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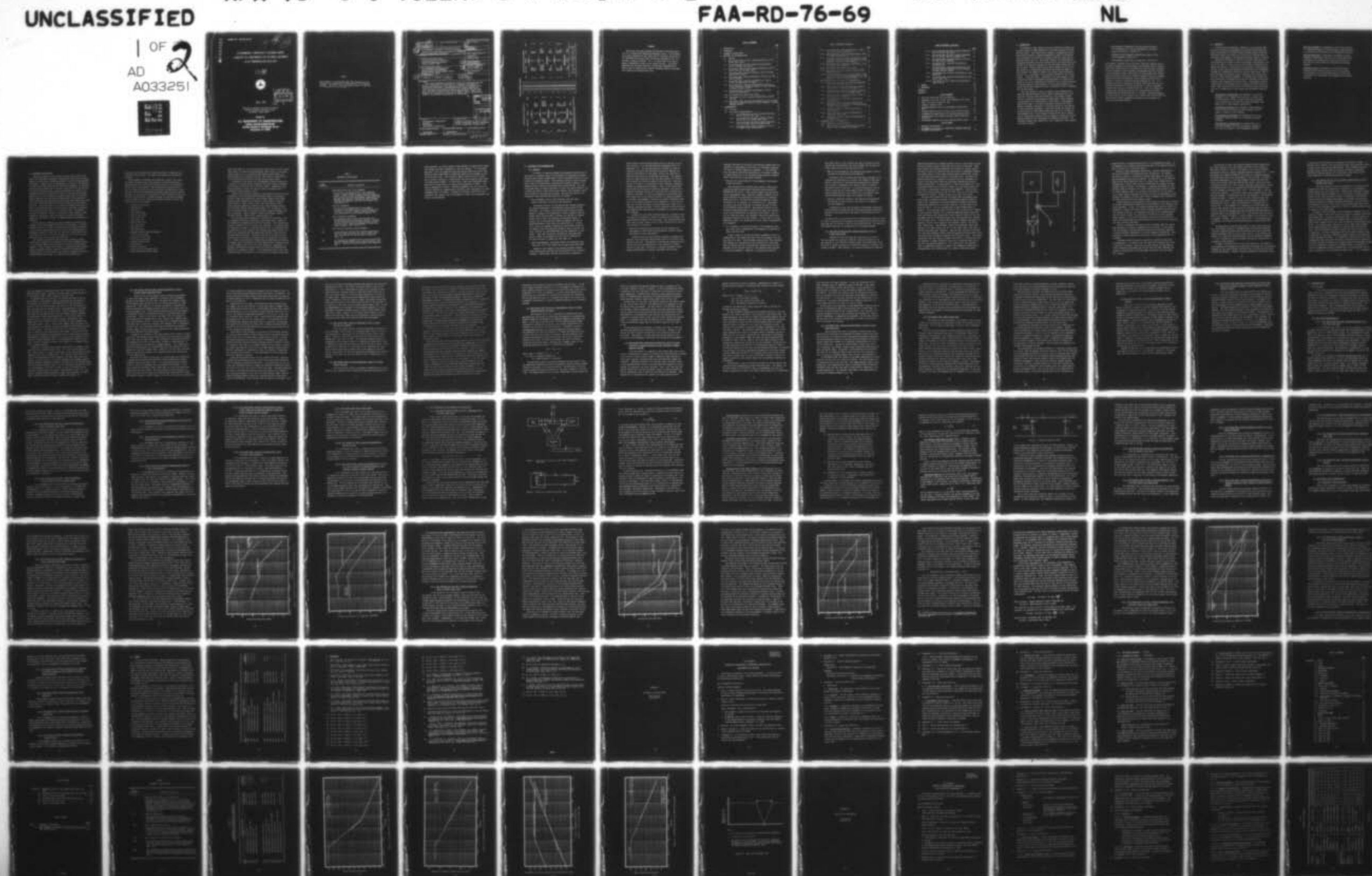

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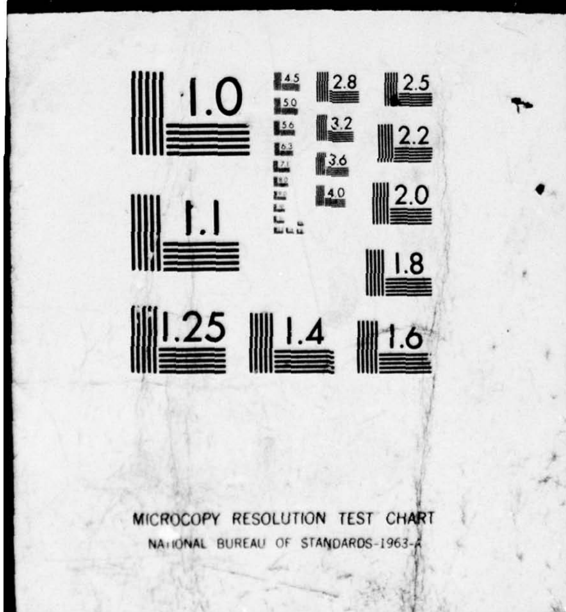
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ELECTROMAGNETIC COMPATIBILITY RATIONALE REPORT
CONDUCTED TEST REQUIREMENTS FOR ELECTRONIC EQUIPMENTS IN AIR TRANSPORTATION FACILITIES

J. C. TOLER
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APRIL 1976

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16. Abstract

This report summarizes the technical efforts and conclusions resulting from an investigation of requirements for a conducted electromagnetic emission and susceptibility test standard applicable to equipments in air transportation facilities. Recommendations are provided regarding the tests that should be performed, acceptable test configurations and procedures, applicable frequency ranges, and performance limits. These recommendations are documented in the format of Federal Aviation Administration notices to be attached to MIL-STD-461A and MIL-STD-462.

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METRIC CONVERSION FACTORS

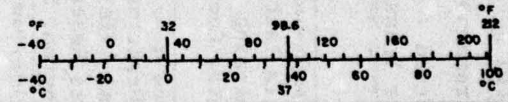
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



FOREWORD

This report was prepared within the Electronics Technology Laboratory of the Georgia Tech Engineering Experiment Station. The investigation results documented by this report were in accordance with Contract No. DOT-FA74WA-3372 and were under the general supervision of Mr. D. W. Robertson, Laboratory Director. Mr. J. C. Toler, Head of the Electromagnetic Compatibility Group, was the Project Director. This report summarizes the activities directed to developing recommendations for Federal Aviation Administration adoption regarding conducted electromagnetic emission and susceptibility tests.

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1. INTRODUCTION

The movement of large numbers of persons traveling for pleasure and business purposes is highly dependent on a safe and efficient air transportation system. This system must be capable of accommodating an estimated annual increase in traveler enplanements of eight to nine percent and an increase in the production of general aviation aircraft that approaches 10,000 yearly [1]. Using these estimates, air transportation forecasters now predict that air transportation in the United States could increase by as much as six percent per year and thereby double over the next 12 years. Concerns resulting from these estimates include the fact that there are no corresponding indications that either the number of major airports, the number of runways, the altitude range available for aircraft use, or the amount of radio spectrum allocated for air traffic control purposes will double. Consequently, the future appears to offer a situation in which a continually increasing number of travelers will attempt to use an air transportation system that (1) is already operating at maximum capacity in many instances, (2) will expand rapidly in the future, and (3) will experience at best a relatively low rate of expansion over the next decade.

With this situation in mind, the Federal Aviation Administration (FAA) has undertaken numerous efforts aimed at maintaining the current high level of flight safety and reliability. This research program, directed to developing Electromagnetic Compatibility control documents for FAA adoption, is representative of these efforts. Electromagnetic Compatibility (EMC) is a technical discipline concerned with electromagnetic performance degradation of electronic devices as they function in their operational environment. Under this program, the research objective has been to develop EMC documentation that can be (1) used as a FAA management guide in establishing an effective EMC control program and (2) contractually imposed on FAA procurements to assure that electromagnetic design and test requirements are adequately considered. The developed documents have numbered four and, in addition to this document, are titled as follows:

- Electromagnetic Compatibility Rationale Report--Radiated Test Requirements for Electronic Equipments in Air Transportation Facilities - FAA-RD-76-70
- Handbook for Electromagnetic Compatibility Design of Electronic Equipments - FAA-RD-76-71
- Electromagnetic Compatibility Program Plan - FAA-RD-76-75

This document, concerned with the rationale supporting conducted test requirements recommended for FAA equipment, was developed during a research effort that included surveys of representative FAA facilities, interviews with FAA personnel in both operational and management positions, analyses of FAA procurement methods, classification of FAA equipment into electromagnetic criticality categories, technical exchanges with other government agencies with EMC responsibilities, and an intensive evaluation of the adequacy of currently imposed military EMC standards [2], [3]. It is organized to provide a glossary of applicable terminology (Section 2) immediately following this introduction (Section 1). Next, an equipment classification listing is provided (Section 3). Then, the rationale for conducted test requirements (Section 4) is presented and test method recommendations are provided (Section 5). Finally, referenced documents are listed (Section 6) and appendices are provided that stipulate editorial modifications by which recommended procedures may be incoporated into existing military EMC standards.

2. TERMINOLOGY

A clearly defined terminology is essential to the efficient communication of concepts and requirements in any technical discipline area. This is particularly true within the EMC discipline because of both the similarity between many commonly used terms and the expanding number of areas where electromagnetic interactions have become a matter of concern.

Numerous EMC definitions for specific technical applications have been documented, but because of their narrow range of applicability, they have often tended to become a barrier to the effective communication of broader EMC concerns. To assure that this difficulty is avoided within the FAA, the EMC terminology presented in MIL-STD-463 [4] is recommended. Although this terminology is directed to military applications, there is more than adequate functional overlap to permit an easy transfer from military to FAA electronic equipments. To expedite usage of this document, definitions of fundamental EMC terms are transferred from military language to FAA language and presented herein. Additionally, technical terms peculiar to this document but not included in MIL-STD-463 are defined. These definitions plus those in MIL-STD-463 provide a sufficient base for the communication of EMC concepts and requirements within the FAA.

Electromagnetic Compatibility--The capability of electronic equipments in air transportation facilities to operate, with a defined margin of safety, in their operational environment and at designed levels of efficiency without performance degradation due to electromagnetic interactions.

Electromagnetic Emission--Electromagnetic energy propagated from an electronic equipment via either radiation (air coupling) or conduction (wire coupling).

Electromagnetic Interference--The manifestation of an electromagnetic emission incident on a susceptible electronic equipment.

Electromagnetic Susceptibility--The characteristic of an electronic equipment that permits performance degradation as a result of exposure to an electromagnetic emission.

Electronic Equipment--An assemblage of circuit devices mounted in a chassis and designed to perform either a signal generation or conditioning function within an air transportation facility.

Electronic Subsystem--A configuration of multiple electronic equipments interconnected via either air or wire coupling and performing an air transportation facility function that is generally more complex than that performed by an individual equipment.

Electronic System--A configuration of multiple electronic subsystems interconnected via either air or wire coupling and performing an air transportation facility function that is generally more complex than that performed by an individual subsystem.

3. EQUIPMENT CLASSIFICATION

During early phases of this program, attention was directed to the matter of establishing an equipment classification listing for use during subsequent considerations regarding equipment criticality versus applicable test methods. However, prior to adopting such a listing, it was necessary to define more precisely what was to constitute an equipment. It was noted that the term "equipment" was not defined in MIL-STD-463 and that MIL-STD-461A and MIL-STD-462 generally considered an equipment to consist of an individual electrical or electronic chassis with its associated cabling. Essentially, all of the figures (for example, Figure CE02-1, MIL-STD-462, Typical Probe Test Setup for Conducted Measurement of Interconnecting Cables) depicting test configurations show an individual chassis positioned on top of a bench and bonded to the ground reference plane covering the bench top. It was also noted that the specific equipment names given in Table I of MIL-STD-461A were, for the most part, indicative of electrical and electronic devices housed in an individual chassis. For example, receivers, transmitters, counters, oscilloscopes, power supplies, signal generators, auto-pilots, flight instruments, arc welders, electrical gauges, etc. are typical listings for communication and non-communication equipments.

In one instance, computers and digital equipment are mentioned as examples of non-antenna communication-electronic equipments. In reviewing other sources of information regarding MIL-STD-461A and MIL-STD-462, it was noted that figures depicting the various test configurations were described as tending "to imply that the test item is either small (e.g., a few cubic feet $\approx 0.1\ m^3$, or less) or consists of only one or two black boxes with power and interconnecting cables" [5].

The figures in MIL-STD-461A and MIL-STD-462, therefore, convey a concept of an equipment as an assemblage of electronic components housed in an individual chassis and interconnected to perform an identifiable function. If this concept were extended, a system would become an assemblage of equipments typically housed in a multirack configuration and interconnected to perform multiple inter-related or sequential functions. Somewhat between the extremes of a single chassis equipment and a multirack system configuration of chasses would exist a subsystem level involving a limited number of equipments performing a few identifiable functions.

When equipments, subsystems, and systems were viewed in this sense and surveys were made of major FAA facilities, it became obvious that a high percentage of the critical electronic devices must be classified as systems rather than equipments. This classification resulted from the fact that these electronic devices were multirack configurations of extensively interconnected equipments which performed complex and inter-related functions. In most cases, the name given to these configurations indicated that they were considered to represent systems, not individual equipments. A typical example of such a system was the Central Computer Complex (CCC) that consisted of the following:

- System Control Console
- Computing Unit
- Storage Unit
- High Speed Printer
- Printer and Keyboard
- Disk Storage Unit
- Time Source Unit
- Data Receiver Group
- Data Control Unit
- Tape Drive Unit
- Tape Control Unit
- Random Access Plan Position Indicator
- Interface Control Unit
- Card Read and Punch Unit
- Input/Output Control Unit
- Peripheral Adapter Unit
- Switching Unit
- Flight Strip Printer
- Flight Strip Printer Control Unit
- System Maintenance Monitor Console

Additional examples of system configurations would include the Radar Display System (RDS), the Remote Transmitter/Receiver (RTR) System, the Instrument Landing System (ILS), the Automated Radar Terminal System (ARTS), etc. These systems are not consistent with the "test items" for which MIL-STD-461A and MIL-STD-462 provide test methods and performance limits.

Discussions of this matter with FAA management personnel resulted in a directive to consider devices consistent with those presently addressed by MIL-STD-461A and MIL-STD-462 during this program. Subsequently, standards applicable to system level devices could be developed by FAA if a demonstrated need was shown to exist.

Surveys of FAA facilities revealed a large number of electronic devices conforming to the MIL-STD-461A and MIL-STD-462 concept of an equipment. Typical of these were numerous Very High Frequency (VHF) and Ultra-High Frequency (UHF) transmitters and receivers, tape recorders, regulated output amplifiers (ROA), teletype units, time code generators (TCG), backup emergency communication (BUEC) devices, radio frequency monitors, inner and outer markers, ground movement radars, etc. In addition, there was an appreciable number of standard electronic equipments commonly used for test purposes. These equipments included oscilloscopes, counters, spectrum analyzers, signal sources, power supplies, etc.

When analyzing these equipments for the purpose of developing a suitable equipment classification procedure, efforts were made to conform to the classification commonly used by facility personnel. This classification separated equipment into the following four categories: (1) communications, (2) automated processing, (3) electro-mechanical, and (4) navigational aids. Although useful for many purposes, this classification scheme could not be adopted for identifying which equipments were required to comply with the applicable EMC test methods. The major difficulty lay in the fact that a classification method based on equipment type, not utilization, was necessary. Without the type-oriented classification, transmitters and receivers, for example, would be classified in three (communications, automated processing, and navigation aids) of the four above categories. Consequently, an equipment classification patterned after the one used in MIL-STD-461A was adopted and is presented in Table I. Class designations used in this table incorporate some of the features of the classification commonly used by FAA

TABLE I

EQUIPMENT CLASSIFICATION

Class Designation	Equipment Description
I	**Communication-Electronic (C-E) Equipments** All electronic equipments which in their operation transmit, receive, generate, store, or process information. Included in this classification are transmitters with antennas, receivers with antennas, transceivers with antennas, regulated output amplifiers, backup emergency communication equipment, inner and outer markers, plan view displays, etc.
II	**Electronic Equipments** All electronic equipments which are *not Class* I. Included in this classification are oscilloscopes, signal sources, test sets, counters, spectrum analyzers, time code generators, radio frequency monitors, etc.
III	**Electro-Mechanical Equipments** All equipments which in their operation have both a mechanical and electrical/electronic function. Included in this classification are teletype machines, portable electrical tools, repair shop equipment, kitchen and/or lounge equipment, office devices, etc.
IV	**Motor Vehicles and Engine-Driven Equipments**
IVA	All motor-driven vehicles which in their operation may interrupt normal operations via ignition system radiation. Included are tug vehicles used at remote C-E sites, etc.
IVB	All engine-driven equipments which in their operation may emit interference signals from an ignition system or commutator. Included are gasoline engines, motor generators, etc.

field personnel, yet differ enough to make possible a classification scheme that assigns individual equipments to only one category. It is extremely important to note that numerous electronic devices which must now be classified as either subsystems or systems may qualify as an equipment in the not-to-distant future. This situation results because the use of solid state circuitry continues to reduce device size and, therefore, make bench top mounting more feasible. As this occurs, these newly designated equipments must be added under their appropriate designation in Table I. The Class I designation in Table I identifies equipments that are critical to safe and reliable air transportation; therefore, test requirements for these equipments must be stringent. Equipments in Classes II and III are progressively less critical, and the stringency of their test requirements can decline correspondingly.

4. RATIONALE FOR RECOMMENDATIONS

4.1 Approach

In efforts to determine whether FAA equipments required particular types of conducted tests, it was necessary to establish an analysis procedure that assured consideration of major influencing factors in a consistent and systematic manner. This procedure basically involved answering a series of questions while analyzing the technical aspects of test methods currently specified by MIL-STD-461A and MIL-STD-462. The questions asked were not equally applicable to every test method analysis, and no effort was made to treat them as such; however, they provided a satisfactory basis for the analysis procedure. The questions asked and the information base associated with each were as follows:

- What equipments exist at FAA facilities, what are their modes of operation, and how are they installed?

Information relative to this question was obtained primarily via surveys conducted at a representative cross-section of FAA facilities. For example, the Air Route Traffic Control Centers (ARTCC) at Hampton, GA and Nashville, TN were surveyed as was the Flight Service Station (FSS) in Atlanta, GA, and the Air Traffic Control Towers (ATCT) and Terminals at Hartsfield Airport in Atlanta, GA, the International Airport in Memphis, TN, and the Huntsville/Madison County Airport in Huntsville, AL. In addition, surveys of equipment grounding and installation practices at numerous other facilities were conducted under an earlier contract (Contract No. DOT-FA72WA-2850) and were applicable to this effort. These other facilities included the long range radar sites at Aiken, SC and Smyrna, GA, the ATCT at Jacksonville, FL, and the airport at Robins Air Force Base, GA.

- What electromagnetic interference and/or susceptibility problems exist now or have existed in the past at FAA facilities?

Answers to this question were obtained primarily through formal and informal meetings with FAA personnel at the facilities surveyed. Additionally, meetings were held with engineering groups within the FAA Southeast Region Office in Atlanta, GA and with personnel in the FAA ARD-350 project management office in Washington, D.C. The meetings generally followed the format of technical discussions and interviews during which emphasis was placed on descriptions of the number, nature, and resolution of observed interference and susceptibility problems. The dominate result of these meetings was that most EMC problems are "environment related" and involve transmitters and receivers. There was little or no report of interference, either conducted or radiated, between non-communication equipments. Also, it was learned that the persons interviewed had no definite knowledge of the electromagnetic environment within their facilities and no analyses were planned to determine (1) what electromagnetic influence new equipments might have on the reliable operation of existing equipments or (2) what electromagnetic influence the existing equipments might have on the reliable operation of new equipments. It was also evident that facility and region office personnel have almost no information regarding the extent to which equipments in FAA facilities have complied with conducted test requirements in currently imposed EMC standards.

In addition to interviews with FAA personnel, a limited literature search was conducted to ferret out reports of interference and susceptibility problems at FAA facilities. This search yielded less than twenty relevant reports, most of which reinforced the information obtained via interview.

- What are the technical justifications for the present test requirements in MIL-STD-461A and MIL-STD-462, and what changes are planned in these requirements?

A formal meeting was held with Navy personnel responsible for efforts of the tri-service EMC standards committee to obtain information in this area. Additionally, a meeting was subsequently held with the Air Force representative to this committee to discuss matters in this area. No written or published information delineating justifications for present requirements was obtained.

Although firm plans for modifying the existing standards have been underway for approximately three years, no information regarding the nature of planned changes was available. It was concluded that information justifying requirements in the present standards is either nonexistent or is scattered through numerous documents, some of which may not be generally available.

- What are the characteristics of electromagnetic environments in FAA facilities?

This information was obtained from a series of FAA reports prepared by American Electronics Laboratory under Contract No. DOT-FA72-NA-728 [6]-[9]. These reports present data from extensive electromagnetic tests conducted to measure radiated and conducted emission and susceptibility characteristics in selected ARTCC facilities. The facilities surveyed included the centers at Oakland, CA, Los Angeles, CA, and New York, NY. Measurement procedures were either verbatim, or modified versions of these in MIL-STD-461A and MIL-STD-462. When modified versions of the military standard measurement procedures were used, the technical basis for the modification was generally not provided. Also, it was not indicated whether the equipments tested had complied with applicable portions of any EMC standard. In some cases, the recommendations tended to be inconclusive in that further investigations were suggested.

- Is it feasible to specify performance of electromagnetic emission tests without complementary electromagnetic susceptibility tests, and vice versa?

A major tennent of the EMC philosophy recommended for FAA implementation in the Program Plan dealt with how equipment level test data were to be used. This philosophy requires that, where possible, both emission and susceptibility data be obtained for each equipment in a manner such that susceptibility characteristics of each equipment can be analyzed relative to the emission characteristics of all other equipments. Therefore, in analyzing the need for particular types of tests, efforts were made to assure that both emission and susceptibility data were obtained over the same frequency range and in the same electrical units.

- What is the rationale for the conducted test methods currently specified by MIL-STD-461A and MIL-STD-462?

  Knowledge of this rationale would have been invaluable in determining the applicability of present test methods to FAA needs. However, essentially no documentation presenting this rationale was available; consequently, the extent to which it applies to FAA needs is one of conjecture. In limited instances it was possible to postulate why certain agencies with the Department of Defense desired specific test methods, but the technical considerations underlying the present test methods are unknown.

- Based on a technical analysis of MIL-STD-461A and MIL-STD-462 test methods, to what extent do they appear to be adequate for FAA equipments?

  Information in this area was gained by performing a method-by-method analysis including the applicable modifications stipulated by notices to essentially every test method in MIL-STD-461A and MIL-STD-462.

As noted earlier, the procedure used in determining the need for specific types of conducted tests consisted of answering the above questions while analyzing each test method in MIL-STD-461A and MIL-STD-462. The results of this analysis procedure are presented in the following paragraphs.

4.2 Test Methods CE01 and CE03, Conducted Emission, 30 Hz to 50 MHz, Power Leads

Although the test procedures and configurations for these two test methods are separately presented, they are performed for the same purpose but over different frequency bands (Test Method CE01 covers the 30 Hz to 20 kHz band while Test Method CE03 extends in frequency from 20 kHz to 50 MHz). Their purpose is to provide procedures for measuring undesired narrowband and broadband emission levels on power lines to determine the necessary extent to which EMC control must be exercised. These desired power line conducted emissions are partially of concern because they may be coupled via radiation into other lines or equipments; however, the primary concern is that these emissions may be conductively coupled into the power distribution system of an installation. From there, the undesired emissions can readily be conducted into other equipments connected to the same power system and performance degradation becomes a definite possibility. The applicability of these test methods is to both alternating current (ac) and direct current (dc) lines which either provide power or interconnect externally with equipments. The particular lines to be tested include not only the "hot" line, but also lines used as grounds or neutrals. Bonding straps do not have to be tested.

The basic Test Method CE01 and Test Method CE03 measurement procedures purport to measure narrowband and broadband conducted emissions using a test configuration involving impedance standardization devices (feedthrough capacitors) in the power lines and a current probe as the detection device. The test configuration is shown schematically in Figure 1. The feedthrough capacitors have a 10 μfd value and are intended to serve the dual purpose of (1) preventing undesired power source emissions from being routed through the current probe and coupled to the test instrument and (2) preventing undesired test item emissions from coupling into the power source. At 60 and 400 Hz (the two commonly used power frequencies), each of these capacitors has impedance values of 265 and 40 ohms, respectively. Such impedance values are considerably above those expected of the power source, but are in the range of what could exist at the test item power input terminals. When the test item and 10 μfd capacitor have equal impedance values, undesired emissions from the power source flow equally well through the capacitor and the current probe. Under these conditions, which may range in frequency from 500 Hz to as much as 10 kHz, the capacitor is highly ineffective in-so-far as isolating power source and test item undesired emissions. Also, since the 10 μfd capacitors offer an appreciable impedance at power line fundamental frequencies up through 400 Hz, their effectiveness as a means of measuring harmonic

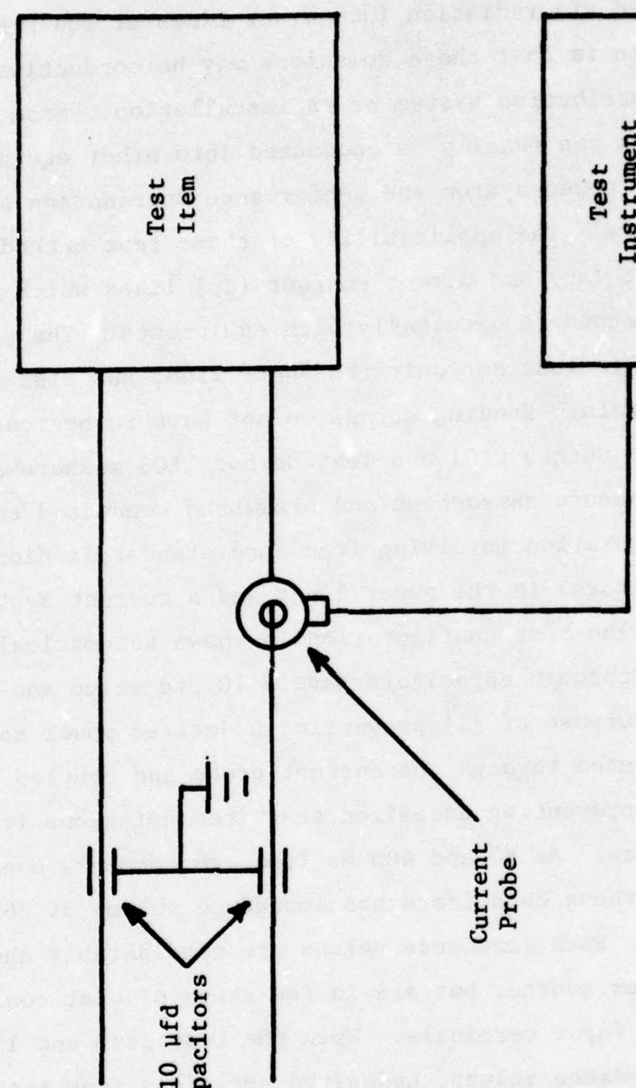

Figure 1. Basic Test Method CE01 Test Configuration.

emission levels at frequencies below 400 Hz is correspondingly reduced. As a consequence, the required capacitors negate much of the overall effectiveness of this 30 Hz to 20 kHz test method.

Because of these measurement difficulties, numerous modifications to the basic MIL-STD-462 test method have been incorporated. For example, the Air Force (Notice 2, MIL-STD-462) deleted requirements for all broadband measurements using this test method. The Army (Notice 3, MIL-STD-462) made the test method applicable only to dc power lines, changed the test configuration to add an audio isolation transformer and extended the upper frequency limit to 50 kHz. Additionally, a separate test method was added by which undesired emissions on ac power lines were measured over a 10 kHz to 50 MHz frequency range. The isolation transformer in the test method for dc power lines was apparently intended to reduce the measurement problem caused by the change in current probe transfer impedance that occurred over the lower portion of the test frequency range.

During interviews with personnel at FAA facilities, there were no reports of facility interference problems directly attributable to low frequency conducted emissions. In fact, the reported problems were stated as being "environmental" in nature and usually involved radiated emissions entering sensitive receiver circuits. It is possible that some of the radiated signals were the result of power line emissions in the 30 Hz to 20 kHz frequency range; however, in view of the wavelengths involved and the inefficiency that would be associated with either generating or receiving these emissions, this was considered improbable.

Efforts to determine the conditions that originally made Test Method CE01 necessary for military equipments were to no avail. It was assumed that low frequency conducted emissions existed with sufficient amplitude to cause performance degradation in certain equipment installations. Documentation of these emissions and the nature of their degradation was not available.

Although MIL-STD-462B was not available for analysis during these investigations, it is reported [10] that power line conducted tests below 15 kHz will be deleted. This action is taken because "of high emission levels ordinarily associated with ac power lines and their harmonics and because of difficulties in isolating power line noise from test sample EMI currents."

The analysis of power line conducted narrowband and broadband emission tests performed at the three ARTCC facilities [6]-[9] revealed a distinctive pattern of results. For example, at all three facilities, measurements involving automated equipment generally revealed that "...broadband power line conducted emissions from nearly all equipments exceeded the MIL-STD-461A limits from approximately 1 kHz to 50 MHz." Conversely, narrowband measurements on this same equipment yielded data which generally did not exceed applicable MIL-STD-461A limits. Concern was noted in several instances [12], [13], however, when the broadband and/or narrowband emission levels not only exceeded the MIL-STD-461A emission limits but also exceeded the susceptibility limits. In these cases, it was concluded that emissions "...from power lines to most automated system equipment may represent a problem area from the EMC standpoint." This possible problem was based "...primarily on the fact that conducted power line emissions from so much of the automated system equipment exceeded the susceptibility limits." These conclusions were the foundation for a caution that "...new equipment to be installed at the ARTCC might malfunction when powered by lines serving the automated system in spite of the fact that the new equipment may have met MIL-STD-461A requirements for conducted power line susceptibility" [12]. This caution, which was applicable to the Oakland, CA ARTCC, is offset somewhat by the situation in the Los Angeles, CA ARTCC. There it was noted that "...the automated system is unlikely to be affected by EMI generated within a typical ARTCC site" [14].

The same general conditions also existed at these three facilities for non-automated equipments. Broadband power line conducted emissions invariably exceeded the applicable MIL-STD-461A limits while narrowband emissions exceeded limits to a much lesser extent. In one facility (Los Angeles, CA), power line conducted emission for non-automated equipments "...is not a problem for any new equipment meeting the susceptibility requirements of MIL-STD-461A."

In spite of patterns noted in some of the above data, the number of both broadband and narrowband tests performed on automated and non-automated equipment at the three different facilities did not yield any consistently observed EMC problems. Instead, situations described as warranting caution at one facility were found to be no problem at a different facility. It remained a fact, however, that situations did exist with sufficient severity to urge caution about probable EMC problems. Also, broadband conducted emission levels on power lines were not only in excess of applicable MIL-STD-461A emission limits, but in many cases, these levels also exceeded applicable MIL-STD-461A susceptibility limits.

4.3 Test Methods CS01 and CS02, Conducted Susceptibility, 30 Hz to 400 MHz, Power Leads

The stated purpose of these test methods is to determine whether communication-electronic equipments are susceptible to electromagnetic energy injected onto their power lines. Concern with this mode of susceptibility results because equipments are often coupled to hostile emission sources via the power distribution system. Consequently, effective EMC control requires an a priori determination as to whether these emission sources are capable of causing performance degradation. The test methods are applicable to both ac and dc power lines and Test Method CS01 covers a 30 Hz to 50 kHz frequency range while a 50 kHz to 400 MHz frequency range is covered by Test Method CS02.

In general, the test methods involve injecting a continuous wave test signal onto primary power lines by means of either an isolation transformer (Test Method CS01) or capacitor (Test Method CS02). The test signal frequency is slowly scanned while its specified level is maintained at the power intput terminals and the test item is monitored for performance degradation. The injected signal levels for ac and dc lines differ slightly and no signal modulation is required for tests on either type of power line. The test configuration used is required for tests on either type of power line. The test configuration used for the lower frequency range is such that the isolation transformer secondary permits series injection of the susceptibility signal. It is important to exercise care with this configuration when large power currents are involved because a significant portion of the source voltage can be dropped across the transformer secondary. To aid in avoiding this situation, procedural details are specified by which the transformer secondary impedance may be calculated when the primary is connected to the susceptibility signal source. It is recommended that this impedance be maintained less than 0.5 ohms over the 30 Hz to 50 kHz frequency range. Otherwise, the power source voltage may have to be increased to assure correct voltage to the test item.

