THE ORIGIN OF MILITARY EMI SPECIFICATIONS

INTRODUCTION

Within the past few years, there has been a great deal of activity in the generation of new interference specifications which, to a certain extent, have made a break with their predecessors. This trend was started by Mil-Standard-826 in 1964 and by the issuance of Military Standards 461 and 462. The changes in these specifications are not merely ones of organization and methods of testing, but apply to the test limits themselves. Such changes in limits lead one to question why the changes were made and, further, how the original and present interference limits were generated.

EARLY ELECTROMAGNETIC INTERFERENCE SPECIFICATIONS

One of the earliest electromagnetic interference specifications was the joint Army/Navy specification JAN-I-225 (Ref. 1) of June 1945. This specification set forth no interference limits, but merely prescribed methods of measurement over the frequency range of 150 kilohertz (kHz) to 20 megahertz (MHz). It was used in conjunction with specification AN-I-27, which was established as an early criterion for control of interference in aircraft electrical systems.

These documents provided for measurement of conducted and radiated interference, the latter utilizing both a rod antenna and a loop probe. The rod antenna was to be located at a distance not greater than one foot from the nearest point of the test sample; the loop probe could be put in actual physical contact with the test sample, since the test consisted of probing the equipment and wiring to obtain the maximum indicated level of interference, which was then compared to a sine-wave signal injected into the receiver. Such measurements introduced many variables dependent upon the position of the probe and upon the noise versus sine-wave sensitivity of the receiver; the criterion of success or failure of a measurement was a function of the operator's skill in handling the probe.

AN-I-27 was superseded by AN-I-42 which was, in turn, superseded in June of 1950 by Mil-I-6181 (Ref. 2). This last specification contained specific interference limits for the particular measurements required by JAN-I-225. In addition, susceptibility tests and limits were established. Radiated interference limits were defined in terms of equivalent input microvolts for particular measuring instruments over the applicable portions of the frequency range.

In general, these limits appeared to be at the threshold of equipment sensitivity, i.e., the limit represents the minimum discernible signal of the particular receiver used to establish the limit. The limits were not differentiated for broadband or continuous wave (CW) measurements, and the instrument was merely operated in a wideband position when making broadband measurements.

In evaluating these specifications, the historical context must be kept in mind, as well as the intended use of the documents. They were to apply only to aeronautical equipment for the Army/Air Force and Navy, and were directed toward the control of interference to voice communication receivers operating in the frequency range of 2 to 30 MHz. Such receivers were connected to an aircraft long-wire antenna via an unshielded lead-in which was run within the fuselage of the aircraft. The receiver would thus be extremely susceptible to interference picked up via this lead-in, and all interference reduction efforts were directed toward reducing any radiated energy in this frequency range within the aircraft, which might be picked up by the affected receiver antenna lead-in. It should also be noted that little by-passing or filtering was provided on power leads to receivers, and, in many cases, as little as 10 to 20 millivolts (mV) of interference coupled to these power leads could cause undesired or unintentional responses in the receiver. The constant possibility of such responses furnished the rationale for conducted interference and susceptibility measurements on power leads and led to a further rationale for radiated interference measurements. The antenna lead-in represented a high impedance antenna and, as such, was primarily responsive to high impedance fields; it was for this reason that the rod antenna was chosen as the most realistic type of antenna to be used for radiated interference testing.

Early in 1950, one of the first Tri-Service Committee approaches to a unified interference specification was attempted. This Committee, reporting through the Interference Reduction Panel of the Research and Development Board to the Defense Supply Management Agency, was charged with developing a proposed Military Standard No. 225 to standardize interference measurement techniques among the three military agencies. In January of 1953, this Committee produced a draft of the proposed Mil-Std-225, but it was never officially approved by the three departments. The Bureau of Ships made some modifications to the content and issued it as Mil-I-16910, (Ref. 3), while Wright Air Development Center and the Navy Bureau of Aeronautics generated another version as the basis for revision of Mil-I-6181, which resulted in Mil-I-6181B (Ref. 4) in May of 1953.

