Line Impedance Stabilization Is In Its Seventieth Year, and Going Strong

What a long, strange trip it's been…

***Introduction*[1]**

Seventy years ago this month, the 5 uH Line Impedance Stabilization Network (LISN) made its debut in MIL-I-6181B.[2] Aside from the EMI receiver itself, the LISN is one of the oldest and most successful pieces of EMI test equipment in existence. And while EMI receivers have changed a great deal since 1953 (see images in the companion MIL-I-6181B anniversary article in this issue), the 5 uH LISN is not only still with us, but almost unchanged and used in commercial aviation and the automotive industry, as well as military applications worldwide.[3] Other LISNs have come and gone, and others are with us still. The way we use LISNs has changed over time, not always for the better. But the LISN is here to stay in the world of EMI testing.

In The Beginning

Radio receivers used on WWII Army aircraft were quite susceptible to very low levels of noise on their primary (28 Vdc) power input. Further, unshielded antenna lead-ins (see MIL-I-6181B anniversary article in this issue) were very susceptible to capacitive crosstalk from noisy 28 Vdc electrical power feeds. The first EMI standards tried to control both these radio frequency interference (rfi) coupling paths. Prior to 1953, Figure 1 shows that JAN-I-225[4] used a pair of 4 uF bypass capacitors in shunt (8 uF total capacity between power feeder and ground plane) and a 10' length of power wire suspended not more than ¼" from the ground plane for what they called power supply stabilization. Given that JAN-I-225 conducted and radiated emission measurements covered 0.15 – 20 MHz, one can work out (roughly) that the resonant frequency of the 10' wiring and 8 uF capacity occurred below the test frequency range, so that the impedance looking back into the capacitors through 10' of wiring was inductive in character.

JAN-I-225 was superseded in 1953 by MIL-I-6181B, which included both required impedance (Figure 2) and construction drawings (Figure 3) for the 5 uH LISN. These same drawings, with minor tweaks, appeared in RTCA/DO-160 for commercial aircraft avionics, up to 1989.[5] After that, they required the extended impedance control as in DEF STAN 59-411, but don't include the construction details of DEF STAN 59-411. Two tweaks already appeared in MIL-I-6181C[6] which replaced MIL-I-6181B in 1957: a 1 kΩ bleeder resistor from the EMI port center conductor to case, and the removal of the 1 Ω resistor in series with the input side 1 uF filter capacitor. The upper frequency of the controlled impedance bounced around some over the years. MIL-I-6181B has it at 25 MHz, as does MIL-I-6181D[7] (1959), but the intervening "C" in 1957 pushed it out to 100 MHz. It had settled down to 30 MHz in most specifications and standards, as that was the upper limit for conducted emissions and radiated emissions with the rod antenna. But in the past few decades, various specifications have pushed the upper end as far up as 400 MHz for rf conducted susceptibility, and the automotive world (CISPR 25[8]) has pushed it to 100 MHz for conducted emissions.