No modifications to these basic test methods were made by the Air Force (Notice 2, MIL-STD-462); however, Army modifications (Notice 3, MIL-STD-462) were extensive. Test Method CS01 was made applicable to dc power lines only and provisions were made for a 100 μfd capacitor to shunt the power line and thereby prevent the susceptibility test signal from coupling back into the power source. Typical equipment arrangements were also provided by which test item outputs could be monitored for indications of performance degradation. In Test Method CS02, the capacitor used to couple the 50 kHz to 400 MHz susceptibility test signal onto ac and dc power lines was replaced by a line impedance stabilization network. Also, a current probe clamped around the power line and connected to an EMI meter provides the means for monitoring the susceptibility current. A modulation that varies as a function of test item type is required on the susceptibility test signal. Provisions are also made for the performance of susceptibility tests in which special purpose line impedance stabilization networks are used to inject signals over the 150 kHz to 65 MHz frequency range. The susceptibility signals include a scan of discrete frequency continuous wave signals and a broadband signal from an impulse generator.

Results of interviews with personnel and surveys of equipment in FAA facilities were presented earlier (Para. 4.2) for Test Methods CE01 and CE03. These results are directly applicable to Test Methods CS01 and CS02; therefore, they are not repeated here. This situation also holds for results of the measurement series performed in the three ARTCC facilities; however, in this situation, it is worth repeating that broadband emission levels from most equipments at Oakland, CA facility not only exceeded applicable MIL-STD-461A emission limits, but also exceeded susceptibility limits. It is interesting to note that, in spite of this, no EMC problems were reported. *Emission levels in excess of* susceptibility limits led to the general conclusion that susceptibility limits were unrealistic for equipments in ARTCC facilities at both Los Angeles and Oakland, CA.

4.4 Test Methods CE02 and CE04, Conducted Emissions, 30 Hz to 50 MHz, Control and Signal Leads

These two test methods impose conducted emission requirements on control and signal lines comparable to the power line requirements imposed by Test Methods CE01 and CE03. The applicable frequency ranges for Test Methods CE02 and CE04 are 30 Hz to 20 kHz and 20 kHz to 50 MHz, respectively. Their purpose is to provide procedures for measuring undesired narrowband and broadband emission levels on all control and interconnecting signal lines. These measured emission levels are then compared to performance limits to determine the extent to which EMC control must be exercised. Typical of the control and signal lines of interest are those associated with communication, clock, digital data, computer interface, and activation circuits. As with power lines, undesired emissions on these lines may be coupled via radiation into adjacent lines or equipments. In either case, tests performed using these test methods are intended to provide a means by which control can be maintained over undesired emissions that could otherwise cause EMC problems.

In general, the presence of the desired signal on the control or signal lines poses a measurement problem more difficult than what must be contended with in the case for power lines. Tests performed in accordance with these test methods must in fact be specifically tailored to characteristics of the desired signal as determined by <u>a priori</u> analyses. It is highly probable that these analyses will establish that these test methods can not be imposed over certain frequency bands. However, it is noted that, even when these test methods are exempted, the radiated emission test methods must still be complied with.

The basic test methods require use of a current probe and an EMI meter to measure both narrowband and broadband undesired emissions on properly terminated control and signal lines. If a control line carries ac power, it must be tested in accordance with Test Methods CE01 and CE03. Procedural details are provided by which cables made up of multiple control and signal lines are to be tested. The major concern in this situation is to assure that tests are not conducted on cables which include both the "high" and "return" lead for a circuit (except in the case of twisted pair conductors).

It is also necessary to isolate and separately test the culprit lines in a cable bundle where measured emission levels are found to be excessive. The current probe must be moved along the line being tested until the position of highest emission is noted. Subsequent tests are then performed with the probe in this position.

Modifications to the basic test methods have been relatively minor. For example, the Air Force (Notice 2, MIL-STD-462) made no changes in the test method while the Army (Notice 3, MIL-STD-462) specified both a measurement bandwidth and a set of procedures by which shielded lines are to be tested. The specified measurement bandwidth is 50 to 75 Hz. In the case of a shielded line or groups of lines, a non-shielded line extension must be fabricated and used with the current probe. It is reported [15] that MIL-STD-462B will relegate Test Method CE02 to a position of an optional test method while retaining Test Method CE04. Whether Test Method CE02 is optional or not will be determined by the procuring agency and for the particular equipment being procured.

Interviews with FAA personnel and surveys of FAA facilities revealed no particular EMC probelms in which undesired control and signal line emissions in the 30 Hz to 50 MHz frequency range were the culprit. In fact, the reported problems were stated as being "environmental" in nature and generally involved radiated emissions entering sensitive receiver circuits. It is possible that some of the radiated signals were the result of control and signal line emissions in the 30 Hz to 50 MHz frequency range; however, when the wavelengths are considered in terms of efficiency in generating and receiving these emissions, it seems improbable that these radiations caused any significant problem.

During the measurement series [6]-[9] at ARTCC facilities, undesired broadband and narrowband emissions on control and signal lines associated with the automated equipment were measured. In all facilities, it was concluded that broadband emissions exceeded the applicable MIL-STD-461A limits over much if not all of the 1 kHz to 50 MHz test range. Narrowband emissions in excess of applicable MIL-STD-461A limits were observed, but generally over restricted portions of the 1 kHz to 50 MHz frequency range. When the measured broadband emission levels were compared with the susceptibility limits of MIL-STD-461A, it was observed that the limits were exceeded. Such was not the case when narrowband emissions were compared with applicable susceptibility limits. The overall conclusion drawn for each of the facilities was "...that these emission levels do not represent problem areas because the automated system is compatible within itself and because the signals appear to be those signals intended to be carried on the signal lines. Similar operational compatibility which should also assure compatibility from the conducted signal line emission standpoint, would also be required by the normal specifications for new equipment to be installed at the ARTCC in the automated system complex" [16]. No emission measurements were performed on non-automated equipments and those performed on automated equipments appear to have involved signal rather than control lines. Further, if the emission levels reported to be in excess of MIL-STD-461A limits were the intentional or desired signals, they were in fact exempt from the MIL-STD-462 test requirements.

4.5 Test Method CE05, Conducted Emissions, 30 Hz to 50 MHz, Inverse Filter Method

This test method provides an adjunct measurement procedure for tests involving a current probe for monitoring power, control or signal line emissions of a single shot or low repetition rate (5 pps or less) nature. Therefore, the adjunct procedure may be used in lieu of Test Methods CE01, CE02, CE03, or CE04. The procedural changes necessary to accommodate this test method consist of coupling the current probe output to appropriate band-limiting filters and then to an inverse filter. This inverse filter compensates for variations in the individual test method limit curves by providing a response that is the inverse of the limit curves. Requirements for this test method have subsequently been deleted by both the Air Force and the Army (Notices 2 and 3, respectively, MIL-STD-462).

4.6 Test Method CE06, Conducted Emissions, 10 kHz to 12.4 GHz, Antenna Terminal

This test method provides an equipment configuration and procedure for use in measuring both broadband and narrowband characteristics of undesired emissions conducted on lines intended for connection to antennas. The range of test frequencies is 10 kHz to 12.4 GHz while the range of test item fundamental frequencies is 10 kHz to 1.24 GHz; therefore, the test procedure will measure antenna terminal undesired emissions up to a frequency ten times the test item fundamental frequency. Test items to which the measurement procedures are applicable include transmitters in both the key-up and key-down mode, receivers, and radio frequency (rf) amplifiers. Test items to which the measurement procedures do not apply include transmitters with power output levels in excess of five kilowatts, and transmitters, receivers, and amplifiers which operate with fundamental frequencies greater than 1.24 GHz. For these test items, the radiated measurement procedures in Test Method RE03 are applicable. Three different test configurations are provided for use as a function of test item fundamental frequency and power output level. Procedural details provide techniques for rejecting the desired emission during tests, thereby preventing test equipment damage and the generation of erroneous responses in the test equipment.

Modifications to the basic test method have been minor. The Air Force (Notice 2, MIL-STD-462) accepted the test method verbatim while the Army (Notice 3, MIL-STD-462) made only editorial changes in the test procedures. These changes clarified some of the procedural details and improved the test method format.

Data defining typical antenna terminal emission levels for FAA receivers, transmitters, and amplifiers were not available; consequently, it was not possible to make any quantitive judgements regarding the prevalence of undesired antenna terminal emissions at FAA facilities. However, previous testing experience has repeatedly shown that these emissions are common and represent a potential source of interference. This is especially true in situations where transmitters are colocated with sensitive receivers and other equipments which operate with low level signals. It has been noted that "...antenna radiation, originating as conducted emissions on the output of RF devices, is one of the most significant culprit sources of inter-system EMI among communications-electronic equipments" [17]. Examples of these undesired antenna terminal emissions include harmonic, spurious, and unnecessary modulation sideband emissions from transmitters; harmonic and spurious emissions from local oscillators and crystal oscillators; and frequency synthesizer emissions from receivers. In addition to these narrowband emissions, it is not uncommon for broadband antenna terminal emissions to be generated by relay switching, blower motors, thermostats, etc. within an equipment. In view of these emission possibilities and the large number of transmitters, receivers, and amplifiers used at most FAA facilities, it is probable that much of the reported "environmental" interference is caused by undesired emissions from colocated antennas.

4.7 Test Method CS03, Conducted Susceptibility, 30 Hz to 10 GHz, Intermodulation, Two Signal

This susceptibility test is performed on receivers and tuned amplifiers for the purpose of determining the presence of intermodulation products formed by the mixing of two undesired signals in non-linear elements. In the case of FAA facilities, the two undesired signals might represent two transmitters operating at out-of-band frequencies and colocated with the receiver or tuned amplifier. In general, to produce intermodulation products, the undesired signals are coupled through the preselector and into the RF amplifier or mixer with sufficient level to mix in the non-linear region of operation. Sum and difference frequencies are generated by this mixing action, and if any of these frequencies occur within the amplifier passband, they will be processed along with the desired signal. Mathematically, signals capable of producing intermodulation products are defined by the equation

$$\left| mf_1 \pm nf_2 \right| = f_o, \qquad (1)$$

where m and n = integers (1, 2, 3, ...),

f_1 and f_2 = undesired signals, and

f_o = tuned frequency of operation.

The Test Method CS03 test procedure requires that the output of signal generators representing undesired emissions be coupled through suitable filters to two ports of a three-port network. The third port of the network is connected through an attenuator to the input terminals of the test item. The signal generator output levels, frequencies, and modulations are varied in accordance with detailed procedures until a frequency of $10f_o$ or 10 GHz, whichever is less, is reached. As each intermodulation product is generated, the test item output is monitored for indications of performance degradation. Precautions are provided to guard against the possibility of intermodulation occurring in the signal generators and against signal generator harmonic signals being coupled into the test item.

Modifications to this basic test method incorporate only minor changes. In fact, the Air Force (Notice 2, MIL-STD-462) did not change any of the Test Method CS03 requirements. The Army (Notice 3, MIL-STD-462) rewrote the procedure, added a considerable amount of helpful explanation regarding the purpose and precautions associated with procedural steps, deleted applicability to tuned amplifiers and required test frequencies only as necessary to evaluate second, third, and fifth order positive and negative mixes. It is reported [18] that MIL-STD-462B will be essentially identical to MIL-STD-462, except that its frequency range will be 15 kHz to 10 GHz.

No measured data were available to indicate the extent to which FAA receivers and amplifiers are susceptible to this test. However, it was obvious that both receivers and amplifiers are extensively used at FAA facilities. Additionally, the most often reported EMC problem at FAA facilities was environmental interference with communications equipments.

4.8 Test Method CS04, Conducted Susceptibility, 30 Hz to 10 GHz, Rejection of Undesired Signals at Input Terminals (2-Signal Generator Method)

This test method is a companion to Test Method CS03, and its purpose is to determine the response of receivers and tuned amplifiers operating in the 30 Hz to 10 GHz frequency range to undesired signals applied to their input terminals (intermodulation and cross modulation signals are excluded). Although applicable to all receiver types, the major concern is with superheterodyne receivers in which high level signals are coupled through the preselector and reach the mixer. There, they (and their harmonics) combine with the local oscillator signal to produce sum and difference frequencies, some of which may lie within the IF passband. These signals will be processed by the receiver as normal signals and will generate undesirable receiver responses. Mathematically, signals producing spurious responses in superheterodyne receivers are those defined by

$$\left| pf_{LO} \pm qf_{SR} \right| = f_{IF}, \qquad (2)$$

where p and q = integers (1, 2, 3, ...),

f_{LO} = local oscillator frequency,

f_{SR} = spurious response frequency, and

f_{IF} = intermediate frequency of receiver.

In general, the smaller the integer values for p and q, the more pronounced the spurious response.

The test equipment configuration and procedure required by this test method is very nearly identical to that required by Test Method CS03. Two signal generators (one of which is tuned to the desired frequency and provides the standard reference output while the other represents an unmodulated interference signal) provide external signals which are coupled through filters and isolators to two ports of a three-port network. The third port on the network is connected through an attenuator to the test item input terminals. The frequency, modulation, and signal level of the signal generators are varied in accordance with the specified procedures while the test item output is monitored for indications of performance degradation. The frequency range over which the signal generators must be tuned is $0.05f_1$ to $20\ f_2$, where f_1 and f_2 are lower and upper cutoff frequencies, respectively, defined by the test procedure. Precautions are provided regarding the possibility of coupling signal generator harmonic or spurious emissions into the test item and observing erroneous test results. No precautions are provided regarding the possibility of receiver desensitization taking place because of the automatic gain control (AGC) action. This effect (present only in receivers with AGC) is subtle to detect and causes a reduction in the desired signal with an associated compromise in performance.

Modifications to this test method as a result of notices added by the various military departments have been relatively minor. For example, the Air Force (Notice 2, MIL-STD-462) added the requirement that this test method be applicable to control and signal lines as well as the conventional radio frequency (rf) input terminals. It was also stipulated that the upper frequency limit for amplifiers should be 400 MHz. Army changes (Notice 3, MIL-STD-462) deleted applicability to tuned amplifiers and explained more thoroughly the test requirements imposed by the basic test method. This notice did, however, note the problem with desensitization of receivers with AGC and incorporated requirements for disabling both AGC and AFC. It is reported [19] that the only modification of any consequence to be made by MIL-STD-462B is to change the applicable frequency range from 30 Hz to 10 GHz to 15 kHz to 10 GHz.

As was noted in the discussion of Test Method CS03, receivers and amplifiers are extensively used at FAA facilities and, in many cases, are critical to safe and efficient air transportation. Also, the most often reported incidences of EMI at FAA facilities was attributed to "environmental" interference to communications equipments. No data base defining the abilities of FAA receivers and amplifiers to reject out-of-band signals was available for analysis.

4.9 Test Method CS05, Conducted Susceptibility, 30 Hz to 10 GHz, Cross Modulation

This susceptibility test is performed on receivers and tuned amplifiers for the purpose of determining the extent to which cross modulation products are formed and cause unacceptable performance degradation. The cross modulation products of interest are those formed by an adjacent channel signal which reaches the rf amplifier and modulates its output via non-linearities. Because the desired signal is also acted upon by the rf amplifier, the adjacent channel signal variations become modulated upon the desired signal. In general, cross modulation is not therefore the result of the undesired signal mixing with the local oscillator; in fact, if there is no desired signal, there can be no cross modulation.

In Test Method CS05, the outputs of two signal generators are coupled directly into two ports of a three port network. The third network port is coupled directly to the test item. The signal generator output levels, modulations, and frequencies are varied in accordance with the detailed procedures while the test item ouput is monitored for indications of performance degradation. The frequency scan range on the signal generator providing the undesired signal is $f_o \pm f_{IF}$.

No modifications to the basic test method were incorporated by the Air Force (Notice 2, MIL-STD-462). The Army (Notice 3, MIL-STD-462) deleted the entire test method because it conflicted with procedures in another applicable standard [20]. In the forthcoming MIL-STD-462B, the lower frequency limit is reportedly [20] changed from 30 Hz to 15 kHz.

Test data indicating the extent to which FAA receivers and amplifiers are susceptible to the requirements of this test method were not available. However, it was obvious from the facility surveys that both receivers and amplifiers are extensively used by the FAA. It is noted that the EMC problem most often reported during interviews with FAA personnel was identified as "environmental" interference with the performance of communication equipments.

4.10 Test Method CS06, Spike, Power Leads

The purpose of this test method is to provide a test procedure by which the susceptibility of equipments to power line transients may be determined. The test method is applicable to both ac and dc ungrounded power lines.

The test procedure requires a transient generator capable of providing a variable amplitude output with a 10 microsecond duration and independent synchronization and triggering capabilities. This output is injected onto ungrounded ac power lines by means of an isolation transformer, the secondary of which is connected in series with the power line under test. For dc power lines, the generator output is coupled directly across the power lines at their point of entry into the test item. A shunt capacitor and series inductor are used with ac and dc lines, respectively, to (1) isolate the transients from the power source and thereby force them to be developed across the test item power terminals and (2) prevent the power source from excessively loading the transient generator. An oscilloscope must be connected across the test item's power input terminals to assure that the required transient is present. Performance of the test involves applying transients with various amplitudes, synchronizations, polarities, and repetition rates while observing the test item's response for indications of performance degradation. In the case of digital circuitry, the transient must be triggered to occur within the time frame of gates or pulses generated by the logic circuitry. During all of the tests, the transient amplitude must be maintained at twice the power line voltage, or 100 volts, whichever is less.

Modifications to the basic test method have been relatively minor; however, the Air Force (Notice 2, MIL-STD-462) required the contractor to provide a detailed test description in his Test Plan "as the specified procedure often can not be accomplished." The Army (Notice 3, MIL-STD-462) did not stipulate the type of power line (ac or dc) that the series and parallel injection configurations were to be used with; therefore, it is assumed that either configuration may be used with either line. It is reported [21] that MIL-STD-461B will not require the transients to have a duration of exactly 10 microseconds, but permit any duration equal to or greater than 10 microseconds. It is further reported [22] that MIL-STD-462B will have provisions for a second transient test signal whose duration will be five nanoseconds. This shorter duration transient will more closely stimulate the transients observed on most facility power lines.

Interviews with personnel in FAA facilities did not reveal any consistent EMC problems attributable to power line transients. However, facility operations are of such a nature that transients are being almost continuously generated. The fact that they apparently didn't represent a problem at surveyed facilities is a tribute to suppression measures at either the generator or receptor, or both. During both the interviews and the facility surveys, it was evident that the FAA is using an increasing amount of digital equipment. This increases the possibility of transient interference problems.

The susceptibility of automated equipments to transients injected onto their power lines was measured during the series of tests [6]-[9] conducted at three representative ARTCC facilities. Results from these tests consistently showed that "most of the automated system equipments were not susceptible to power line conducted signals injected in accordance with MIL-STD-461A requirements." These power line conducted signals included transients. The only documented exceptions to this were instances [23] in which 20 volt transients on the M1 Console power line caused Vertical Display interference lines. Also, status lights on the System Control Console were subject to spurious lighting when 100 volt transients were injected onto its power line. No conducted transient susceptibility tests were performed on non-automated equipments. The overall conclusion drawn from these tests was that "automated equipments are not susceptible to the power line conducted signals normally found at ARTCC sites."

4.11 Test Method (T) CS07, Conducted Susceptibility, Squelch Circuits

This test is conducted on receivers to determine if their squelch circuits are adequate to prevent operation when impulsive noise is applied at the antenna terminals. In the first of the two required procedures, an impulse generator is connected to the receiver antenna terminals through an isolating pad. The squelch circuit is then adjusted so that it just opens when the required rf input signal is applied to the input terminals. Using this squelch circuit adjustment, an impulse generator output is applied to the receiver input and the receiver is observed to determine if the squelch circuit opens. In the second procedure, impulse generator and signal generator outputs are simultaneously applied to the receiver's input through an isolation network. The signal generator output level is unmodulated and adjusted to 0.667 times the level which would normally open the squelch circuit. Again, the receiver output is observed to determine whether the combination of these two signals causes opening of the squelch circuit. Both of these tests are conducted to determine the ability of the squelch circuit to be captured by the presence of impulsive noise.

Neither the Army nor the Air Force modify the requirements of this test method in their notices to MIL-STD-462. Further, it is reported [24] that MIL-STD-462B will retain this test method without change.

4.12 Test Method CS08, Conducted Susceptibility, 30 Hz to 10 GHz, Rejection of Undesired Signals at Input Terminals (1-Signal Generator Method)

This test method serves the same purpose as Test Method CS04 in that it provides procedures for determining the response of receivers and tuned amplifiers operating in the 30 Hz to 10 GHz frequency range to undesired signals applied to their input terminals. To accomplish this purpose, a signal generator is connected to the input terminals of the test item through a filter intended to reduce signal generator spurious outputs. This signal generator is adjusted to yield a test item standard response. The input signal amplitude is then increased to the specified level above that necessary for the standard resonse. For amplifiers, the frequency is then scanned from 0.05 f_1 to f_1 and from f_2 to 20 f_2, where f_1 and f_2 are the lower and upper cutoff frequencies. For receivers, the frequency is scanned either from 0.05 f_1 to 20 f_2 as is applicable for amplifiers, or from 0.2 (IF) to 5 f_{LO} + IF. Receiver frequencies within the 80 dB down points on the selectivity curve are exempted. Precautions are provided to assure that spurious responses and not intermodulation products are observed.

5. RECOMMENDATIONS

5.1 Overview

In the previous paragraphs (Section 4), a description was provided of the basic requirements in each of the MIL-STD-462 Test Methods. Additionally results of the analysis conducted to determine the rationale for each test method were presented. In this Section, these descriptions and results are condensed to a format that permits specific recommendations to be made regarding the applicability of individual test methods to the needs of FAA equipments. These recommendations are first presented in terms of the test methods that should be adopted, then the test configurations and procedures that should be used, and finally the limits to be imposed on equipment performance.

5.2 Test Method Recommendations

5.2.1 Test Methods CE01 and CE03, Conducted Emissions, 30 Hz to 50 MHz, Power Lines

It is recommended that Class I, II, and III equipments be required to comply with power line conducted broadband and narrowband emission requirements over a 30 Hz to 50 MHz frequency range. This recommendation is made with a full awareness that (1) the measurement procedure currently required by MIL-STD-462 is unacceptable at low frequencies and (2) that the new MIL-STD-462B is reported to delete low frequency test requirements. Previous testing experience involving complex assemblages of analog and digital equipments has repeatedly shown the necessity for stringent control on power line conducted emissions. This necessity is substantiated in large part by the data obtained at the Oakland, CA, Los Angeles, CA and New York, NY ARTCC facilities.

To circumvent low frequency measurement problems associated with impedance standardizing devices such as the 10 μfd feedthrough capacitors, it is recommended that power line emission levels be measured on dc power lines over a 30 Hz to 50 kHz frequency range. It is further recommended that ac power line emission levels be measured over a 10 kHz to 50 MHz frequency range. The upper frequency limit of 50 MHz for ac power line tests is important since it is in this range that signal cross-coupling between lines becomes of concern. Also, it is noted that the 3 to 30 MHz frequency band is heavily used for communication-electronic services; therefore, low conducted emission levels on power lines are helpful in providing interference-free operation for these services.

5.2.2 Test Methods CS01 and CS02, Conducted Susceptibility, 30 Hz to 400 MHz, Power Lines

It is recommended that Class I and II equipments comply with the requirements in these test methods. The test methods are applicable in the following manner: (1) Test Method CS01 applies to dc power lines only and covers a 30 Hz to 50 kHz frequency range and (2) Test Method CS02 applies to both ac and dc power lines and covers a frequency range of 50 kHz to 400 MHz. The primary basis for this recommendation is the fact that these test methods are the susceptibility counterparts for the emission tests required by Test Methods CE01 and CE03. It is noted that the test results obtained during the measurements made in typical ARTCC facilities do not fully support this recommendation. These results show that most of the automated and non-automated equipments are not susceptible to the conducted signals imposed by the requirements of MIL-STD-461A. However, certain key tests are necessary if effective EMC control measures are to be implemented on FAA equipments. Conducted emission and susceptibility tests are among these key tests. Additionally, extensive previous experience in attempting to implement EMC controls on large assemblages of complex electronic equipments has shown the definite need for control of power line emission levels and susceptibility thresholds.

5.2.3 Test Methods CE02 and CE04, Conducted Emissions, 30 Hz to 50 MHz, Control and Signal Lines

It is recommended that the requirements of these test methods be adopted by the FAA for Class I, II, and III equipments. In making this recommendation, it is strongly urged that careful attention be given to assuring that only undesired narrowband and broadband emissions are measured. Undesired emissions on control and signal lines demand as much test and control attention as undesired emissions on power lines.

This is because the primary concern is with the possibility of equipment performance degradation from conducted emissions, not whether the port of entry is the power line or some control/signal line.

5.2.4 Test Method CE05, Conducted Emissions, 30 Hz to 50 MHz, Inverse Filter Method

It is recommended that this test method not be retained by the FAA since it was not possible to establish its particular usefulness during this investigation.

5.2.5 Test Method CE06, Conducted Emissions, 10 kHz to 12.4 GHz, Antenna Terminals

It is recommended that Class I transmitters, receivers, and amplifiers be required to comply with the provisions of this test method. This recommendation is based on the fact that undesired antenna terminal emissions, if not controlled, will contribute excessively and unnecessarily to the electromagnetic environment at FAA facilities. These environment contributions will enhance the probability of interference and especially so in the case of FAA facilities where sensitive and complex equipments are extensively used and colocated.

5.2.6 Test Method CS03, Conducted Susceptibility, 30 Hz to 10 GHz, Intermodulation

It is recommended that Class I receivers and tuned amplifiers be required to comply with provisions of this test method. However, the applicable frequency range should be as necessary to evaluate test item response to second, third, and fifth order positive and negative mixes. If no second or third order mixes are observed, there should be no requirement to test for fifth order mixes. The primary basis for recommending performance of this test method is the criticality of receivers and tuned amplifiers to FAA facility operations and the number of these items in simultaneous use at FAA facilities. Also, extensive test experience has clearly shown the necessity for minimizing receiver and amplifier susceptibility in providing effective EMC control.

5.2.7 Test Method CS04, Conducted Susceptibility, 30 Hz to 10 GHz, Rejection of Undesired Signals at Input Terminals (2-Signal Generator Method)

It is recommended that Class I receivers and tuned amplifiers be required to comply with the provisions of this test method. However, the applicable frequency range should be changed such that only receivers and tuned amplifiers operating in the 15 kHz to 10 GHz range are tested. The primary basis for this recommendation is the criticality of the receivers and tuned amplifiers to safe and efficient functioning of air transportation facilities and the fact that receivers and tuned amplifiers are used in large numbers at most FAA facilities. Also, extensive test experience has repeatedly proven the necessity of minimizing receiver and amplifier susceptibility in providing effective EMC control. The recommended change in lower frequency limit (from 30 Hz to 15 kHz) is based on the lack of receivers and tuned amplifiers which operate over this range in FAA facilities.

5.2.8 Test Method CS05, Conducted Susceptibility, 30 Hz to 10 GHz, Cross Modulation

It is recommended that Class I receivers and tuned amplifiers be required to comply with the requirements of this test method; however, this recommendation is applicable to receivers and tuned amplifiers operating only in the 15 kHz to 10 GHz frequency range. The primary basis for this recommendation is the criticality of receivers and tuned amplifiers to the safe and efficient operation of air transportation facilities and the fact that these devices are used so extensively in FAA facilities. Also, extensive testing experience has clearly shown the necessity of minimizing receiver and amplifier susceptibility in providing effective EMC control. The recommended change in lower frequency limit (from 30 Hz to 15 kHz) is based on the lack of receivers and tuned amplifiers which operate over this range in FAA facilities.

5.2.9 Test Method CS06, Spike, Power Leads

It is recommended that the ac and dc power lines of Class I equipments be required to comply with the transient susceptibility provisions of this test method. The primary basis for this recommendation is the increased use of digital equipments for critical functions at FAA facilities. The lack of susceptibility when transients were conducted onto the power lines of automated equipments at ARTCC facilities was noted; however, rather than providing a basis for deleting this test method, this lack of response to transients was considered to be the result of satisfactory design practices. Continuing to impose this test method in the future will be a means of assuring that these desirable design practices continue to be followed.

5.2.10 Test Method (T) CS07, Conducted Susceptibility, Squelch Circuits

It is recommended that Class I receivers used by the FAA and containing squelch circuits be required to comply with this test method. This recommendation is based primarily on the criticality of receivers in the operation of FAA facilities and the necessity to reduce interference effects in these receivers.

5.2.11 Test Method CS08, Conducted Susceptibility, 30 Hz to to 10 GHz, Rejection of Undesired Signals at Input Terminals (1-Signal Generator Method)

It is recommended that FAA receivers and tuned amplifiers not be required to comply with provisions of this test method. This recommendation is based on the fact that data defining front-end rejection characteristics of receivers and tuned amplifiers are obtained by Test Method CS04. It was recognized that Test Method CS04 requires the use of two signal generators while this test method only requires one. However, the two signal generator test configuration is required in performing the intermodulation test of Test Method CS03; consequently, front-end rejection characteristics using the two signal generator method can be defined as a natural continuation of Test Method CS03.

5.3 Test Configuration and Procedure Recommendations

5.3.1 Test Methods CE01 and CE03, Conducted Emissions, 30 Hz to 50 MHz, Power Lines

From a "quick look" point-of-view, the accurate and reliable measurement of power line conducted emissions is deceptively simple. For example, it is generally correct to say that the measurement task only involves rejecting the power source and externally induced currents while measuring the noise current generated by the test item. In spite of this apparent simplicity, these rejection and measurement efforts over any appreciable frequency range are fraught with difficulty [25], [26]. This difficulty is primarily caused by the multi-component nature of the power line current and the random variations in line impedance which influence the current magnitude.

Some of the difficulty associated with the multi-component nature of the power line current can be seen by referring to Figure 2. The total line current is the sum of the desired power source current and undesired emission currents generated by the test item plus other equipments located in close proximity to the test item. For example, the actual current at the power input terminals of the test item may be expressed as

$$I_T = i_s + i_r + i_c + i_n \qquad (3)$$

where i_s is the power current required by the test item for operation, i_r is the current induced onto the power line by radiations from Equipment #3, i_c is an undesired current generated by Equipment #2 and conducted into the test item via the power distribution system, and i_n is the undesired "noise" or emission current generated by the test item and conducted onto the power distribution system. It is this latter component, i_n, that is to be measured on ac and dc power lines by Test Methods CE01 and CE03. Obviously, an accurate measurement of i_n must involve some technique by which the other current components are excluded.

Aside from the concern with multiple current components on the power line, there is also a measurement difficulty associated with the fact that the impedance of the power line influences the magnitude of i_n. Consequently, if this impedance is not the same at both the equipment's test location and final installation location, the measured value of i_n will not accurately reflect the value of i_n at the installation location. This is seen in Figure 3 where i_n is generated by a test item "noise" voltage source v_n and

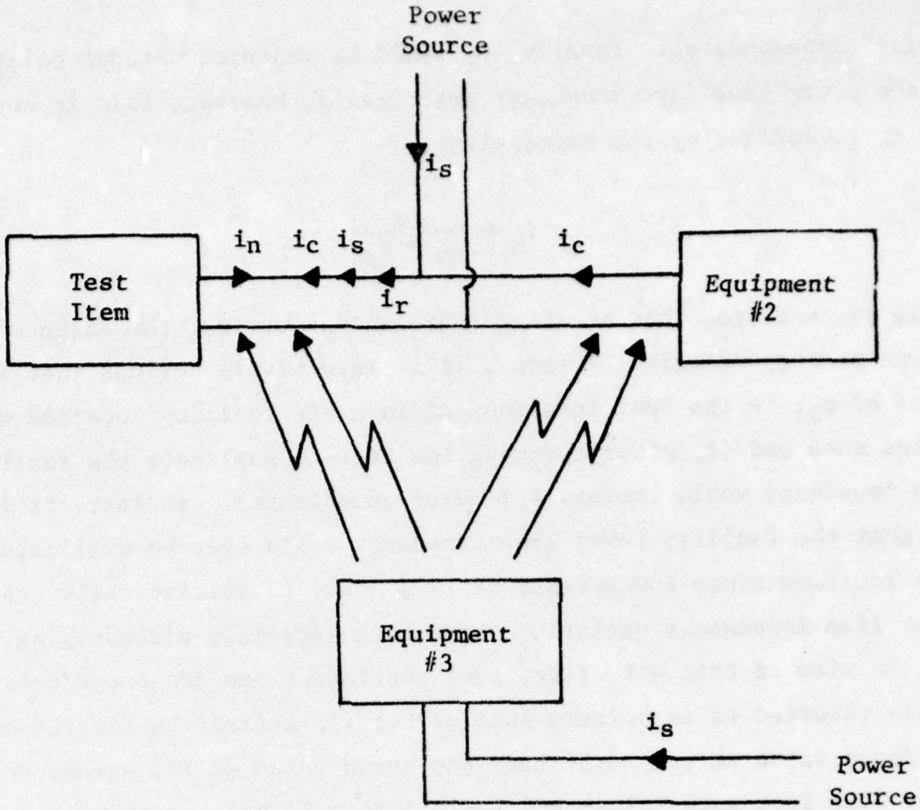

Figure 2. Components of Current at Power Input Terminals of Test Item.

