A Procedure For Measuring LISN Impedance

The LISN is required for all measurement procedures specified by MIL-STD-462D unless otherwise stated in a particular test method.

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INTRODUCTION

The recently released military standard for the measurement of the electromagnetic interference characteristics of subsystems and equipments, MIL-STD-462D,[1] contains the general test methods necessary to demonstrate compliance with the requirements of MIL-STD-461. This new standard is designated revision "D" to coincide with its companion document, MIL-STD-461D. Revisions "A," "B," and "C" of MIL-STD-462 were never issued.

One of the important changes made in MIL-STD-462D is the use of a line impedance stabilization network (LISN) between the power source and the equipment under test (EUT). The LISN replaces the two 10-µF feedthrough capacitors that were previously used. The LISN is required for all measurement procedures specified by MIL-STD-462D unless otherwise stated in a particular test method. The purposes of the LISN are to provide a known power source impedance for the EUT, thereby assuring reproducible power line test results, and to provide a frequency-selective path between the EUT power line and the measurement receiver.

The control of the power line impedance is necessary because of the wide variations in the characteristics of shielded room filters and power line impedances between test laboratories. By using a LISN, the power line test results are more likely to be repeatable regardless of where the tests are made.

A frequency-selective connection is necessary between the power line and the measurement receiver to substantially attenuate the 115-volt fundamental power line frequency. This prevents receiver overload while conducting with little attenuation the spurious emissions above 10 kHz which are to be measured.

Because the LISN impedance has a significant effect on the power line emanation levels, it is important that the impedance characteristic of the LISN be periodically confirmed by measurement. Paragraph 4.6, page 8, MIL-STD-462D, specifies that the LISN impedance "shall be measured at least annually ..." and "... the impedance measurement results shall be provided in the EMI Test Report (EMITR) required by MIL-STD-461."

Although MIL-STD-462D does specify the conditions under which the LISN impedance is to be measured, there are no suggestions or references as to how this measurement is to be made. The measurement procedure and instrumentation to be used is left to the discretion of the test supervisor. Several types of impedance meters that can be used to measure the LISN impedance over the 10-kHz to 10-MHz frequency range are commercially available, but because of their high cost and infrequent use, such instruments may not be available in some EMI test laboratories. Instead of a seldom-needed and specialized instrument such as an RF-impedance meter, it would be more convenient if the LISN impedance measurement procedure required only equipment already available in the test lab.

This article will discuss a procedure for measuring the impedance of a 50-µH LISN using a digital voltmeter, a decade resistor box, a signal generator and a frequency counter. The proposed LISN measurement procedure will allow the LISN impedance measurements to be conveniently performed at little or no extra cost by the average EMI technician. No unfamiliar test equipment is needed and the procedure is simple and straightforward.

SCHEMATIC DIAGRAM OF MIL-STD-462D LISN

Figure 1 shows the schematic diagram of the MIL-STD-462D LISN. This LISN is distinguished from other LISNs by the 50-µH inductor. The inductance of 50 µH was selected to maintain a standardized control on the LISN impedance down to 10 kHz. In the past, 5-µH LISNs were commonly used, but because this relatively small inductance was not able to provide adequate impedance control down to 10 kHz, the inductance was increased to 50 µH.

The 8-µF capacitor and 5-ohm resistor across the power input port of the LISN resonate with the 50-µH inductor near 10 kHz, thus making the LISN impedance as seen at the LISN EUT port about 5 ohms at 10 kHz when the LISN power source port is open-circuited. However, when the LISN is

