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Recommended Insertion Loss Test Methods for EMI Power Line Filters

RATIONALE

The document is still a valid standard which may benefit from a future update. The basic technology described in the document is still valid. The subcommittee designated to update the document is not currently active, so stabilization of the document is the best approach until such time as a committee can be established to open a WIP.

STABILIZED NOTICE

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

1. SCOPE:

This document presents standard methods to evaluate the common mode and differential mode insertion loss of passive electromagnetic interference power line filters from 10 kHz through 10 GHz. Insertion loss test methods for both quality assurance and performance prediction purposes are described. The performance prediction tests are selected to more closely approximate operating impedances. They are not intended to be inclusive or to represent worst case conditions. However, the methodology of this document can be used to determine the performance in an arbitrary impedance circuit.

2. APPLICABLE DOCUMENTS:

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1 SAE Publications:

Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

ARP936 Capacitor, 10 µF for EMI Measurements

2.2 ANSI Publications:

Available from ANSI, 11 West 42nd Street, New York, NY 10036-8002.

ANSI C63.13:1991 Guide on the Application and Evaluation of EMI Power Line Filters for Commercial Use

2.3 U.S. Government Publications:

Available from DODSSP, Subscription Services Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

MIL-STD-220A Method of Insertion-Loss Measurement
MIL-STD-462D Measurement of Electromagnetic Interference Characteristics

2.4 Underwriter Laboratories Publications:

Available from Underwriter Laboratories Publications, 333 Pfingsten Road, Northbrook, IL 60062.

UL-1283 Electromagnetic Interference Filters

2.5 Other Publications:

CISPR-17: 1981 Methods of Measurement of the Suppression Characteristics of Passive Radio Interference Filters and Suppression Components

3. BACKGROUND:

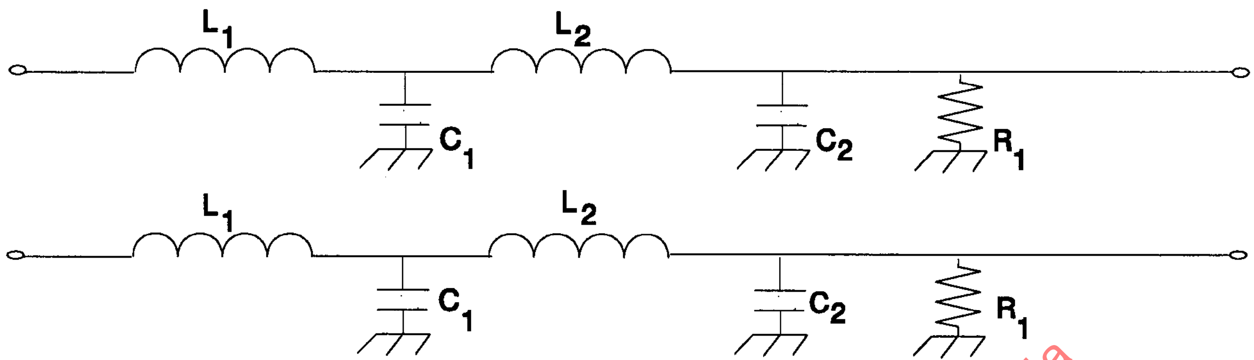
3.1 Status Quo:

The ANSI C63.13 document is a good overall reference on the use and function of power line filters. This document supplements the ANSI document by defining a test method for other than in a 50 Ω system. Prior to the issuance of this document, the insertion loss performance of EMI power line filters has been evaluated using the test methods of MIL-STD-220A, or variations thereof. Those variations, together with the inherent shortcomings of that standard, have caused confusion among filter users, and have prevented or delayed acquisition of effective power line filters for specific applications. CISPR-17 also presents a no load test method with mismatched impedances (0.1/100 Ω), which is supported by the IEC as a filter standard for measuring insertion loss. Reports indicate it functions okay for up to 60 dB isolation but is limited in evaluating 100 dB power line filters.

3.2 Shortcomings of MIL-STD-220A (Rev. 15 Dec. 1959):

3.2.1 MIL-STD-220A addresses the insertion loss testing of more traditional filters (“Type 1”), such as depicted in Figure 1 herein; its methods are inadequate for more recently developed filter designs (“Type 2”) such as shown in Figure 2. Filter schematics shown are generalized. Either type of filter may have more or fewer sections. Capacitors may also have small value "Q-killer" resistors (typically 1 to 10 Ω) placed in series. Filters may have "bleeder" resistors placed in parallel to capacitors as per UL-1283. Although MIL-STD-220A does cover testing of “multi-circuit” filters, it makes no distinction between common mode and differential mode insertion loss performance, which, for a Type 2 filter, can be markedly different. The user requirement for either can also differ, depending upon the particular problem to be solved by use of the filter. Numerous filter users and manufacturers have established in-house filter test methods to measure both types of insertion loss, but the lack of a common set of methods has hindered meaningful and useful communication and comparison of competing filter designs.

