, the effects of the power line source impedance on CS101, CE101, and CS109 testing was significant and could explain the difference in results from testing at different locations or in different shielded enclosures.

Another problem that the DoD had to confront was the different effects of wye-configured power for ground facilities and delta-configured power for ships and aircraft. Tests were run to determine whether or not a difference of interference levels would be measured between delta- and wye-configured single-phase power. The testing was thorough, and although there were many unusual observations,. none could be attributed to the wye or delta configuration of the power source.

The DoD's concerns were complicated by the type of power used. Aircraft uses 28-V dc, 115-V 3-phase delta, and 400-V dc and both 26-V and 115-V 400-Hz ac. Ships use 60-Hz, 400-Hz, 120-V, 240-V and 480-V 3-phase delta. The question as to whether a different LISN should be specified for each power source or whether an impedance curve for the power source should be provided had to be addressed, since the LISN impedance changes with different prime power characteristics. If the impedance curve was to be imposed, then a corresponding test method was needed which would be utilized by the laboratory at the start of each test series. The impedance of the power source was also somewhat dependent upon the amount of current being drawn.

The research included more than tests. A series of technical papers on the subject were collected and reviewed, including "RF Impedance of United States and European Power Lines" by John A. Malak and John R. Engstrom, which appeared in the February 1976 issue of the *IEEE Transactions on EMC*. Figures 2 through 5 show the results of some of the measurements performed by R&B Enterprises using a network analyzer with a scattering parameter adaptor.

These studies made one thing very clear: the 10-μF capacitor was not a good representation of the power source impedance. However, for the sake of "simplicity," a single LISN configuration and 50/60 Hz impedance was specified. The committee voted to ignore the variances in power source impedances and their effects for the time being. The test configurations which have the initials ICP (impedance control point) in lieu of a LISN were placed in the archives. Now that the EMC community is more familiar with coherent measurements, the ICP concept could be revised for the low frequency tests in the future.

It should be obvious that the control of EUT output or load impedances is also important. When testing a power supply, for instance, the RF impedance characteristics of the load can significantly change the interference emis-

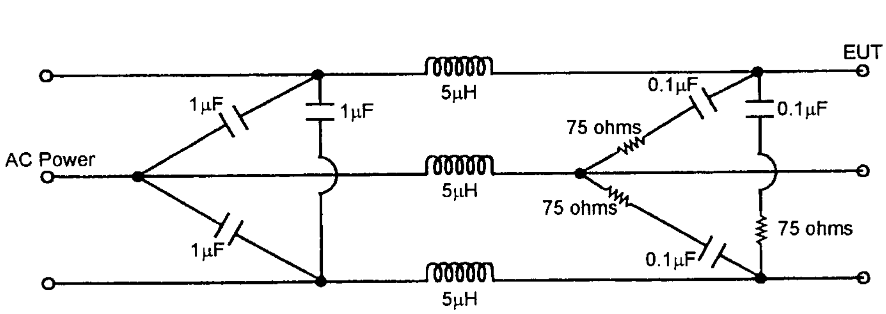

Figure 1. *Impedance Control Network for Three-phase Delta Power Systems.*

sion from the dc supply. Different types of load banks are typically used, ranging from light bulbs and wire-wound resistors to inductive heaters. If the ICP concept were going to be adopted, it was going to be used for loads whenever an active interface was not utilized. A lot of technology was developed and much was learned through this exercise even though the only configuration change made to the standard was a switch from a 10-μF capacitor to a LISN. Draft test procedures for the measurement of impedance control points (ICPs) under load conditions using scattering parameters (coherent measurement) technology now exist in the archives and the influence that these impedances have on the measurement results is better understood. Even a calibration method for a LISN was developed but, unfortunately, never published.

GROUND PLANE INTERFERENCE TESTING (PROPOSED RS107)

The ground plane interference (GPI) susceptibility test was devised in 1972 by Phil McBrayer, then at McDonnell Aircraft Company. The test was first used as a rapid means of testing EMI immunity on the F-15 flight test instrumentation system. The test was further developed in 1974 by Dave Fassberg of the Naval Avionics Center for use on the A-6 aircraft. The procedure was subsequently used by McDonnell Aircraft to determine the effects of GPI in composite air frames and incorporated in the F/A-18 EMC Control Plan. In October, 1988, a paper entitled "Ground Plane Interference Testing" prepared by Harry Franz, Pacific Missile Test Center, Point Mugu, CA and Douglas Wong, VSE Corporation was published. This paper stated that the original GPI test was designed to simulate the difference in