INTERFERENCE LIMITS

The radiated interference limits in Mil-I-6181B reflected the awareness that suitable differentiation in terms of the bandwidth of the measurement instrument must be made between the limits for broadband and CW interference. Thus, while curves of the equivalent input microvolts (μV) and correction factor curves for pulse repetition rate were given for particular instruments; standard interference limits, in terms of microvolts and microvolts-per-kilohertz bandwidth of antenna-induced voltage for the standard 41-inch rod and dipole antennas, were also given.

A BC-348Q airborne radio receiver, part of the AN/ARC-21 (with a sensitivity of 5 to 7 μV over the 200 kHz to 18.0 MHz frequency range), was installed inside a shielded room with a 24-inch lead to a 12-foot straight-wire antenna located outside the shielded room to simulate the aircraft set-up; it should be noted that the 24-inch lead was unshielded, as is typical of antenna lead-ins for aircraft at that time period. Various types of radio interference sources, such as dc motors, poorly shielded dynamotor cables, and adjustable output ignition sources, were installed at a distance of one foot from the lead-in. At those frequencies where the interference sources happened to produce an interference signal which was slightly above the background level of the receiver within the shielded room, a measurement was made by means of the newly developed AN/PRM-1 interference instrument (NM-20A) with a rod antenna located one foot from the noise source. The measurement was taken as an approximation of the desired broadband radio interference limit. Figure 1 shows these test values and the broadband limit itself.

Shown on this figure is the background level of the AN/PRM-1 receiver (NM-20A); this is contrasted with the earlier limit of Mil-I-6181, which was roughly at the level of receiver sensitivity.

In Mil-I-6181B, the dipole antenna was used above 20 MHz, and the broadband limit represented the maximum allowable open-circuit voltage which could be induced in a resonant dipole from the broadband interference source under test. The levels were determined by adjusting the interference source to provide a threshold which was just equal to the old limits of Mil-I-6181 as read on the least sensitive instrument in use and then measuring the interference on an instrument of known bandwidth which was capable of peak measurements. The measurements of broadband impulsive interference were required only to 150 MHz, since this was the upper frequency limit of the interference instruments utilized at the time, (typically, Measurements Corp. Model 58). By the time of the development of Mil-I-26600, interference problems with aircraft ignition systems had been encountered up to 400 MHz, and, since instrumentation was then available (AN/URM 7 or NF-105), the broadband limit was extended to that frequency.