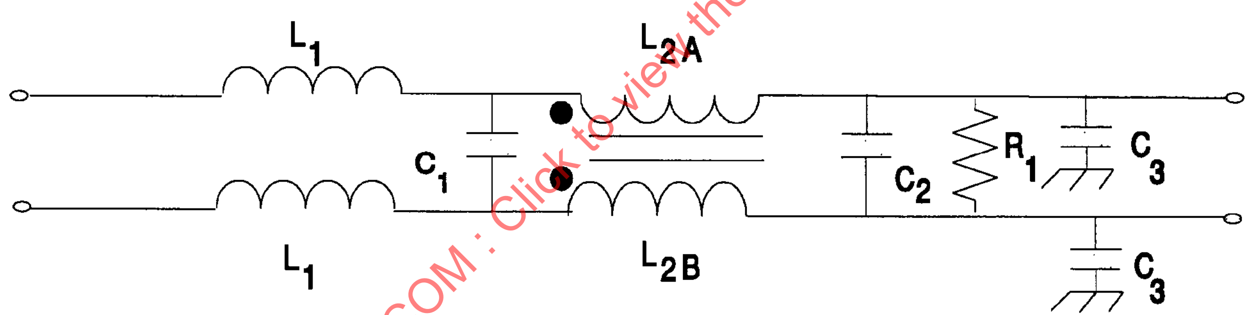
3.2.2 MIL-STD-220A uses a resistive 50 Ω source/50 Ω load system, which is not representative of realistic power line impedances, especially at frequencies much below 1 MHz. The resulting insertion loss data can not realistically be utilized at lower frequencies to approximate filter performance in an actual power circuit. Published 50 Ω test data is almost universally misused by filter users as a first approximation of benefit to be gained by insertion of the filter into a power circuit. Untold time and effort are wasted due to the dissimilarity between 50 Ω published curves and actual in-circuit performance. While the best check of filter performance is insertion into the actual intended circuit, a need exists for a methodology to predict performance more accurately. This is accomplished by using filter terminating impedances in insertion loss test setups which more accurately represent typical circuit terminating impedances.



L_1' L_2' Approx. 20 - 500 µH R_1 = Bleeder Resistor

C_1' C_2' Approx. 0.0001 - 10 µF

FIGURE 1 - “Type 1” EMI Filter



L_1 Approx. 20 - 500 µH

L_{2A} L_{2B} Approx. 0.5 - 30mH

C_1' C_2' Approx. 0.5 - 10 µF

C_3 Approx. 0.001 - 0.05 µF

R_1 = Bleeder Resistor

FIGURE 2 - “Type 2” EMI Filter

3.3 Positive Features of MIL-STD-220A:

3.3.1 The general 50 Ω/50 Ω test setup of MIL-STD-220A advantageously utilizes commonly available 50 Ω RF test equipment, and provides a convenient quality assurance tool for inspecting the performance of EMI filters.

3.3.2 MIL-STD-220A covers the important aspect of measuring insertion loss with simulated load current, to determine adequacy of inductor design.

4. INTENT:

The intent of this document is to expand upon the scope of MIL-STD-220A, while not requiring any extensive new hardware or fixturing for the new test setups mandated by that expansion. The following specific benefits are intended:

a. Separate measurement of both common mode and differential mode insertion loss.
b. Separate measurement methods for quality assurance and performance prediction purposes.
c. Standardization of insertion loss test methods throughout the EMC community.
d. Continued usage of relevant portions of MIL-STD-220A.

5. PROCEDURES FOR INSERTION LOSS MEASUREMENT:

Table 1 summarizes the tests herein, and gives the intent of each test.

TABLE 1

Paragraph	Test	Setup Drawing
5.1	Quality Assurance 50 Ω/50 Ω, Differential Mode, 10 kHz to 5 MHz.	Figure 3
5.2	Quality Assurance 50 Ω/50 Ω, Common Mode, 10 kHz to 30 MHz.	Figure 4
5.3	Performance Prediction High & Low Source Impedances, Differential Mode, 10 kHz to 5 MHz.	Figures 5 and 6
5.4	Performance Prediction Common Mode, 10 kHz to 30 MHz.	Figure 7
5.5	QA & Performance Prediction 50 Ω/50 Ω 30 MHz to 10 GHz	Figure 8

5.1 Differential Mode Quality Assurance Testing:

5.1.1 Test Setup: See Figure 3.

5.1.2 Frequency Range: The frequency range is 10 kHz to 5 MHz, with and without load current.

5.1.3 Rationale: This test uses line impedance stabilization networks (LISN's) to present more realistic source and load impedances than the 50 Ω resistive terminations of MIL-STD-220A. The LISN's are networks with 50 microhenries of series inductance, per Figure 2 of MIL-STD-462D.