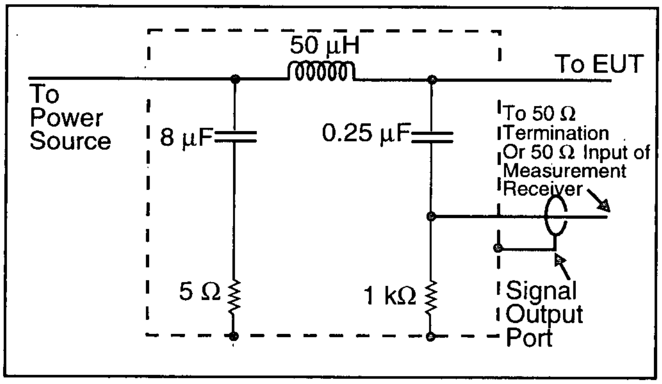

Figure 1. Schematic Diagram of a LISN from MIL-STD-462D.[2]

connected to the power source, the impedance of the power source will have some minor effect on the LISN impedance at 10 kHz. This is because the absolute mains impedance of typical power networks at 10 kHz can vary from less than 1 ohm to less than 4 ohms, with the impedance increasing as the frequency increases.[3] However, the effect of the power source impedance on the LISN impedance measurement is not important because MIL-STD-462D specifies in paragraph 4.6c, page 8, that: "The power input terminal on the power source side of the LISN shall be unterminated."

When the test frequency reaches the 1-to-10-MHz range, the LISN impedance increases to a level equal to the parallel combination of the 1 kohm resistor and the 50-ohm input impedance of the measurement receiver. The upper test frequency is limited to 10 MHz because the permissible length of the power leads between the LISN and the EUT (2 to 2.5 meters long) may cause resonances which affect the accuracy of the measurements. Consequently, the likelihood of power line resonances causing incorrect levels to be measured is eliminated by restricting the power line conducted measurements to below 10 MHz.

The 0.25-μF capacitor, in combination with the parallel connection of the 50-ohm impedance of the measurement receiver and the 1-kohm resistor, provides 47 and 30.5 dB of loss at 60 and 400 Hz, respectively. The purpose of the 1-kohm resistor is to provide a discharge path to ground for the 0.25-μF capacitor. This frequency-selective coupling circuit minimizes the coupling of the power line voltage levels to the measurement receiver input while passing frequencies above 40 kHz with less than 0.5 dB of attenuation. However, frequencies between 10 kHz and 40 kHz have enough attenuation that a coupling-loss correction factor (between 4.4 and 0.5 dB, respectively) must be added to the signal level indicated by the measurement receiver.[4]

At 60 Hz, the 115-volt power line voltage attenuation of 47 dB results in a root mean square (rms) voltage level of about 0.5 volts at the signal output port of the LISN when the port is terminated in 50 ohms. A BASIC program was used to calculate the attenuation of the LISN coupling circuit for various power line frequencies and the level of the power line voltage which appears at the LISN signal output port when it is terminated in 50 ohms. See Appendix A for the program listing and the tabulated output.

The voltage level at the LISN signal output port is further reduced by the 20-dB attenuator specified to be placed between the LISN signal output port and the measurement receiver. Thus, the 50-mV level which appears at the measurement receiver input may be low enough that an overload problem is not caused. However, if there is an overload problem, a 50-ohm, 9-kHz high-pass filter may be placed in front of the receiver to obtain more than 60 dB attenuation to all signals below 5 kHz.[5] This filter is especially appropriate for power line filtering applications because the last reactance at the receiver end of the filter is a shunt inductor to ground which provides the receiver input with a dc connection to ground. For test frequencies above 100 kHz, the 9-kHz highpass filter should be replaced with a 5-element, 50-ohm, 100-kHz high-pass filter using the inexpensive construction techniques described in ITEM 1991.[6]

If the line voltage and frequency of the LISN power source is 115 volts and 400 Hz, the 0.25-µF coupling capacitor allows about 3.4 volts to be developed across a 50-ohm load connected to the LISN signal output port. The 20-dB attenuator between the LISN and the receiver reduces this 400-Hz signal level to 340 millivolts at the receiver input terminals. If this level causes an overload problem, the previously recommended 9-kHz high-pass filter can be used to further reduce the levels of the 400-Hz fundamental and its harmonics to the point where all danger of receiver overload is eliminated.