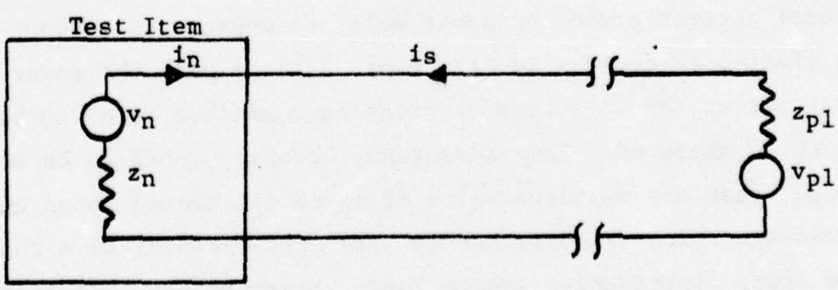

Figure 3. Model of i_n Source Within Test Item.

"noise" impedance z_n. Ideally, i_n would be measured without being affected by the power line impedance z_{pl}; practically, however, this is not possible and i_n is defined by the expression

$$i_n = \frac{v_n}{z_n + z_{pl}} \quad . \tag{4}$$

It is evident from this equation that, as z_{pl} varies, the value of i_n will change correspondingly. Further, it is intuitively obvious that (1) the value of z_{pl} in the test location and in a FAA facility location will not be the same and (2) efforts during the test to duplicate the facility power line impedance would represent a major undertaking. In fact, it is doubtful that the facility power line impedance could ever be duplicated at a test location since investigations [27], [28] to statistically characterize power line impedances variations have been extremely discouraging.

In view of this situation, test configurations and procedures have generally resorted to techniques that either (1) attempt to fix the power line impedance value at some arbitrary but known value or (2) assume that the power line impedance values and variations will not excessively influence the accuracy of measurement results. In the former case, the test techniques are generally referred to as stabilizing techniques while in the latter case the test techniques are said to be non-stabilizing. During this program, three non-stabilizing and two stabilizing techniques were investigated in efforts to identify a suitable power line conducted test configuration and procedure.

The non-stabilizing test techniques involved use of an absorbing clamp, directional current probe and power meter to measure i_n without directly inserting electronic devices in series or parallel with the power line. They, therefore, offer the advantage of creating a minimum of disturbance to the current to be measured. This advantage, however, tends to be overshadowed by the fact that the measured value of i_n is influenced by an unknown power line impedance which is suspected to vary significantly as a function of time and power distribution system load. Nevertheless, non-stabilizing test techniques are still required by some standards; therefore, their merits were investigated and are summarized below.

Absorbing Clamp--specified for use in some European EMC standards [29], [30], the absorbing clamp consists of a number of ferrite rings arranged side by side to enclose the power cable. The currents i_r and i_c are suppressed by the directional nature of the clamp. The clamp is moved along the power line length until an indication of maximum emission level is observed [31]. Its applicable frequency range of 30 to 300 MHz is only a small portion of the frequency range considered necessary for FAA equipments, and there is no apparent means of using the absorbing clamp for susceptibility testing. For these reasons, the absorbing clamp is not recommended for FAA adoption.

Directional Current Probe--the directional current probe measurement technique [32] involves the use of two current probes, a length of lossy line, and an electronic summing circuit. The current probes are spaced one-quarter wavelength apart, and the lossy line is used to achieve an additional quarter wavelength phase shift. This configuration results in the cancellation of the undesired currents i_r and i_c while boosting the level of i_n by a factor of two at the output of the summing circuit. In addition to the general disadvantages of non-stabilizing techniques, the directional current probe measurement is impractical at frequencies below approximately 20 MHz due to the necessity of the quarter wavelength spacing between probes. Consequently, it is not recommended for power line conducted emission measurements on FAA equipments.

Maximum Available Power (MAP) Technique--the MAP technique [33] for conducted power line emission measurements has been considered for several years and is appealing because of the intuitive feeling that equipment susceptibility is a function of neither voltage nor current, but of voltage and current; consequently, a power measurement appears to offer the possibility of combining both of these parameters in one measurement approach. The MAP technique indirectly determines this power by using an instrument such as the EMI Conducted Power Meter (Solar Electronics Company Model 6863-1) to measure the current and impedance of the interference source internal to the test item. The measured current and impedance values are then converted to power units by the meter and visually displayed for observation. The interference current is measured under virtual short circuit conditions; therefore, the resulting power computation yields the maximum interference power level available from the test item. In spite of its initial appeal, the MAP approach is limited because the currently available instrumentation has a frequency range of only 15 kHz to 30 MHz. In recent conversations with personnel in the Solar Electronics Company Engineering Department, it was learned that development efforts are now underway to reduce the lower frequency limit from 15 kHz to 5 kHz; however, no related efforts for extending the upper frequency limit above 30 MHz are planned. Conclusions regarding the MAP technique were, therefore, as follows:

(1) The measurement of power conducted onto power lines by an interference source internal to the test item may be a satisfactory approach to power line conducted emission tests. However, at present this power can be accurately and repeatedly measured at discrete frequencies between 15 kHz and 30 MHz. Broadband power measurements are not possible because of the inability to determine the root mean square (rms) value of the interference voltage. The frequency range over which dc and ac power line conducted narrowband and broadband measurements need to be made is 30 Hz to 50 MHz.

(2) The ability to perform susceptibility tests using the EMI Power Meter is nonexistent; consequently, the instrument could become a costly piece of equipment used only during emission tests.

(3) Susceptibility of an equipment may be a separate function of voltage and current. Measurement of MAP provides only a combination of these parameters.

For these reasons it was decided that further improvements and investigations must be made before the MAP approach can be recommended for FAA adoption.

In addition to the three non-stabilizing techniques discussed above, two stabilizing techniques for power line emission measurements were investigated. These techniques involved line impedance stabilization networks and feedthrough capacitors as impedance stabilizers. In concept, both test techniques require measuring i_n after a known impedance z_k has been inserted into the power line. It is assumed (erroneously) that this impedance has negated the influence of z_{pl} on i_n and that the resulting data either (1) accurately reflect the value of i_n at both the test and installations or (2) represent a worst-case value of i_n for all locations. In fact, i_n can be expressed as follows for stabilizing test techniques:

$$i_n = \frac{v_n}{z_n + z} \qquad (5)$$

where z is the combination of z_k and z_{pl}. The two stabilizing techniques for which Equation (5) is applicable involve the use of a LISN and a capacitor. Their relative merits are summarized below.

Line Impedance Stabilization Network--Figure 4 presents a circuit diagram for a typical LISN [34] specified for use in earlier military specifications. The shunt capacitors are designed to isolate the 60 Hz power current from the higher frequency interference currents. The inductor prevents i_c and i_r from mixing with i_n. The circuitry is also designed so that the impedance across resistor R_1 is nominally 50 ohms throughout the applicable frequency range. Therefore, when the LISN is used, $z_k \approx 50$ ohms and i_n is determined by measuring the voltage it develops across R_1.

Like all stabilizing techniques, the LISN technique involves inserting a "foreign" network into the power line of the equipment being tested. As a result, some error is expected. Unfortunately, the magnitude of the error due to this network can be large and either increase or decrease the measured value of i_n for non-reactive power sources [35].

Feedthrough Capacitor--As noted earlier (Para. 4.2), this capacitor technique [36] is required by Test Method CE01 in MIL-STD-462 and its deficiencies at low frequencies have already been discussed. At frequencies of approximately 10 kHz and above, the capacitor theoretically offers essentially a short circuit current path for i_n and $i_c + i_r$. Under these conditions,

$$i_n = \frac{v_n}{z_n} \qquad (6)$$

and the measured value of i_n is the actual "noise" current generated by the test item. In practice, however, the capacitor impedance is not zero and the influence of the power line impedance z_{pl} is still present. As a result, measurement error is again expected and has, in fact, been shown

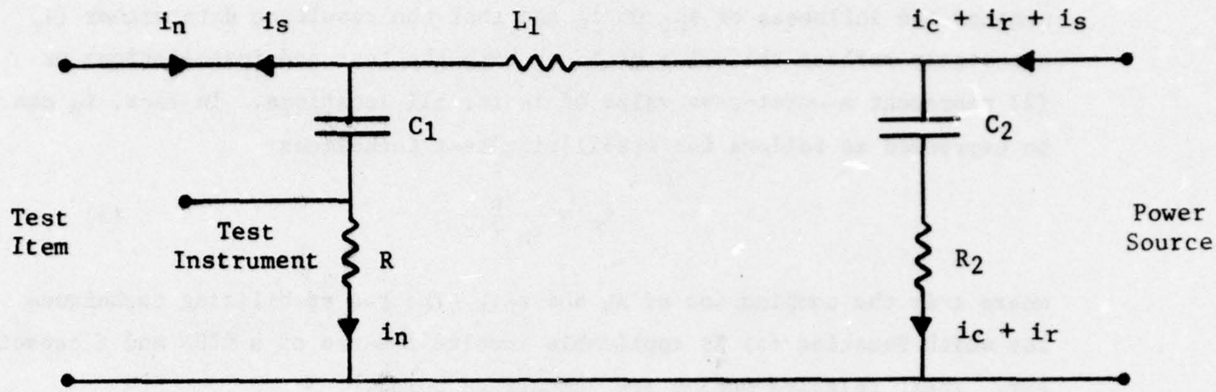

Figure 4. Schematic Diagram of LISN

[37] to exceed that resulting from use of the LISN technique. However, the primary difference between the two techniques is that the error resulting from the use of the capacitor is more likely to increase the measured value of i_n for non-reactive power sources [35].

In view of the above considerations regarding stabilizing and non-stabilizing measurement techniques, different test configurations and procedures are recommended as a function of test method frequency ranges. For the 30 Hz to 50 kHz range where the test method is applicable only to dc power lines, the test configuration and procedure required by Notice 3 to MIL-STD-462 are recommended. Since this test configuration and procedure are applicable to dc power lines only, the problems associated with low frequency characteristics of impedance standardizing devices are eliminated; therefore, the feedthrough capacitor can be effectively used. This recommended test configuration provides an audio isolation transformer as a replacement detection device for the current probe. This transformer does not have the problem of large variations in low frequency transfer impedance that are common to the current probe. By proper selection of signal coupling circuits (procedure provided), the problem with inadequate current probe sensitivity is also eliminated.

For ac power lines and a frequency range of 10 to 50 kHz, the test configuration and procedure required by Notice 3 to MIL-STD-462 are recommended. In this configuration, line impedance stabilization networks are inserted in each power line on which emission levels are to be measured. A current probe can be used as the detection device because transfer impedance and sensitivity are not problems in this higher frequency range. If the optional band-reject or high pass filters are used, caution should be exercised to assure that filter characteristics do not influence test results in an unknown manner.

The final test configuration and procedure recommendation for Test Methods CE01 and CE03 is applicable to both ac and dc power lines and to a frequency range of 50 kHz to 50 MHz. The test configuration is essentially the same as for the ac power line tests from 10 to 50 kHz; however, line impedance stabilization networks inserted in each power line must exhibit satisfactory characteristics at these higher frequencies. These characteristics are adequately provided in designs presented in Figures 7 and 9 of Notice 3 to MIL-STD-462. It is noted that, in this frequency range, the current probe position along the power line must be varied until the maximum emission level is located.

5.3.2 Test Methods CS01 and CS02, Conducted Susceptibility, 30 Hz to 400 MHz, Power Lines

The recommended test configurations and procedures are those required by Test Methods CS01 and CS02 in Notice 3 to MIL-STD-462. Test Method CS01 couples low frequency test signals onto dc power lines by means of the secondary of an isolation transformer and is applicable over the 30 Hz to 50 kHz frequency range. The 50 kHz to 400 MHz frequency range is covered by Test Method CS02, which requires a modulated test signal to be coupled onto both dc and ac power lines via a line impedance stabilization network. For both test methods, the test signal frequency range is slowly scanned while the test item is monitored for indications of performance degradation.

5.3.3 Test Methods CE02 and CE04, Conducted Emissions, 30 Hz to 50 MHz, Control and Signal Lines

The recommended test configuration and procedure are those required by Notice 3 to MIL-STD-462. These configurations and procedures do not differ substantially from those in the basic test method; however, the presentation of requirements offers improved clarity and explanation. In most measurement situations, it will be possible to jointly perform narrowband and broadband tests. This will require a quick scan of the 30 Hz to 50 MHz frequency range and an identification of each significant emission as either narrowband or broadband. For each emission, appropriate bandwidth changes must then be made on the receiver and the resulting level displayed on the monitor is recorded.

5.3.4 Test Method CE06, Conducted Emission, 10 kHz to 12.4 GHz, Antenna Terminals

The test configurations and procedures recommended for FAA use in performing this test are those required by Notice 3 to MIL-STD-462. As was noted in Para. 4.6, these requirements are, from a technical point-of-view, essentially the same as those in the basic test method. However, their format is better and clarifications regarding procedural details are provided. The precautions provided to preclude equipment damage and erroneous data are adequate, and the procedures define a test that will yield reliable data.

5.3.5 Test Method CS03, Conducted Susceptibility, Intermodulation

The test configurations and procedures required by Notice 3 to MIL-STD-462 are recommended for FAA adoption for both receivers and tuned amplifiers operating within the 15 kHz to 10 GHz frequency range. Tests conducted using these configurations and procedures yield accurate and repeatable data. Adequacy of the configurations and procedures is indicated by the fact that they are the accepted standard for receiver and amplifier performance evaluation.

5.3.6 Test Method CS04, Conducted Susceptibility, Rejection of Undesired Signals at Input Terminals (2-Signal Generator Method)

The test configurations and procedures required by Notice 3 to MIL-STD-462 are recommended for FAA adoption for both receivers and tuned amplifiers operating within the 15 kHz to 10 GHz frequency range. Tests conducted using these configurations and procedures yield accurate and repeatable data. Adequacy of the configurations and procedures is indicated by the fact that they are the accepted standards for receiver and amplifier-evaluations.

5.3.7 Test Method CS05, Conducted Susceptibility, Cross Modulation

The configurations and procedures recommended for use in performing this test are those currently required by MIL-STD-462. These configurations and procedures will yield accurate and repeatable data and they are the generally accepted standard for receiver and amplifier performance evaluation.

5.3.8 Test Method CS06, Conducted Susceptibility, Transients, Power Lines

The basic test configurations and procedures required by MIL-STD-462 are adequate for the performance of this test method; however, in Notice 3 to MIL-STD-462, the basic test method has been rewritten with minor changes that clarify the procedure and improve the test configuration. Therefore, the power line conducted transient susceptibility configurations and procedures required by Notice 3 to MIL-STD-462 are recommended for FAA adoption.

5.3.9 Test Method (T) CS07, Conducted Susceptibility, Squelch Circuits

The test configurations and procedures required by MIL-STD-462 are recommended for adoption by the FAA to perform this test. These configurations and procedures are adequate to yield reliable and repeatable data regarding capture of receiver squelch circuits by impulsive noise.

5.4 Performance Limit Recommendations

5.4.1 Approach to Limit Derivation

Many of the requirements in present EMC standards are confusing and without apparent explanation; however, no aspect of EMC standards is as thoroughly unexplained as are the performance limits that have evolved as one standard after another has emerged. It has been correctly noted that "the historical road from the first formulation of interference limits to their present state has been long in time but short in technical advancement" [38]. Almost every effort to analyze their scientific basis ends with the general conclusion that they are arbitrary in origin, perhaps irrelevant and bear little or no direct relationship to the achievement of system level EMC. Consequently, efforts to establish new performance limits based on existing limits is at best a speculative venture.

5.4.2 Test Methods CS01 and CS02, Conducted Susceptibility, 30 Hz to 400 MHz, Power Lines

With this *a priori* knowledge of the effort involved in establishing valid performance limits for recommendation to FAA, a rather simplified approach generally unencumbered by limits in present and past standards was adopted. This approach began with analyses of all available data defining the operational electromagnetic environment at FAA facilities. This environment is known to vary considerably as a function of such factors as time of day, facility type, relative size of facility, nature of activity, etc. Therefore, it is not possible to have definitive data for each of these conditions. Fortunately, a series of measurements [6]-[9] were recently completed in which the operational electromagnetic environment in three typical ARTCC facilities was extensively defined. A portion of these measurement results were in the form of narrowband conducted signal levels on 175 power lines chosen to reflect contributions from both automated and non-automated electronic equipments. Measurement results for these locations were presented for each of the three ARTCC facilities. Additionally, comparable measured data was presented for conducted broadband signal levels. The applicable frequency range for both narrowband and broadband data was 1 kHz to 50 MHz.

To reduce these data to a usable form, four frequency bands (10 to 100 kHz, 0.1 to 1 MHz, 1 to 10 MHz, and 10 to 50 MHz) were selected. Then the highest reported narrowband and broadband signal levels in each frequency band and at each facility location were tabulated. From this tabulation, composite signal levels which approached the maximum measured emission level were identiifed for each frequency band at all three facilities.

These levels were then plotted in units of dBμV and dBμV/MHz versus frequency, and a straight line curve was used to connect the data points. The resulting curves, shown in Figures 5 and 6, then provided a composite view of the operational narrowband and broadband conducted emissions on 175 power lines in three typical ARTCC facilities. As is evident in the figures, the maximum level of narrowband emission was approximately 86 dBμV at 1 kHz. Similarly, the maximum broadband emission was approximately 168 dBμV/MHz at 50 kHz. Any new equipments installed in these facilities will have to be capable of tolerating these narrowband and broadband emission levels on their power lines. Therefore, these measured emission levels can be used to provide the starting point for the derivation of power line conducted susceptibility limits for future equipments.

In deriving power line conducted susceptibility limits, there was an awareness that the measured levels plotted in Figures 5 and 6 were maximum values applicable to only three ARTCC facilities; therefore, they were not necessarily representative of the levels for all FAA facilities. No measured data defining such levels at other facilities existed; consequently, a 20 dB factor was added across the 1 kHz to 50 MHz frequency band to account for the fact that other FAA facilities might have higher power line conducted emission levels. The maximum narrowband and broadband emission levels at 1 kHz then became 106 dBμV and 179 dBμV/MHz, respectively. A safety factor of 24 dB was then chosen, largely for convenience, to make the final narrowband and broadband emission levels at 1 kHz 130 dBμV and 203 dBμV/MHz, respectively. These levels are also plotted in Figures 5 and 6 and represent the final emission levels which equipments installed in FAA facilities are assumed to have to withstand. These levels therefore provide a basis for deriving recommended power line conducted susceptibility levels.

The 130 dBμV level at 1 kHz was compared with the narrowband susceptibility limits required by MIL-STD-461A and Notice 3 to MIL-STD-461A. It was noted that, in both cases, these documents required exposure to a level corresponding to ten percent of the power supply voltage or three volts, rms, whichever was less. In FAA facilities, the supply voltage for DC equipments would be 28 volts; therefore, the applicable power line conducted susceptibility limit becomes 28 volts rms. The 130 dBμV level at 1 kHz yields a voltage of 3.17 volts, so the correlation between present and derived limits is excellent at 1 kHz.

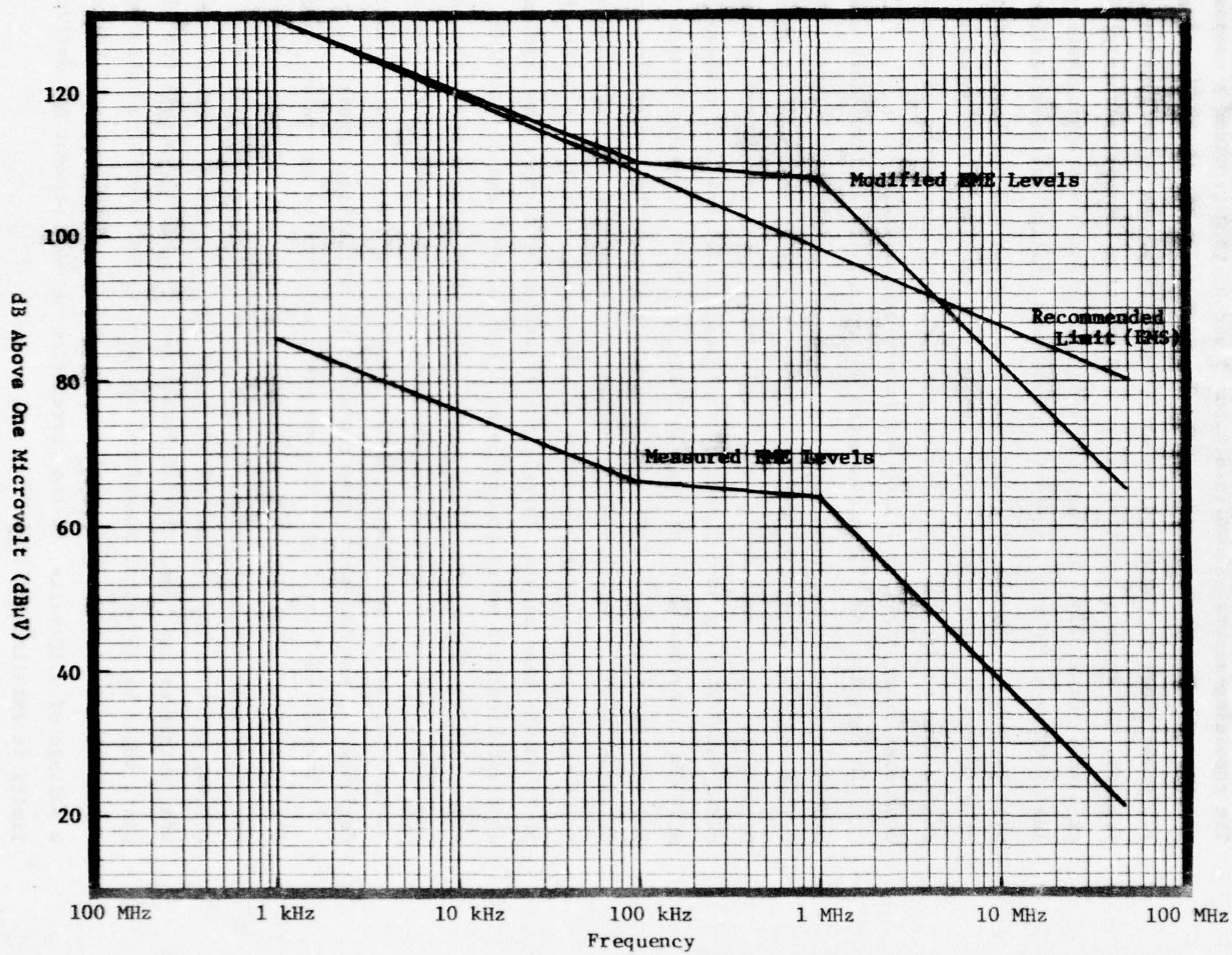

Figure 5. Narrowband Emission Levels and Recommended Susceptibility Limit.

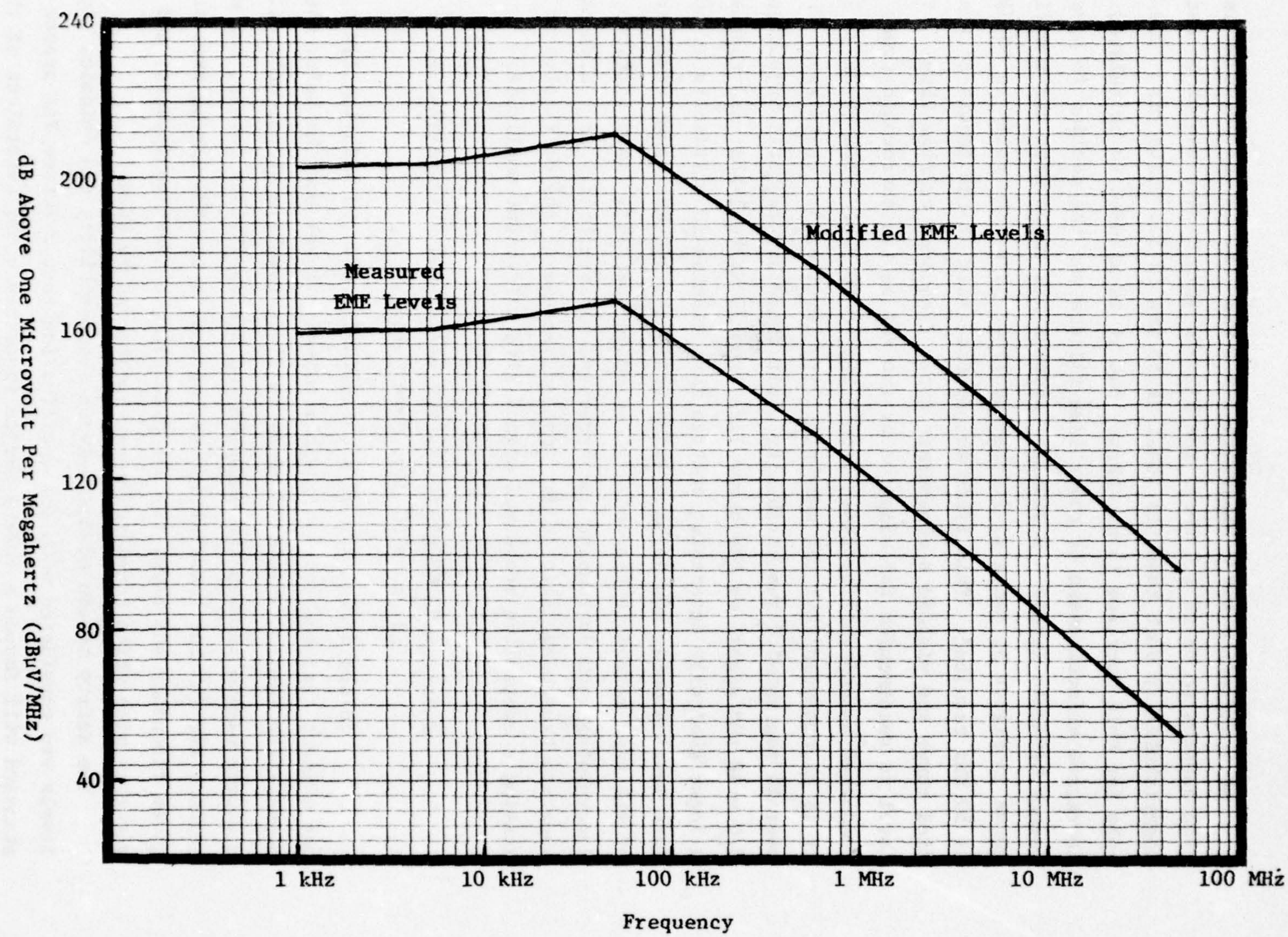

Figure 6. Broadband Emission Levels for Power Lines in FAA Facilities.

At frequencies above approximately 1 kHz (the actual point of inflection appears to be at 1.5 kHz), the MIL-STD-461A limits begins to decrease logarithmically such that its level at 50 kHz is 1.2 volts rms. The rationale for this decrease is not known, but it is assumed to be related to the increased effectiveness of power line filters and the decline in power frequency harmonic levels. A similar approach was taken with the modified curve in Figure 5, and a limit that declined logarithmically to 80 dBμV at 50 MHz resulted. This limit encompassed most of the levels of the modified curve and yielded a convenient upper frequency voltage level. This level is recommended for adoption by the FAA as its narrowband power line conducted susceptibility limit from 1 kHz to 50 MHz. From 30 Hz to 1 kHz, it is recommended that the susceptibility level be 3.0 volts rms. The overall recommended susceptibility limit therefore requires injection of a 3.0 volt rms signal on the power line from 30 Hz to 1 kHz, and thereafter a logarithmically decreasing voltage that reaches 10 millivolts at 50 MHz. This level should then be maintained until the 400 MHz upper frequency limit of the test method is reached. It is noted that this limit suffices for determining both narrowband and broadband susceptibility of equipments. A separate broadband limit is not imposed because of the difficulty in generating a controlled broadband signal with sufficient amplitude.

5.4.3 Test Methods CE01 and CE03, Conducted Emissions, 30 Hz to 50 MHz, Power Lines

In the derivation of a narrowband conducted emission limit, it was evident that the total allowable emission level must be below the susceptibility level. This difference in limit levels must not only allow for a safety margin between the emission and susceptibility levels, but must also account for (1) the possibility that more than one EME may be present at a given frequency and time, (2) the decoupling between equipments, and (3) the accuracy with which conducted measurements can be made.

The safety margin needed between susceptibility and emission limit levels was considered with the anticipation that a future FAA system level standard will impose a safety margin (possibly 6 dB) regardless of the equipment level standard. Consequently, a 6 dB separation between limit levels was felt to be sufficient for inclusion in the equipment level standard.

It was considered unlikely that two or more narrowband emissions would occur at the same time and frequency and in phase; however, to account for the possibility that at least two such emissions might so occur, the emission limit level was further reduced by 6 dB. The accuracy of commercially available test equipment and personnel operation of this equipment provided the basis for an additional 3 dB reduction in the EME limit level. The decoupling between equipments within a FAA facility is virtually impossible to predict. Equipments may be located side-by-side or separated by a hundred feet and a metal wall. As an arbitrary estimate of this decoupling, a further reduction of 3 dB in the emission limit level was established. Finally, an additional 40 dB reduction in the EME level was incorporated as a means of assuring that undesired emissions were reduced to a point that they didn't unnecessarily contribute to spectrum pollution. This overall value of 58 dB was then rounded off to 60 dB and then subtracted from the recommended susceptibility limit shown in Figure 5. The result was then converted [39] to units of dBμA in order to permit comparison with corresponding limits in MIL-STD-461A. For example, at 1 kHz the 60 dB overall factor was subtracted for 130 dBμV, and a 38 dB conversion was added to the resulting 70 dBμV to yield a 108 dBμA recommended emission limit. The results are plotted in Figure 7 and the resulting curve is recommended for FAA adoption as the narrowband power line conducted emission limit. Also shown for reference is the narrowband emission limit imposed by the Comite' International Special des Perturbations Radioetectriques (CISPR) and the Verband Deutscher Elektrotechniker (VDE) organizations [40] in Europe. Below 1 kHz, the limits shown in Figure 7 are projected because measurements in FAA facilities did not extend below 1 kHz. Relative to the MIL-STD-461A limit, the recommended limit is seen to be more lenient by a maximum of 16 dB at 2 MHz. As was the case for the recommended susceptibility limits, there was a desire to make these recommended limits consistent with those existing in MIL-STD-461A; however, the available data defining the electromagnetic environment at FAA facilities would not permit this without introducing totally arbitrary "correction" factors.

Derivation of a recommended broadband emission limit was undertaken along two independent courses. The first of these was parallel to the course pursued in deriving the recommended narrowband emission limit.