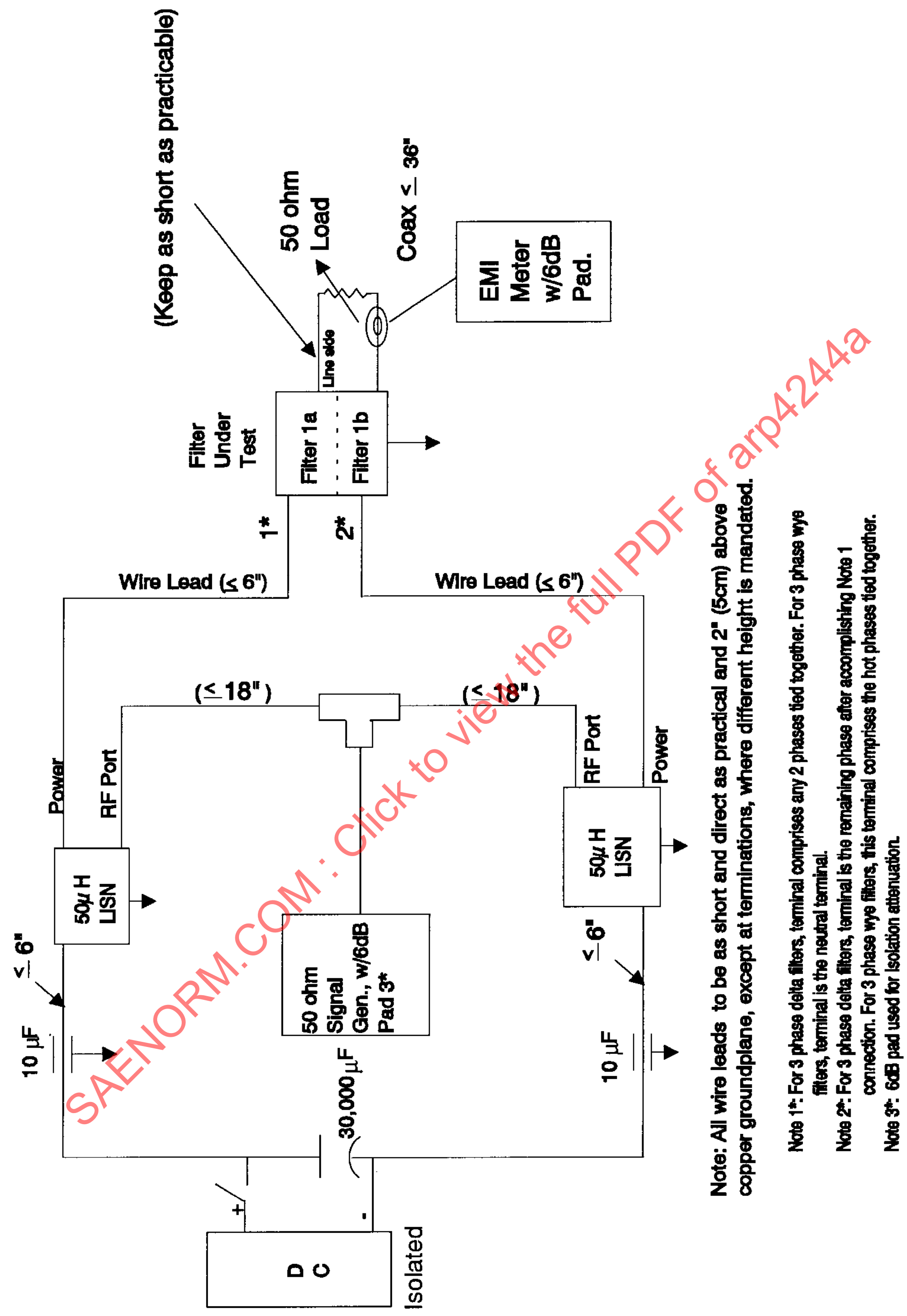


FIGURE 3 - Differential Mode QA Test,
10 kHz to 5 MHz

5.1.4 Applicability: This test should be performed on a sampling basis, or per other contract requirements, to verify compliance of manufactured filters with a minimum insertion loss performance curve. For differential mode quality assurance purposes, this test replaces MIL-STD-220A, from 10 kHz to 5 MHz.

5.1.5 Procedure: Set up per Figure 3 using series shorting wires to replace the two filter circuits to be tested.

NOTE: Two filters or two filter circuits of a multi-circuit filter are required for this test method.

Attach the test sample power terminals to the load keeping all leads as short and direct as practicable. For load testing, insert the DC power supply as shown. For no load testing, remove the supply or open its output breaker. Bond the 10 microfarad feed-through capacitors and the LISN’s to a conductive test ground plane large enough to accommodate those devices, as well as the filters to be tested. The ground plane should be of copper (0.25 mm minimum thickness) or brass (0.63 mm minimum thickness), with dimensions adequate to allow convenient layout per Figure 3. Connect the RF ports of the two LISN's to the tee with coaxial cables, and likewise connect the filter bypass to the load. Connect a 50 Ω, 10 kHz to 5 MHz, signal source to the input lines to the load and a 50 Ω EMI meter, spectrum analyzer, or other RF voltmeter to the current probe.

Adjust the output of the signal generator to produce a signal level over the test range of 10 kHz to 5 MHz that is above the noise floor of the EMI meter by at least the required amount of attenuation plus 10 dB, as measured by the EMI meter on the load. This will ensure readings above the noise floor of the EMI meter. Record the signal levels received by the EMI meter. Without changing the output level of the signal generator, insert the two filter circuits to be measured into the test setup. Measure the filtered levels now seen at the EMI meter. The difference, in decibels, between the original signal level at each frequency and the filtered level is the filter insertion loss at that frequency:

$$\text{Original level (dB } \mu\text{V)} - \text{Filtered level (dB } \mu\text{V)} = \text{Insertion Loss (dB)} \qquad \text{(Eq.1)}$$

Swept RF response testing with a scalar network analyzer or spectrum analyzer with tracking generator is recommended to reduce test time and maximize the number of data points. If swept techniques are not used, a minimum of twelve test frequencies shall be chosen throughout the test frequency range. Required frequencies are 10 kHz, 14 kHz, 20 kHz, 40 kHz, 80 kHz, 100 kHz, 200 kHz, 400 kHz, 800 kHz, 1 MHz, 2 MHz, and 5 MHz. In addition, for non-swept tests, record insertion loss at filter resonant frequencies, which can be found by searching for anomalous responses significantly above or below a curve connecting the responses at the above twelve frequencies. An advantage of swept frequency testing is that the resonant frequencies are readily apparent.