Another problem with a 400-Hz power line frequency is due to the higher current flowing in the LISN 5-ohm resistor because of the lower capacitive reactance of the 8-µF capacitor at 400 Hz as compared to 60 Hz. For example, at 60 Hz the current through the 5-ohm resistor is about 0.347 A, but at 400 Hz, the current rises to about 2.3 A where the power dissipated in the 5-ohm resistor is about 26 watts!

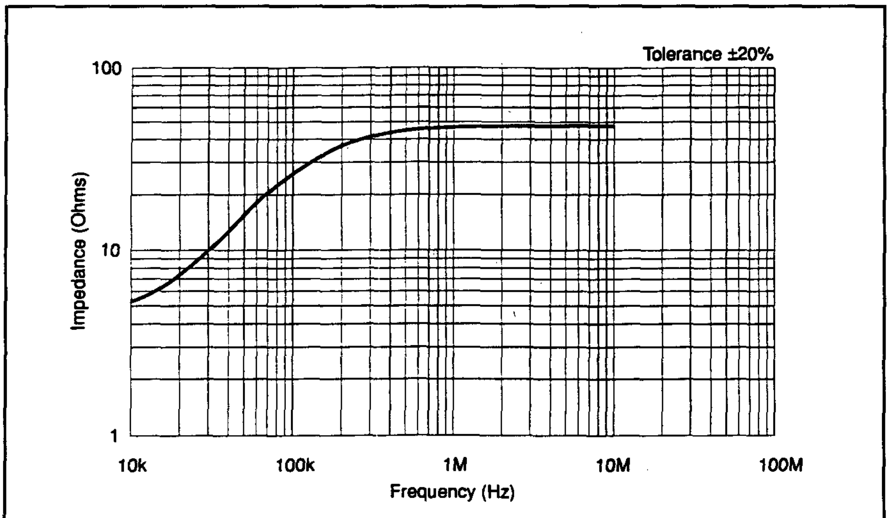

Figure 2. *The curve shows the acceptable magnitude of the LISN impedance from 10 kHz to 10 MHz as measured at the EUT power port with the power source port unterminated and with the LISN signal output port terminated in 50 ohms. Source: MIL-STD-462D.*[7]

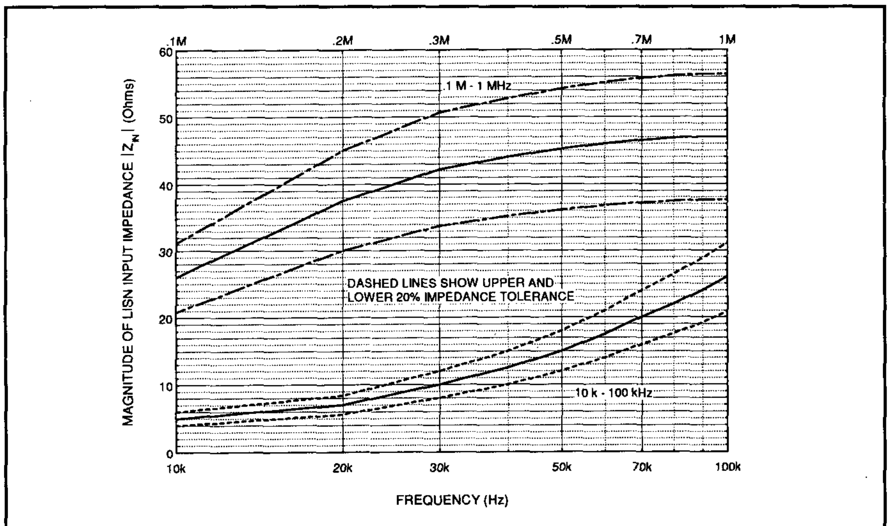

Figure 3. *Computer-calculated magnitude of the LISN impedance based on the schematic diagram and component values shown in Figure 1. For the computer calculation, the LISN power source port was unterminated and the signal output port was terminated in 50 ohms.*

LISN IMPEDANCE

The LISN impedance versus frequency looking into the EUT power port is shown in Figure 2. In order to provide a more detailed plot, the component values (including the 50-ohm termination at the signal output port) of Figure 1 were entered into a network analysis program and a computer-calculated tabulation of impedance versus frequency was obtained over the 10 kHz-to-10 MHz frequency range. Figure 3 shows the plot of the computer-calculated impedance in two curves from 10 kHz to 100 kHz and 100 kHz to 1 MHz. The 20% impedance tolerance specified in Figure 1 is also included in the plots. The impedance between 1 MHz and 10 MHz was not plotted because the impedance is essentially flat, increasing by only 0.6 ohms from 47.0 ohms at 1 MHz to 47.6 ohms at 10 MHz.