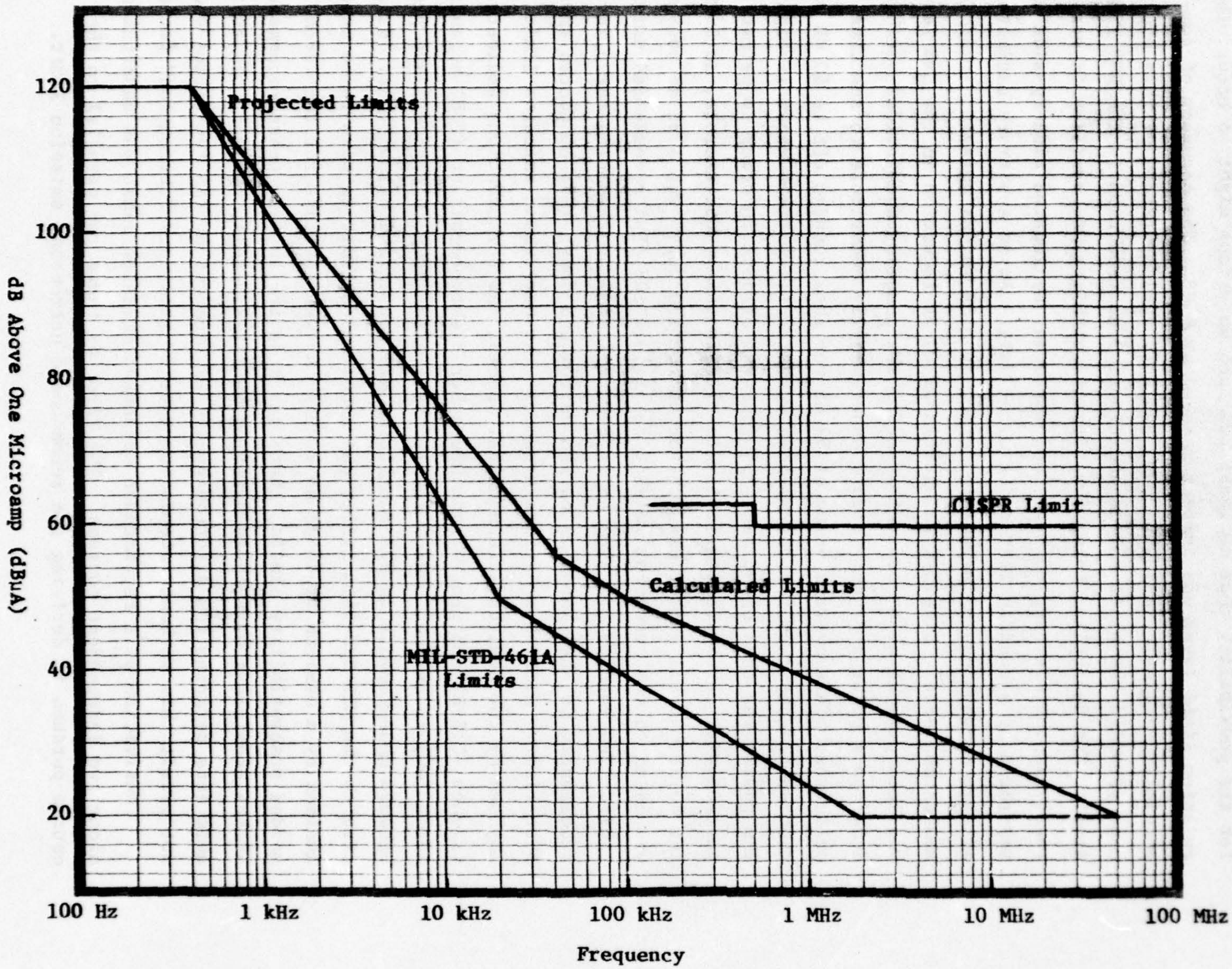

Figure 7. Recommended Narrowband Power Line Conducted Emission Limit.

Therefore, the broadband emission levels measured at the ARTCC facilities and modified to account for (1) a 20 dB factor related to the possibility that higher level signals might exist at other types of FAA facilities and (2) a safety factor of 24 dB. The result is shown as the modified emission level in Figure 6 and represented a broadband susceptibility limit. Then to assure that broadband emissions were not allowed to exist with sufficient amplitude to exceed this limit, various factors were derived to modify this susceptibility limit and thereby yield an emission limit. In the case of the narrowband emission limit, these factors totaled approximately 60 dB and when they were applied to the broadband susceptibility levels, they yielded a broadband emission limit as shown in Figure 8.

The second course taken during this effort involved deriving broadband emission limits from existing narrowband emission limits.

The broadband limits were to be derived such that the previously derived narrowband emission limits were not exceeded. Two factors had to be considered in this derivation. First, there exists the possibility that the maximum peak level resulting from the uncorrelated components of a broadband signal will not be present during the short time over which a measurement is made. If this maximum level is present, there is an additional possibility that it will be of such short duration that the measuring device will indicate the average peak amplitude rather than the desired maximum peak amplitude. The maximum peak amplitude of the combined signals is the quantity which must not exceed the narrowband emission limit. Therefore, the broadband limit must conservatively restrict the average peak amplitude to some level below the permissible narrowband level. Secondly, a broadband emission by definition exhibits a frequency spectrum wider than the bandwidth of the measuring instrument. Consequently, the bandwidth of the measuring instrument will influence the detected level. Even for a uniformly flat spectrum, the detected voltage level will increase in proportion to the bandwidth of the measuring instrument. The broadband limit must reflect this proportionality in order to maintain consistencies between measurements made with different bandwidth instruments. These factors were separately considered in the establishment of broadband limits to the extent indicated in the following discussion.

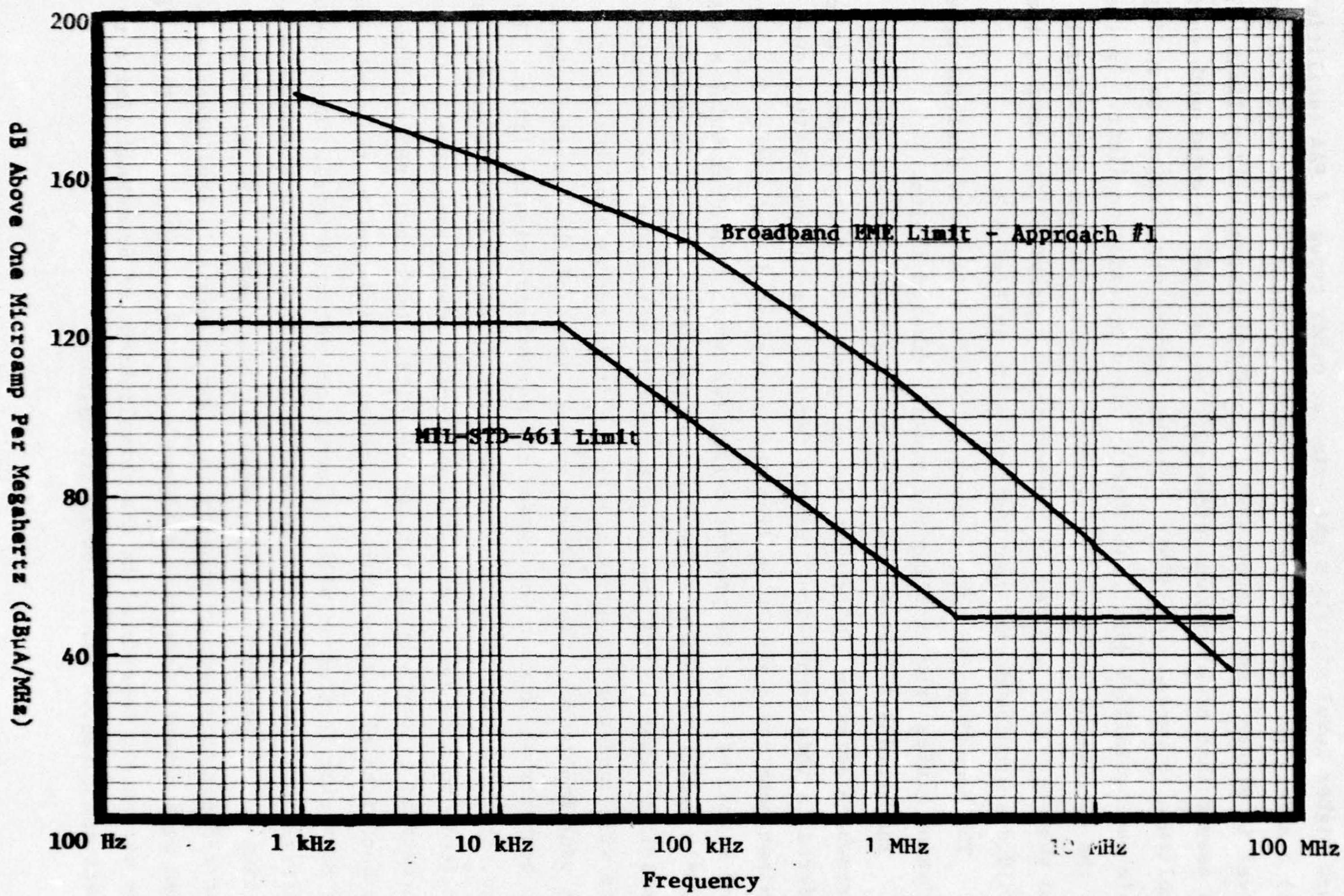

Figure 8. Broadband Power Line Conducted Emission Limit Calculated by Approach #1.

If the signals within the measurement bandwidth are uncorrelated, the peak signal level at the instant of measurement will not necessarily be the maximum level which could result if all signals simultaneously added together. The probability of random signals adding together to produce a signal in excess of some predetermined level has been explored in detail by communications specialists. If the narrowband limit is viewed as a "signal" level and the broadband limit as a "noise" level, then a separation factor can be established which will minimize the possibility that the broadband signal will ever equal or exceed the narrowband limit.

The likelihood of the peak level of an uncorrelated broadband signal equaling or exceeding the narrowband limit can be reduced to 1:100 by reducing the broadband limit to at least 10 dB below the narrowband limit [41]. An order of magnitude improvement to 1:1000, which represents a potential error of less than 0.1 percent, can be achieved by reducing the broadband limit to 12 dB below the narrowband limit. To reflect this high confidence level of 99.9 percent, the broadband emission limit should be expressed as:

Broadband Limit = Narrowband Limit - 12 dB.

Since the bandwidth of the measuring instrument also affects the indicated level on the field intensity meter, a correction factor based on the ratio of the impulse bandwidth (IBW) to a reference bandwidth is necessary to relate broadband emissions to narrowband emissions. The IBW is the equivalent noise bandwidth (sometimes referred to as the instrument bandwidth) of the measuring instrument. The equivalent noise bandwidth is defined as that ideal rectangular passband function which would transfer the same noise power to the receiver detector as is actually transferred by the RF and IF filters.* Historically, in the establishment of broadband limits, a typical or maximum IBW has been assumed and the narrowband limit then increased by the amount of the resulting correction factor. With currently available instrumentation the IBW will vary from 100 Hz to as much as 10 kHz over a frequency range of 1 kHz to 30 MHz. Since test instruments

*For a specific mathematical definition, see Information Transmission, Modulation, and Noise by Mischa Schwartz, McGraw-Hill Book Co., Inc. New York, 1959.

with different bandwidths may be used by different organizations, the proper correction factor is difficult to predict in advance. Consequently, instead of presenting the broadband limits in a graphical form based on some assumed bandwidth, it is recommended that the broadband limit be derived from the narrowband limit and be a function of the specific measuring instrument employed. The IBW must therefore be determined for each measuring instrument if it is unknown. Generally, the IBW is relatively constant across the tuning range of a particular tuning head since it is generally determined by the IF stage. However, it quite likely will be different for different tuning heads. For measuring instruments such as spectrum analyzers and the continuously tunable field intensity meters, the IBW is probably constant over a particular swept frequency region.

A first-order approximation of the equivalent noise bandwidth of a synchronously tuned filter is given by the 6 dB bandwidth. This approximation is not valid, however, for many types of filter responses. The IBW of a field intensity meter may be accurately determined through the use of a standard signal generator and an impulse generator calibrated in terms of voltage per frequency unit. First, the field intensity meter is tuned to a narrowband signal of known level (determined by the calibrated output attenuator of the signal generator) and the indicated reference level is noted. The field intensity meter function switch is then switched to the broadband or "Peak" position. The calibrated impulse generator is then substituted for the narrowband source and the level is adjusted to obtain the previously noted reference level. The IBW in MHz is then determined from the following relationship:

$$IG\ Output - SG\ Output = 20 \log_{10} \frac{1\ \text{MHz}}{\text{IBW}} ,$$

where IG Output = impulse generator output in dBμV/MHz and

SG Output = signal generator output in dBμV.

This bandwidth correction factor in dB is added to the basic limit. Consequently, the expression for the broadband emission limit then becomes

$$\text{BB Limit} = \text{NB Limit} + 20 \text{ Log}_{10} \frac{1\ \text{MHz}}{\text{IBW}} - 12\ \text{dB},$$

where BB Limit = broadband limit in dBμA/MHz, and

NB Limit = narrowband limit in dBμA.

To illustrate the relative levels which might be obtained for various instruments, some typical measurement bandwidths were assumed and the resultant limits were calculated over a 30 Hz to 50 MHz frequency range. These limits are compared in Figure 9 with the limits presently imposed by MIL-STD-461A and the limits derived by the first approach described above. For further comparison, the broadband emission limit used for European EMC tests [40] and imposed by Comite' International Special des Perturbations Radioelectriques (CISPR) and Verband Deutscher Elektrotechniker (VDE) standards are also plotted in Figure 9. From the figure, it is seen that the limits derived by the first approach are more lenient than the current required MIL-STD-461A limits by as much as 48 dB over the 100 kHz to 1 MHz frequency range. Limits derived by the second approach approximate those required by MIL-STD-461A from 10 kHz to 50 MHz. Below 10 kHz, both of the derived limits are significantly more lenient than those required by MIL-STD-461A.

The broadband power line conducted emission limits recommended for FAA adoption are also shown in Figure 9. They represent a compromise between those derived by the two above described approaches and those currently required by MIL-STD-461A. Based on the actual broadband conducted environment measured in representative FAA facilities, a relaxation of MIL-STD-461A limits was considered appropriate; however, a 48 dB relaxation in the 100 kHz to 1 MHz frequency range was felt to be excessive. Between 400 Hz and 10 kHz, there was also concern with the leniency in the derived limits. This range, however, is one characterized by high broadband emission levels even in well designed equipments. These levels exist in part because of the ineffectiveness of conventional power line filters below 10 kHz. In view of these considerations, the compromise limit was felt to offer some relationship to actual facility environments, yet not deviate without justification from currently required limits.

5.4.4 Test Methods CE02 and CE04, Conducted Emissions, 30 Hz to 50 MHz, Control and Signal Lines

The performance limits recommended for adoption by the FAA are the same as those recommended for power line emissions (Para. 5.4.3). The basis for this recommendation is the fact that, when intentional signal

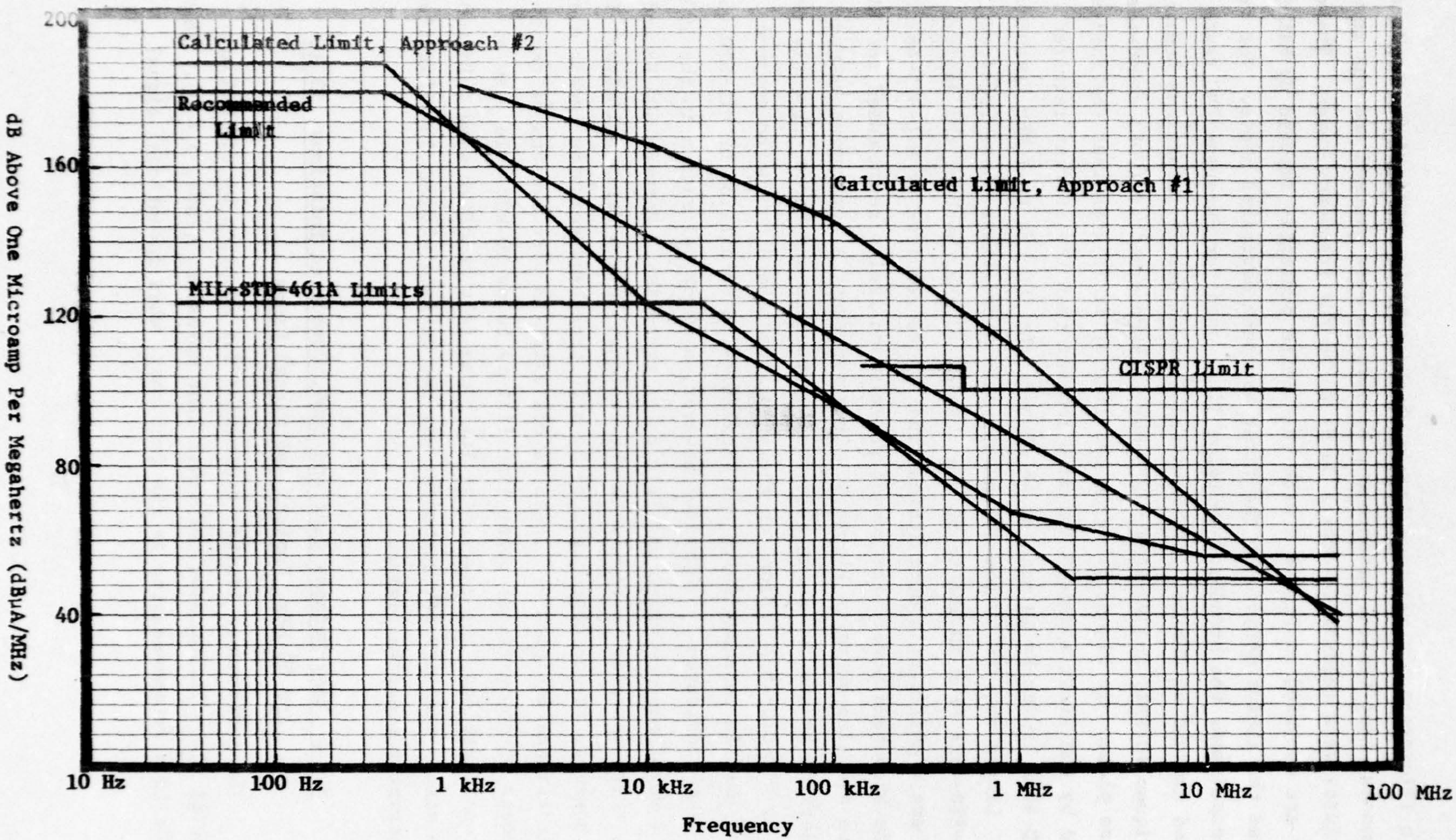

Figure 9. Recommended Broadband Power Line Conducted Emission Limit.

emissions are exempted, the undesired emission requirements applicable for control and signal lines do not differ from those for power lines.

5.4.5 Test Method CE06, Conducted Emissions, 10 kHz to 12.4 GHz, Antenna Terminals

No specific data were available on the levels of antenna terminal emissions from transmitters and receivers at FAA facilities; however, it was considered necessary that these emissions be reduced to the maximum permissible by the state-of-the-art. The primary basis for this was the fact that (1) FAA operations require the use of large numbers of transmitters and receivers and (2) the most often expressed interference problem at FAA facilities was caused by environmental radiation. Previous experience in spectrum signature testing had established that well-designed transmitters with relatively low peak power outputs typically emitted low order harmonic signals that were reduced approximately 60 dB below the fundamental. As either the power output level or harmonic number increased, the harmonic signal level must be correspondingly reduced if interference and spectrum pollution are to be prevented. In most instances, well designed output stages in transmitters result in spurious emission levels that are somewhat below the permissible harmonic signal levels.

In reviewing the MIL-STD-461A limits for this test method, it was noted that a constant -60 dB level for both spurious and harmonic emissions was required over an appreciable range of output power levels--100 to 10,000 watts peak. The fact that the allowable emission levels were identical and the constant limit over a wide range of transmitter output power levels were both considered undesirable. In Notice 4 to MIL-STD-461A, it was observed that a more desirable limit was imposed. This limit required different emission levels for spurious and harmonic emissions, has a variable level as a function of transmitter output, and requires emission levels to be consistent with the state-of-the-art in signal reduction. This limit is therefore recommended for FAA adoption.

5.4.6 Test Method CS03, Conducted Susceptibility, Intermodulation

The limits imposed by MIL-STD-461A require that there be no detectable response to intermodulation products generated by two undesired signals applied to the input terminals and at levels 66 dB above the standard response level of the test item. These limits are not changed by any of the Notices to MIL-STD-461A nor are they reported [42] to be changed by MIL-STD-461B. They are recommended for adoption by the FAA.

5.4.7 Test Method CS04, Conducted Susceptibility, Rejection of Undesired Signals at Input Terminals (2-Signal Generator Method)

The limits imposed by MIL-STD-461A, Notice 4, require a receiver and amplifier front-end rejection level that is consistent with the state-of-the-art in design and one which experience has shown to be realistic in providing an effective degree of EMC control. These limits are reported [43] to be adopted by MIL-STD-461B and are recommended for FAA adoption.

5.4.8 Test Method CS05, Conducted Susceptibility, Cross Modulation

The performance limits imposed by MIL-STD-461A require that cross modulation products be rejected by a level of 66 dB for test signals occurring in the $f_o \pm f_{IF}$ frequency range. These same limits are recommended for FAA adoption.

5.4.9 Test Method CS06, Conducted Susceptibility, Transients, Power Lines

It is recommended that the FAA require equipments to function without unacceptable performance degradation during exposure to the transient waveform required by Test Method CS06 in MIL-STD-461A. Specialized test equipments are available to generate this transient waveform and there are insufficient test results to justify requiring a higher amplitude waveform.

5.4.10 Test Method (T) CS07, Conducted Susceptibility, Squelch Circuit

The 90 dBμV/MHz impulse noise required by MIL-STD-461A to be applied at the receiver antenna terminals is an adequate test for squelch circuit capture. It is therefore recommended for FAA use.

6. SUMMARY

In the preceding paragraphs, conducted emission and susceptibility test requirements currently imposed by MIL-STD-461A and MIL-STD-462 have been extensively analyzed to determine their applicability to FAA equipments. Resulting from this analysis has been a series of recommendations aimed at assuring that only justified test requirements are imposed by the FAA, and that these requirements yield data which are accurate, repeatable and useful in establishing system level EMC. To assist in determining the recommended tests and their applicable limits, Table II has been prepared and presents the recommended test methods as a function of frequency range and equipment class.

In the Appendices, modifications to the conducted requirements in MIL-STD-461A and MIL-STD-462 are presented. These modifications when used with the two basic standards, comprise a FAA document to be included in future electronic equipment Procurement Specifications for the purpose of imposing realistic electromagnetic emission and susceptibility controls.

It is noted as a part of this Summary that, throughout these technical investigations, efforts were made to determine whether recommendations herein were consistent with the conclusions drawn in the reports [6]-[9] which documented measured conducted levels in ARTCC facilities. For the most part, consistency has been realized. Where inconsistencies exist, they are largely attributable to a difference in philosophy. To illustrate, the measurement reports recommend in several instances that conducted performance limits in MIL-STD-461A be changed to conform with the measured electromagnetic environment. This recommendation does not consider adequacy of the procedures used to measure the environment, the reliability and repeatability of the resulting data, or the fact that the electromagnetic environment can be changed via a program of EMC control. During these investigations, engineering judgements were made to account for these factors by means of a philosophical stance that viewed equipment performance and the conducted electromagnetic environment as integrally related. A degree of latitude was then possible in recommending levels for emission and susceptibility performance limits.

TABLE II

RECOMMENDED TEST METHODS AS A FUNCTION OF FREQUENCY RANGE AND EQUIPMENT CLASSIFICATION

Number	Test Method Description: Title	Frequency Range	Equipment Classification
CE01	Conducted Emissions, dc Power Lines	30 Hz to 50 MHz	I, II, and III
CE02	Conducted Emissions, Control and Signal Lines	30 Hz to 20 kHz	I, II, and III
CE03	Conducted Emissions, ac Power Lines	10 kHz to 50 MHz	I, II, and III
CE06	Conducted Emissions, Antenna Terminals	10 kHz to 12.4 GHz	I
CS01	Conducted Susceptibility, dc Power Lines	30 Hz to 50 kHz	I and II
CS02	Conducted Susceptibility, ac and dc Power Lines	50 kHz to 400 MHz	I and II
CS03	Conducted Susceptibility, Intermodulation	15 kHz to 10 GHz	I
CS04	Conducted Susceptibility, Rejection of Undesired Signals	15 kHz to 10 GHz	I
CS05	Conducted Susceptibility, Cross Modulation	15 kHz to 10 GHz	I
CS06	Conducted Susceptibility, Transients, ac and dc Power Lines	--	I
CS07	Conducted Susceptibility, Squelch Circuits	15 kHz to 10 GHz	I

7. REFERENCES

1. Marce Eleccion, "The Promise of Air Safety," IEEE Spectrum, Vol. 12, No. 7, July 1975, p. 26.

2. MIL-STD-461A, "Electromagnetic Interference Characteristics, Requirements for Equipment," dated 1 August 1968.

3. MIL-STD-462, "Electromagnetic Interference Charactersitics, Measurement of," dated 31 July 1967.

4. MIL-STD-463, "Definitions and System of Units, Electromagnetic Interference Technology," dated 9 June 1966.

5. D. R. J. White, "Electromagnetic Interference and Compatibility, Vol. 2, EMI Test Methods and Procedures," Don White Consultants, Inc., Germantown, MD, 1974, p. 9.24, para. 9.2.2.2.

6. M. V. Stone, "Test Report Radiofrequency Interference/Electromagnetic Interference Measurements, Los Angeles Air Route Traffic Control Center," Report No. FAA-RD-74-11, March 1974.

7. M. V. Stone, "Test Report Radiofrequency Interference/Electromagnetic Interference Measurements, Oakland Air Route Traffic Control Center," Report No. FAA-RD-74-28, May 1974.

8. M. V. Stone, "Test Report Radiofrequency Interference/Electromagnetic Interference Measurement, New York Air Route Traffic Control Center," Report No. FAA-RD-74-110, August 1974.

9. M. V. Stone, "Radiofrequency Interference (RFI)/Electromagnetic Interference (EMI) Measurements Air Route Traffic Control Centers," Final Report No. FAA-RD-75-30, April 1975.

10. Op cit., Ref. 5, White, p. 7.3, para. 7.1.

11. Op cit., Ref. 6, Stone, p. 16, para. 8.1.1.

12. Op cit., Ref. 7, Stone, p. 16, para. 8.1.1.

13. Op cit., Ref. 8, Stone, p. 15, para. 8.1.1.

14. Op cit., Ref. 6, Stone, p. 17, para. 8.1.9.

15. Op cit., Ref. 5, White, p. 7.22, para. 7.2.

16. Op cit., Ref. 7, Stone, p. 18, para. 8.1.2.

17. Op cit., Ref. 5, White, p. 7.31, para. 7.3.

18. Op cit., Ref. 5, White, p. 8.20, para. 8.2.1.

19. Op cit., Ref. 5, White, p. 8.28, para. 8.2.2.

20. Op cit., Ref. 5, White, p. 8.35, para. 8.2.3.

21. Op cit., Ref. 5, White, p. 8.13, para. 8.1.3.1.

22. Op cit., Ref. 5, White, p. 8.14, para. 8.1.3.2.

23. Op cit., Ref. 7, Stone, p. 20, para. 8.1.5.

24. Op cit., Ref. 5, White, p. 8.39, para. 8.3.1.

25. R. B. Cowdell, "The Evolution of Conducted Interference Measurements," Frequency Technology, July 1969, pp. 14-16.

26. D. L. Jobe, "Is Your Black Box Out of Spec - Or Are You Measuring Power Line Conducted Ambient?" Frequency Technology, November 1968, pp. 26-27.

27. J. A. Malack and J. R. Nicholson, "RF Impedance of Power Lines and Line Impedance Stabilization Networks in Conducted Interference Measurements," IEEE Transactions on Electromagnetic Compatibility, Vol. EMC-25, No. 2, May 1973, p. 84.

28. R. A. Southwick, "Impedance Characteristics of Single Phase Power Lines," Proceedings of the IEEE Symposium on Electromagnetic Compatibility, June 1973, New York, NY, p. 241.

29. Comite' International Special des Perturbations Radioelectriques (CISPR) Publication 2, "Specification for CISPR Radio Interference Measuring Apparatus for the Frequency Range 25 to 300 MHz," Para. 4.1.3.

30. Verband Deutscher Elektrotechniker (VDE) Specification 0877, Part 2.

31. "Absorbing Clamp MDS-20 for Interference Measurements in the VHF Range," News from Rohde and Schwartz, No. 46, p. 20.

32. J. Willman and G. Van Steenberg, "Directional Current Probe Technique for Conducted EMI Measurements," IEEE Transactions on Electromagnetic Compatibility, Vol. EMC-11, No. 2, May 1969, p. 96.

33. J. Mills, "Study to Establish Electromagnetic Interference Specification Limits," Final Report No. TR7-2873-9005, Contract No. NAS8-20142, Genisco Technology Corp., June 30, 1966.

34. S. H. Eisbruck and K. Oishi, "A Low Frequency Line Impedance Stabilization Network for Measuring Conducted Radio Interference," IEEE Transactions on Electromagnetic Compatibility, Vol. 6, No. 3, October 9, 1964, p. 21.

35. J. A. Malack and J. R. Nicholson, "Effects of Measurement Devices on Conducted Interference Levels," IEEE Transactions on Electromagnetic Compatibility, Vol. EMC-15, No. 2, May 1973, pp. 61-65.

36. D. E. Groff, "The Performance of 10 μfd Power Line Feedthrough Capacitors," Report No. RADC-TR-69-67, Contract No. F30602-68-C-0178, July 1969.

37. Op cit., Ref. 35, Malack and Nicholson, p. 62.

38. C. B. Pearlston, "Historical Analysis of Electromagnetic Interference Limits," Air Force Report No. SSD-TR-67-127, Contract No. AF 04(695)-1001, April 1967, p. 45.

39. Op cit., Ref. 9, Stone, p. 5, para. 5.1.

40. P. M. Rostek, "Electromagnetic Emissions and Susceptibility in Digital Computers," National Cash Register Company, Data Processing Division, San Diego, CA.

41. A. Hiroshi, "The Error Rates in Multiple FSK Systems and The Signal-to-Noise Characteristics of FM and PCM-FSK Systems," Technical Note 167, NBS, Boulder, CO, March 1963, AD 492 243.

42. Op cit., Ref. 5, White, p. 8.23, para. 8.2.1.2.

43. Op cit., Ref. 5, White, p. 8.31, para. 8.2.2.2.

APPENDIX A

FAA Notice to MIL-STD-461A

MIL-STD-461A
FAA Notice 1C

FAA STANDARD

CONDUCTED ELECTROMAGNETIC INTERFERENCE CHARACTERISTICS

REQUIREMENTS FOR EQUIPMENT

This notice is applicable to all FAA procurements. It should be filed in front of MIL-STD-461A, dated 1 August 1968 and supersedes that document in those areas detailed herein.

TO ALL HOLDERS OF MIL-STD-461A:

Make the following changes.

1. Page i - Delete "Military" and substitute "FAA", then change remainder of title to read "Conducted Electromagnetic Interference Characteristics, Requirements for Equipments."

2. Page ii - Delete "Department of Defense" and substitute "Federal Aviation Administration."

   Delete zip code 20360 and replace with zip code 20590.

   Delete Paragraphs 1 and 2 and substitute:

   1. This standard is mandatory for use by all Departments and Agencies of the FAA.
   2. Recommended corrections, additions or deletions should be addressed to the Systems Research and Development Service, Code 350, Federal Aviation Administration, Washington, DC 20590.

3. Page iii - In second paragraph, delete "military" and substitute "FAA".

4. Pages iv through vi - Delete and substitute the attached Table of Contents, List of Figures and List of Tables.

5. Paragraph 1.1 - In the third and fourth lines, delete "for general or multi-service procurements and single service procurements" and substitute "for FAA procurement."

6. Paragraph 1.1.2 - Delete "MIL-STD-462" and substitute "MIL-STD-462, FAA Notice 1C".

7. Paragraph 2.1 - Add the following documents:

PROGRAM PLAN

FAA-RD-76-75 - Electromagnetic Compatibility Program Plan

STANDARDS

Delete MIL-STD-462 and substitute:

MIL-STD-462, FAA Notice 1C - Conducted Electromagnetic Interference Characteristics, Measurement of

8. Paragraph 3 - Delete and substitute:

3. DEFINITIONS

3.1 Definitions. The terms used in this standard and not defined herein are defined in MIL-STD-463.

3.1.1 Equipment. For the purpose of this standard an equipment is defined as any electrical, electronic, or electromechanical device intended to operate as an individual unit and performing a singular function.

3.1.2 Subsystem. A subsystem is defined as an assemblage of devices and/or equipments designed and integrated to function as a single entity but wherein any device or equipment is not required to function individually as defined in paragraph 3.1.1.

3.1.3 System. A system is a collection of equipments and/or subsystems integrated as a functional whole and intended for installation in fixed locations.

9. Paragraph 4.1.2 - Delete and substitute:

4.1.2 FAA Furnished Equipment. - Equipment furnished by the FAA to a contractor may, unless the test data is furnished by the FAA, require additional testing by the contractor for conformance to the equipment item class and limit requirements. Application of suppression measures to meet the requirements of this standard shall be detailed in the Control Plan.

10. Paragraph 4.1.3.2 - Delete and substitute:

4.1.3.2 When Government approved equipments are selected for use with or to become a part of any FAA equipment configuration, the requirements of 4.1.3.1 apply.

11. Paragraph 4.1.3.3 - Delete without replacement.

12. Paragraph 4.1.4 - Delete the phase "shall meet the appropriate requirements specified in Appendix A of this standard" and substitute "shall meet the requirements of this standard. Any deviation from the application of these test requirements must be submitted for evaluation and approval by the FAA."