5.1.5 (Continued):

For no load testing, the 10 microfarad feed-through capacitors (per ARP936) and the 30,000 microfarad electrolytic capacitor will supply an adequate AF/RF short across the DC power source, so it may be left out of the setup. For full load testing, the DC current equal to the rms rating of the filter should be applied. A DC current equal to the peak AC current may be used if saturation concerns exist, but care needs to be taken not to cause overheating of the filter in this condition. Refer to notes 1 and 2 on Figure 5 for treatment of multiphase filters.

5.2 Common Mode Quality Assurance Testing:

5.2.1 Test Setup: See Figure 4.

5.2.2 Frequency Range: The frequency range is 10 kHz to 30 MHz, with and without load current.

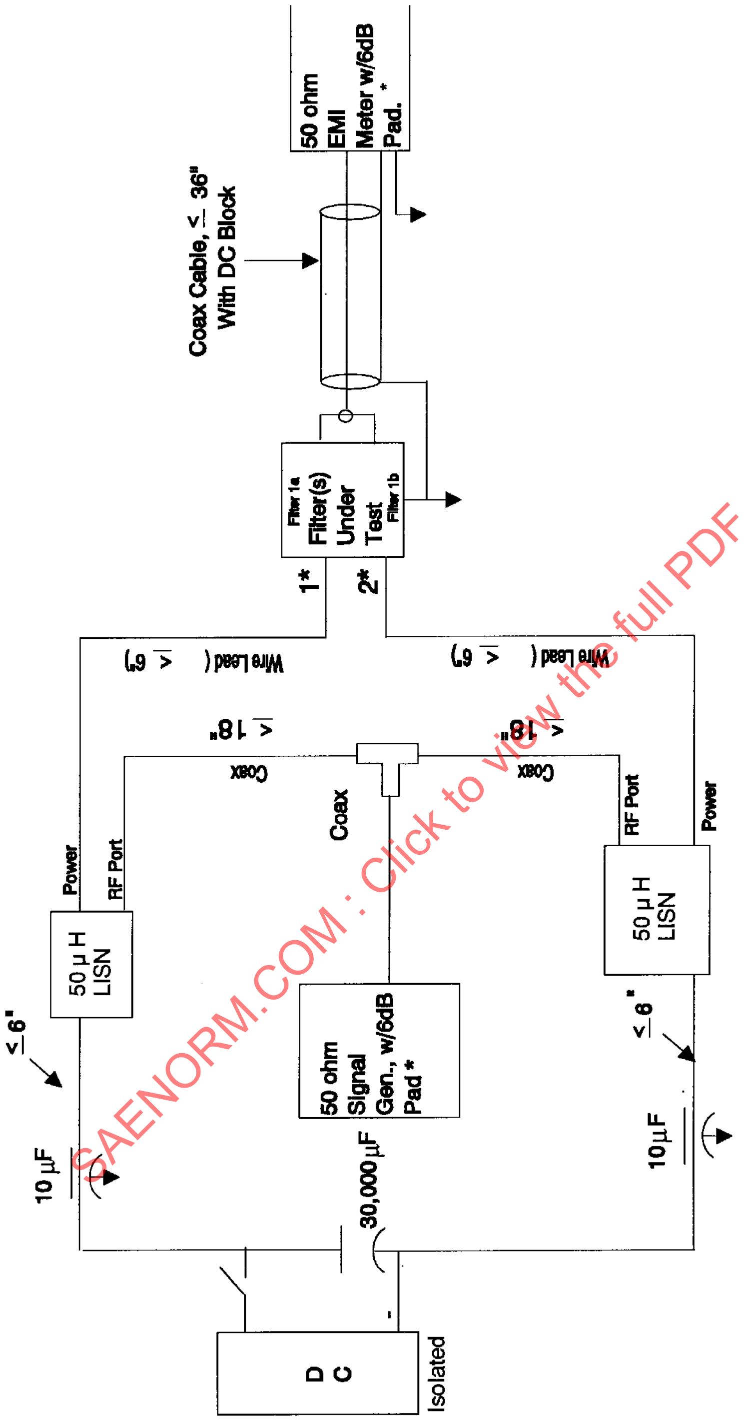
5.2.3 Rationale: This test uses LISN's as source impedances and a 50 Ω EMI meter as the load impedance. The test signal from a 50 Ω signal generator is common mode injected into the two LISN's through a coaxial tee fitting and their respective RF ports. The two filter circuits under test are shorted together on the load side. The DC current for the full load condition flows differentially through the two filter sections and the output side short, while the RF test signal is injected and received common mode.

5.2.4 Applicability: This test should be performed on a sampling basis, or per other contract requirements, to verify compliance with a minimum insertion loss performance curve. For common mode quality assurance purposes, this test replaces MIL-STD-220A, from 10 kHz to 30 MHz.

5.2.5 Procedure: Set up per Figure 4 using series wire shorts to replace the filter circuits to be tested.

NOTE: Two filters or two filter circuits of a multi-circuit filter are required for this test method.