Near 10 kHz, the reactances of the 50-µH inductor and the 8-µF capacitor essentially cancel, leaving the 5-ohm resistor to establish the LISN impedance as seen at the EUT power port. The reactance of the 0.25-µF capacitor at 10 kHz is about 64 ohms, which can be considered an open

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circuit relative to 5 ohms. As the frequency increases above 10 kHz, the reactance of the 50-µH inductor increases, causing the LISN impedance to increase. At 1 MHz, the reactance of the 50-µH inductor becomes more than 300 ohms, which effectively appears as an open circuit. At 1 MHz, the 0.25-µF capacitor has a reactance of less than 0.7 ohms and looks like a short circuit. Consequently, the LISN impedance at 1 MHz is 47.0 ohms, which is 0.6 ohms less than the parallel combination of the 1 kohm resistor and the 50-ohm impedance of the measurement receiver. At 10 MHz, the LISN impedance is 47.6 ohms.

The purpose of this LISN impedance measurement procedure is to confirm that the LISN being tested has an impedance versus frequency characteristic that falls within the tolerance bands shown in Figure 3. The most interesting portion of the LISN impedance occurs between 10 kHz and 500 kHz where the design impedance increases from 5 ohms to about 45 ohms.

If the LISN design impedance of 47.0 ohms is correct at 1 MHz, measurements between 1 and 10 MHz can very likely be omitted because resonances in the 50-µH inductor generally appear only above 10 MHz. If the 0.25-µF coupling capacitor is a non-inductive type and its total lead length is kept as short as possible (not more than 0.5 inch), there should be no problem with resonances in the coupling circuit below 10 MHz. Consequently, it is usually unnecessary to test a commercial LISN or a properly designed and assembled lab-built LISN above 1 MHz after an initial test has established that the impedance between 1 and 10 MHz is within tolerance.

IMPEDANCE MEASUREMENT PROCEDURE

MIL-STD-462D states that the LISN impedance shall be measured at least annually under the following conditions: (a) the impedance shall be measured between the power output lead on the load side of the LISN and the metal enclosure of the LISN; (b) the signal output port of the LISN shall be terminated in 50 ohms; and (c) the power input terminal on the power source side of the LISN shall be unterminated.

If the EMI test lab has access to a commercial impedance meter, the LISN impedance measurement can be completed quickly and easily. However, if such expensive and specialized instrumentation is not available, the proposed measurement procedure requiring less expensive instrumentation may be used.

One of the requirements of LC filter testing is to measure the filter input impedance, and a procedure for using an ac voltmeter, a signal generator and a calibrated resistor is described in most books discussing filter design and testing.[8,9,10] Although the LISN is not considered to be a filter, its impedance can be measured using the same test procedure as if the LISN were a filter. The proposed LISN impedance measurement procedure was taken from Reference 8.

The proposed measurement procedure consists of placing a calibrated resistor in series between the signal generator output and the LISN power port to the EUT. For a given frequency, the resistor is varied until the voltages measured across the resistor and the LISN are equal. When this occurs, the resistance of the resistor is equal to the impedance magnitude of the LISN.