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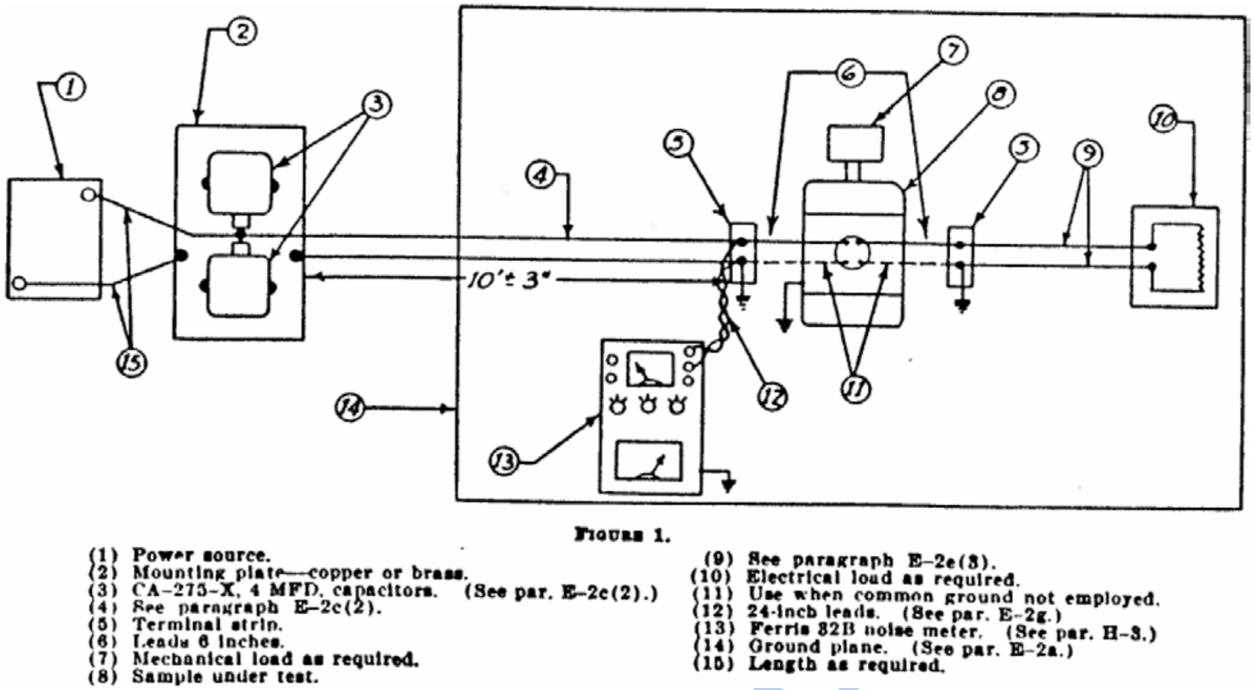


Figure 1: *JAN-I-225 EMI test set-up, showing details of how line impedance stabilization was achieved without a "LISN in a box."*

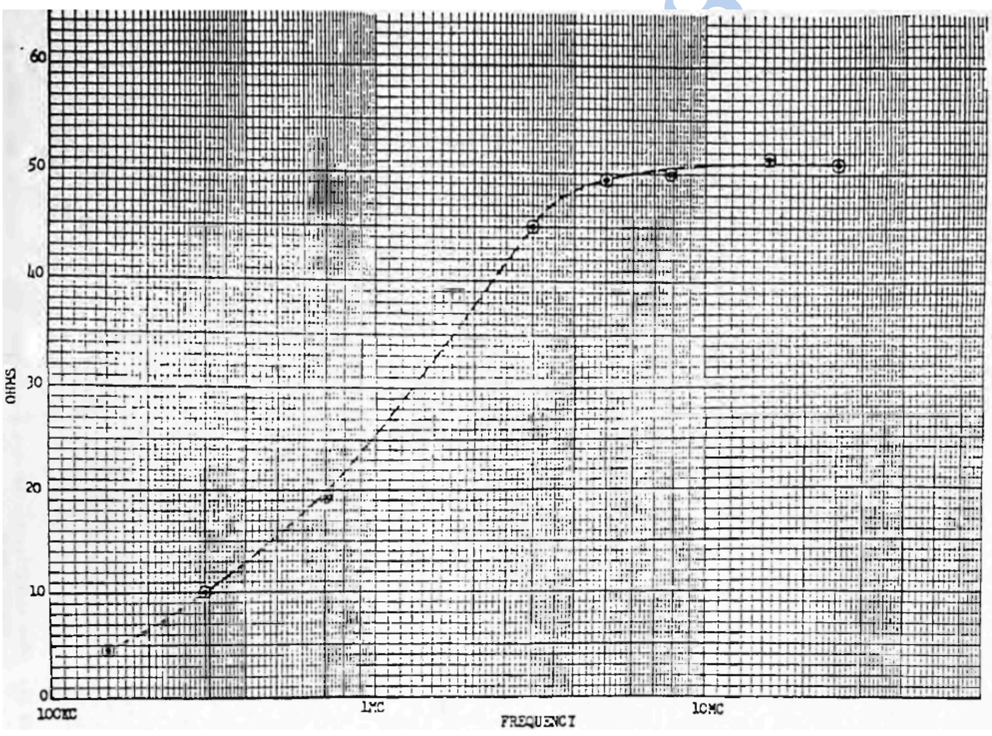
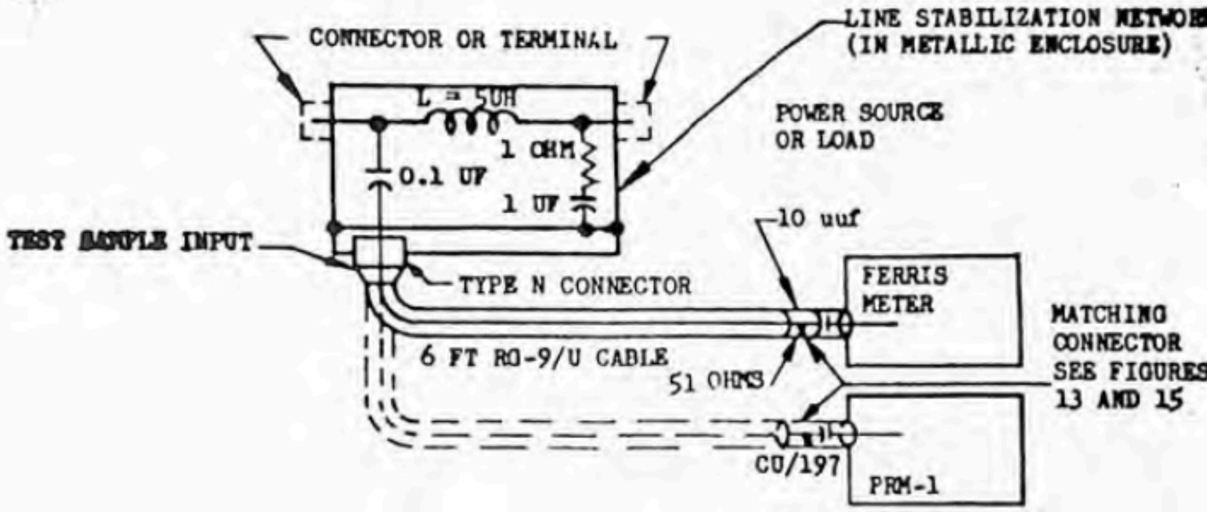