Attach the test sample coupled terminals to each other and to the input of a 50 Ω EMI meter, or other 50 Ω input receiving device. For load testing insert the DC power supply as shown. Provide current limiting other controls to limit the current (since the load is a short circuit) to provide a very low impedance load below the frequency when the LISN inductors become effective. For no load testing, remove the power supply or open its output breaker. Bond the 10 microfarad feed-through capacitors and the LISN's to the ground plane. Connect the RF ports of the two LISN's to the 50 Ω coaxial cables and a coaxial tee fitting.



Note 1*: For 3 phase delta filters, terminal comprises any 2 phases tied together. For 3 phase wye filters, terminal is the neutral terminal.

Note 2*: For 3 phase delta filters, terminal is the remaining phase after accomplishing Note 1 connection. For 3 phase wye filters, this terminal comprises the hot phases tied together.

* Note 3: 3dB pad used for isolation attenuation.

Verify absence of dc voltage at filter load terminal prior to connection to EMI meter.

FIGURE 4 - Common Mode QA Test,
10 kHz to 30 MHz

5.2.5 (Continued):

Adjust the output of the signal generator to produce a signal level above the test range of 10 kHz to 30 MHz that is over the EMI meter noise floor by at least the required amount of filter attenuation plus 10 dB, as measured by the EMI meter, between the power terminals and the ground plane. Without changing the output level of the signal generator, insert the two filter circuits to be measured into the test setup. A sealed RF compartment should be considered for mounting on the load end of the filter assembly to provide input to output isolation and to facilitate termination of the shorted outputs of the two filter circuits in a coaxial fitting. Connect the RF fitting on the RF compartment to the EMI meter with a coaxial cable. Measure the filtered level versus frequency at the EMI meter. The decibel difference between the original signal level and filtered level at each frequency is the common mode filter insertion loss at that frequency:

$$\text{Original level (dB } \mu\text{V)} - \text{Filtered level (dB } \mu\text{V)} = \text{Insertion Loss (dB)} \qquad \text{(Eq.2)}$$

Swept response techniques are encouraged. If swept techniques are not used, a minimum of 15 frequencies, shall be chosen. Required frequencies are 10 kHz, 14 kHz, 20 kHz, 40 kHz, 80 kHz, 100 kHz, 200 kHz, 400 kHz, 800 kHz, 1 MHz, 2 MHz, 4 MHz, 8 MHz, 16 MHz, and 30 MHz. In addition, for non-swept tests, a search shall be made for resonant frequencies, and insertion loss recorded for these points.

5.3 Differential Mode Performance Prediction Testing:

5.3.1 Test Setup: See Figure 5.

5.3.2 Frequency Range: The frequency range is 10 kHz to 5 MHz, with and without load current.

5.3.3 Rationale: This test produces results approximating the low frequency differential mode performance of power line filters in actual power line circuits. Filters are largely used to produce compliance with conducted emission specifications as measured in test setups with standardized source impedances. The two test methods herein use, respectively, the two common standard line impedance representations: 1) the 10 microfarad feed-through capacitor, and 2) the 50 microhenry line impedance stabilization network. In each test circuit, a 30,000 microfarad electrolytic capacitor is connected across the DC power source, to swamp its output impedance. For the test circuit using LISN's, 10 microfarad feed-through capacitors are utilized on the power source side of the LISN's for the same purpose. The EMI test signal is coupled into the circuit differentially, using a common passive EMI current probe. As with previous tests, two filter circuits are needed to perform the test. The DC power supply is set for the rms value of the rated voltage, and the non-inductive load resistor is adjusted to produce peak equivalent of rated current. For no load testing, the DC power source is simply removed, and the load resistor is adjusted in turn to 1, 10, and 100 Ω. The filtered test signal level is measured differentially on the load side of the filter with a standard EMI current probe.