Most of the test equipment needed to perform the proposed LISN impedance measurement is available in practically every EMI test lab because this equipment is used on a regular basis in performing EMI tests. The equipment specifications are:

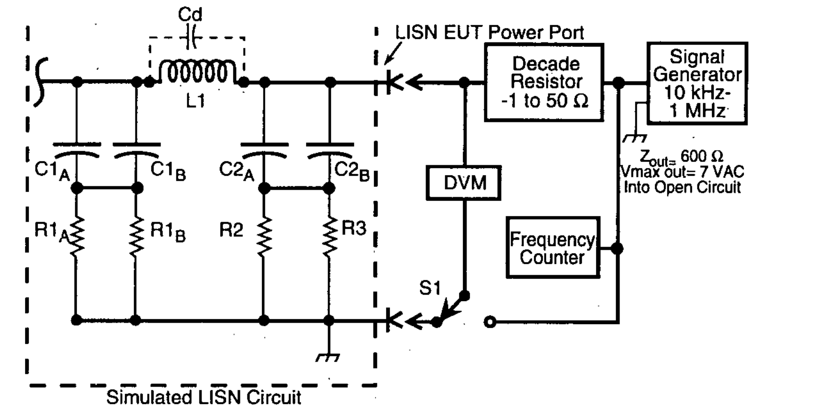
- Sinewave signal generator: 10 kHz to 1 MHz, 50- or 600-ohm output impedance with an output voltage of about 7 volts rms into an open circuit.
- Frequency counter: 10 kHz to 1 MHz with a high-impedance input.
- Decade resistor box or potentiometer: zero to 50 ohms, preferably with a resolution of 0.1 ohm.
- Battery-operated digital multimeter with an ac voltage frequency response of 100 kHz, an ohms measurement resolution of 0.01 ohm with an accuracy of about 0.07% + 2 digits + 0.02 ohms. The Fluke Model 8060A or the Hewlett-Packard Model 974A handheld multimeters will be satisfactory for this application.

NOTE: Both the Fluke and HP multimeters have the capability of measuring frequency up to 200 kHz. Consequently, the 10 kHz to 1 MHz frequency counter can be omitted and the frequency measurements can be made with the multimeter even though it is limited to a maximum of 200 kHz. Limiting the frequency measurement using a digital meter to 200 kHz is not critical because the LISN impedance changes only about 10 ohms above 200 kHz, and the dial reading of the signal generator will be sufficient to indicate the frequency.

The signal generator and frequency counter needed for the LISN impedance measurement are common generic types with no special capabilities. If the frequency dial accuracy of the signal generator is within 2%, the frequency counter can be omitted.

The decade resistor or the 50-ohm linear taper carbon composition potentiometer should have a zero to 50-ohm range with a 0.1-ohm resolution for optimum results. A lab-built decade resistor box with switched 0.1-ohm increments was used in preparing this article, and this type of variable resistor is recommended because of its repeatability. Construction details for the decade resistor box are given in Appendix B.

The digital multimeter (DVM) was used for making comparative ac voltage measurements and for measuring the resistance of the decade resistor box. Although the upper frequency limit of the two previously suggested ac voltmeters is only 100 kHz, they are usable up to 1 MHz because only comparative measurements are needed and the absolute voltage level is not important. As long as the meter is sensitive enough to give some indication at any frequency less than 1 MHz, the meter will be satisfactory because it is necessary only to compare one voltage reading with another.



C1 A,B 3.9 μF/100 V metallized Mylar capacitors (both 2.5% high) paralleled to make 8.0 μF.
C2 A 0.10 μF/100 V, 1% Mylar capacitor.
B 0.15 μF/100 V, 1% Mylar capacitor.
R1, A,B 10 Ω, 1/4 watt, 1% resistors paralleled to make 5.0 Ω.
R2 1000 Ω, 1/4 watt, 1% resistor.
R3 49.9 Ω, 1/4 watt, 1% resistor (to simulate the input impedance of a 50 Ω detection system).
L1 50 μH air-core inductor; 37 turns of #24 AWG film-insulated wire wound on a 1.7-inch o.d. cardboard cylinder and spaced over a 1.2-inch length. Self-resonant frequency of inductor = 17.4 MHz; Cd = distributed capacity of inductor = 1.67 pF
DVM Fluke Model 8060A True RMS Digital Multimeter (on 2-VAC range).
Decade Resistor Decade resistance box (See Figures B1, B2, B3 and B4).
Signal Generator Leader Model LAG-120A Audio Generator.
Frequency Counter Global Specialties, Model MAX-100A, 5 Hz - 100 MHz.