Figure 2: *MIL-I-6181B 5 uH LISN impedance plot.*



DATA FOR A TYPICAL 50-AMPERE NETWORK

1. COIL DATA:-
   INDUCTANCE = 5 uh
   TURNS = 13 SINGLE LAYER WOUND
   WIRE = AN16 SPEC MIL-W-5086
   LENGTH = 4 INCHES
   FORM LENGTH = 5-1/4 INCHES (DRILL 3/8 INCH DIA HOLE 7/16 INCH FROM EACH END FOR COIL ANCHORING PURPOSES)
   FORM DIAMETER ≐ 3 INCHES OD (0.125 WALL THICKNESS)

2. ENCLOSURE DATA:-
   MATERIAL = 0.064 INCH ALUMINUM
   SIZE = 4 x 4 x 9-3/8 INCHES

3. MATERIAL:-
   1 EA 1. UF/600 WORKING VOLTS DC/BATHTUB
   1 EA 0.1 UF/600 WORKING VOLTS DC/BATHTUB
   1 EA 1 OHM ±5 PERCENT, 2 WATT, FIXED, COMPOSITION RESISTOR (OR EQUIVALENT PARALLEL COMBINATION).
   1 EA UG-58A/U ("SAMPLE SIDE" CONNECTOR)
   2 EA AN3102-18-6S BOX MOUNTING ("POWER TERMINALS" CONNECTOR)

CONNECTIONS TO CONDENSERS SHOULD BE AS SHORT AS POSSIBLE

FOR USE ABOVE 50 AMPERES, REPLACE COIL WITH 5 UH COIL OF SUITABLE DIMENSIONS CAPABLE OF CARRYING DESIRED CURRENT.

THE VALUES GIVEN FOR THE COMPONENT PARTS OF THE NETWORK ARE NOMINAL. REGARDLESS OF THE CONSTRUCTION OR DEVIATION FROM NORMAL VALUES, THE NETWORK MUST HAVE AN INPUT INPEDANCE TO WITHIN 10 PERCENT OF THAT GIVEN IN FIGURE 12.