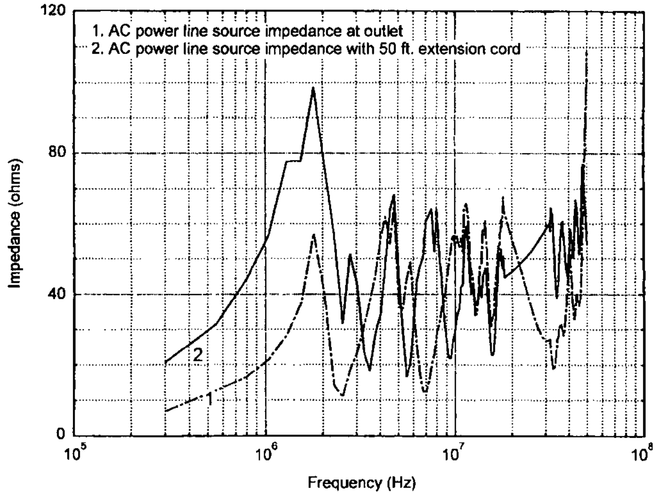

Figure 2. AC Power Line Source Impedance with Specified Cord.

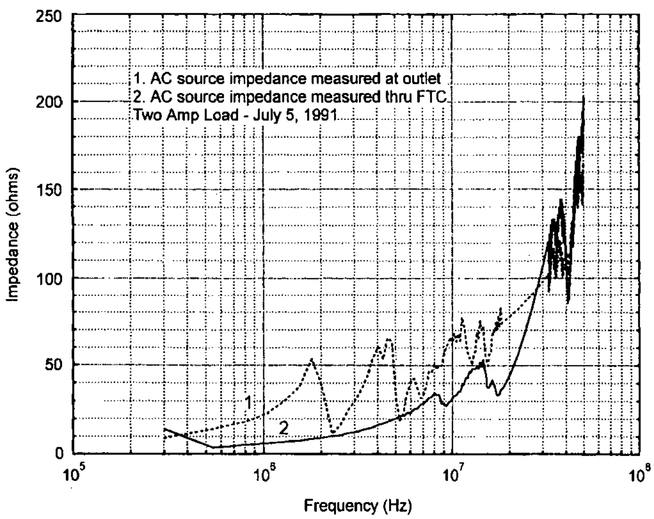

Figure 3. AC Power Line Source Impedance with Specified Load.

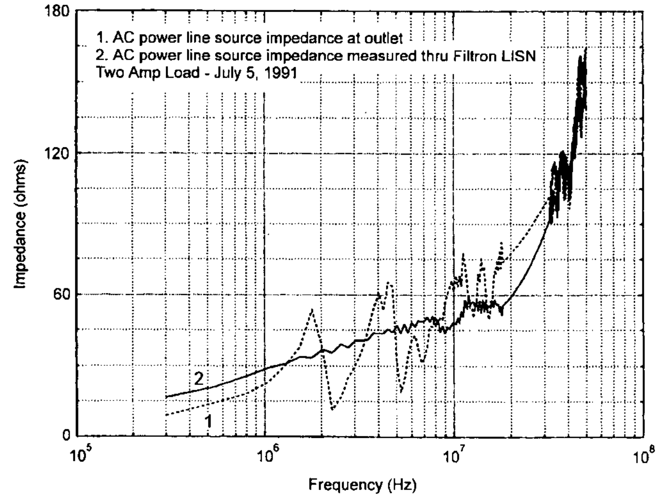

Figure 4. AC Power Line Source Impedance with Specified LISN.

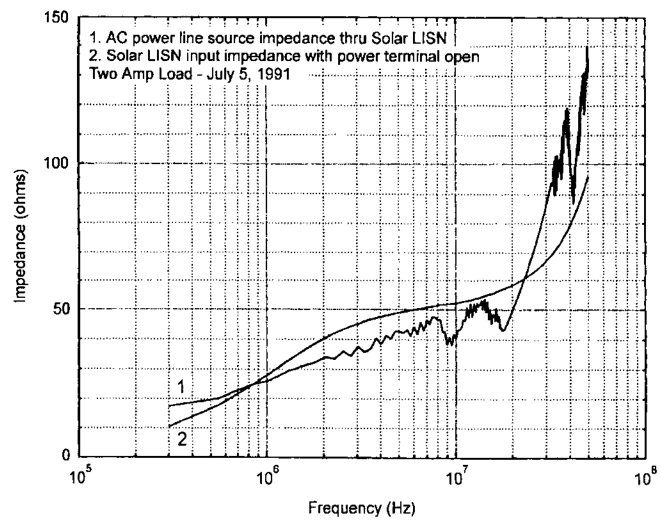

Figure 5. AC Power Line Source Impedance with Specified LISN.

ground potential between two interconnected systems. Another paper, entitled "Proposed RS107 Ground Plane Interference Testing (Draft)," dated January 23, 1991 (author unknown) indicated that single unit GPI testing was valid since these tests evaluate the interference with the input power generator.