Figure 4. *Schematic/block diagram of the simulated LISN circuit and the associated instrumentation used to evaluate the proposed LISN impedance measurement procedure.*

LISN SIMULATION FOR TEST PROCEDURE CONFIRMATION

To confirm that the proposed LISN impedance measurement procedure gives accurate results, a LISN circuit was assembled with components having the values specified in Figure 1. The proposed instrumentation was then connected to the LISN and impedance data were obtained at 14 frequencies over the 10 kHz to 1 MHz range. Figure 4 shows the simulated LISN circuit along with the associated instrumentation. All LISN components and instrumenation are described in the notes under the figure.

The LISN impedance measurement procedure consists of the following steps:

1) Adjust the signal generator for maximum output voltage and set it to the frequency for which the LISN impedance is to be measured. Assume a frequency of 30 kHz is used for this example.
2) Adjust the decade resistor to a resistance equal to the expected LISN impedance (9.7 ohms) at 30 kHz as shown by the solid line in the graph of Figure 3. Change switch S1 (Figure 4) so that the DVM measures the ac voltage across the decade resistor. Record the voltage level indicated by the DVM.
3) Change S1 so that the DVM reads the ac voltage across the LISN. Compare the second voltage reading with the first. If the compared voltage levels are exactly identical, then the LISN impedance is identical to the decade resistor setting and the LISN impedance measurement for 30 kHz is completed. If the compared voltages are not equal, then vary the decade resistor in small increments until the voltages become as close as possible. When the closest match is reached, record the resistor setting. The resistor value equals the LISN impedance at that frequency. Continue the test at the next frequency.

The switched increment of the decade resistor used to evaluate

FREQ. (kHz)	ACROSS DECADE RESISTOR (VOLTS)	ACROSS LISN EUT PORT (VOLTS)	RESISTOR SETTING (OHMS)	COMPUTER-CALCULATED IMPEDANCE (OHMS)	ERROR (%)
10	0.0625	0.0628	5.3	5.0	+6.00
20	0.0830	0.0830	7.2	7.1	+1.41
30	0.1093	0.1096	9.7	9.7	0
40	0.1368	0.1367	12.3	12.4	-0.81
50	0.1635	0.1629	14.9	15.1	-1.32
70	0.2111	0.2112	19.6	20.0	-2.00
100	0.2704	0.2708	25.8	26.1	-1.15
150	0.3318	0.3318	33.1	33.3	-0.60
200	0.3655	0.3654	37.7	37.8	-0.26
300	0.3764	0.3775	42.4	42.4	0
400	0.3428	0.3428	44.7	44.4	+0.68
600	0.1722	0.1724	46.3	46.1	+0.43
800	0.0804	0.0804	46.6	46.7	-0.21
1000	0.0384	0.0384	46.7	47.0	-0.64

NOTES:
1. The percentage error was based on the difference between the measured and computer-calculated LISN impedances relative to the computer-calculated impedance.
2. All voltages were measured with a Fluke Model 8060A True RMS Digital Multimeter. The 2-VAC range was used for alll measurements. A second set of comparative voltage measurements was made using the HP 974A multimeter on its 5-V range, and all resistor settings were essentially identical with the above listed values.
3. The DVM was switched across the decade resistor and then from the LISN EUT power port to ground. The decade resistor was varied until the two voltages were as nearly equal as possible. A voltage match was usually obtained within 0.6 mVAC.
4. See Figure 4 for the schematic/block diagram of the test setup used to obtain the above data.

Table 1. *Voltages measured across the decade resistor box and from the LISN EUT power port to ground. The corresponding resistor settings are listed for comparison with the computer-calculated LISN impedances.*

the simulated LISN circuit was 0.1 ohm. The data obtained in the evaluation of the simulated LISN is tabulated in Table 1. Except for the 10-kHz measurement, all measurements were within 2% of the computer-calculated LISN impedance. The large measurement error at 10 kHz is attributed to the relatively low impedance at this frequency which makes the measurement more sensitive to resistance error as compared to the higher frequencies which have correspondingly higher impedance levels.