Figure 3: *LISN construction details in MIL-I-6181B*

It would surely be gratifying to the originator of the 5 uH LISN that his work has gained this much success and acceptance worldwide. Who was this person, and how did the 5 uH LISN come about in the first place? The author is indebted to Mr. A. T. Parker (1915 – 2000), for the following historical snippet. Mr. Parker founded Solar Electronics, a designer and supplier of EMI test equipment. Previously he had worked at the Stoddart Aircraft Radio Company, which was the company that produced the first commercial 5 uH LISN. In Mr. Parker's own words:

> "Early in WW2, an aircraft propulsion engineer named Alan Watton working for the Air Corp was concerned about the r.f., being conducted along wiring in a military aircraft of the Douglas DC-3 type. He devised the first Line Impedance Stabilization Network which simulated the impedance of the d.c. power leads in the aircraft. It used a five microhenry choke and a means for coupling voltages developed across this inductance to a 50 ohm receiver over the frequency range 150 KHz to 25 MHz."[9]

This is all Mr. Parker has to say about its inception. The following deductions are the author's own.

The DC-3 (military version C-47 "Skytrain") was all aluminum. Aluminum aircraft return current on structure, except where inductance causes excessive voltage drop. No such problem with dc power. Electrical power was from engine-mounted generators. Engine centerlines were about three meters from the aircraft centerline. Thus, using a nominal value such as one microhenry per meter for a wire suspended above a ground plane, 5 uH seems a reasonable value if the measurement was taken in the cockpit-mounted breaker boxes, which act as the point of distribution for electrical power in the aircraft. This point is critical. People often assume that a LISN represents the impedance the test sample sees as installed in the platform. This is not the case.[10] As per Figure 4, a LISN simulates the common bus impedance seen by all loads, so that noise currents drawn by a culprit load, acting through the common bus impedance, generate a noise potential inflicted on all other victim loads.

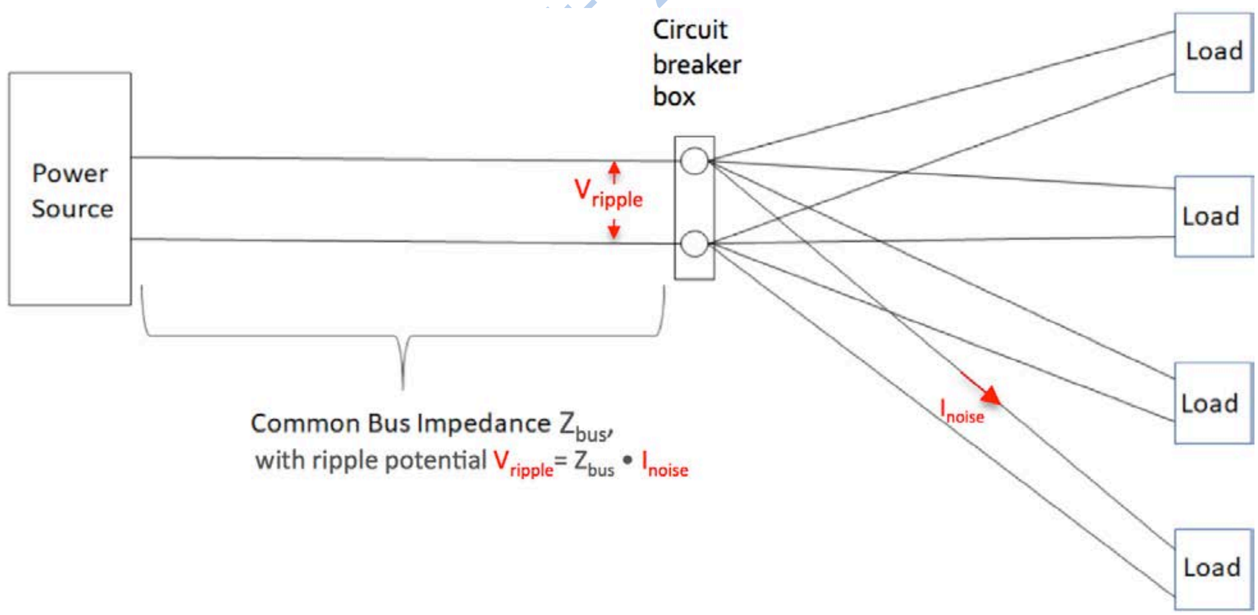


Figure 4: *A LISN simulates the common bus impedance, not power source-to-load impedance.*

It is specifically this property of a LISN that allowed it to be used in MIL-I-6181B through "D" (the last revision prior to MIL-STD-461) in mirror image roles when measuring conducted emissions (Figure 5) and conducted susceptibility (Figure 6).