13. Paragraph 4.1.6 - Delete and substitute:

4.1.6 Short-Duration Interference. - Short duration interference, such as produced by switching transients is not exempt from the requirements of this standard unless specifically indicated by the individual equipment specification.

14. Paragraph 4.2 - Delete and substitute:

4.2 Interference Control Plan. - A detailed Control Plan as described in FAA-RD-76-75 shall be submitted to the FAA. This Control Plan shall outline the interference control or reduction program, the engineering design procedures and proposed techniques that will be used to determine conformance with the requirements of this standard and that will enable the equipment to perform its operational function within its specified design parameters without adversely affecting or being affected by nearby equipments, subsystems, or systems.

15. Paragraph 4.2.1 - Delete without replacement.

16. Table I - Delete and substitute the attached Table I.

17. Table II - Delete and substitute the attached Table II.

18. Paragraph 4.2.1.1 through Paragraph 4.2.1.7 - Delete without replacement.

19. Paragraph 4.3 - Delete and substitute:

4.3 EMI/EMC Test Plan. - A Test Plan as described in FAA-RD-76-75 shall be submitted and approved before the start of formal testing. The Test Plan shall detail the means of implementation and application of the typical test procedures depicted in MIL-STD-462, FAA Notice 1C that will be performed to verify compliance with the applicable requirements of this standard.

20. Paragraph 4.4 - Delete and substitute:

4.4 Test Report. - A report presenting the results of the tests described in the Test Plan shall be submitted to the FAA. The contents and the format of this report shall be as described in FAA-RD-76-75.

21. Paragraph 4.4.1 through Paragraph 4.4.3 - Delete without replacement.

22. Paragraph 5. - Delete and substitute:

5. MEASURING EQUIPMENT. - A list of suggested measuring equipments, their characteristics, and procedures for verification of these characteristics for FAA approval is presented in the measuring equipment paragraphs of MIL-STD-462, FAA Notice 1C.

23. Paragraphs 5.1 through 5.8.2 - Delete without replacement. Refer to the measuring equipment paragraphs of MIL-STD-462, FAA Notice 1C.

24. Paragraphs 6.1 through 6.19 - Delete and substitute:

6.1 Limits for CE01, CE02, CE03, and CE04.- Electromagnetic emissions shall not appear on dc and ac power lines (control lines, signal lines or interconnecting lines), in excess of the values shown in Figures 12 and 13. Intentional transmissions of electrical power at the specified power level are exempt from requirements of this standard. For Class III equipments, these limits may be relaxed by 10 dB.

6.2 Limit for CE06.- Electromagnetic emissions shall not appear at antenna terminals in excess of those presented below for transmitters in the key-up mode and receovers. For transmitters in the key-down mode, electromagnetic emissions shall not appear at antenna terminals in excess of those presented in Figure 16. This limit is not applicable within the transmitter's emission bandwidth as defined in the Test Plan. If the emission bandwidth is not defined in the Test Plan, the limit does not apply within ± 5% of fo.

6.2.1 Narrowband Emissions. - 34 dBμV.

6.2.2 Broadband Emissions. - 40 dBμV/MHz.

6.3 Limits For CS01 and CS02. - Performance of Class I and II equipments shall not be degraded beyond the tolerances provided in either the equipment specification or Test Plan when exposed to conducted signals equal to or less than the values shown in Figure 17. From 50 to 400 MHz, the exposure signal shall be 10 millivolts rms. In addition, the requirements of this test are considered to be met when a source designed to dissipate 50 watts into a 0.5 ohm load cannot develop the required voltage at the test item power input terminals and the test item is not susceptible to this source.

6.4 Limit for CS03. - Intermodulation products from two signals shall not be present in the frequency range of 15 kHz to 10 GHz when

(a) Signal generator one is set 66 dB above the level required to produce the standard reference output as specified in Test Method CS03 of MIL-STD-462, FAA Notice 1C.

(b) Signal generator two is set 66 dB above the level required to produce the standard reference output as specified in Test Method CS03 of MIL-STD-462, FAA Notice 1C.

6.5 Limit for CS04. - The test item shall not exhibit any undesired responses when subjected to the test signal shown in Figure 18.

6.6 Limit for CS05. - The test item shall not exhibit, due to cross modulation, any malfunction, performance degradation or deviation from specified indication, beyond those identified in the technical specification or Test Plan, when subjected to the following level:

Signal generator two: 66 dB above the level required to obtain a standard reference output.

6.7 Limit for CS06. - The test item shall not exhibit any malfunction, performance degradation or deviation from specified indication, beyond those identified in the technical specification or Test Plan, when the transient shown in Figure 19 is applied to the dc and ac power line input terminals.

6.8 Limit for CS07. - Squelch circuits shall not open when the output of a 50 ohm impedance impulse generator, set at 90 dBμV/MHz, is applied and matched to the input terminals of the test item.

25. Paragraphs 7 and 7.1 - Delete without replacement.

26. Page 15 - Delete without replacement reference to Custodians, Preparing Activity, Review Activities and User Activities.

27. Figures 1A through 11 - Delete without replacement.

28. Figure 12 - Delete and replace with the attached Figure 12.

29. Figure 13 - Delete and replace with the attached Figure 13.

30. Figures 14 and 15 - Delete without replacement.

31. Figures 16 through 18 - Delete and replace with the attached Figures 16 through 18.

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LIST OF FIGURES

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TABLE I

EQUIPMENT CLASSIFICATION

Class Designation	Equipment Description
I	Communication-Electronic (C-E) Equipments All electronic equipments which in their operation transmit, receive, generate, store, or process information. Included in this classification are transmitters with antennas, receivers with antennas, transceivers with antennas, regulated output amplifiers, backup emergency communication equipment, inner and outer markers, plan view displays, etc.
II	Electronic Equipments All electronic equipments which are not Class I. Included in this classification are oscilloscopes, signal sources, test sets, counters, spectrum analyzers, time code generators, radio frequency monitors, etc.
III	Electro-Mechanical Equipments All equipments which in their operation have both a mechanical and electrical/electronic function. Included in this classification are teletype machines, portable electrical tools, repair shop equipment, kitchen and/or lounge equipment, office devices, etc.
IV	Motor Vehicles and Engine-Driven Equipments
IVA	All motor-driven vehicles which in their operation may interrupt normal operations via ignition system radiation. Included are tug vehicles used at remote C-E sites, etc.
IVB	All engine-driven equipments which in their operation may emit interference signals from an ignition system or commutator. Included are gasoline engines, motor generators, etc.

TABLE II

RECOMMENDED TEST METHODS AS A FUNCTION OF FREQUENCY RANGE AND EQUIPMENT CLASSIFICATION

Test Method Description			Equipment
Number	Title	Frequency Range	Classification
CE01	Conducted Emissions, dc Power Lines	30 Hz to 50 MHz	I, II, and III
CE02	Conducted Emissions, Control and Signal Lines	30 Hz to 20 kHz	I, II, and III
CE03	Conducted Emissions, ac Power Lines	10 kHz to 50 MHz	I, II, and III
CE06	Conducted Emissions, Antenna Terminals	10 kHz to 12.4 GHz	I
CS01	Conducted Susceptibility, dc Power Lines	30 Hz to 50 kHz	I and II
CS02	Conducted Susceptibility, ac and dc Power Lines	50 kHz to 400 MHz	I and II
CS03	Conducted Susceptibility, Intermodulation	15 kHz to 10 GHz	I
CS04	Conducted Susceptibility, Rejection of Undesired Signals	15 kHz to 10 GHz	I
CS05	Conducted Susceptibility, Cross Modulation	15 kHz to 10 GHz	I
CS06	Conducted Susceptibility, Transients, ac and dc Power Lines	--	I
CS07	Conducted Susceptibility, Squelch Circuits	15 kHz to 10 GHz	I

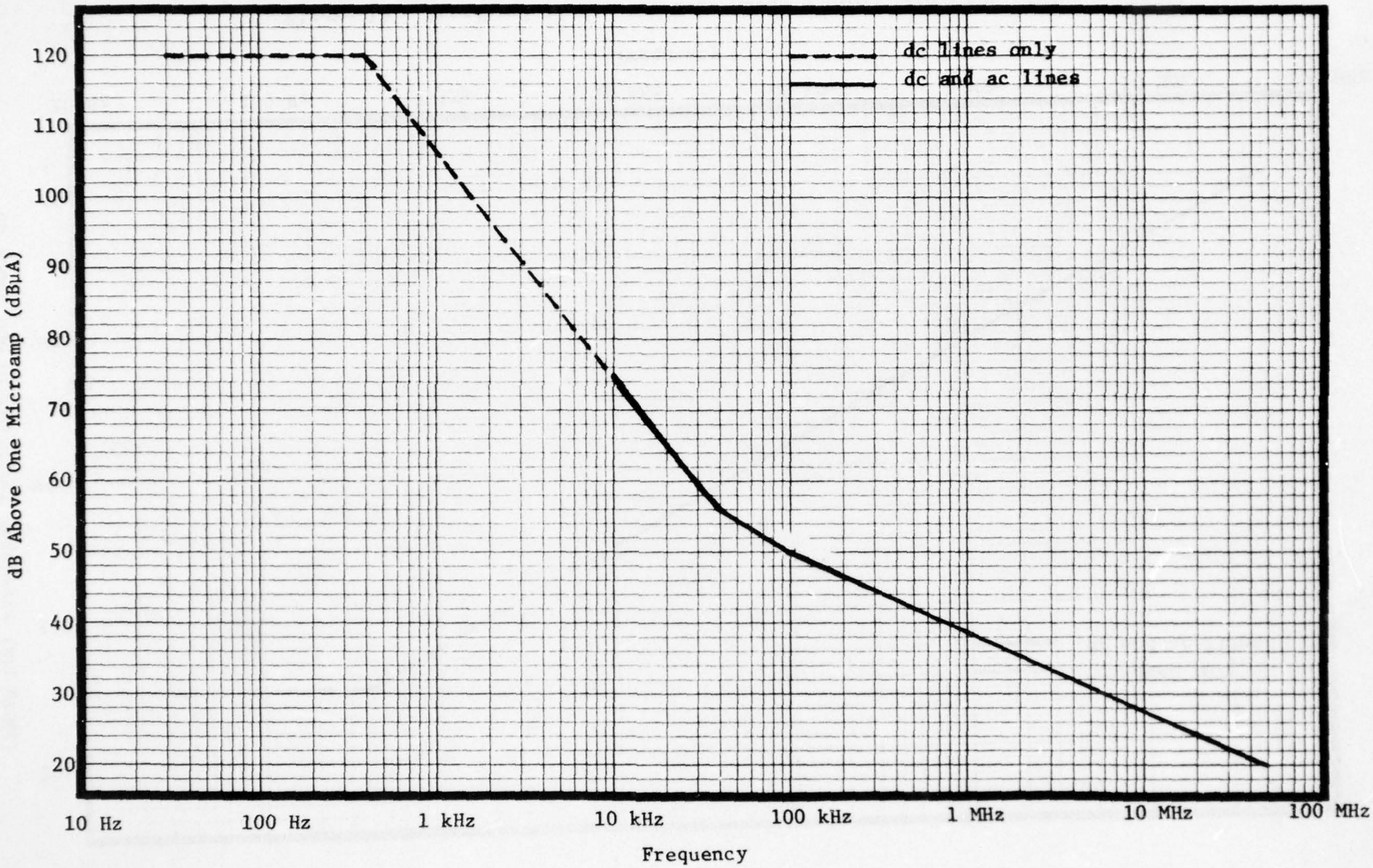


Figure 12. Narrowband Limit for Test Methods CE01, CE02, and CE03.

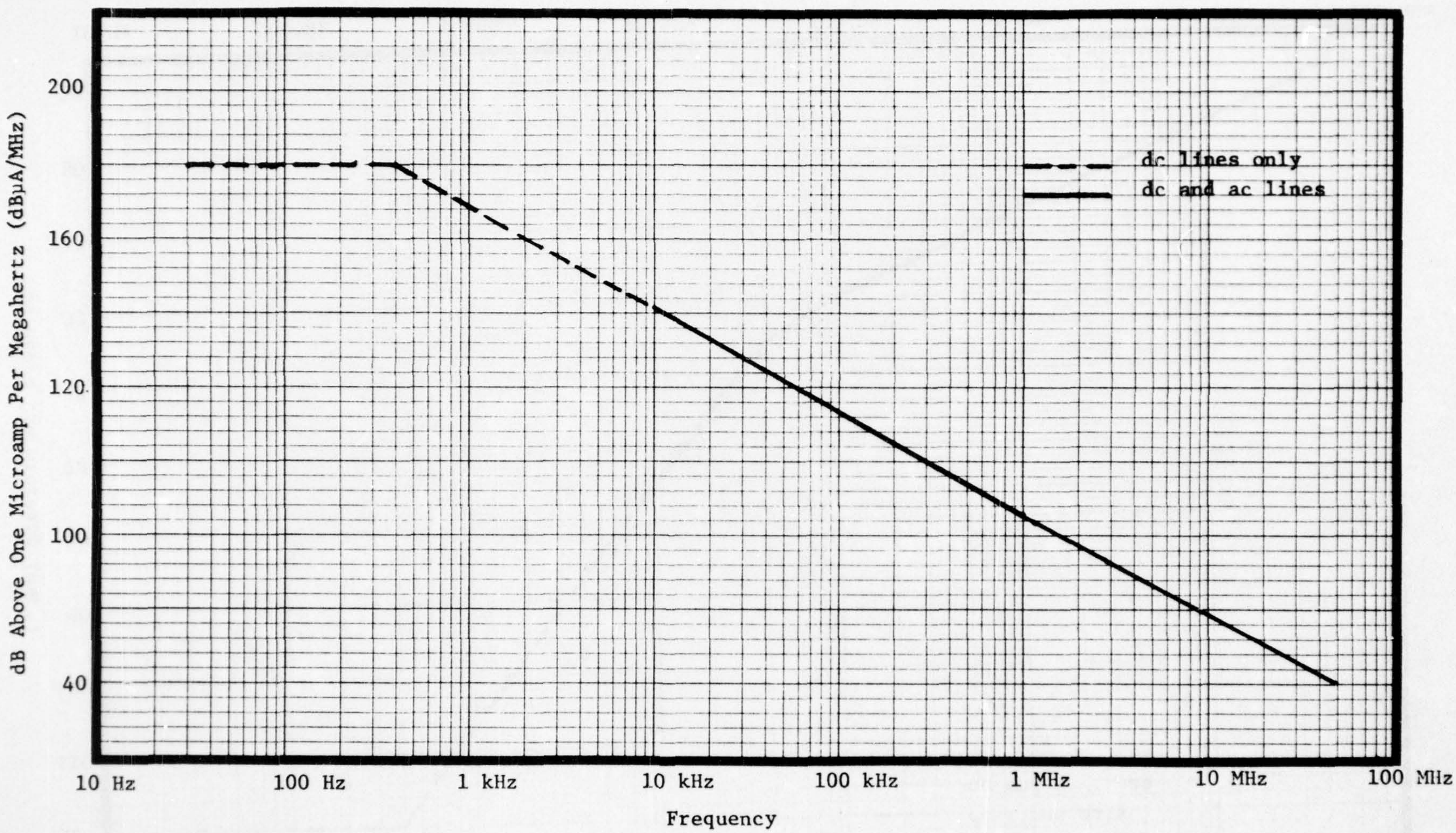


Figure 13. Broadband Limits for Test Methods CE01, CE02, and CE03.

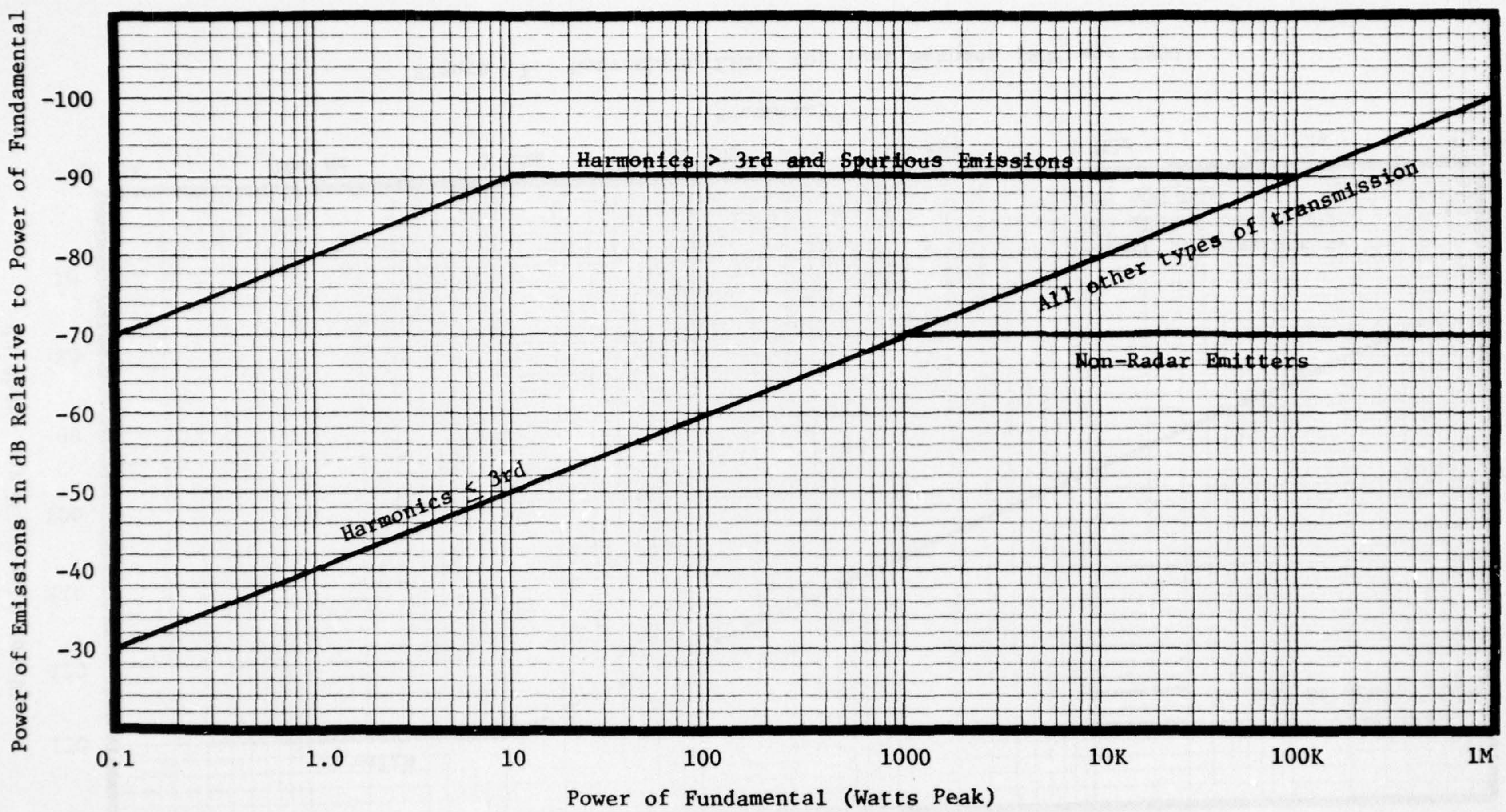


Figure 16. Limit for Test Method CE06.

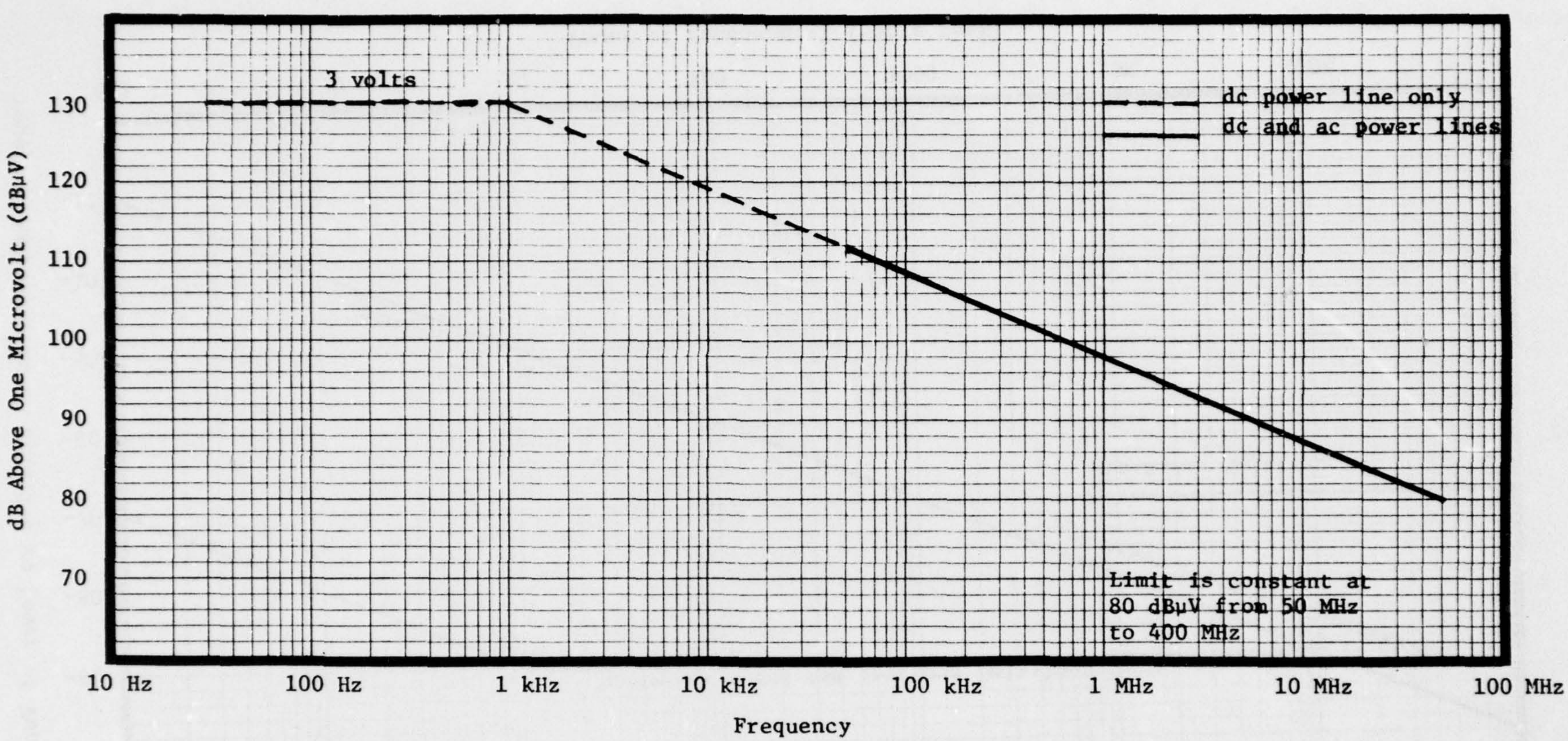
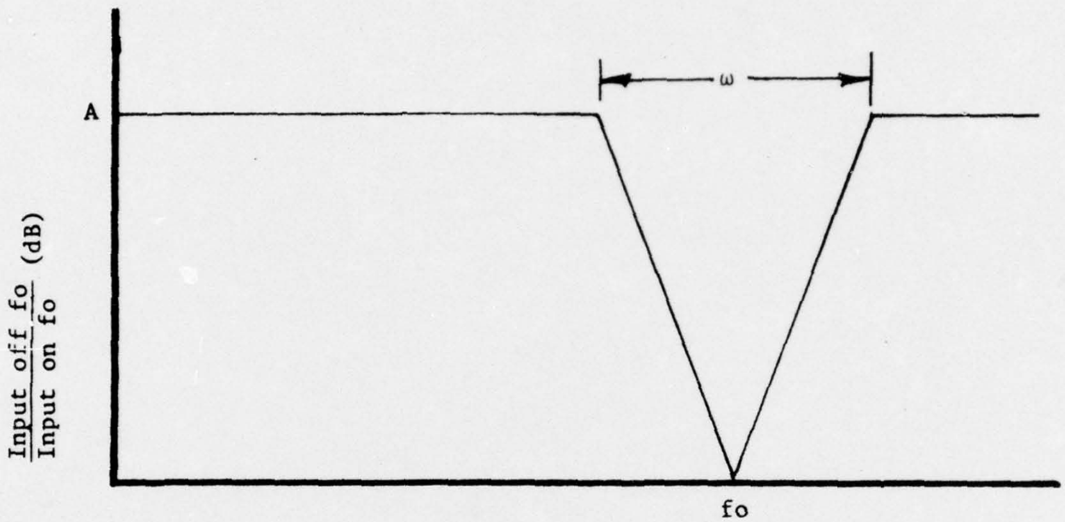


Figure 17. Narrowband Limit for Test Methods CS01 and CS02.



Notes:

1. fo = Receiver Tuned Frequency or Band Center of Amplifier

2. ω = 5% of fo or ± 2.5% of fo.

3. The limit at A is as stated in the test item's technical specification or control plan. If no limit is specified, the limit at A shall be 80 dB above the input level required to produce the standard reference output.

Figure 18. Limit for Test Method CS04.

APPENDIX B

FAA Notice to MIL-STD-462

MIL-STD-462
FAA Notice 1C

FAA STANDARD

CONDUCTED ELECTROMAGNETIC INTERFERENCE CHARACTERISTICS, MEASUREMENT OF

This notice is applicable to all FAA procurements. It should be filed in front of MIL-STD-462, dated 31 July 1967, and supersedes that document in those areas detailed herein.

TO ALL HOLDERS OF MIL-STD-462:

Make the following changes.

1. Page i - Delete "Military" and substitute "FAA".

   Delete DoD seal and substitute FAA seal.

2. Page ii - Delete "31 July 1965" and substitute "31 July 1967" in upper left hand corner of page.

   Delete "Department of Defense" and substitute "Federal Aviation Administration".

   Delete zip code "20301" and substitute zip code "20590".

   Delete "MIL-STD-426" and substitute "MIL-STD-462" in title.

   Delete Paragraphs 1 and 2 and substitute:

   1. This standard is mandatory for use by all Departments and Agencies of the FAA.

   2. Recommended corrections, additions, or deletions should be addressed to the Systems Research and Development Service, Code 350, Federal Aviation Administration, Washington, DC 20590.

3. Page iii - Delete the entire table of contents and substitute the attached table of contents.

4. Pages iii and iv - Delete the list of figures and substitute the attached list of figures.

5. Paragraph 1.1 - Delete "MIL-STD-461" and substitute "MIL-STD-461A, FAA Notice 1C".

6. Paragraph 1.2.1 - Delete "R = Radiated" without replacement. Delete subparagraphs (b) and (d) without replacement.

7. Paragraph 1.2.2 - Delete without replacement.

8. Paragraph 1.2.3 - Delete second and third sentences without replacement.

9. Paragraph 2.1 - Add the following documents:

PROGRAM PLANS

FAA-RD-76-75	Electromagnetic Compatibility Program Plan

STANDARDS

MIL-STD-220A	Method of Insertion-Loss Measurement
MIL-STD-285	Attenuation Measurements for Enclosures, Electromagnetic Shielding, for Electronic Test Purposes, Methods of
MIL-STD-461A FAA Notice 1C	Electromagnetic Interference Characteristics, Requirements for Equipments
EL-CD-6003-0009A	
SAE-ARP-936	
MIL-C-45662	

10. Paragraph 3.1 - Delete "MIL-STD-463" and substitute "MIL-STD-461A, FAA Notice 1C and MIL-STD-463".

11. Paragraph 4.1 - Delete and substitute:

4.1 General Requirements. - General requirements pertaining to the application of this standard and the applicable test limits are specified in MIL-STD-461A, FAA Notice 1C. The test procedures contained in this standard shall be used in complying with MIL-STD-461A, FAA Notice 1C, measurement requirements and in preparing the EMI Test Plan.

12. Paragraph 4.2.1.1 - Delete and substitute:

4.2.1.1 Ambient Electromagnetic Level. - During testing the ambient electromagnetic field level measured with the test item de-energized shall be at least 6 dB below the allowable specified limit. Precautions for avoiding ambient signals generated by the test equipment shall be observed. If a test site does not meet the requirements specified herein, measurements shall be performed using the procedure specified in Paragraph 4.2.8 after receiving approval of the FAA.

13. Paragraph 4.2.1.2 - Delete and substitute:

4.2.1.2 Ground Plane. - A circular copper or brass ground plane (solid plate) shall be used. It shall have a minimum thickness of 0.158 centimeters for brass and a minimum diameter of 122 centimeters. The ground plane shall be bonded to the shielded room such that the dc resistance is no greater than 2.5 milliohms.

14. Paragraph 4.2.1.6 - Delete without replacement.

15. Add the following new paragraphs:

4.2.1.7 Test Site. -

4.2.1.7.1 Shielded Enclosures. - Shielded enclosures shall be of sufficient size to adequately accept the test item without sacrificing test accuracy or requiring deviation from the methods specified herein. Shielding and filtering characteristics shall meet the following minimum requirements:

a. Shielding effectiveness to electric fields and plane waves, as measured in accordance with MIL-STD-285, shall be at least 80 dB over the frequency range of test.
b. Power line filtering must be included and shall have an attenuation to frequencies above 10 kHz of at least 80 dB as measured in accordance with MIL-STD-220A.

4.2.1.7.2 Open Areas. - Open field sites may be used when sufficiently large screen rooms are not available or when the nature of the equipment tested precludes their usage. The ambient requirements of Paragraph 4.2.1.1 must be observed.

16. Paragraph 4.2.2.4.2 - Delete last sentence.

17. Paragraph 4.2.3 through Paragraph 4.2.3.6 - Delete and substitute the following paragraphs. Refer to Paragraph 4.2.3.3 through Paragraph 4.2.3.8.

4.2.3 Measuring Equipment. - This section describes the test equipment used in the test methods contained in this standard.

4.2.3.1 Equipment Characteristics. - Requirements for measuring equipment characteristics are contained in Specification EL-CD-6003-0009A along with the techniques for measurement of these characteristics. Table I represents a suggested list of equipments for each test. In some cases the list presents more than one model capable of performing a given function. Any equipment equivalent to those listed may be used with approval of the FAA.

4.2.3.1.1 Signal Sources. - Signal sources shall meet the following requirements:

a. Frequency Accuracy - Frequency accuracy shall be within $\pm$ 2 percent.

b. Harmonic Content - Harmonics and spurious outputs shall be not more than -30 dB as related to the fundamental power.

4.2.3.1.2 Susceptibility Signals. - Susceptibility signals shall have characteristics, e.g., amplitude and type, degree, and frequency of modulation, which will have the maximum effect on the test item. The rationale for selecting the signals shall be presented in the Test Plan.

4.2.3.1.3 Ten Microfarad Capacitors. - The 10 μF capacitors shall conform to the requirements of SAE-ARP-936. An insertion loss curve shall be included in the Test Report as required by FAA-ER-350-023.

4.2.3.1.4 Line Impedance Stabilization Network. - Line impedance stabilization networks shall be designed as shown in Figure 1 and exhibit characteristics as shown in Figure 2.

4.2.3.2 Use of Measuring Equipment. - All equipment shall be operated as prescribed by the applicable instruction manuals unless otherwise specified herein. This standard takes precedence in the event of conflict with instruction manuals or other such documents.