The 461 Revision Committee studied all of the papers and arguments presented concerning GPI testing. Their conclusion was that, at best, this test is a system-level test and belongs in a system-level test standard. MIL-STD-461 applies only to subsystems and equipments and this test has little application when applied to a single unit. One study reported that approximately 32 single equipments were tested over a period of six months and none of the EUTs was susceptible to GPI. Thus, GPI was not included in MIL-STD-461D.

Simply stated, the GPI test involved grounding one end of the interference source to the ground plane and applying the "hot" side of the source to the chassis of the EUT. Interface cables were then run between the EUT and other equipments which were grounded to the ground plane (See Figure 6 and Table 1). The test was performed from 320 Hz through 500 Hz at 3 V rms and from 500 Hz to 100 MHz at 1 V rms. Also applied were 100 PPS of ± 8-V, 100-s pulses. Perhaps this test method will be invented by the EU someday.

CE108: SURFACE CURRENT EMISSIONS

This test method was a proposed replacement for RE102 testing below 200 MHz. The test method assumes that radiated emissions from electrical, electronic, and electromechanical equipment are coupled to the cables interfacing with this equipment and that the radiated emissions measured only common mode currents on the cables. It was acknowledged that some of the interference emissions produced by the equipment will not be radiated from the interface cables. Thus, it was proposed that the surface currents of the EUT enclosure, as well as the bulk currents being conducted by the cables, be measured.

Using a half of a current probe placed on a metallic surface to measure the current flowing through the surface was initially an interesting concept. However, it did not take the committee very long to dispense with this proposal since its advantages and benefits could not be substantiated.

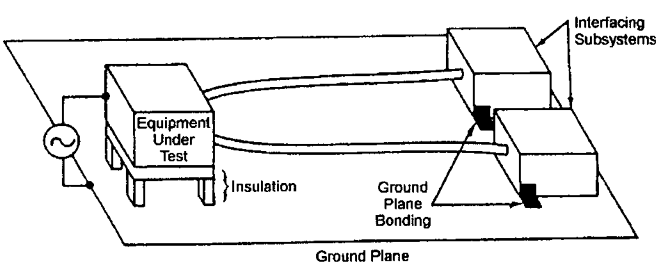

Figure 6. *Ground Plane Test Configuration.*

All equipment interface circuits shall be capable of specified performance when subjected to the following aircraft chassis noise between the interfacing weapon-replaceable assemblies (WRAs):

(a) Three volts (rms) from 320 Hz to 500 Hz
(b) One volt (rms) from 500 Hz to 100 MHz
(c) ± Eight volts, 100 µs pulses at a repetition rate of 100 pulses per second

Table 1. *GPI Test Requirements from MCAIR's F/A-18 EMC Control Plan.*

Status of DIESC

The Defense/Industry EMC Standardization Committee (DIESC) is still reviewing commercial EMC requirements and comparing their applicability to military requirements. The guidance for military equipment acquisition managers is still being prepared in the form of a handbook. At this writing, a meeting is scheduled for the first week of February 1998. A handbook draft is to be distributed to committee members and reviewed. At the end of the meeting, the government will open discussions on the updating of MIL-STD-461/462. The status of these activities will be reported on www.RBitem.com and in the *IEEE EMCS Newsletter* and the *JSC E^3 Bulletin*. The need for and the work of the DIESC will be perpetual. However, perpetual DoD support or funding cannot be assured.

Summary

I hope that this article illustrates that the preparation of an EMI standard as significant as MIL-STD-461 is a major responsibility requiring extensive study, analysis and experimentation. Ultimately, because the objectives of the standard were kept in mind, more requirements were rejected than accepted. To prepare this article, I needed only to reference four file folders. However, my records consist of over 20 folders containing files of detailed studies. This information will certainly be of significant value when the time comes to develop an internationally-accepted EMC standard.

Reference

1. MDS-201-0004. Electromagnetic Compatibility Standard for Medical Devices. FDA, October 1, 1979.

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