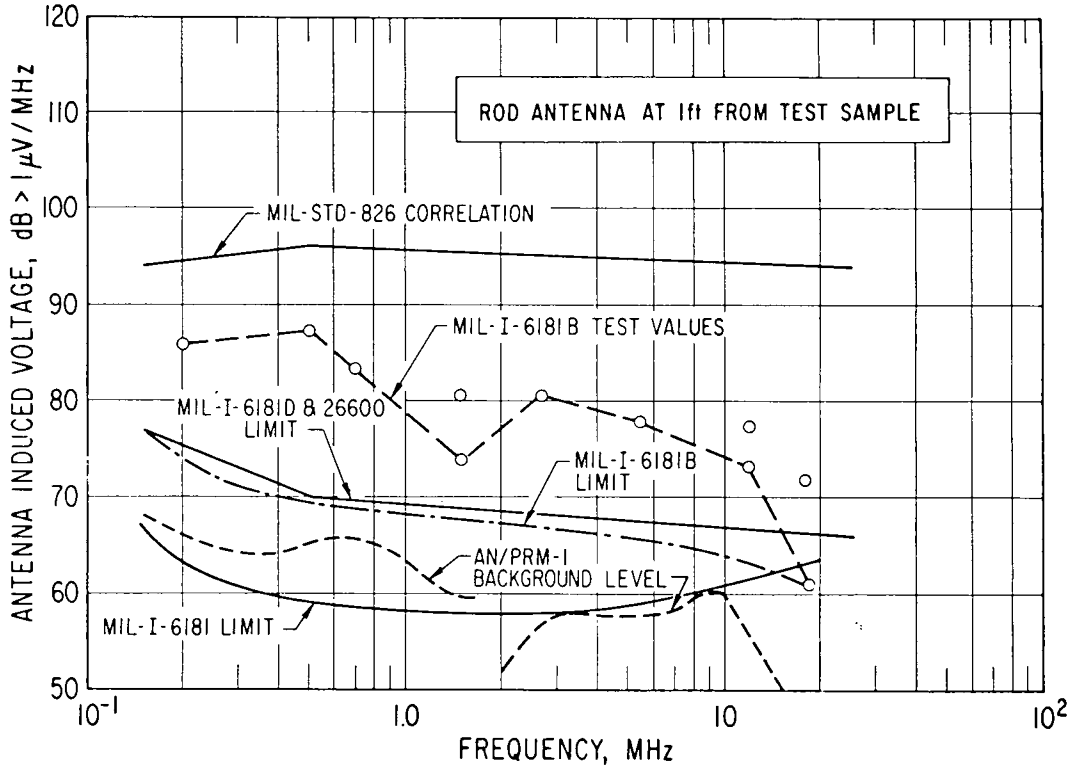

Figure 1. Development of Broadband Radiated Interference Limits (0.15 to 20 MHz)

In Mil-I-26600, the frequency for CW and pulsed CW radiated interference was extended from 1 gighertz (GHz) to 10 GHz, and a newly developed field intensity meter (FIM) was called out as the applicable measuring instrument.

Historically, there has been a steady upward revision in the tolerable levels of radiated interference. The specification limits have been based on voice communication receivers with sensitivities in the range of -95 dBm in typical aircraft installations; the earliest limits were based on tests with VHF receivers and, from time to time, other tests have been done in UHF and in the S, C, and X bands. The limits thus derived are not necessarily applicable to the needs of space systems or highly sensitive receivers operating in other systems, but are largely arbitrary, even though following an historical evolutionary development.

Conducted Interferences Limits

The conducted interference measurements required by specification JAN-I-225 over the range of 150 kHz to 20 MHz utilized the test set-up illustrated in Figure 2. The test sample was mounted on a ground plane and connected by 10-foot leads to the power source whose positive side was bypassed to ground by two 4-microfarad (µf) capacitors; this had the effect of a line stabilization function and provided filtering of interference from the power source. The interference measuring instrument or meter was connected across the line at the test sample by 24-inch leads, and the test sample was connected to its load by 2-foot leads.

The conducted interference limit was based (as was the radiated limit) on the rationale of an open-wire antenna lead-in to a voice communication radio-receiver. The test set-up used a radiating wire placed near the antenna lead-in; the level of signal in the radiating wire, just sufficient to cause an indication in the receiver, was indicated as the interference limit.

Early in 1950, the Line Impedance Stabilization Network (LISN) was developed, based on measurements of typical aircraft power lines indicating an impedance of a few ohms (Ω) in the area of 150 kHz, increasing to ~ 50-Ω at the higher frequencies. The network was developed with an impedance of 4.5-Ω at 150 kHz, increasing to 50-Ω at 5 MHz. The previous 8 µf of capacitance from power line to ground of JAN-I-225 was replaced in the LISN with 1 µf in series with a 1-Ω resistor, both in parallel with a 5-microhenry (µH) choke. At the higher frequencies, the 50-Ω impedance was supplied by the usual 50-Ω input circuit impedance of the measuring equipment.

Mil-I-6181B utilized the same conducted limit as Mil-I-6181, but, since the LISN higher impedance at the lower frequencies developed a higher interference voltage, the limit had to be raised to preserve the same interference-effect criterion. Mil-I-26600 and Mil-I-6181D changed the broadband interference limits slightly, but left the CW limit unchanged. At that time, the use of the current-probe was introduced for measurements on interconnecting cables and high-current power conductors. Readings on the current-probe were correlated with those obtained utilizing the LISN to establish the current-probe limits.