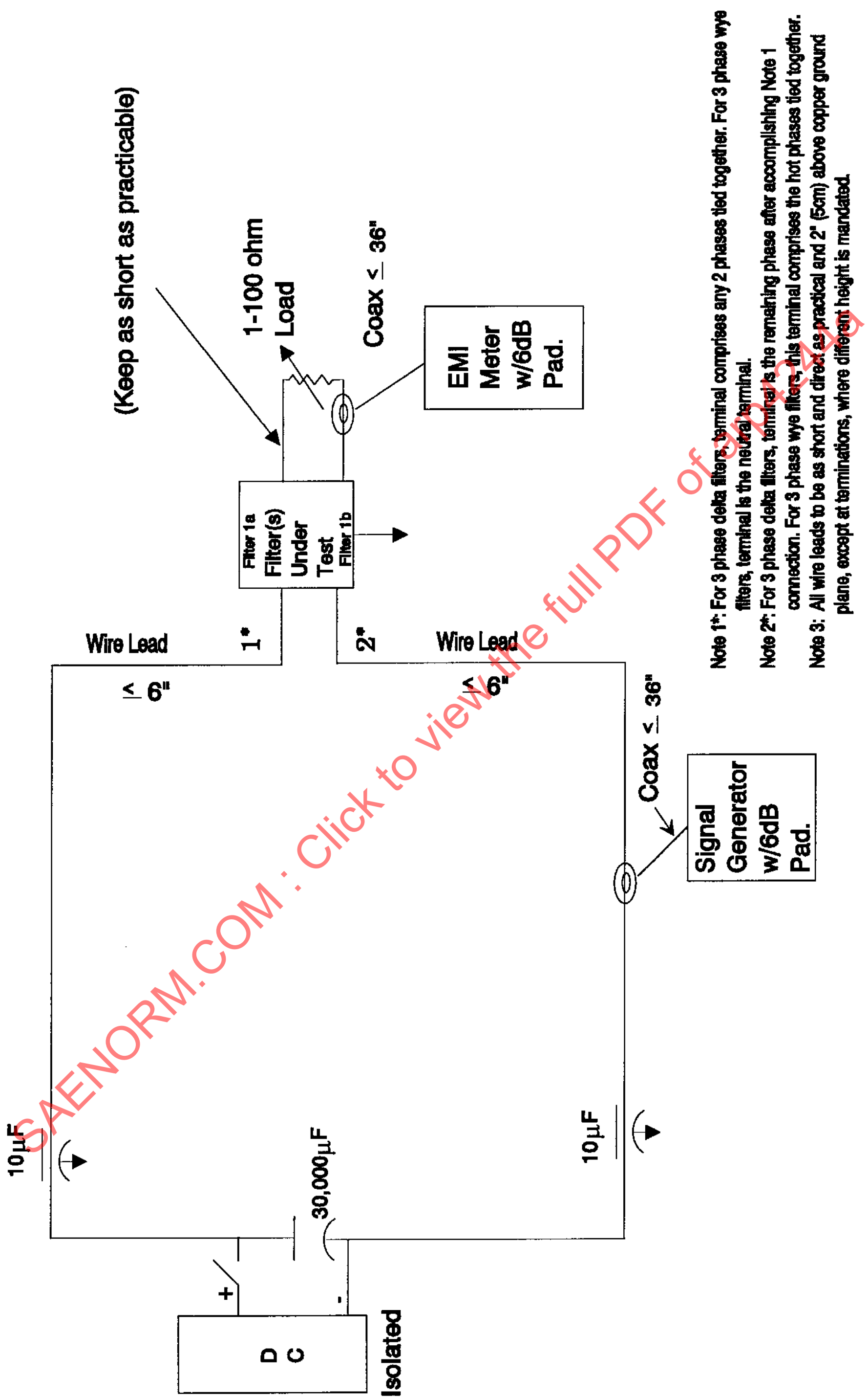


FIGURE 5 - Differential Mode Performance Prediction Test, With Low Source Impedance, 10 kHz to 5 MHz

5.3.4 Applicability: One or both of the two test methods described below should be used, once only, on a given filter, to produce performance prediction data for that filter. This data can then be used by filter suppliers and users to predict nominal performance in an intended EMI test circuit. For differential mode performance prediction purposes, these two methods replace MIL-STD-220A, from 10 kHz to 5 MHz.

These two test methods are not intended to be used for quality assurance purposes; their sole intent is to help engineering evaluation of potentially useful filter designs.

5.3.5 Procedure: Set up per Figure 5 (with 10 microfarad feed-through capacitor, for low source impedance) or Figure 6 (with 50 microhenry LISN, for higher source impedance), without the filter circuits to be tested. Bond the 10 microfarad feed-through capacitors (and the LISN's for the high source impedance test) to the ground plane. For load testing, adjust the DC power supply and non-inductive resistive load for DC equivalent of peak rated voltage and current respectively. For no load testing, adjust the load in turn to 1, 10, and 100 Ω, taking care not to over heat the filter under test. Attach an EMI current probe to the output of the RF signal generator as shown, and clamp the probe around one of the input power leads between the 10 microfarad capacitor and the load (for the low source impedance test) or between the LISN and the load (for the higher source impedance test). Attach an EMI current probe to the input of an EMI meter, and clamp the probe around one of the load leads, adjacent to the load resistor. Adjust the output of the RF signal source to produce a level on the EMI meter which is above the noise floor by the estimated filter attenuation at each frequency plus 10 dB. Record the EMI meter readings. A sealed RF compartment should be mounted on the load end of the filter assembly to provide input to output isolation and to facilitate termination of the shorted outputs of the two filter circuits in a coaxial fitting. Without changing the signal source/output levels, insert the two filter circuits and measure the resultant filtered levels at the load. The difference in decibels of the original signal level and the filtered level at each frequency is the filter insertion loss at that frequency:

$$\text{Original level (dB }\mu\text{V)} - \text{Filtered level (dB }\mu\text{V)} = \text{Insertion Loss (dB)} \qquad \text{(Eq.3)}$$

Swept RF response testing is encouraged. If swept techniques are not used, a minimum of twelve test frequencies shall be chosen. Required frequencies are 10 kHz, 14 kHz, 20 kHz, 40 kHz, 80 kHz, 100 kHz, 200 kHz, 400 kHz, 800 kHz, 1 MHz. 2 MHz, and 5 MHz. In addition, for non-swept tests, a search should be made for filter resonant frequencies, where insertion loss shall also be recorded.