TABLE I

SUGGESTED TEST EQUIPMENT

Equipment	Manufacturers	Model	Frequency Range	CE01	CE02	CE03	CE06	CS01	CS02	CS03	CS04	CS05	CS06	CS07
Capacitors (10 μF)	Filtron	ESR-710		•									•	
	Solar	6512-106R		•									•	
Current Probes	Electro-Metrics	PCL-10	30 Hz to 50 kHz		•	•								
	Electro-Metrics	PCL-25	14 kHz to 100 MHz	•	•	•								
	Stoddart	91197-1	14 kHz to 1 MHz	•	•	•			•					
	Stoddart	91550-1	1 MHz to 100 MHz	•	•	•								
	Stoddart	94106-1	500 kHz - 400 MHz						•					
Audio Frequency Coupling Transformer	Solar	6220-1A	20 Hz to 150 kHz	•				•						
Spectrum Analyzers	Hewlett Packard	8552A 8553L	1 kHz to 110 MHz	•	•	•		•						
Amplifiers	McIntosh	200B	10 Hz to 50 kHz					•						
	Krohn-Hite	DCA-10R	dc to 1 MHz					•						
Spectrum Display Units	Electro-Metrics	SPD-125		•	•	•								
	Electro-Metrics	"Adapter"		•		•								

(continued)

AD-A033 251 GEORGIA INST OF TECH ATLANTA ENGINEERING EXPERIMENT --ETC F/G 20/14
ELECTROMAGNETIC COMPATIBILITY RATIONALE REPORT, CONDUCTED TEST --ETC(U)
APR 76 J C TOLER, J A WOODY, C L ESPY DOT-FA74WA-3372

UNCLASSIFIED FAA-RD-76-69 NL

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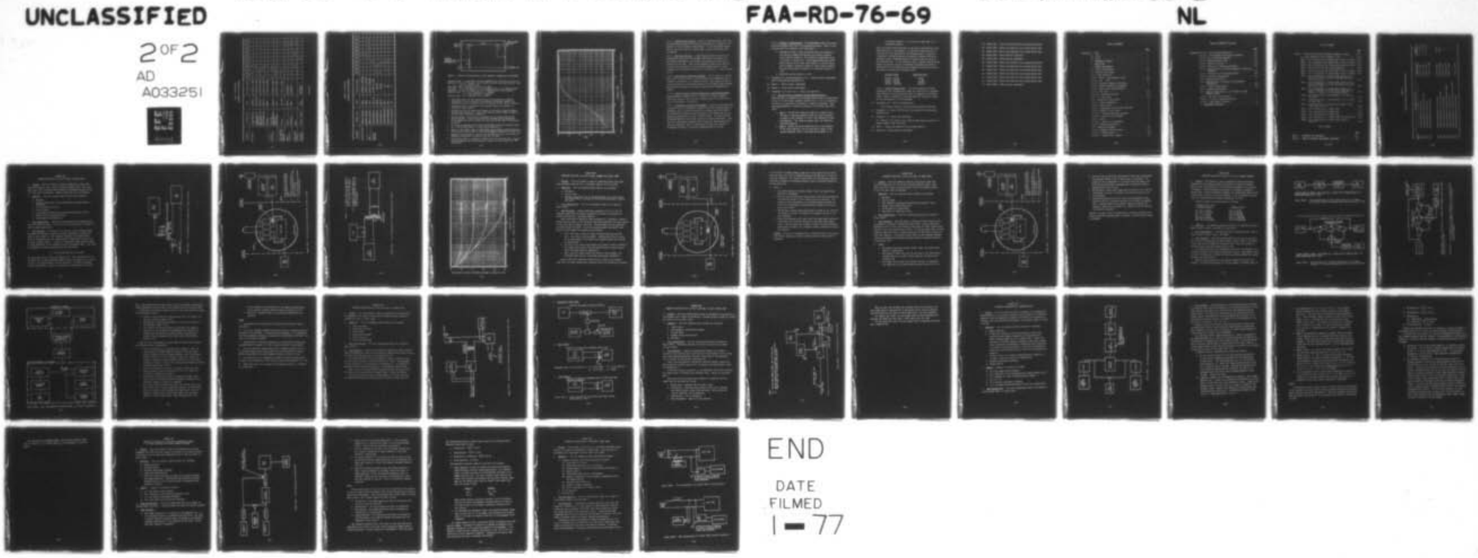

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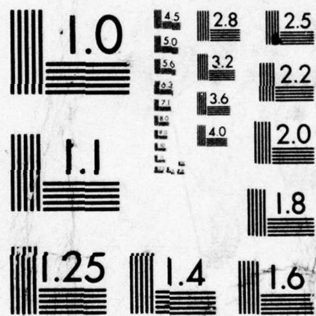

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

TABLE I (continued)

SUGGESTED TEST EQUIPMENT

Equipment	Manufacturers	Model	Frequency Range	CE01	CE02	CE03	CE06	CS01	CS02	CS03	CS04	CS05	CS06	CS07
EMI Meters	Singer-Metrics	NF-108A	14 kHz to 1 GHz	●	●		●							
	Singer-Metrics	EMA-910-10	1 GHz to 22 GHz				●							
	Fairchild Electro-Metrics	EMC-10E	20 Hz to 50 kHz	●	●	●								
	Fairchild Electro-Metrics	EMC-25R	14 kHz to 1 GHz	●		●	●							
	Stoddart	NM62A	1 GHz to 10 GHz				●							
Automatic Scan System	Fairchild Electro-Metrics	FSS-250	14 kHz to 1 GHz	●		●	●							
	Weinschel Engineering	130A	20 Hz to 1 GHz	●	●	●	●							
Line Impedance Stabilization Networks	Filtron	FSQ-70256	2 MHz to 50 MHz	●	●	●								
Signal Generators	Solar	6254-5	Transient										●	
	Honeywell	4881	Transient										●	
Directional Couplers	Narda						●			●	●			
Pin Diode Modulators	Hewlett Packard	8730 Series	400 MHz to 12.4 GHz						●					

(continued)

TABLE I (continued)

SUGGESTED TEST EQUIPMENT

Equipment	Manufacturer	Model	Frequency Range	CE01	CE02	CE03	CE06	CS01	CS02	CS03	CS04	CS05	CS06	CS07
Balanced Mixers	Hewlett Packard	10514	200 kHz to 500 MHz						●					
	Hewlett Packard	10534	50 kHz to 150 MHz						●					
VTVM	Hewlett Packard	410C	20 Hz to 200 MHz					●	●	●	●	●	●	
Rejection Networks	Electro-Metrics	TRF11-15	14 kHz to 1 GHz				●							
	Electro-Metrics	HPK-10	400 Hz	●		●								
	Electro-Metrics	NRG-10	400 Hz	●		●								
	Electro-Mechanics	3011	LF				●							
	Electro-Mechanics	3012	MF				●							
	Electro-Mechanics	3013	HF				●							

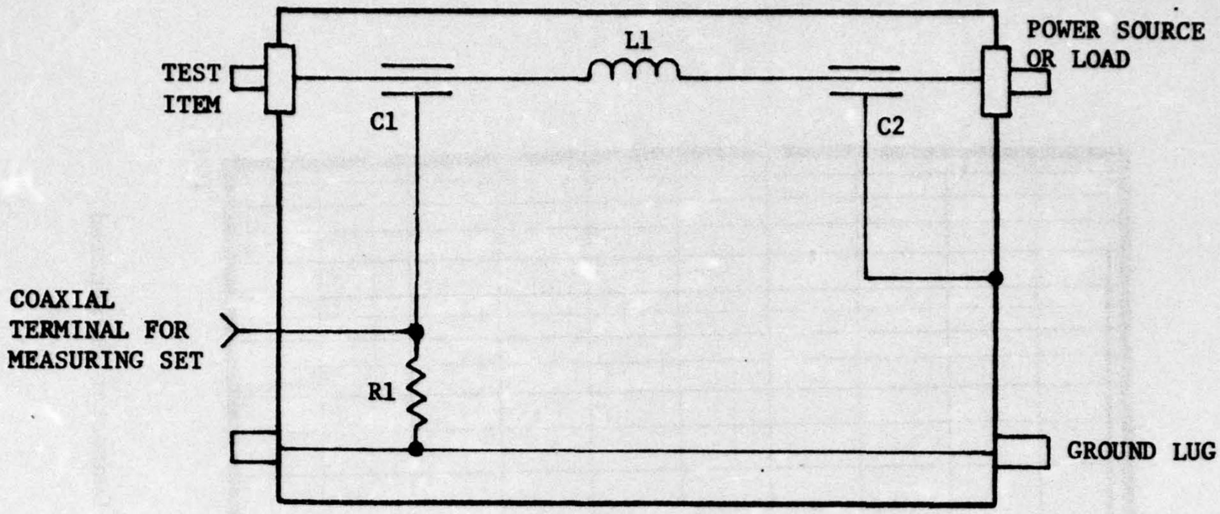

Figure 1. Powerline Stabilization Network Schematic Diagram per ES-DL-198697.

Enclosure Data: 14 gage (B&S) aluminum suggested size 9-3/8 in. by 4 by 4 in.
Form Data: 5-1/4 in. length, 3 in. dia (OD), 0.125 in. wall drill 3/8 in. hole 7/16 in. from each end.
Wire Data: AWG 6, 600 volt, 0.310 in. dia (OD).
Coil Data: L1 - 5 microhenries, 13 turns single layer, 4 in. winding length.
Capacitor: C1 shall be mounted on 1 in. insulating block above ground.
Capacitor Data: C1 = 0.1 UF, 600-volt dc, feedthru
C2 = 1 UF, 600-volt dc, feedthru
Resistor Data: R1 = 5,000-ohm, 5-watt carbon

1. The values given for the component parts of the network are nominal. Regardless of the construction or deviation from nominal values, the network must have an impedance within 20 percent of that given in Figure 2.

2. Connecting leads to condensers and resistors should be as nearly as possible to zero length.

3. Networks may also be constructed having a 1-ohm series resistor between the line and capacitor C2. This 1-ohm resistor shall be made up from ten 10-ohm, 1-watt composition resistors.

4. The data given in this figure is suitable for the construction of 50-ampere networks. Larger current-carrying networks may be constructed by increasing the wire size given for the coil and the size of the overall enclosure.

5. The 50-ohm transmission line should be extended within the enclosure right up to the location where it connects with capacitor C1.

6. Caution: The network shall be prominently and permanently marked "Caution-Shock Hazard--Connect Case to Earth Ground Before Connecting A-C Power Line."

7. Networks procured prior to the date of this specification, but meeting the impedance requirements of Figure 2 may still be used.

8. Each network shall be permanently labeled with the following data: Current rating in amperes and voltage rating in volts at direct current, 60, 400, and 800 CPS.

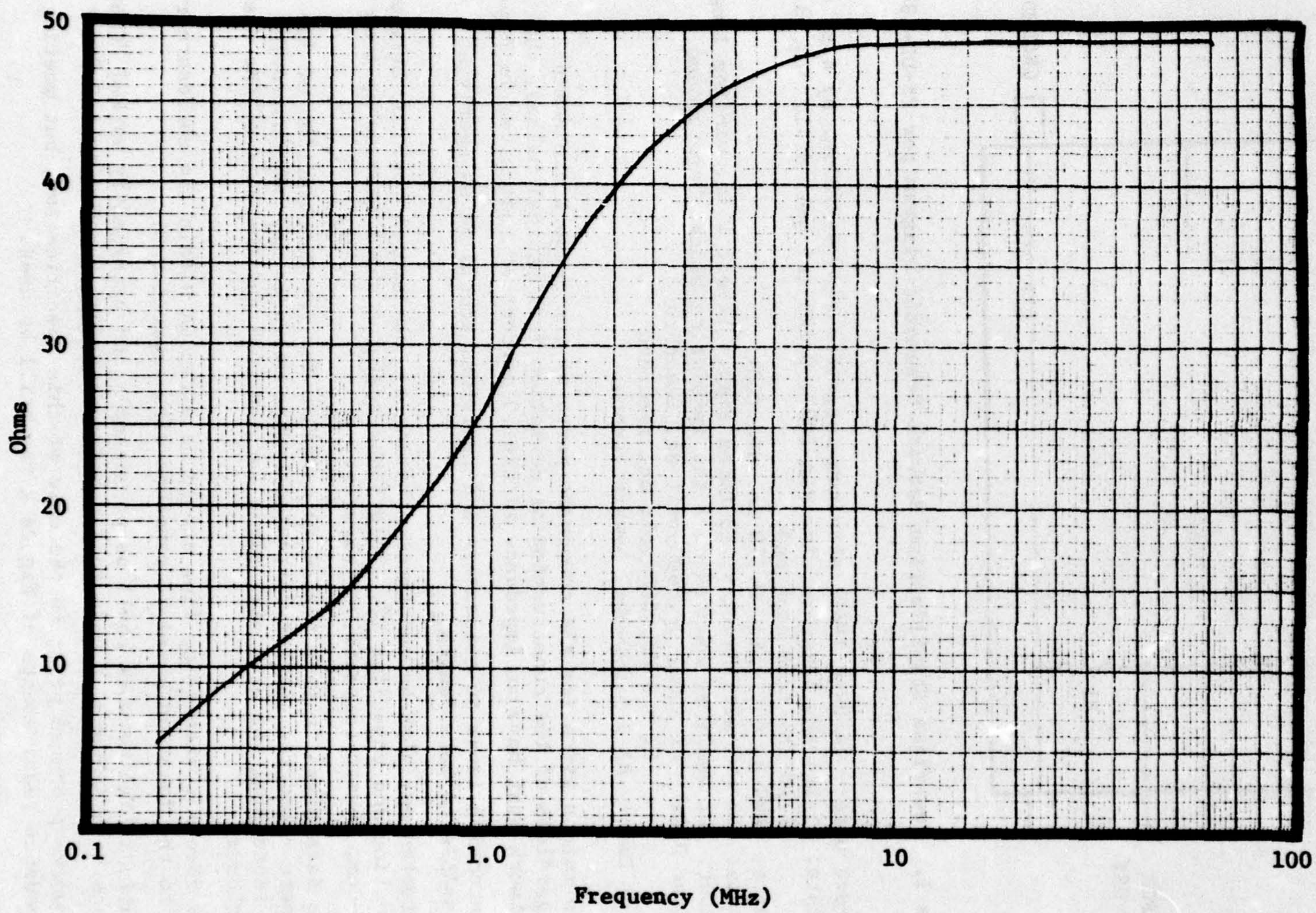

Figure 2. Input Impedance at Test Item Terminal of LISN with Type N Connector Terminated in 50 Ohms, Power Terminal Open.

4.2.3.3 Equipment Warm-Up Time. - Prior to commencing data collection, the measuring equipment shall have been energized for a period of time adequate to allow parameter stabilization. If the operational manual does not specify a specific warm-up time, a period of one-hour shall be observed.

4.2.3.4 Detection Function. - A peak detector shall be used for all measurements required by MIL-STD-461A, FAA Notice 1C; however, for narrowband measurements, the average or rms function may be used if authorized by the FAA. Substitution generator output levels shall be corrected when the detector output and the signal generator output calibration are different functions of a sine wave, i.e., peak, average, or rms.

4.2.3.5 Monitoring of Measuring Equipment. - The IF output of the EMI meter shall be monitored with a device that gives an amplitude versus frequency presentation on a cathode ray tube. This monitor is used to obtain information on the characteristics of the signals being measured. The measuring equipment shall also be monitored with headphones or a speaker.

4.2.3.6 Identification of Spurious Responses in Measuring Equipment. - The measurement equipment shall be checked for spurious responses. False data caused by such spurious responses shall be so identified on the X-Y recordings or data sheets.

4.2.3.7 Calibration of Measuring Equipment. - Measuring instruments and accessories used in determining compliance with this standard shall be calibrated under an approved program in accordance with MIL-C-45662. The calibration program document required by MIL-C-45662 shall be submitted for FAA approval as part of the Test Plan. See Specification EL-CD-6003-0009A for calibration methods for impulse generators. Calibration of measurement equipment and accessories, impulse generators, and other equipments shall be verified at any time upon request of witnessing officials or authorized representatives of the FAA.

4.2.3.8 Accuracy of Measurements. - All measurements made in accordance with this standard shall have the following accuracies. Proof of such accuracy shall be documented in the Test Report.

a. Frequency Accuracy - Where specified limits are exceeded in the spurious response and harmonic and spurious emission tests (antenna terminal), the frequency of measurement shall be accurate to within ± 1%. Since signal generators and EMI meters usually do not offer this accuracy, it will be necessary to employ a frequency counter or other similar standard. All other tests shall be subject to a frequency accuracy of ± 2%.

b. Amplitude accuracy shall be ± 2 dB.

17. Paragraph 4.2.4 through Paragraph 4.2.4.4 - Delete without replacement. Refer to MIL-STD-462, FAA Notice 1R.

18. Figure 1 - Delete without replacement.

19. Figure 2 - Delete without replacement.

20. Paragraphs 4.2.6 and 4.2.6.1 - Delete and substitute:

4.2.6 Identification of Broadband and Narrowband Emissions. - Identification of broadband and narrowband emissions may be accomplished by use of the monitoring equipment specified in 4.2.3.6 or by observing affects due to switching of bandwidths or detection functions. When switching bandwidths or detector functions, the following tests shall apply:

a. Test 1: The EMI meter shall be tuned over a range of plus and minus 2 impulse bandwidths around its center frequency. A change in peak response of 3 dB or less indicates a broadband emission. Any change of greater than 3 dB indicates a narrowband emission.

b. Test 2: Measure the pulse repetition rate of the emission. If the pulse repetition rate is less than or equal to the impulse bandwidth (IBW) of the measuring equipment, it is a broadband emission. If it is greater than IBW, it is a narrowband emission.

Also, an optional differentiation can be made by measuring the pulse repetition rate of the emission. If the pulse repetition rate is less than the rate specified in the following table, it should be considered a broadband emission and should be measured with an instrument having a bandwidth equal to or greater than the value of the specified rate. If the repetition rate is greater than specified below, the emission should be considered narrowband and should be measured with an instrument having a bandwidth less than or equal to the value of the specified repetition rate.

Frequency Range	Repetition Rate
20 kHz - 150 kHz	200 Hz
150 kHz - 30 MHz	5 kHz
30 MHz - 400 MHz	100 kHz
400 MHz - 1000 MHz	300 kHz

4.2.6.1 Pulsed CW Requirements. - The pulse repetition criteria expressed in the foregoing shall apply for pulsed CW up to 1000 MHz. Above 1000 MHz pulsed CW emissions shall be compared to narrowband limits; however, bandwidth corrections should be employed to normalize the measurements to 1 MHz bandwidth.

20. Paragraph 4.2.8 - Add the following note:

    This technique shall not be used unless approved by the FAA.

21. Paragraph 5.1 - Delete "MIL-STD-461" and substitute "MIL-STD-461A, FAA Notice 1C".

22. Paragraph 5.2 - Delete and substitute:

    5.2 Table II is an index of the conducted measurement procedures by method, number, date, and title.

23. Table I - Delete and substitute the attached Table II.

24. Page 11/12 - Delete without replacement.

25. Method CE01 - Delete and substitute the attached Method CE01.

26. Method CE02 - Delete and substitute the attached Method CE02.

27. Method CE03 - Delete and substitute the attached Method CE03.

28. Method CE04 - Delete without replacement.

29. Method CE05 - Delete without replacement.

30. Method CE06 - Delete and substitute the attached Method CE06.

31. Method CS01 - Delete and substitute the attached Method CS01.

32. Method CS02 - Delete and substitute the attached Method CS02.

33. Method CS03 - Delete and substitute the attached Method CS03.

34. Method CS04 - Delete and substitute the attached Method CS04.

35. Method CS06 - Delete and substitute the attached Method CS06.

36. Method CS08 - Delete without replacement.

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LIST OF FIGURES

LIST OF TABLES

TABLE II

INDEX OF CONDUCTED MEASUREMENT PROCEDURES

Number	Test Method Description: Title	Frequency Range	Equipment Classification
CE01	Conducted Emissions, dc Power Lines	30 Hz to 50 MHz	I, II, and III
CE02	Conducted Emissions, Control and Signal Lines	30 Hz to 20 kHz	I, II, and III
CE03	Conducted Emissions, ac Power Lines	10 kHz to 50 MHz	I, II, and III
CE06	Conducted Emissions, Antenna Terminals	10 kHz to 12.4 GHz	I
CS01	Conducted Susceptibility, dc Power Lines	30 Hz to 50 kHz	I and II
CS02	Conducted Susceptibility, ac and dc Power Lines	50 kHz to 400 MHz	I and II
CS03	Conducted Susceptibility, Intermodulation	15 kHz to 10 GHz	I
CS04	Conducted Susceptibility, Rejection of Undesired Signals	15 kHz to 10 GHz	I
CS05	Conducted Susceptibility, Cross Modulation	15 kHz to 10 GHz	I
CS06	Conducted Susceptibility, Transients, ac and dc Power Lines	--	I
CS07	Conducted Susceptibility, Squelch Circuits	15 kHz to 10 GHz	I

METHOD CE01

CONDUCTED EMISSIONS, 30 Hz TO 50 MHz, DC POWER LINES

1. Purpose. - This test method is used for measuring dc power line conducted emissions over a 30 Hz to 50 MHz frequency range. Both input and output lines, including neutrals which are grounded external to the test item, shall be measured. Bonding straps are not to be measured.

2. Apparatus. - The test apparatus shall include the following:

   a. EMI Meter

   b. Isolation Transformer (Solar Electronics Co. Model 6220-1A or equivalent)

   c. 10 μF Feedthrough Capacitor

   d. Current Probes

   e. Line Impedance Stabilization Networks (see Figures 1 and 2)

   f. Headset and IF Monitoring Devices

   g. 50 ohm Resistive Terminations

3. Test Configuration. - The test configuration shown in Figures CE01-1 and CE01-2 shall be used for the 30 Hz to 50 kHz and 50 kHz to 50 MHz frequency ranges, respectively.

4. Test Procedure. - For tests in the 30 Hz to 50 kHz frequency range, determine the isolation transformer transfer impedance by shunting the primary with resistor R. This transfer impedance (correction factor) shall be determined using the configuration in Figure CE01-3 and plotted as shown in Figure CE01-4. A value of R less than 5 ohms should be chosen to yield essentially a flat response across the frequency range. The transfer impedance can also be determined by the calculation

$$Z = 20 \log \frac{R}{2} \text{ (dB relative to one ohm)}$$

The correction factor is just the negative of Z. The calculation will be in slight error if the transformer turns ratio is not exactly 2:1. In such a case, $Z = 20 \log \frac{R}{n}$, where n is the turns ratio. In order to maintain required sensitivity, a value of R less than 0.5 ohms should not be used.

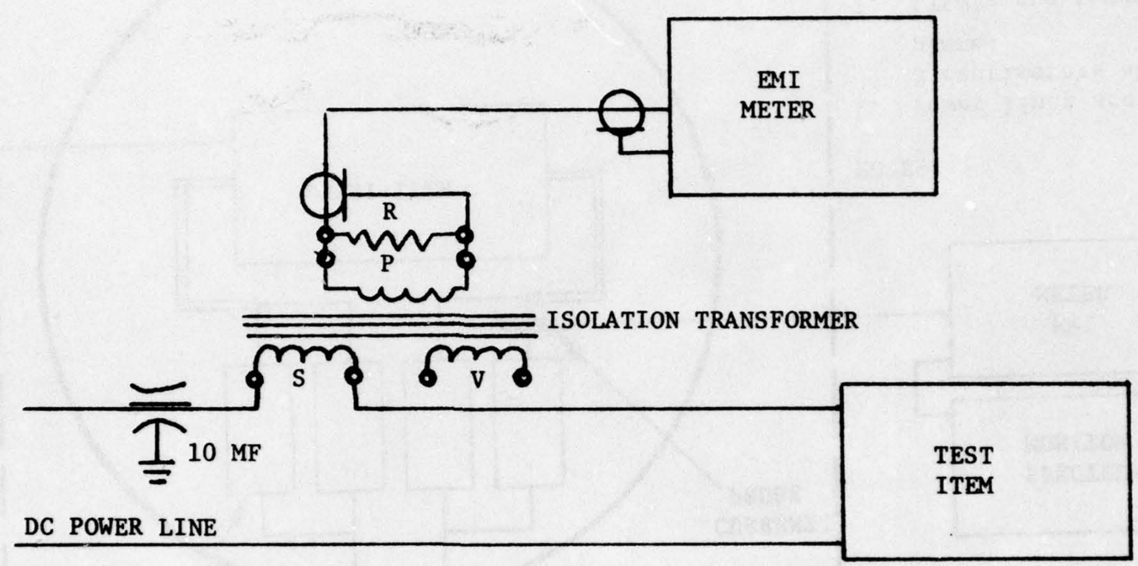
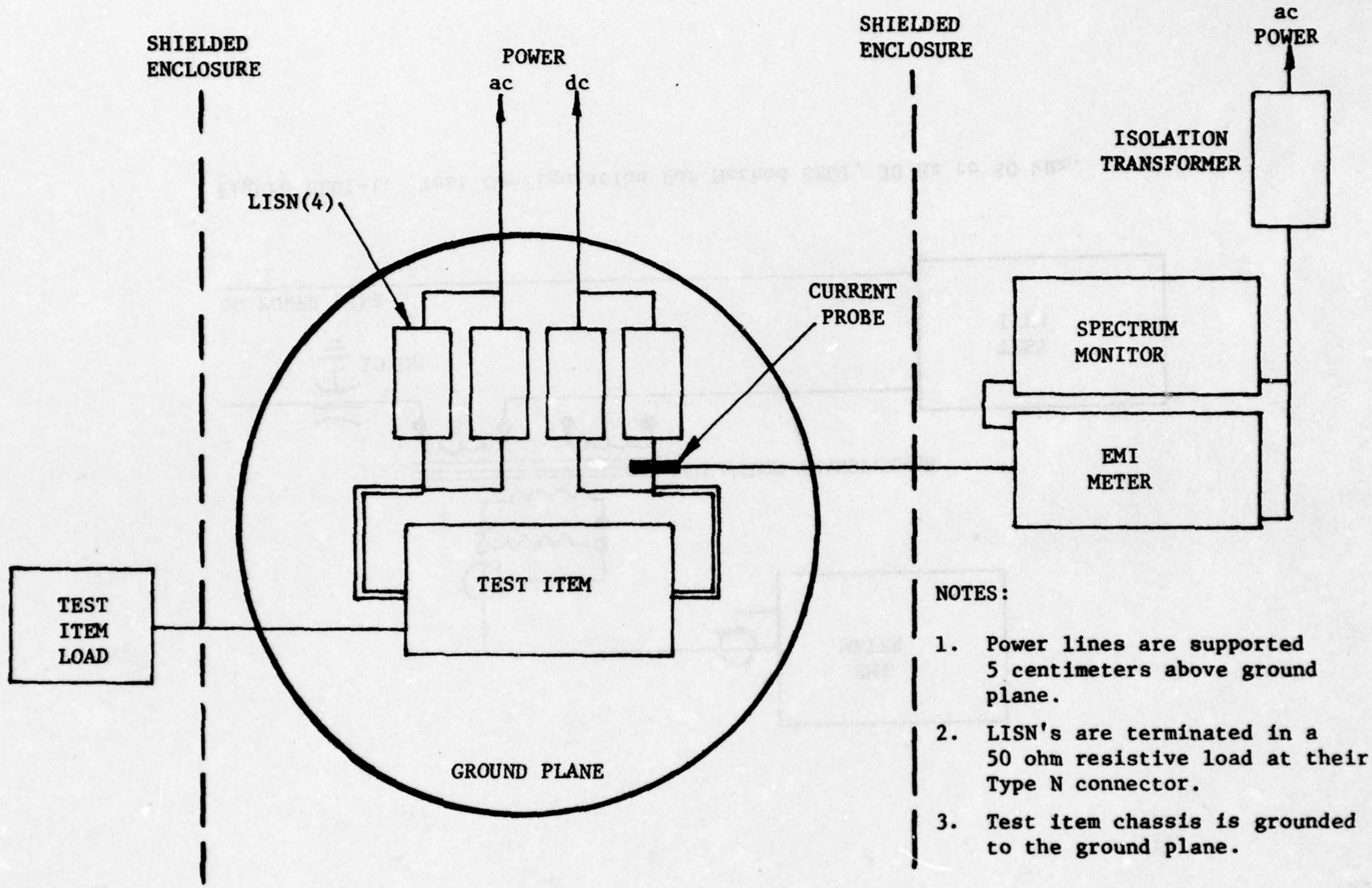


Figure CE01-1. Test Configuration for Method CE01, 30 Hz to 50 kHz.



NOTES:

1. Power lines are supported 5 centimeters above ground plane.
2. LISN's are terminated in a 50 ohm resistive load at their Type N connector.
3. Test item chassis is grounded to the ground plane.

Figure CE01-2. Test Configuration for Method CE01, 50 kHz to 50 MHz.

NOTES: (1) IF INPUT CIRCUIT TO EMI METER IS REACTIVE, USE A MINIMUM LOSS "T" PAD AT THE INPUT TO THE METER.

(2) MAINTAIN AF GENERATOR OUTPUT FOR CONSTANT VOLTAGE DROP ACROSS THE 10-OHM RESISTOR.

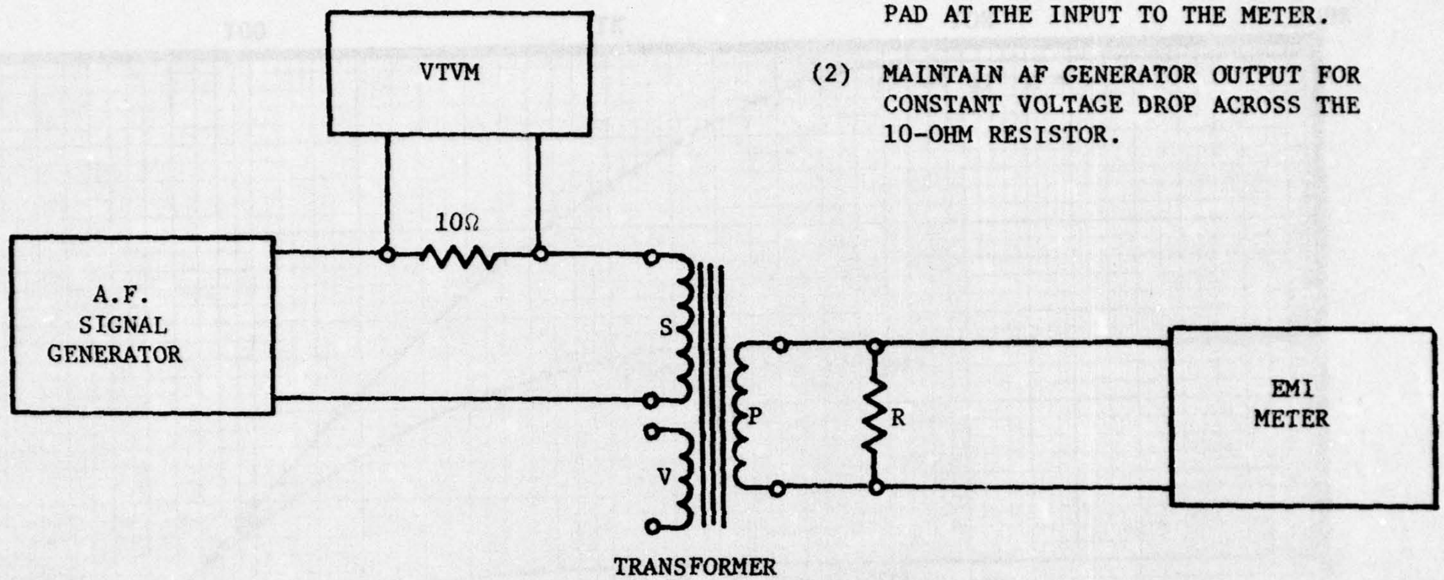


Figure CE01-3. Test Configuration for Determining Correction Factor.

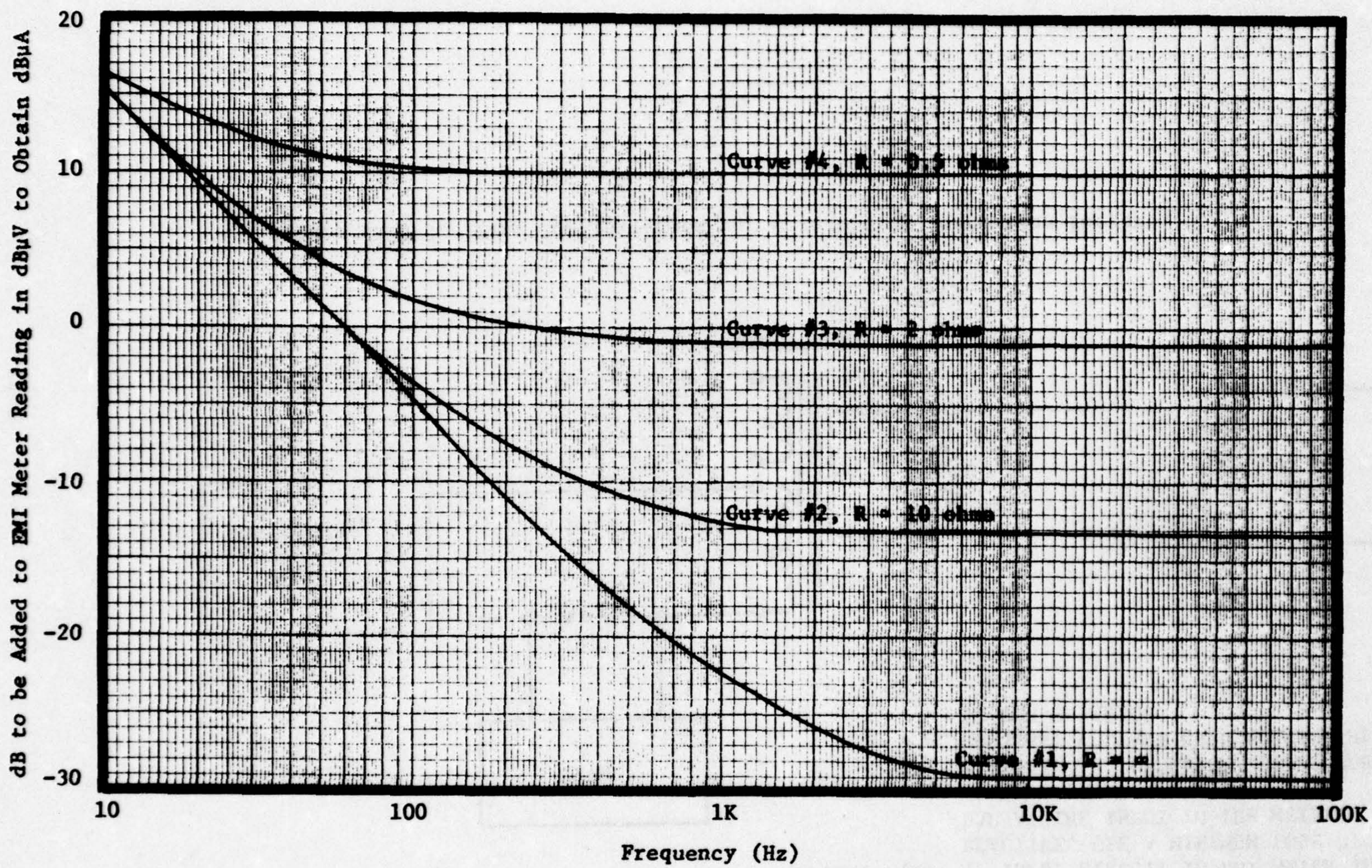


Figure CE01-4. Typical Correction Data versus Frequency.