Low Frequency Conducted Measurements

The original limit for conducted interference in the lower frequency range was derived by Boeing in its document D2-2444 (Ref 10) in February of 1959. In that document, the peak-to-peak ripple on the dc bus was restricted to 5% of the nominal dc bus voltage when measured with a wideband (20 Hz to 150 kHz) vacuum tube voltmeter (VTVM) directly connected across the dc leads. For the nominal 28-volt dc power system then common to aircraft, the 5% limitation would yield 1.4 volts peak-to-peak or 0.7 volt peak over the frequency range of 20 Hz to 150 kHz. This limitation was, in turn, based on the requirement of Mil-E-7894A (ASG), (Ref 13) which was the applicable requirement for aircraft power systems. This specification required the dc peak ripple not to exceed 2.1 volts as measured by a peak-reading VTVM in a series with a 4-µf capacitor across the power lead.

Interference measurements were not required below 0.15 MHz by the earlier interference specifications, but, with the development of large-scale complex systems such as Minuteman, the range ot interference measurements was extended down to 30 Hz. The limit from BSD Exhibit 62-87 (Ref. 10) was the forerunner for the others.

The Boeing document was used as the basis for the Minuteman interference specification (Ref. 14) in which the original broadband measurement was converted into both narrowband and broadband measurements utilizing the NM40 and NM10 instruments. To make this transformation, interfer-