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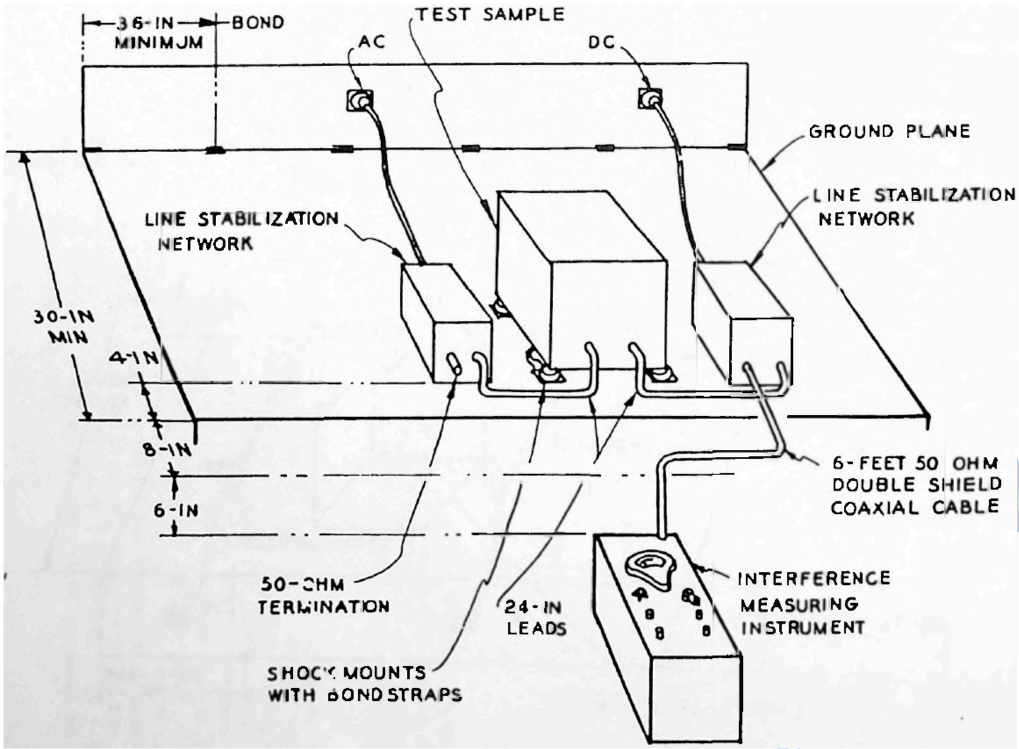

Figure 5: *MIL-I-6181B conducted emission set-up (figure actually copied from MIL-I-6181C, because easier to see what is going on for instructional purposes).*

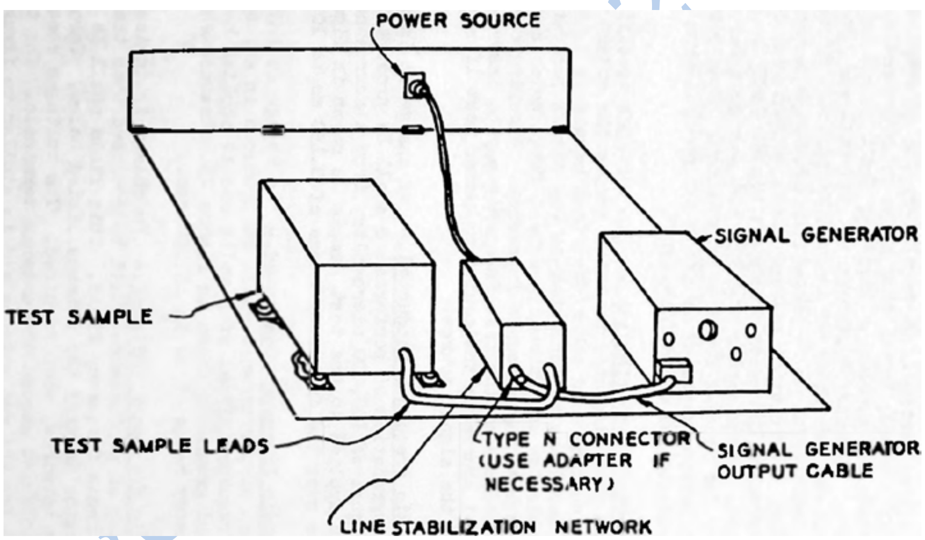

Figure 6: *MIL-I-6181B conducted susceptibility set-up (figure actually copied from MIL-I-6181C, because easier to see what is going on for instructional purposes).*