METHOD CE02

CONDUCTED EMISSIONS, 30 Hz TO 50 MHz, CONTROL AND SIGNAL LINES

1. Purpose. - This test method is used for measuring control and signal line conducted emissions over a frequency range of 30 Hz to 50 MHz.

2. Apparatus. - The test apparatus shall include the following:

   a. EMI Meter

   b. Current Probe

   c. Matching Transformer (may be required between the current probe and the EMI Meter to provide the sensitivity necessary to perform the test)

3. Test Configuration. - The test configuration shall be as shown in Figure CE02-1.

4. Test Procedure. - Using an EMI Meter bandwidth of 50 to 75 Hz, the frequency range shall be slowly scanned while the meter is observed for maximum indications of undesired emission.

Where individual or groups of lines contained in a shielded or sheathed bundle must be tested, a line extension fabricated especially for the purposes of this test must be added to the line. This extension will be unsheathed and will include no shields. Rules for grouping signal and control lines within the same bundle for testing are as follows:

   a. In no case shall a group of lines be probed with both the high and return lines in the test group. Twisted pairs will be tested in the same manner at the bundle test extension where the twisting is discontinued.

   b. The size of the group tested should not exceed 1/2 inch in diameter. Each group which results from the division should contain approximately the same number of conductors.

   c. When a group of lines exceeds the limits of this standard, the offending lines shall be identified and measured separately.

Using an EMI meter bandwidth between 50 and 75 Hertz, the frequency range shall be slowly scanned while emission levels are observed and recorded.

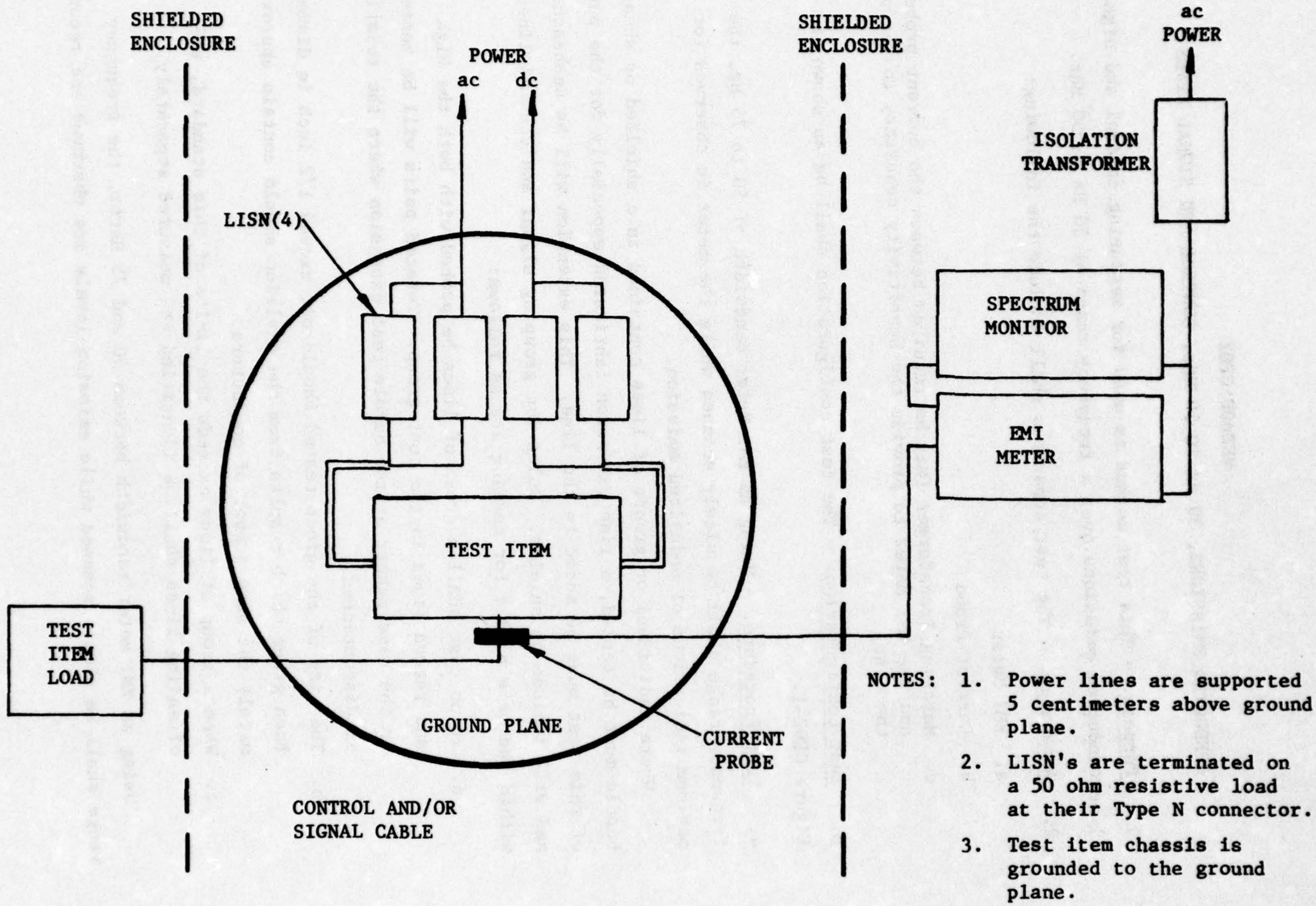


Figure CE02-1. Test Configuration for Method CE02, 30 Hz to 50 MHz.

In the 50 kHz to 50 MHz frequency range the current probe shall be moved along the power line until a maximum reading on the EMI meter is noted for each test frequency. The recorded levels shall be these maximum readings. Conducted narrowband and broadband emissions shall be measured separately on each power line.

5. Notes. -

   a. The minimum separation between cables, lines, and ground plane shall be 5 centimeters.

   b. The test item and EMI Meter should derive their power requirements from separate phases of the ac power source, if possible. The purpose of this requirement is to provide isolation between the test item and measurement instrumentation through the enclosure power line filters.

   c. The EMI Meter chassis power ground must be broken at the isolation transformer to prevent circulation of RF ground currents in the test equipment.

   d. Calibration generators and other electronic measurement instrumentation must not contribute adversely to the power line ambient level. Separate power source phases, filters, reversed impedance stabilization networks, etc. should be used as required to provide RF isolation.

   CAUTION: Be sure the instrumentation is properly bonded to the ground plane before applying ac power to prevent potential shock hazard to personnel.

METHOD CE03

CONDUCTED EMISSIONS, 10 kHz TO 50 MHz, AC POWER LINES

1. Purpose. - This test method is used for measuring ac power line conducted emissions over the 10 kHz to 50 MHz frequency range. Both input and output lines, including neutrals which are grounded external to the test item, shall be measured.

2. Apparatus. - The test apparatus shall include the following:

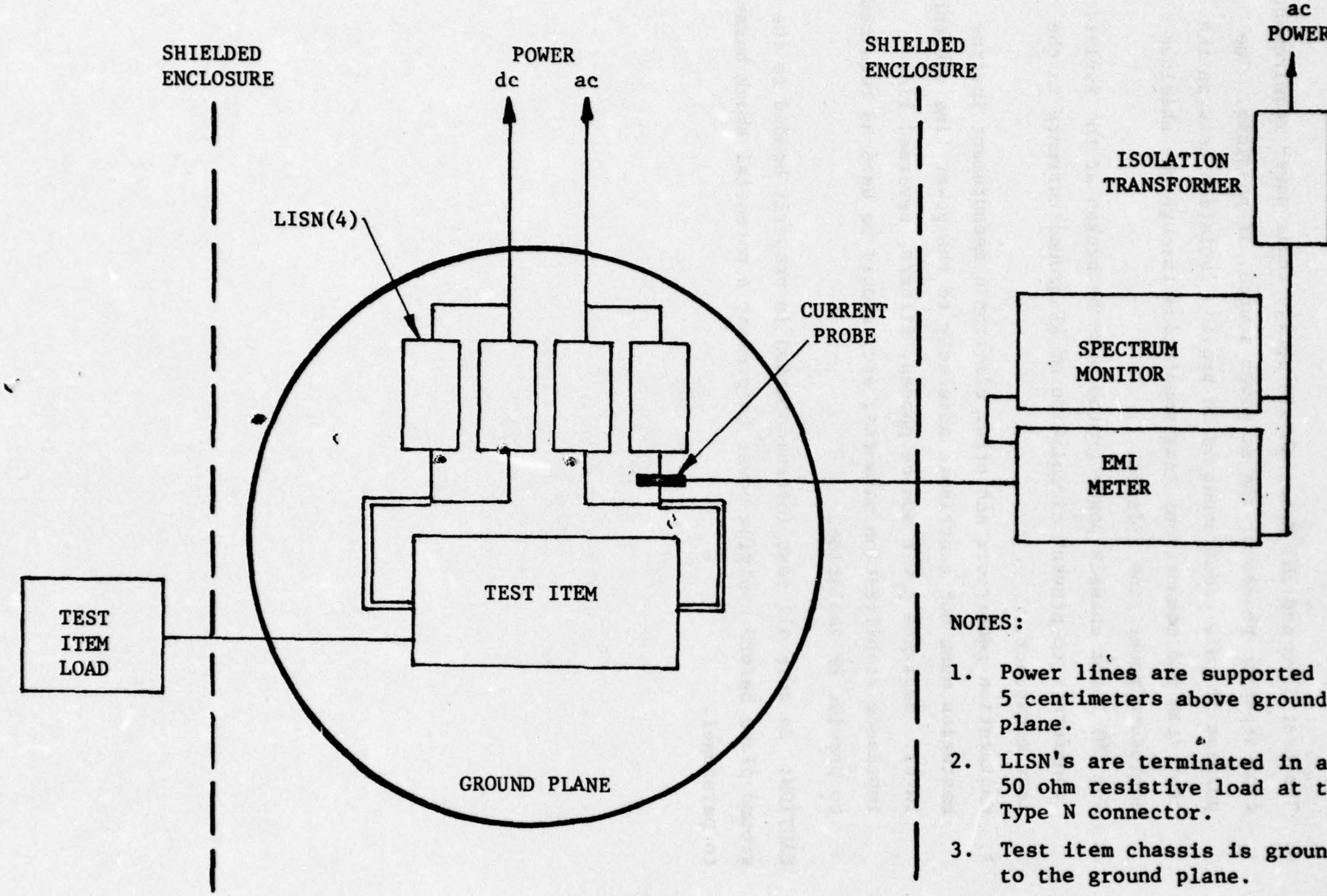
   a. EMI Meter
   b. Current Probes
   c. Line Impedance Stabilization Networks (see Figures 1 and 2)
   d. Headset and IF Monitoring Device
   e. 50 ohm Resistive Terminations
   f. Band Reject or High Pass Filters

3. Test Configuration. - The test configuration shall be as shown in Figure CE03-1.

4. Test Procedure. - The band reject or high pass filters shall be used as necessary to attenuate frequencies below 10 kHz. Using an EMI Meter bandwidth of 50 to 75 Hz, the frequency range shall be slowly scanned while emission levels are observed and recorded. The current probe shall be moved along the power line until a maximum reading on the EMI Meter is noted for each test frequency. The recorded levels shall be these maximum readings. Conducted narrowband and broadband emissions shall be measured separately on each power line.

5. Notes. -

   a. The minimum separation between cables, leads, and ground plane shall be 5 centimeters.
   b. The length of power line from the test item to the stabilization networks shall be at least 2 meters long but not greater than 3 meters long.
   c. The length of each power line between the point of separation and connection to the stabilization network shall be 30 ± 2 cm.



NOTES:

1. Power lines are supported 5 centimeters above ground plane.
2. LISN's are terminated in a 50 ohm resistive load at their Type N connector.
3. Test item chassis is grounded to the ground plane.

Figure CE03-1. Test Configuration for Method CE03, 10 kHz to 50 MHz.

d. The test item and EMI Meter should derive their power requirements from separate phases of the ac power source, if possible. The purpose of this requirement is to provide isolation between the test item and measurement instrumentation through the shielded enclosure power line filters.

e. The EMI Meter chassis power ground must be broken at the isolation transformer to prevent circulation of RF ground currents in the test equipment.

f. Calibration generators and other electronic measurement instrumentation must not contribute adversely to the power line ambient level. Separate power source phases, filters, reversed line impedance stabilization networks, etc. should be used as required to provide RF isolation.

CAUTION: Be sure all test instrumentation is properly bonded to the ground plane before applying power to prevent a potential shock hazard to personnel.

METHOD CE06

CONDUCTED EMISSIONS, 10 kHz to 12.4 GHz, ANTENNA TERMINALS

1. Purpose. - This method is used for measuring conducted emissions appearing at the antenna terminals of receivers, transmitters (key-up and key-down), RF amplifiers, and other devices designed to be connected to antennas. These procedures do not apply to equipments designed to operate into a fixed non-removable antenna, for transmitters whose average output power is greater than five kilowatts, or for transmission systems above the frequency where multimode propagation can exist.

Frequency range of the test shall be as follows:

Equipment (Test Item) Operating Range	Range of Test
VLF (10 to 30 kHz)	0.01 to 10 MHz
LF (30 to 300 kHz)	0.01 to 100 MHz
MF (.3 to 3 MHz)	0.01 to 600 MHz
HF (3 to 30 MHz)	0.01 to 1,000 MHz
VHF (30 to 300 MHz)	0.01 to 3,000 MHz
UHF (300 to 1240 MHz)	0.01 to 12,400 MHz

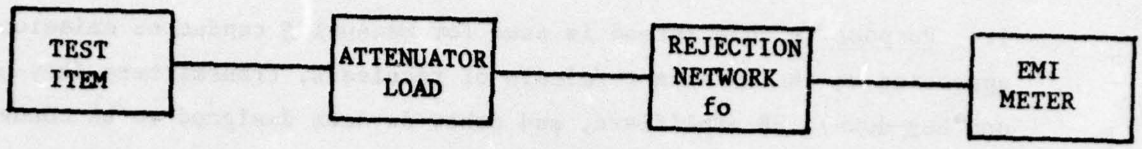
2. Apparatus. - The measuring apparatus shall be as indicated in Figures CE06-1, CE06-2, CE06-3, and CE06-4, as applicable.

3. Test Configuration. - The applicable test configurations are shown in Figures CE06-1, CE06-2, CE06-3, and CE06-4.

4. Test Procedure. - The test procedure shall be selected in accordance with the title descriptions of Figures CE06-1, CE06-2, CE06-3, and CE06-4. If the test item is designed for operation into a specified antenna, it shall be tested using this antenna as the load.

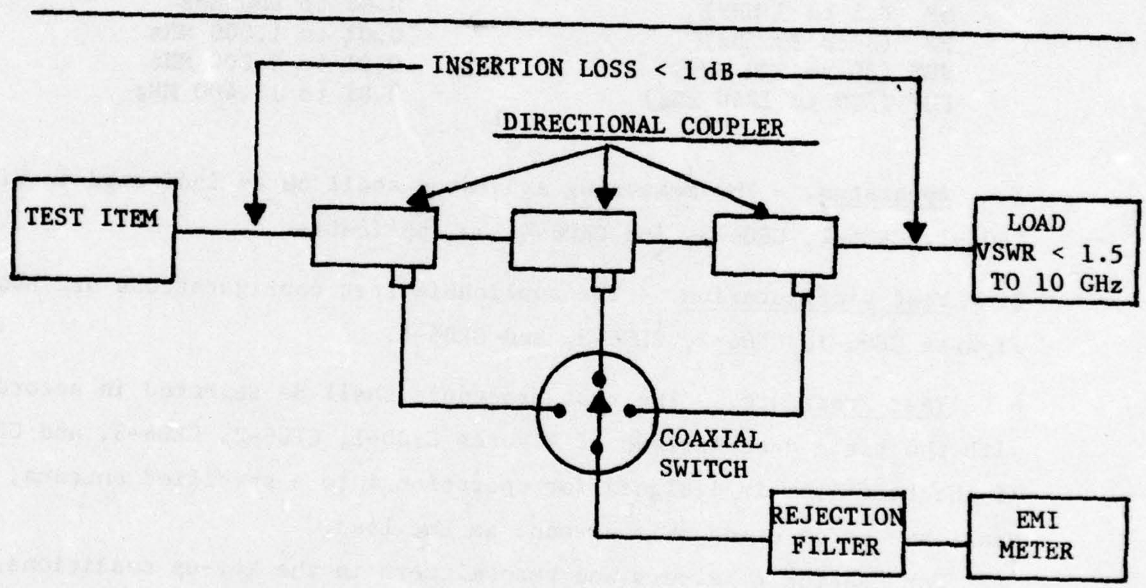
For testing receivers and transmitters in the key-up conditions, the rejection networks and attenuators should not be used. Measurements should be made by interposing an appropriate matching network between the antenna terminal and the EMI Meter.

When the power available at the antenna terminals is greater than 30 dBW, or the operating frequency of the test sample is greater than 1.24



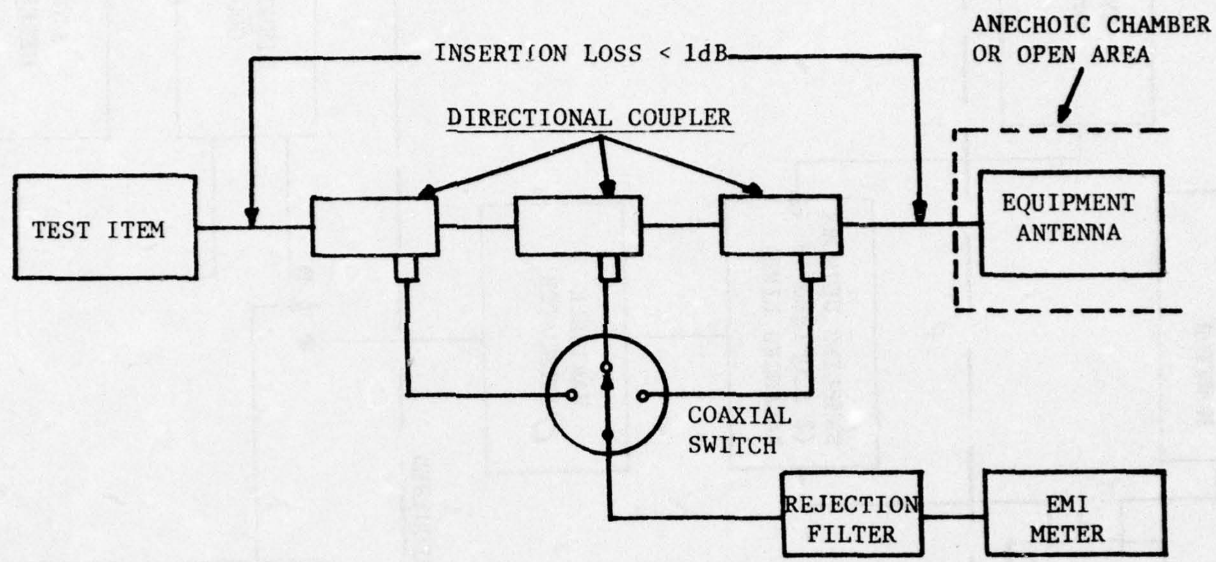
AVERAGE POWER AT INPUT TO EMI METER AT fo SHOULD NOT BE GREATER THAN 40 dB ABOVE METER SENSITIVITY LEVEL.

Figure CE06-1. Test Configuration for Method CE06, where fo is in Range of 10 kHz to 100 MHz and Average Power Does Not Exceed 30 dBW.



AVERAGE POWER AT INPUT TO EMI METER AT fo SHOULD NOT BE GREATER THAN 40 dB ABOVE METER SENSITIVITY LEVEL.

Figure CE06-2. Test Configuration for Method CE06 where fo is in Range 100 MHz to 1.24 GHz and Average Power Does Not Exceed 30 dBW.



AVERAGE POWER AT INPUT TO EMI METER AT fo SHOULD NOT BE GREATER THAN 40 dB ABOVE METER SENSITIVITY LEVEL.

Figure CE06-3. Test Configuration for Method CE06 Where fo is in Range 100 MHz to 1.24 GHz and the Equipment is Designed to Operate with a Specified Antenna.

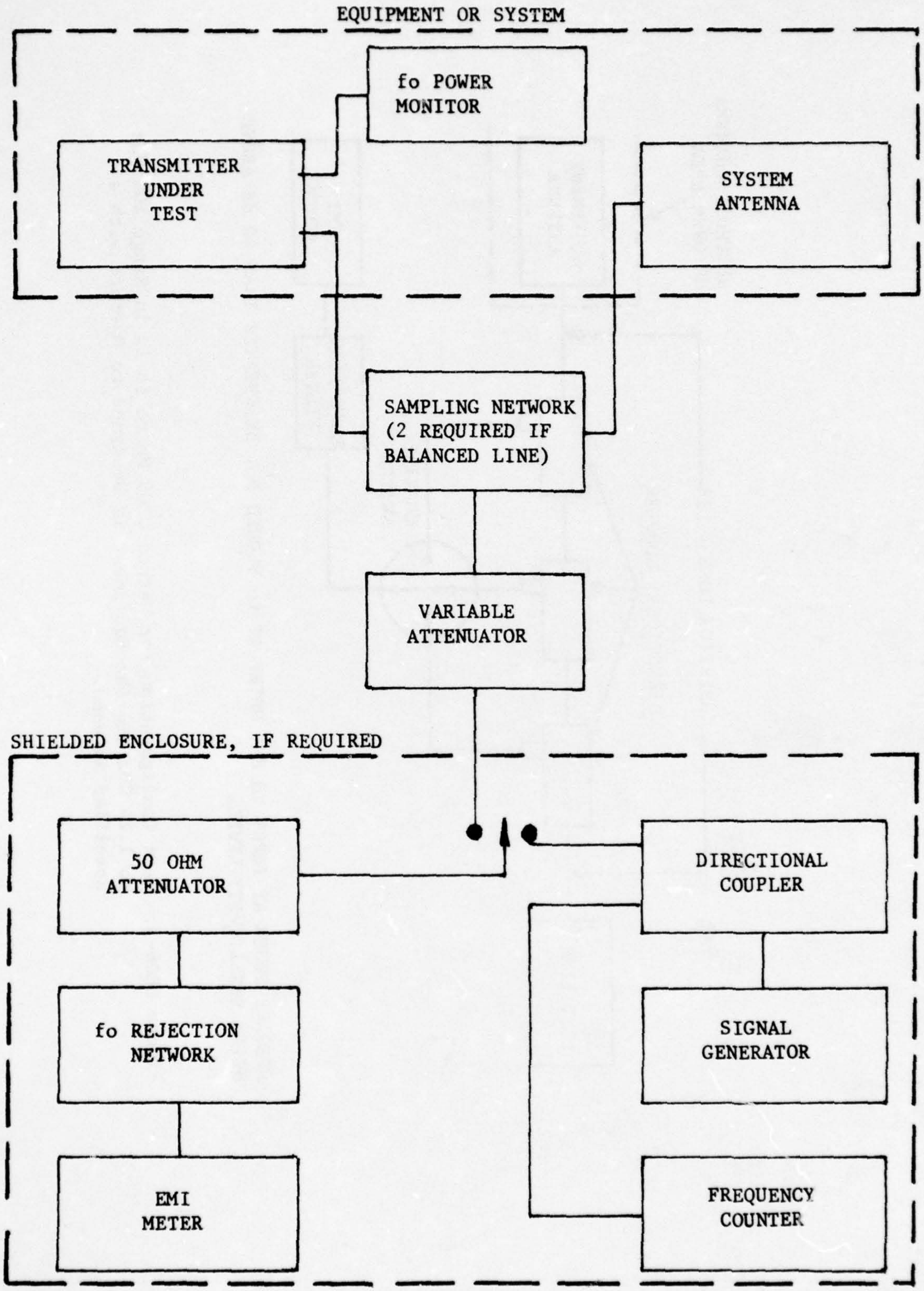


Figure CE06-4. Test Configuration for Method CE06, to be Used as Applicable.

GHz, or multimode emissions exist below 12.4 GHz in waveguide transmission lines, measurements shall be made in the radiated field using Method RE03. Selection of directional couplers for use in this test should be based on the following criteria:

a. Insertion loss between test item and load shall not exceed 1 dB over the frequency range of test.

b. Coupling arm calibration error shall not exceed ± 0.25 dB over the frequency range of test.

c. The coupling arm isolation shall be consistent with adequate reduction of the transmitter's fundamental power and the test configuration sensitivity required to measure spurious and harmonic levels indicated in the limit curve of MIL-STD-461, FAA Notice 1C.

When the test configuration of Figure CE06-4 is used, the following test procedure shall be applicable:

a. Tune the transmitter to a specified test frequency. With the coaxial switch of Figure CE06-4 in position 1 and the fundamental frequency rejection network bypassed, tune the frequency-selective voltmeter to the transmitter frequency. Adjust the variable attenuator and the voltmeter controls for a convenient reading on the meter. Record all settings and attenuator positions including power monitor level.

b. Using the transmitter settings of (a) above, insert the fundamental frequency rejection network and tune it to reject the transmitter fundamental frequency.

c. With minimum system attenuation and maximum instrument sensitivity, tune the frequency selective voltmeter through its full frequency range(s) to detect all emissions.

d. Each time a spurious transmitter output is observed, adjust the meter sensitivity to give a convenient reading. Set the coaxial switch to position 2 and determine the signal level of the responses by substituting an equivalent signal from the signal generator. Record these values. When determining the level of the responses, the attenuation of the signal coupling device at the spurious frequency shall be known to within ± 0.25 dB.

e. Repeat the foregoing steps at each specified transmitter test frequency.

NOTES:

1. An impedance match between the test item and the EMI Meter shall be maintained.

2. It is easy to damage equipment during this test or to generate spurious responses in the EMI Meter. To minimize these problems, it is recommended that the fundamental frequency be attenuated to approximately -30 dBW at the input to the rejection network.

3. Identification of spurious responses can be simplified by monitoring the measurement instrument's IF with a spectrum analyzer or pan adapter.

4. The test item shall always operate into a matched resistive load for all antenna terminal tests except when the test configuration of Figure CE06-3 is used where the actual equipment antenna is used as a load.

5. The insertion loss of fundamental frequency rejection networks shall be known at the frequencies of the spurious output being measured to ± 1 dB.

6. Dummy loads shall be of adequate power handling capacity to terminate the transmitters.

METHOD CS01

CONDUCTED SUSCEPTIBILITY, 30 Hz TO 50 kHz, DC POWER LINES

1. Purpose. - This test method is used to determine the susceptibility of equipments when signals in the 30 Hz to 50 kHz frequency range are coupled onto their dc power lines.

2. Apparatus. - The test apparatus shall include the following:

   a. Audio Oscillator
   b. Audio Power Amplifier
   c. Oscilloscope
   d. Vacuum Tube Voltmeter
   e. 100 μF Capacitor
   f. Isolation Transformer

3. Test Configuration. - The test configuration shall be as shown in Figure CS01-1.

4. Test Procedure. - The test item shall be connected as shown in Figure CS01-1 and appropriate devices such as shown in Figure CS01-2 shall be used to monitor performance during the susceptibility test.

The oscillator shall be tuned through the required frequency range with the output adjusted to the specified level. Monitor the equipment for (a) malfunction, (b) degradation of performance, or (c) deviation of parameters beyond tolerances indicated in the equipment specification.

When a test item susceptibility is noted, decrease the output level to determine the susceptibility threshold level. Record this value.

The required nominal supply voltage applied to the test item shall be measured and maintained within specified tolerances during the test.

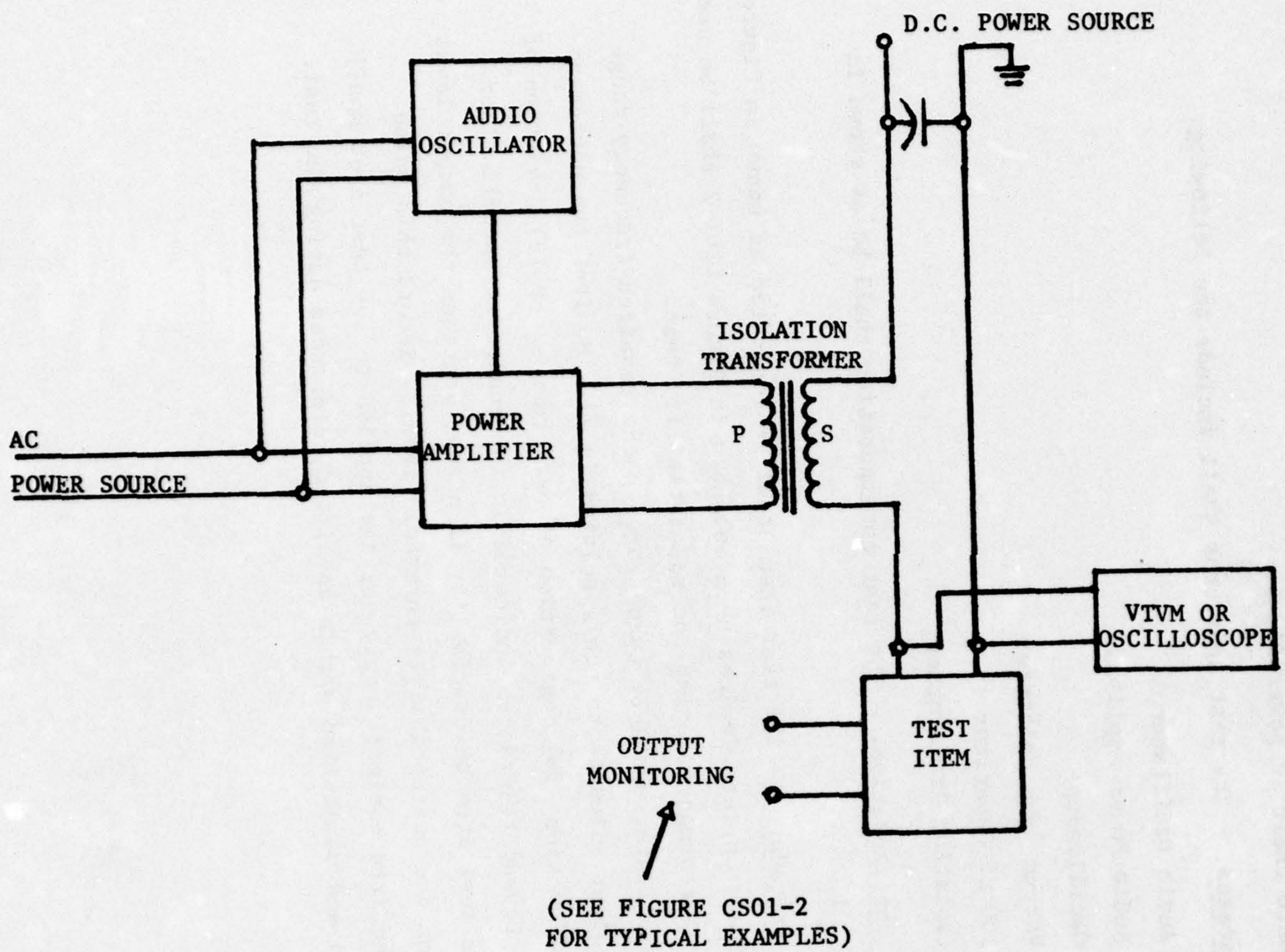
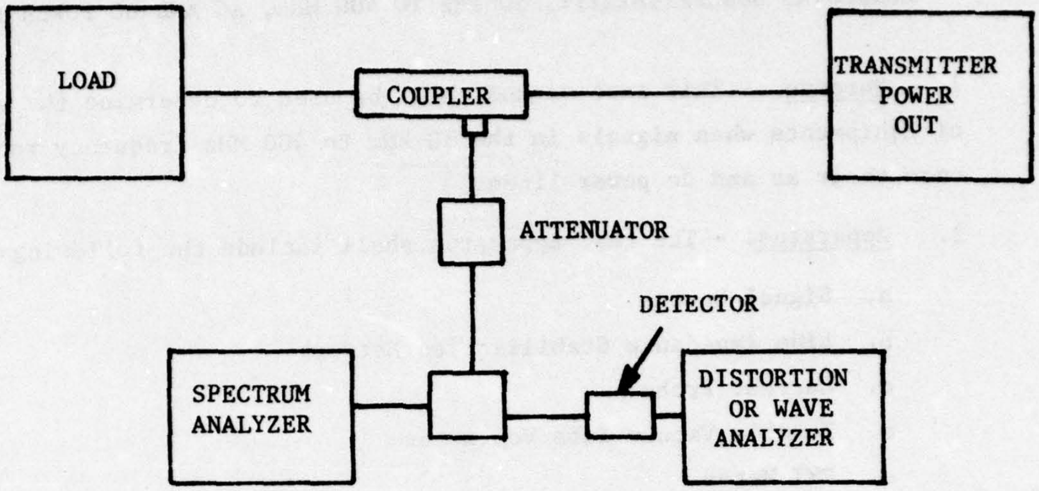


Figure CS01-1. Test Configuration for Method CS01, 30 Hz to 50 kHz, DC Power Lines.