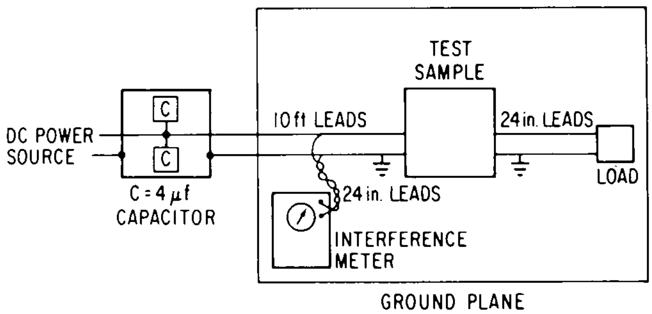

Figure 2. Test Setup for Conducted Interference Measurement per JAN-I-225

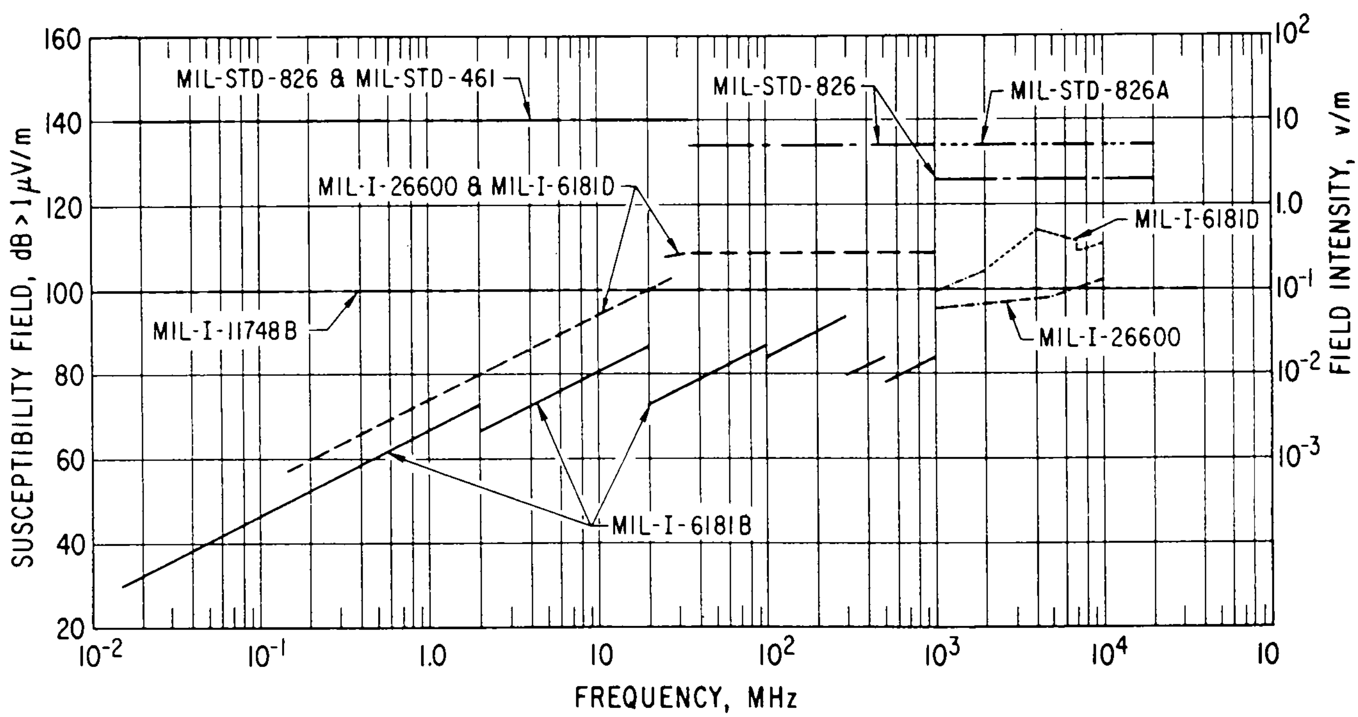

Figure 3. RF Radiated Susceptibility Limits (150 Hz to 1 GHz)

ence current in a line was monitored by a current probe as well as by the required VTVM; the 700-millivolt (mV) peak reading on the VTVM was translated into current in the line over a range of simulated source and load impedances for a typical aircraft bus system over the range of 30 Hz to 15 kHz.

Mil-E-7894A was superseded in 1960 by Mil-Std-704 for Aircraft Power Systems (Ref. 15), and the limit on ac ripple was reduced from 2.1 volts to 1.5 volts, with a recommendation (Ref. 16) that further reduction be made to one volt. Frequency characteristics of the ripple were also included in Mil-Std-704 and no individual frequency component exceed 1.1 volts peak.

SUSCEPTIBILITY

Conducted Susceptibility

Audio Frequency Limits: Conducted susceptibility testing in the audio frequency range was introduced in Mil-I-6181B, wherein a 2-volt rms signal was introduced across the test sample power leads over the range of 60 Hz to 10 kHz. The test was done only on dc power leads and was measured under closed circuit conditions. The interference limit was based upon the requirement of Mil-E-7894A (ASG), which established a peak ripple voltage limit of 2.1 volts for aircraft dc power systems. Mil-I-26600 (and Mil-I-6181D) extended the test to ac power lines and raised the limit to 3 volts rms, but later stipulated that the voltage was to be measured open-circuit before application to the test sample.

Due to the indeterminate nature of an open-circuit voltage test, Mil-Std-826 specified closed-circuit conditions and required a test voltage of 10% of the line voltage (2.8 volts rms for 28 vdc line). Concurrently, Mil-Std-704 replaced Mil-E-7894A as the requirement for aircraft power systems; the criterion for dc bus ripple-voltage was reduced to 1.5 volts peak.

RF Conducted Limits: Mil-I-6181, the earliest of the interference specifications under consideration, utilized a susceptibility limit of one millivolt directly applied to the test sample leads over the frequency range of 150 MHz. When this level of susceptibility voltage is compared to the appropriate conducted interference limits above 150 kHz, a 26-dB margin of safety existed. Mil-I-6181B increased the susceptibility test voltage by an order of magnitude to 10 millivolts, but also changed the method of coupling so that the test voltage was now applied through the LISN.

Mil-I-6181D and Mil-I-26600 further extended the frequency range to GHz, again coupling the signal through the LISN, while the susceptibility test voltage was raised another order of magnitude to 100 millivolts. Mil-Std-826 added yet another order of magnitude increase to the test voltage, eliminated the LISN coupling mechanism, and relied on a coupling capacitor; the test was limited to 400 MHz.

Radiated Susceptibility

Radiated susceptibility testing was initiated with Mil-I-6181B, in which stub antennas ranging from 20 to 3 inches were mounted on a ground plane and connected to a signal generator via a 5-ohm terminating resistor. RF voltages from 0.1 volt to 5 millivolts were applied over the frequency range of 15 kHz to one GHz. Relying on certain theoretical assumptions regarding propagation conditions, the field produced at the test sample (located one foot from the radiating antenna) can be calculated, and is illustrated in Figure 3.