As Time Goes By

In all versions of MIL-I-6181B-D, a LISN is inserted in each power feeder, ac or dc. The return is always through the ground plane. But Navy ships never return current on structure, and Navy EMI specification MIL-I-16910A[11] reflected that practice, inserting a 5 uH LISN in both feeder and return. When all the Service- and platform-specific EMI specifications released prior to 1967 were superseded by the Tri-Service EMI standards MIL-STD-461[12] and MIL-STD-462[13], it was the Navy practice of inserting line impedance stabilization in each power conductor that was adopted for Tri-Service use. That is, instead of running return current back through the ground plane, it is returned through a wire, instead. This has several problematical consequences that reverberate down to the present day. Before delving into that issue, we should note that MIL-STD-461 and MIL-STD-462 1967 releases followed a new practice introduced in MIL-STD-826,[14] replacing the 5 uH LISN with a 10 microfarad feed-through capacitor. This then became the standard practice for a quarter-century, until MIL-STD-461D[15] and MIL-STD-462D[16] reinstated rf potential instead of current control. This necessitated a LISN again, albeit now a 50 uH LISN in lieu of the original 5 uH LISN, for reasons related further on. We return once again to Mr. Parker for the rationale behind current measurements in lieu of measuring rf potential across a LISN.[17] This is follow-on to the material quoted earlier from reference 9.

> So the Line Impedance Stabilization Network (LISN) was born. It was a pretty good simulation of that particular aircraft and the electrical systems it included. But then someone arbitrarily decided to use this artificial impedance to represent **any** power line.
>
> At any rate, this impedance suddenly began appearing in specifications which demanded its use in each ungrounded power line for determining the conducted EMI (then known as RFI) voltage generated by any kind of a gadget. The resulting test data, it was argued, allowed the government to directly compare measured RFI/EMI voltages from different test samples and different test laboratories.
>
> No one was concerned about the fact that filtering devised for suppressing the test sample was based on this artificial impedance in order to pass the requirements, but that the same filter might have no relation to reality when used with the test sample in its normal power line connection.
>
> Not until 1947, that is. At that time, this same Alan Watton, a propulsion engineer having no connection with the RFI/EMI business, decided to rectify the comedy of errors which had misapplied his original brainchild. He was in a position to place a small R and D contract with Stoddart for the development of two probes; a current measuring probe and a voltage measuring probe. Obviously, he felt that one needed to know at least two parameters for a true understanding of conducted interference...[18]
>
> As it turned out, Stoddart was successful in developing a current probe based on Alan Watton's suggestions regarding the toroidal transformer approach which is still the primary basis used today. However, the development of the voltage measurement probe suffered for lack of sensitivity. Watton's hope had been to provide a high impedance voltage probe with better sensitivity than was then available for measurement receivers designed for rod antennas and 50 ohm inputs. Since this effort failed and Watton's funds (and probably his interest in the subject) faded out of the picture, the program came to a halt.
>
> This meant that the RFI/EMI engineer could either measure EMI voltage across an artificial impedance which varied with frequency, or he could measure EMI current flowing through a circuit of unknown r.f. impedance. Either way, the whole story is not known. In spite of the unknown impedance, the military specifications began picking up the idea of measuring EMI current instead of voltage…

The author's take on this is that what Watton was after was a Thévenin-like model of the test sample: "open circuit" output rf potential, and short-circuit rf current. By this means, one could then predict noise potentials and currents into any arbitrary power source impedance. This interpretation is bolstered by material in the appendix of MIL-STD-462D:

> The (LISN) impedance is standardized to represent expected impedances in actual

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installations and to ensure consistent results between different test agencies. Previous versions of MIL-STD-462 used 10 microfarad feedthrough capacitors on the power leads. The intent of these devices was to determine the current generator portion of a Norton current source model. If the impedance of the interference source were also known, the interference potential of the source could be analytically determined for particular circumstances in the installation. A requirement was never established for measuring the impedance portion of the source model. More importantly, concerns arose over the test configuration influencing the design of power-line filtering. Optimized filters are designed based on knowledge of both source and load impedances. Significantly different filter designs will result for the 10 microfarad capacitor loading versus the impedance loading shown in Figure 7 of the main body.