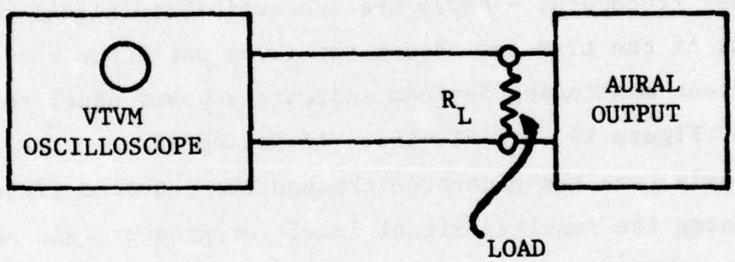
A. TRANSMITTER POWER OUTPUT

MONITOR FOR CHANGE IN OUTPUT SPECTRUM



B. AURAL OUTPUTS

MONITOR FOR CHANGE FROM REFERENCE OUTPUT LEVEL



REFERENCE LEVEL TO BE SPECIFIED AS: (1) NOISE LEVEL (3) 10 dB QUIETING

(2) 10 dB $\frac{S + N}{N}$ (4) OTHER

C. VIDEO OUTPUTS

MONITOR FOR CHANGE IN REFERENCE LEVEL OR DEVIATION FROM SPECIFIED PARAMETERS.

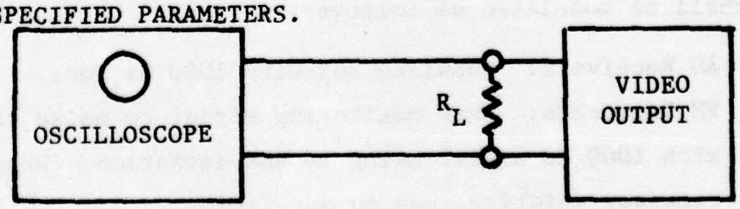


Figure CS01-2. Typical Methods for Monitoring Performance During Susceptibility Tests.

METHOD CS02

CONDUCTED SUSCEPTIBILITY, 50 kHz TO 400 MHz, AC AND DC POWER LINES

1. Purpose. - This test method shall be used to determine the susceptibility of equipments when signals in the 50 kHz to 400 MHz frequency range are coupled onto their ac and dc power lines.

2. Apparatus. - The test apparatus shall include the following:

   a. Signal Source
   b. Line Impedance Stabilization Network
   c. Current Probe
   d. Tunable Vacuum Tube Voltmeter
   e. EMI Meter

3. Test Configuration. - The test configuration shall be as shown in Figure CS02-1. Monitoring devices for the test item shall be as shown in Figure CS01-2.

4. Test Procedure. - Apply the susceptibility signal to the Type N terminal of the LISN and adjust the level until the readings on the voltage and current monitoring devices indicate a power equal to the applicable limit of Figure 19, MIL-STD-461, FAA Notice 1C.

Slowly tune the generator through the required frequency range while maintaining the required signal level (or greater) and monitoring or signs of susceptibility.

If the test item is susceptible to the applicable limit level, decrease the signal output to determine the threshold level. Record all pertinent data.

When the test item includes audio channels or receivers, the test signal shall be modulated as follows:

   a. AM Receivers: Modulate 50% with 1000 Hz tone.
   b. FM Receivers: When monitoring signal-to-noise ratio, modulate with 1000 Hz signal using 10 kHz deviation. When monitoring receiver quieting, use no modulation.
   c. SSB Receivers: Use no modulation.
   d. Other Equipments: Same as for AM receivers.

NOTES:

(1) FOR TWO WIRE POWER SYSTEMS, TEST HOT LEAD ONLY.

(2) SPECIAL CAUTION SHOULD BE EXERCISED TO ASSURE THAT PROPER POWER LEAD IS GROUNDED, WHEN REQUIRED.

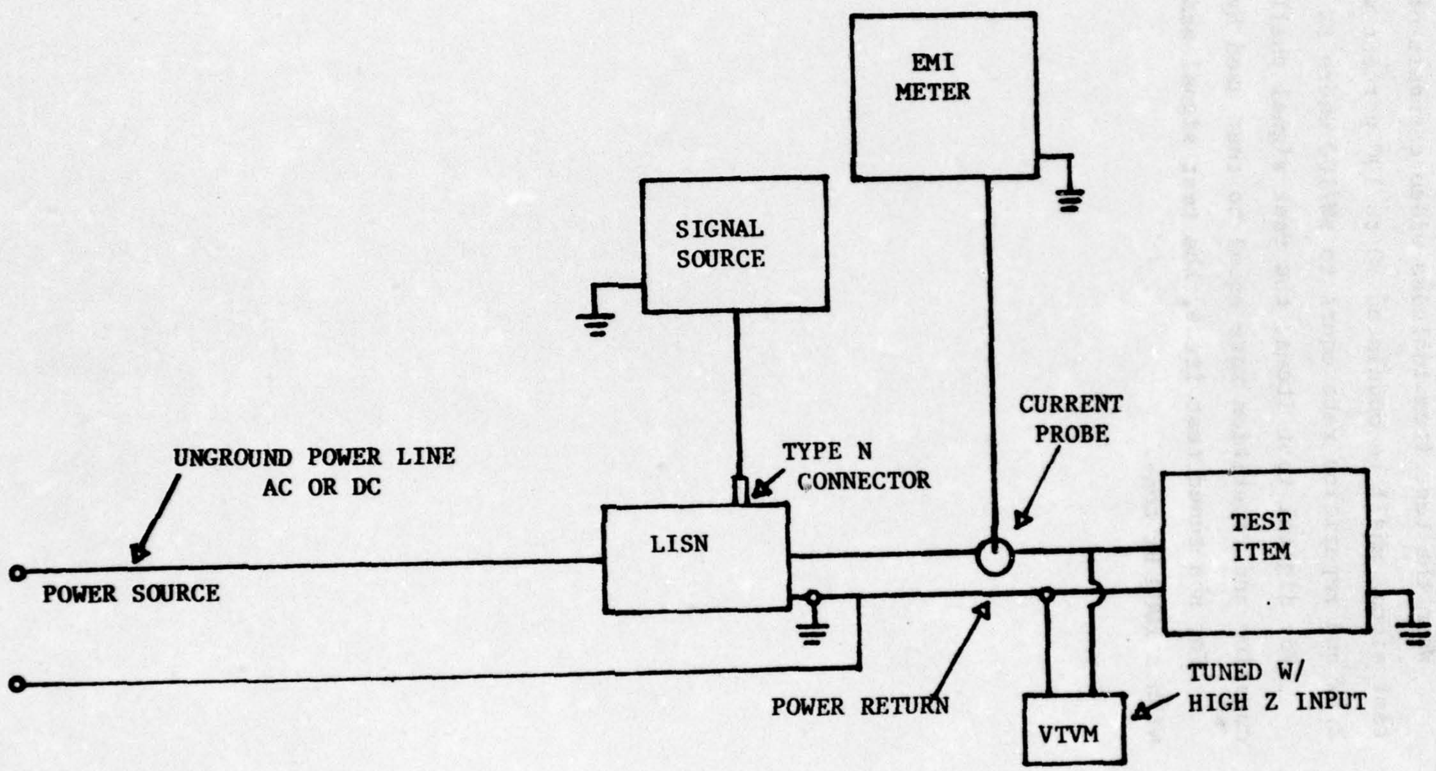


Figure CS02-1. Test Configuration for Method CS02.

When the test item includes video channels other than receivers, the test signal shall be modulated 90 to 100 percent with a pulse of duration 2/BW and repetition rate equal to BW/100 where BW is the video bandwidth.

For digital test items, the test signal shall be pulse modulated with duration and repetition rate equal to that used by the test item.

For non-tuned test items, the test signal shall be modulated 50 percent with a 1000 Hz tone.

METHOD CS03

CONDUCTED SUSCEPTIBILITY, INTERMODULATION

1. Purpose. - This test method is used to determine the susceptibility characteristics of test items resulting from the mixing of two undesired signals to form intermodulation products. The method is applicable to receivers and tuned amplifiers operating in the frequency range of 15 kHz to 10 GHz.

2. Apparatus. - The test apparatus shall include the following:

a. Signal Generators

b. A three-port network or junction providing at least 20 dB isolation between signals generators and maintaining the proper impedance match at all its signal ports. (Since this test does not involve frequency scanning, directional couplers could conveniently be employed in conjunction with attenuators to provide the required isolation. Care must be exercised to assure that these networks are not a source of intermodulation products.)

c. Low-pass Filters (to attenuate signal generator harmonics to a level at least 80 dB below the fundamentals).

d. Frequency Measurement Equipment.

e. Output Monitor.

3. Symbols. - Symbols are defined as follows:

a. fo = test sample tuned frequency.

b. fa = frequency of the interfering source signal nearest to fo.

c. fb = frequency of other interfering source signal.

d. Δf = fa - fo

e. IF = receiver intermediate frequency

f. m, n = integers giving multiples of fa and fb, respectively.

4. Test Configuration. - The test configuration shall be as shown in either Figure CS03-1 or Figure CS04-1.

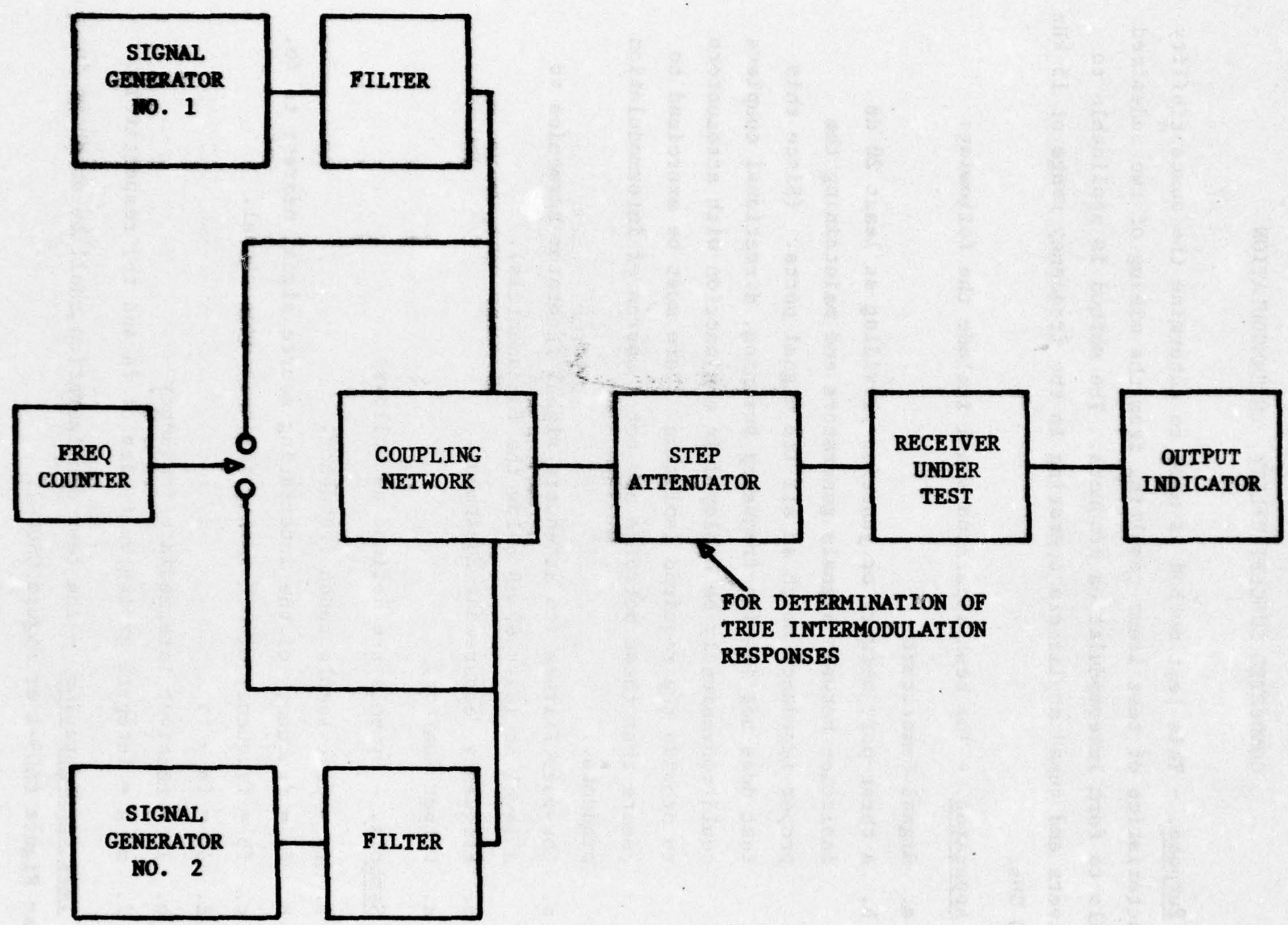


Figure CS03-1. Test Configuration for Method CS03.

5. Test Procedure. - The measurements to be performed shall be confined to the second order positive and negative Δf (fa above and below fo), third order positive and negative Δf, and the fifth order negative products (order =r=m+n). The third order difference mix is potentially the most serious type of intermodulation since both signals may be within the rf pass band of the input circuits. An example of the relationships of this type of mix is given by: fo = 2fa - fb.

Special care must be taken in conducting this test to insure that intermodulation does not occur within the signal generators themselves. Also, appropriate filters shall be employed to remove unwanted generator outputs which may interfere with measurements.

For non-pulse systems, signal generator No. 2 shall be unmodulated, and signal generator No. 1 shall be modulated 30 percent with 1000 Hz for AM receivers or unmodulated for FM and SSB receivers. For pulsed systems, one of the input signals shall be unmodulated, and the other shall be a pulsed signal having a pulse width and repetition rate equal to the nominal pulse characteristics of the system under test.

To measure receiver intermodulation, proceed as follows:

a. Set the receiver controls to the same positions as specified in the detailed equipment specification for the measurement of sensitivity. Tune signal generator No. 1 to the receiver tuned frequency, fo. Adjust the signal generator output level for a standard receiver response. Compute the receiver sensitivity level by subtracting the attenuation (in dB) of the coupling network and filter from the signal generator output (in dBM). Record this level.

b. Commence to measure the intermodulation responses. With signal generator No. 1 turned on and modulated as previously, set output level to 66 dB above the level obtained in step a. Slowly tune generator above fo until there is no longer a response at the receiver output. Measure this frequency to the accuracy indicated above and record as fa. The difference between fo and fa is Δf. Leave generator No. 1 at fa.

c. Tune signal generator No. 2 to fb = fa + fo. The frequency should be measured to the required accuracy and the signal level set to the same level as indicated for signal generator No. 1. Note resulting change in monitored output level of test sample, if any. Tune generator No. 2 as required to peak. Monitor output level. The receiver should not have a response due to either fa or fb alone; if such a response is present, it is not due to intermodulation and should be neglected for this test.

d. When an intermodulation response is present, reduce the levels of both generators until the standard reference output is obtained. Record the level and frequencies associated with each response. The difference between the resulting signal generator levels and the level obtained in step a. is the intermodulation rejection.

e. Repeat steps b., c., and d. only using a negative Δf (fa below fo) and tuning signal generator No. 2 to fb = fo - fa.

f. Repeat steps b., c., and d. to observe third-order intermodulation products for various positive and negative Δf. For each fa determined as indicated in preceding steps, determine an fb which will have a third order product at fo: fb = fo + $2\Delta f$ with Δf = fa - fo. For example, set signal generator to fb = fo + 2 (fa - fo) = 2 fa - fo, or to fb = $\frac{fa - fo}{2}$.

g. In a like manner test for fifth order intermodulation products in accordance with the equation fb = fo + $4\Delta f$ where Δf = fa - fo. However, if no second or third order products were observed, a search for fifth order products need not be undertaken.

NOTES. -

The standard reference output level in this test shall be as specified in the section of the test item's detailed equipment specification pertaining to receiver sensitivity measurements. When the equipment specification does not define this parameter, the following output reference levels shall be used:

a. AM Receivers: $\frac{s + n}{n} = 10$ dB

b. SSB Receivers: $\frac{s + n}{n} = 10$ dB

c. FM Receivers:

(1) Unmodulated: 10 dB quieting

(2) Modulated: $\frac{s + n}{n} = 10$ dB

d. Pulsed Receivers: As above.

Because some generators may drift in frequency, it may be necessary to retune each generator to be sure the maximum response is being measured.

To verify that each product is a receiver intermodulation product and not a signal generator spurious emission, a signal generator intermodulation product, or a receiver spurious response, the following procedure shall be followed:

a. Alternately turn off each signal generator (or greatly attenuate its output). If the receiver response remains when one generator is off, it is not an intermodulation product. If the response disappears, it may be either signal generator intermodulation or receiver intermodulation.

b. For non-pulse receivers, after determining the levels for a standard response, increase the signal generator output levels simultaneously by 3 dB. Record the receiver output level indication. Increase the attenuation on the step attenuator by 3 dB. Receiver intermodulation products will vary non-linearly with the amount of inserted attenuation, while signal generator intermodulation products should vary by the amount of attenuation. Thus, if the receiver output level drops only 3 dB when 3 dB of attenuation is added, the response is not due to receiver intermodulation. Note that with the signal generator levels increased by 3 dB, a standard receiver response should exist for true receiver intermodulation products. For pulse type receivers, the same validation procedure shall be used, but it may be necessary to use a large attenuator and correspondingly larger signal changes in order to observe the proper changes.

For receivers with waveguide inputs, the required frequency range shall be from 0.8 f_{co} to 10 GHz, where f_{co} is the waveguide cutoff frequency.

METHOD CS04

CONDUCTED SUSCEPTIBILITY, REJECTION OF UNDESIRED SIGNALS AT INPUT TERMINALS (TWO-SIGNAL GENERATOR METHOD)

1. Purpose. - This test method is used for determining the spurious responses that result when two signals are applied to the input terminals of receivers and tuned amplifiers operating in the 15 kHz to 10 GHz frequency range.

2. Apparatus. - The test apparatus shall include the following:

   a. Signal Generators

   b. Low Pass Filters

   c. Frequency Measurement Equipment

   d. Output Monitoring Devices

   e. Three-Port Network providing at least 20 dB isolation between the signal generators. This network must maintain the proper impedance match at all its ports and must not generate intermodulation products.

3. Symbols. - Symbols are defined as follows:

   a. fo = test sample tuned frequency.

   b. fsp = frequency at which spurious response occurs.

   c. IF = test sample intermediate frequency.

   d. Flo = test sample local oscillator frequency.

4. Test Configuration. - The test configuration shall be as shown in Figures CS03-1 and CS04-1. Receivers shall have their AVC and AFC disabled.

5. Test Procedure. -

   a. With signal generator No. 2 turned off, tune generator No. 1 to fo and modulate output in accordance with note below. Set level to produce standard reference output as defined in the detailed equipment specification or as indicated in note below. Record level and frequency of generator.

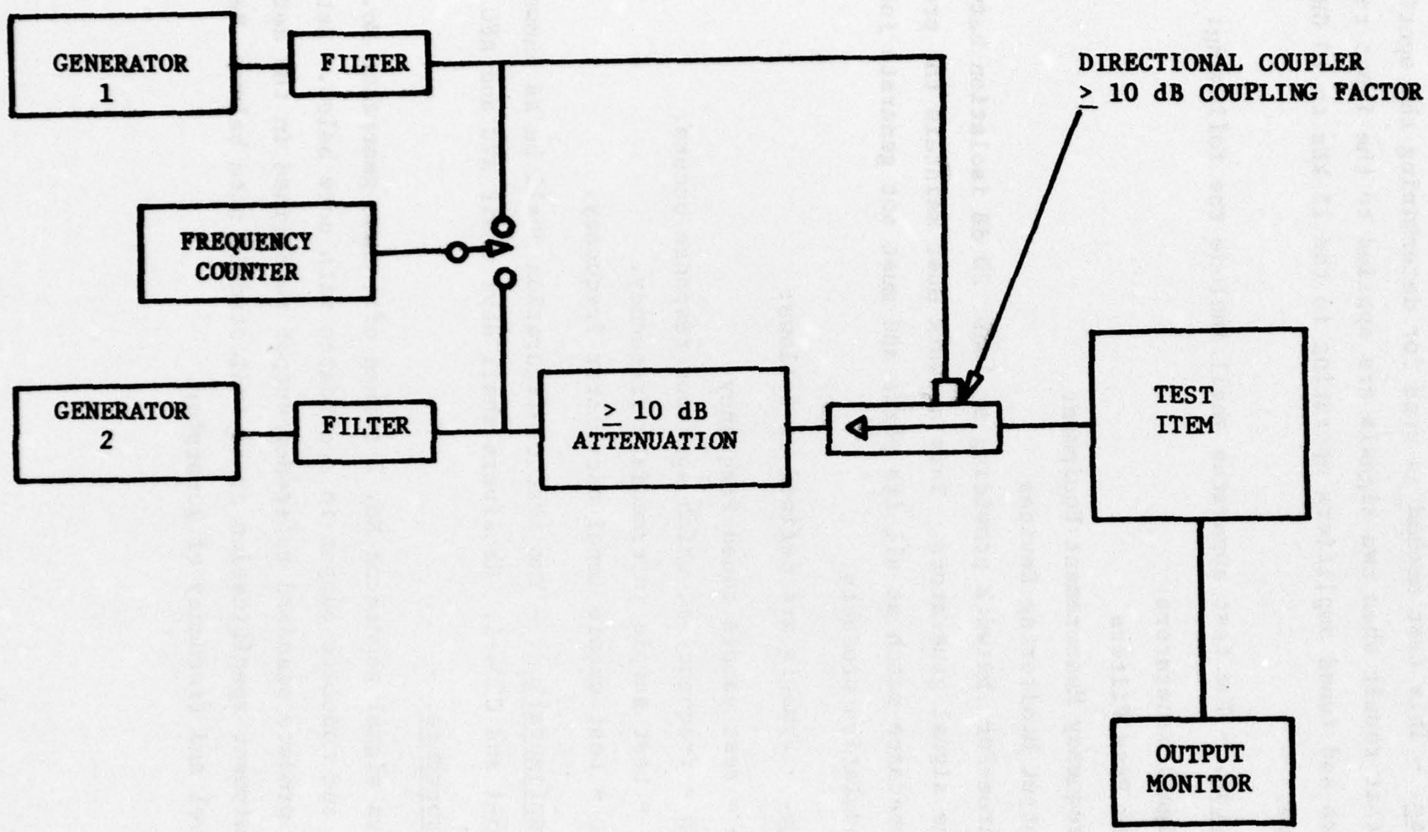


Figure CS04-1. Test Configuration for Method CS04.

b. Repeat step (a) with signal generator No. 1 off and signal generator No. 2 turned on and tuned to fo with desired modulation. Record level and frequency of generator.

c. For the remainder of the test, turn both signal generators on with required modulation on signal generator 1 and signal generator 2 unmodulated.

d. Set signal generator 1 at the level obtained in step (a) with proper modulation and signal generator 2 at the specified level above that required to obtain the standard reference output in step (b).

e. Scan the applicable frequency range with signal generator 2. When a spurious response is obtained, reduce the output of signal generator 2 until the standard reference output is obtained. Calculate the difference in dB between this level and that obtained in step (b). This is the spurious response rejection.

NOTES. -

The modulation used in this test shall be as specified in the section of the test item's detailed equipment specification pertaining to receiver sensitivity measurements. When the equipment specification does not define this criteria, the following modulation shall be used:

a. AM Receivers - The signal generators shall be 30 percent modulated by a 1000 Hz sine wave.

b. SSB Receivers - The signal generators shall be unmodulated.

c. FM Receivers - The signal generators shall be modulated at 1000 Hz with 10 kHz deviation.

d. Pulsed Receivers - The modulation pulse shall be adjusted so that 80 percent of its spectral energy lies within the 3 dB bandwidth of the receiver.

The standard reference output level used in this test shall be as specified in the section of the test item's detailed equipment specification pertaining to receiver sensitivity measurements. When the equipment specification does not define this criteria, the following output reference levels shall be used.

a. AM Receivers: $\frac{s + n}{n} = 10$ dB

b. SSB Receivers: $\frac{s + n}{n} = 10$ dB

c. FM Receivers - Modulated: $\frac{s + n}{n} = 10$ dB

d. Pulse Receivers: As above.

The applicable frequency range for this test is as follows:

a. Signal generator 2 shall be scanned over the entire frequency range determined from the listing shown herein. The frequency range ω as shown in Figure 19 of MIL-STD-461A, FAA Notice 1C is exempt from this test. The lower frequency limit shall be the lowest value obtained from Column A and the upper frequency limit shall be the highest value found in Column B (this upper limit shall not exceed 10 GHz).

Column A	Column B
IF/5	$5F_{lo}$ + IF
.05 fo	20 fo

When testing multiple conversion receivers, the IF of Column A shall be the lowest intermediate frequency while the IF and F_{lo} in Column B shall be the highest frequencies associated with the receiver.

b. For receivers with waveguide inputs, the required frequency range shall be from 0.8 fco to the higher level obtained from Column B (see a.) but shall not exceed 10 GHz (fco is the waveguide cutoff frequency).

All signal generators emit a substantial amount of harmonics and other spurious energy. Care shall be taken not to mistake an emission of the generator falling on fo for a spurious response of the equipment. It is possible to have spurious response indications at fo/2, fo/3, fo/4, etc. which are not due to generator harmonics. Appropriate low pass or band stop filters may be used to eliminate this problem.

METHOD CS06

CONDUCTED SUSCEPTIBILITY, TRANSIENTS, POWER LEADS

1. Purpose. - The purpose of this test is to determine equipment susceptibility to transient interference on power lines. This test shall be performed on all ungrounded ac and dc input power leads.

2. Apparatus. - The test apparatus shall include the following:

a. Transient Generator with characteristics as follows:

(1) Pulse Width of 10 μsec.

(2) Pulse Repetition Rate of 3 to 10 p.p.s.

(3) Voltage Output as required by MIL-STD-461, FAA Notice 1C.

(4) Output Control.

(5) Phase Positioning from 0 to 360 degrees.

(6) Adequate transformer current capacity (commensurate with line being tested).

(7) External Synch capability.

(8) External Trigger capability.

(9) Source impedance of 0.5 ohms or less.

b. 10 μfd Capacitor.

c. Oscilloscope.

3. Test Configuration. - The test configuration shall be as shown in either Figure CS06-1 or Figure CS06-2.

4. Test Procedure. - The applied transient amplitude, rise time, and duration, as measured by the oscilloscope (10 MHz bandwidth required) across the input terminals of the test item, shall follow the typical wave shape specified in the applicable limits. Synchronization and triggering shall be used to position the transient to specific test item signal conditions which will produce maximum susceptibility.

Alternately positive and negative, single and repetitive (6 to 10 p.p.s.) transients shall be applied to the test item's ungrounded input lines for a period not less than 10 minutes in duration. Transients shall be synchronized to the power line frequency and positioned on each

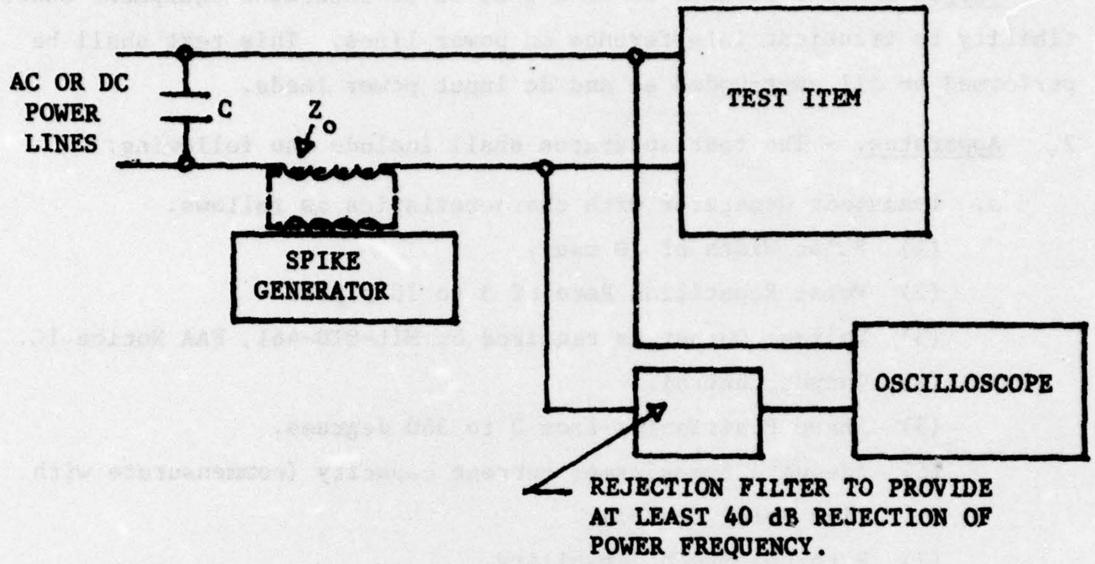


Figure CS06-1. Test Configuration for Method CS06, Series Injection.

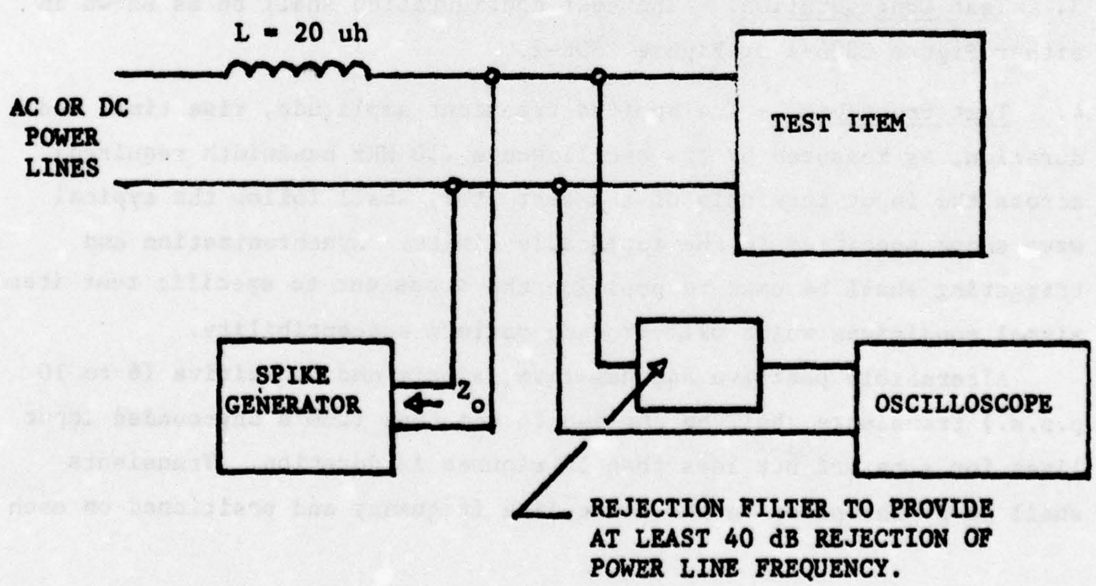


Figure CS06-2. Test Configuration for Method CS06, Parallel Injection.