The fact that the measured LISN impedance was within a few percent of the expected impedance indicates that this proposed impedance measurement procedure is satisfactory and it can be used with assurance to obtain reliable and accurate measurements. Of course, the accuracy of the results will be dependent on the accuracy of the individual resistors used in the decade resistor box, but the ohmmeter function on the 200-ohm range of the Fluke multimeter can be used to confirm the resistance values to an accuracy within 0.07% of the ohmmeter reading plus two digits and 0.02 ohms. The HP 974A DVM has a similar capability.

Both the Fluke 8060A and the HP 974A hand-held digital multimeters were found to be equally satisfactory for making the comparative ac voltage measurements up to 1 MHz and for selecting the resistors for the decade resistor box. However, the HP 974A multimeter has the advantage of costing $95 less than the $465 price of the Fluke meter.

SUMMARY

The newly revised MIL-STD-462D specifies that a 50-µH LISN be used for all EMI measurements and that the LISN impedance vs. frequency be measured at least annually; however, no procedure for performing this measurement is provided or suggested.

This article proposes a LISN impedance measurement procedure which uses standard inexpensive equipment found in every EMI test laboratory. The validity of the proposed procedure was confirmed by using the procedure to measure the impedance of a simulated LISN assembled from components having the same values specified in MIL-STD-462D. The test results showed a close agreement between the measured and computer-calculated LISN impedances, thus confirming the validity of the proposed measurement procedure.

A BASIC computer program for calculating the attenuation of the LISN coupling circuit and the power line voltage levels at the LISN signal port, along with construction details for the decade resistor box used in the impedance measurement procedure were included in two appendices.

Any comments, suggestions or corrections regarding the proposed LISN impedance measurement procedure are welcome.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the suggestions and comments of Rex Cox, Heyward Preacher and St. John Martin resulting from their reviews of this article.

REFERENCES

1. MIL-STD-462D, 11 January 1993, Measurement of Electromagnetic Interference Characteristics, Superseding MIL-STD-462, 31 July 1967. Approved for public release; distribution is unlimited.
2. Ibid., pg. 23.
3. Mark J. Nave, *Power Line Filter Design for Switched-Mode Power Supplies*, (New York: Van Nostrand Reinhold,1991) Figures 4-8 and 4-10.
4. MIL-STD-462D, Method CE102, paragraph 4a(3), page 32 and Figure A-3, page A-45.
5. E. Wetherhold, "Design and Construction of a 9-kHz Highpass Filter and Assembly of a Return Loss Bridge for Filter and PLISN Testing," *ITEM* 1993, pp. 220-240.
6. E. Wetherhold, "Inexpensive Construction Techniques for 50-ohm Signal Line Filters," *ITEM* 1991, pp. 148-170.
7. MIL-STD-462D, Figure 7, page 24.
8. Philip Geffe, *Simplified Modern Filter Design* (Measurement of Filter Terminal Impedance), (New York: John F. Rider Publisher, Inc., 1963) Figures 8-10, pg. 84.
9. Arthur B. Williams and Fred J. Taylor, *Electronic Filter Design Handbook*, 2nd Edition (Input Impedance of Filter Networks), (New York: McGraw-Hill, 1988) pp. 8-22.
10. *A Handbook on Electrical Filters* (Lissajous Pattern Method of Measuring Filter Input Impedance) (Rockville, MD: White Electromagnetics, Inc., 1963) Figure 8.9, pg. 242.
11. Digi-Key Corporation, 701 Brooks Ave. South, P.O. Box 677, Thief River Falls, MN 56701-0677. 1-800-344-4539. Telephone to request a free catalog.