5.4 Common Mode Performance Prediction Testing:

5.4.1 Test Setup: See Figure 7.

5.4.2 Frequency Range: The frequency range is 10 kHz to 30 MHz, with and without load current.

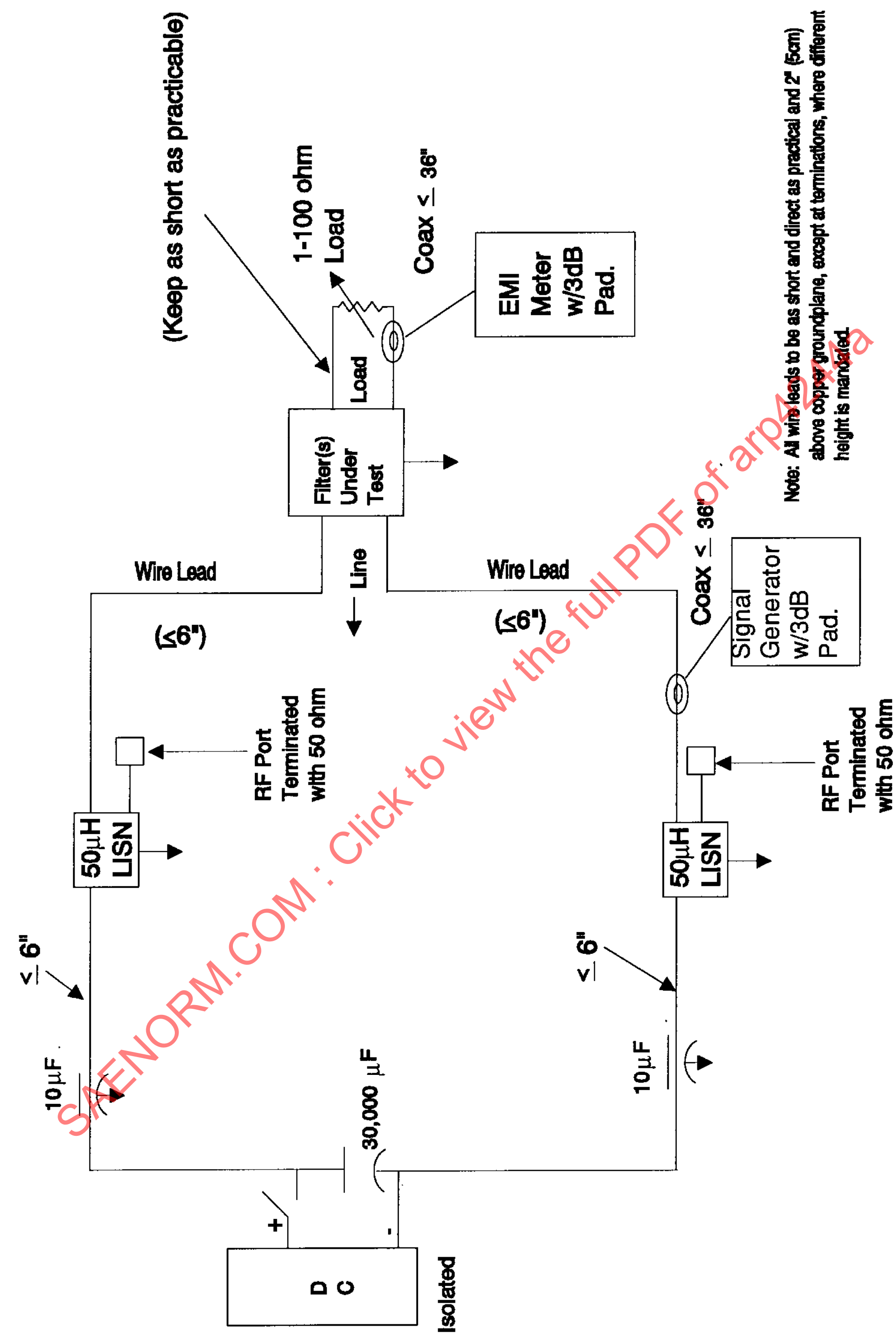


FIGURE 6 - Differential Mode Performance Prediction Test, With Variable Load Impedance, 10 kHz to 5 MHz