Mil-I-26600 and Mil-I-6181D abandoned the use of the special rod test antenna, utilizing instead the antennas employed for radiated interference testing.

Transient Testing

As a result of transistor failures in intercommunications equipment in aircraft, the previously mentioned Boeing specification D2-2444 required a transient conducted test to be performed on 28-volt dc supply leads. The pulse applied was a positive 50-volt, 10-μsec pulse at a rate of two per second. This test requirement was later incorporated into BSD Exhibit 62-87.

Mil-Std-286 incorporated this test with two significant extensions in coverage: the test was applied to ac as well as dc lines, and the 50-volt pulse was applied in negative as well as positive polarity. Mil-Std-826A, on the basis that a 50-volt pulse may not be a rigorous test on a line whose peak amplitude may be 160 volts, requires that the pulse be twice the line voltage or 100 volts, whichever is less.

Mil-Std-461A (Ref 19) now supersedes all the specifications referenced in this report. However, Notice 3 to this standard, states that equipment in inventory which has been designed to an inactive specification should continue to have the inactive specification applied for additional procurements. Thus, the inactive specifications are still active. A Mil-Std-461 requirements tree is shown on the pages 54 & 55.

REFERENCES

1. Jan-I-225, "Interference Measurement, Radio-Methods of, 150 kc to 20 mc (for components and complete assemblies)," 14 June 1945.
2. Mil-I-6181, "Interference Limits and Tests; Aircraft Electrical and Electronic Equipment," 14 June 1950.
3. Mil-I-16910A, "Interference Measurements, Radio, Methods and Limits, 14 kc to 1000 mc," 30 August 1954.
4. Mil-I-6181B, "Interference Limits, Tests and Design Requirements, Aircraft Electrical and Electronic Equipment," 29 May 1953.
5. Mil-I-226600, "Interference Control Requirement, Aeronautical Equipment," 2 June 1958, and as modified 23 April 1959.
6. Mil-I-6181D, "Interference Control Requirements, Aircraft Equipment," 25 November 1959. Change 3, 22 June 1965.
7. Mil-Std-826 and 826A, "Electromagnetic Interference Test Requirements and Test Methods," 20 January 1964 and 30 June 1966.
8. Mil-I-16910C, "Interference Measurement, Electromagnetic, Methods and Limits," 26 October 1964.
9. Mil-Std-461 "Electromagnetic Interference Characteristics, Requirements for," 2 May 1966.
10. Boeing Aircraft Corporation D2-2-2444, "Electro-Interference Control Requirements (Equipment)," 5 March 1959.
11. AF/BSD Exhibit 62-87, "Electro-Interference Control Requirements for Minuteman (WS 133B)", 6 December 1962.
12. NAA Mil-I-26600/MSC-EMI-10A, 28 February 1964.
13. Mil-E-7894 (ASG), "Electric Power, Aircraft, Characteristics of, 17 May 1955.
14. GM07-59-2617A, "Electro-Interference Control Requirements for Minuteman (WS 133A)," 20 October 1959.
15. Mil-Std-704 "Electric Power, Aircraft, Characteristics and Utilization of," 6 October 1959.
16. NADC-EL-6029, Final Report: "Engineering Investigations in the Development of Mil-Std-704 to Replace Specification No. Mil-E-7894," 9 August 1960.
17. Mil-I-11748B (Sig C), "Interference Reduction for Electrical and Electronic Equipment." 4 November 1958.
18. Pearlston, C. B., Jr., "Electromagnetic Compatibility Requirements for Space Systems," TOR-1001(2307)-4 Revision 2, Aerospace Corporation, El Segundo, California (8 November 1966).
19. Mil-Std-461A "Electromagnetic Interference Characteristics, Requirements for;" 1 August 1968, with Notice 3, 1 May 1970.

(The material used in this article was extracted from Aerospace Report No. TR-1001(2307)-12 Historical Analysis of Electromagnetic Interference Limits. April 1967. Prepared by C. P. Pearlston Jr.)