APPENDIX A

The following BASIC program calculates and prints: (a) the LISN attenuation of EUT-generated spurious power line conducted emanations over the 10 kHz-to-70 kHz frequency range; (b) the LISN attenuation of the 60- and 400-Hz power line frequencies and their harmonics; and (c) the levels of the 60- and 400-Hz 115-volt power line fundamental frequencies after they are attenuated by the LISN 0.25-µF coupling circuit when terminated in 50 ohms. See Table A1 for the output of the computer program.

For example, Table A1 shows that the EUT-generated spurious signals on the power line are attenuated by the LISN coupling circuit by 4.5 and 0.8 dB at 10 and 30 kHz, respectively. Consequently, the measured signal levels between 10 and 30 kHz must be corrected by adding an appropriate correction factor between 4.5 and 0.8 dB.

Also from Table A1, the levels of the 60- and 400-Hz power line fundamental frequencies are attenuated by 47 and 30.5 dB, respectively, and the corresponding voltage levels at the 50-ohm terminated LISN signal output port are 516 and 3439 mV. The program may be used to calculate LISN fundamental output voltages for other line voltages by substituting the new line voltage in place of "115" in program lines 40 and 170.

FREQ. (kHz)	ATTEN. (dB)	LISN OUTPUT (MILLIVOLT)
0.06	47.0	516
0.18	37.4	---
0.30	33.0	---
0.40	30.5	3439
1.20	21.0	---
10	4.5	---
20	1.6	---
30	0.8	---
40	0.5	---
50	0.3	---
70	0.2	---

Table A1. *Output of Computer Program.*

```
10 REM FILE: "LISNLOSS.ASC"
20 REM  CALCULATES LISN COUPLING LOSS FOR C= .25µF
30 REM  AND GIVES LISN OUTPUT VOLTS ACROSS 50 OHMS
40 REM  FOR 115-V LINE FREQUENCIES OF 60 AND 400 Hz.
50 REM  EQUATION FROM PAGE A-46 OF MIL-STD-462D.
60 REM  7.48 FACTOR IS BASED ON 2*PI*47.6*.25/10.
70 X = .0000748
80 LPRINT ""
90 LPRINT " FREQ    ATTEN    LISN OUTPUT"
100 LPRINT " (kHz)   (dB)   (Milli-volts)"
110 DATA .06,.18,.3,.4,1.2,  10, 15, 20, 30, 40, 50, 70, 1000
120 REM  DATA IS FREQUENCY IN kHz.
130 READ F: IF F>200 THEN 280
140 F1 = F*1000!          : REM FREQ IN Hz.
150 Y = ((1+(X*F1)^2)^.5)/(X*F1)
160 AT = 20*.4342945*LOG(Y) : REM  ATTENUATION IN dB.
170 VO  = 115/(10^(AT/20))  : REM  V-OUTPUT IN VOLTS.
180 IF F1 = 60 GOTO 230
190 IF F1 = 400 GOTO 230
195 IF F1 = 10000! THEN LPRINT ""
200 LPRINT USING "###.## "; F;
210 LPRINT USING "  ##.# ";AT
220 GOTO 130 : REM  RETURNS TO READ NEXT FREQUENCY.
230 LPRINT USING "###.## "; F;
240 LPRINT USING "  ##.# ";AT;
250 LPRINT USING "     ####" ;VO*1000
260 REM  PRINTS OUTPUT VOLTAGE ONLY FOR 60 & 400 Hz.
270 GOTO 130 :  RETURNS TO READ NEXT FREQUENCY.
280 PRINT: PRINT:PRINT"END OF RUN.": BEEP:BEEP:END
```

APPENDIX B

Figures B1 and B2 show simplified and detailed diagrams of the decade resistor box used in the evaluation of the LISN impedance measurement procedure. Figures B3 and B4 are photographs of the outside and inside of the resistor box.

The 10-, 20-, 40- and 80-ohm values were assembled from 1/4-watt metal-film fixed resistors having a tolerance of 1%. A package of ten of the 20-ohm resistors was obtained from Digi-Key.[11] Each resistor was then measured with the digital ohmmeter and either a single resistor or a combination of parallel or series-connected resistors