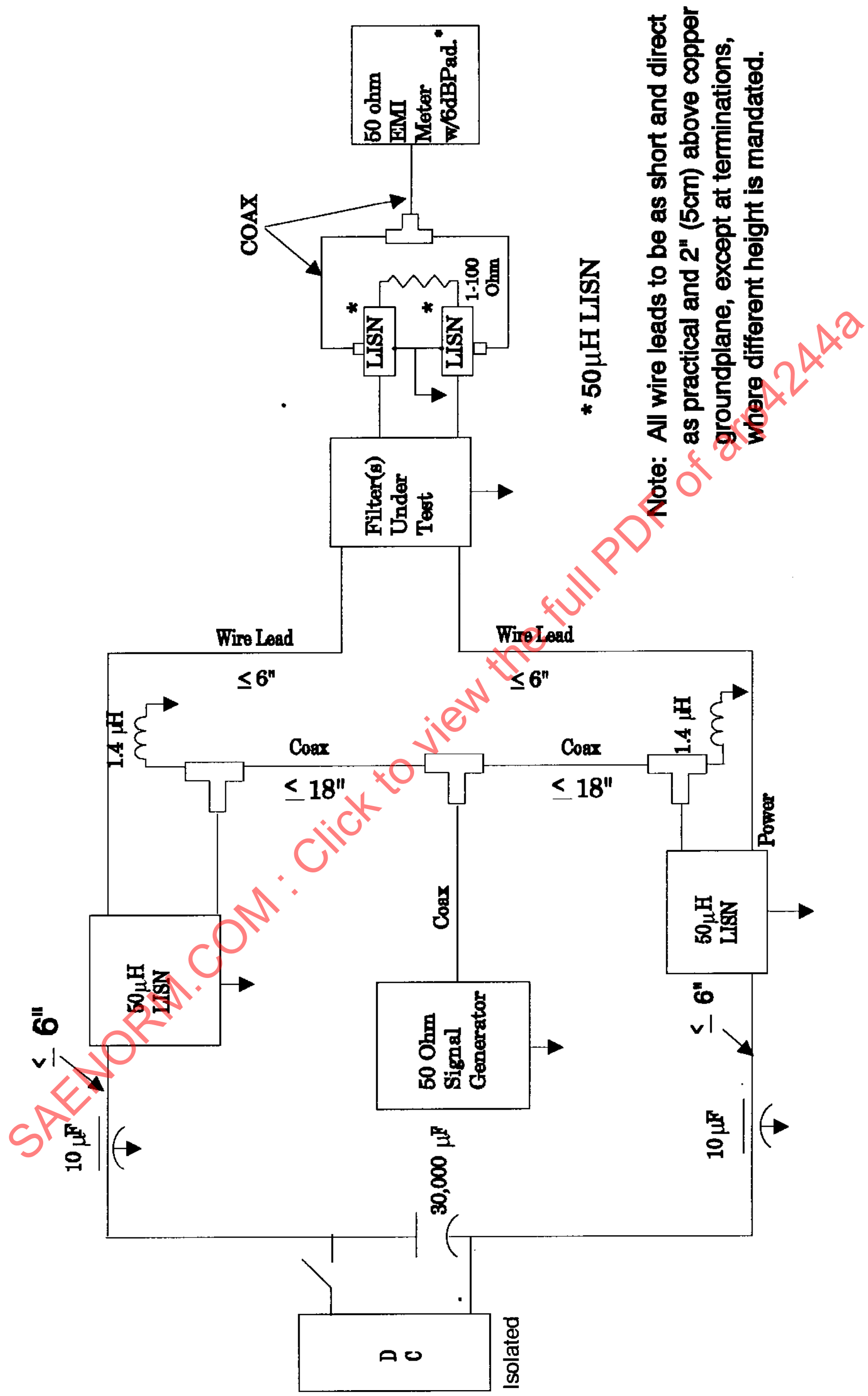


FIGURE 7 - Common Mode Performance Prediction Test
10 kHz to 30 MHz

5.4.3 Rationale: This test uses 10 microfarad feed-through capacitors and 50 microhenry LISN's to establish a realistic source impedance. Testing is performed with and without load current. Load current flows differentially, while the test signal is common mode coupled into the filter circuits under test, and is measured common mode on the load side of the filters.

5.4.4 Applicability : This test should be used on a given filter, to produce common mode performance prediction data for that filter. This data can then be used by filter suppliers and users to predict nominal filter performance in an intended application. For common mode performance prediction purposes, this method replaces MIL-STD-220A, from 10 kHz to 30 MHz.

This test method is not intended to be used for quality assurance purposes; its sole intent is to help engineering evaluation of potentially useful common mode filter designs.

5.4.5 Procedure: Set up per Figure 7, using series shorting wires to replace the filters to be tested. Bond the 10 microfarad feed-through capacitors, the LISN's, and the ground end of the 1.4 microhenry inductors to the ground plane. For load testing, insert the DC power supply as shown. For no load testing, omit the supply; the 30,000 microfarad electrolytic capacitor and the 10 microfarad feed-through capacitors swamp the output impedance of the supply. Complete the differential mode power circuit by joining the power terminals of the LISN's on the load side, with 1, 10, and 100 Ω loads. Terminate the two LISN rf terminals to an RF tee. Connect that tee to the 50 Ω input of an EMI meter. Attach the output of a 50 Ω RF signal source to a coaxial tee, which in turn is connected via coax cable to tee fittings joining the RF ports of the two line side LISN's and the ungrounded ends of the two 1.4 microhenry inductors. Adjust the output of the signal source to produce a signal at the EMI meter that is above its internal noise level by at least the anticipated filter insertion loss plus 10 dB. Without changing the output level of the signal source, insert the two filter circuits to be tested, and measure the resultant filtered signal level with the EMI meter. The decibel difference between the original reference level at each frequency and the filtered level is the filter insertion loss at that frequency:

$$\text{Original level (dB}\,\mu\text{V)} - \text{Filtered level (dB}\,\mu\text{V)} = \text{Insertion Loss (dB)} \qquad \text{(Eq.4)}$$

Swept response techniques are encouraged. If swept techniques are not used, a minimum of 15 frequencies, including 10 kHz and 30 MHz, shall be chosen. Suggested frequencies are 10 kHz, 14 kHz, 20 kHz, 40 kHz, 80 kHz, 100 kHz, 200 kHz, 400 kHz, 800 kHz, 1 MHz, 2 MHz, 4 MHz, 8 MHz, 16 MHz, and 30 MHz. In addition for non-swept tests, a search shall be made for resonant frequencies, where insertion loss shall also be recorded.

5.5 High Frequency Testing:

5.5.1 Test Setup: See Figure 8.

5.5.2 Frequency Range: The frequency range is 30 MHz to 10 GHz; the test is performed only with no load current.