The concern over designing an EMI filter for a specific (but different) source impedance is of the same type that Watton was concerned about a half-century earlier.

The more things change, the more they stay the same!

Completing our "as time goes by theme," it is worth noting why MIL-STD-462D went with a 50 uH LISN instead of the 5 uH LISN. In fact, the original proposal for MIL-STD-462D going in was the 5 uH LISN. The same section of the MIL-STD-462D appendix says,

> A specific 50 microhenry LISN was selected to maintain a standardized control on the impedance as low as 10 kHz.

The low frequency end of the 5 uH LISN is 150 kHz. The desire to begin making rf potential measurements well below 150 kHz nixed the selection of the 5 uH LISN. In turn, the reason for wanting to make rf potential measurements down to audio frequencies was based on the previous quarter-century of making CE03 measurements down to audio frequencies. They wanted the break between CE101 and CE102 to be roughly the same as between CE01 and CE03. None of which is to say that the 50 uH LISN is a better simulation of most vehicle electrical bus impedances…

Simple Things Become Complicated[19]

From MIL-STD-826 (1964) forward, the practice of placing an impedance stabilizing device in each ungrounded power lead (both feeder and return) resulted in at best questionably useful data. When a single device is used, the measured rf potential or current is simply that in the loop comprised of LISN, power feeder, load (test sample), and ground plane. Using two such devices results in measuring vector sums of differential mode (dm) and common mode (cm) currents/potentials.

Figures 7a & b show differential and common mode current paths when current returns above structure on a dedicated ground wire – i.e., isolated from chassis ground within the test sample. Inspection of figures 7a and 7b indicates that when there is an above ground current return path, differential and common mode currents sum in the feeder, but subtract in the return, as indicated in Figure 7c. Figure 7d shows how all current, regardless of the current-generating mechanism, is constrained to flow in the same path in the original structure return 5 uH LISN configuration.

This means that with above ground current return, as shown in Figure 7c, measured single line currents or rf potentials look similar but not identical. The traces are identical for feeder and return when one or the other mode dominates, but where they are of similar amplitude and add on the feeder and subtract on the return, they differ. Separation of cm and dm modes to assist filter design has been a topic of interest since the late 1970s.[20,21,22]

It is of note that in most standards, if there is any question as to how power current will return (structure or dedicated wire), the default test method is to use a pair of LISNs, and measure the vector sums and differences of common and differential mode signals on each LISN separately. It is

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not obvious why this is the go-to default. Particularly for radiated emissions, this technique decreases the radiation efficiency of the differential mode component of the composite noise (especially if, as is common, the wire pair is twisted). Figure 7d makes it clear that using a single LISN keeps the radiation efficiency of each mode identical.

When we know that current will be returned on a dedicated wire, not on structure, a better technique than controlling emissions on each individual lead is controlling emissions by mode. Separating modes may be done directly off the LISN (references 20 – 22) or using current probes. Regardless, if we control emissions via mode, not line, we can then assign limits based on what the modes actually affect:

Differential mode noise currents cause ripple.

Common mode currents cause radiated emissions.

Therefore when the feeder and return wires are twisted or held tightly together throughout the vehicle, it is reasonable to relax the differential mode limit compared to the common mode limit. Even if no radios operate in the conducted emission frequency range, it may be worthwhile to control common mode emissions to limit crosstalk to adjacently placed cables that might carry potentially susceptible low level signals.[23]

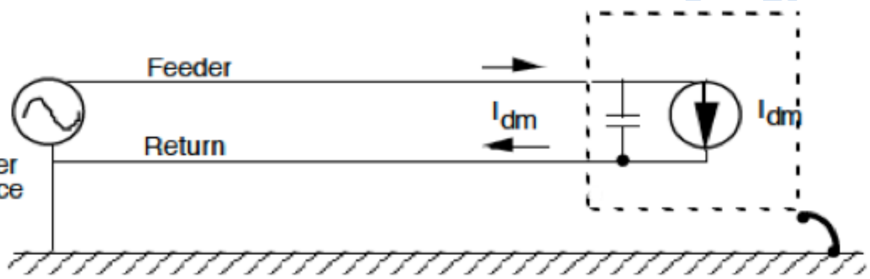

Figure 7a: *Differential mode current path*

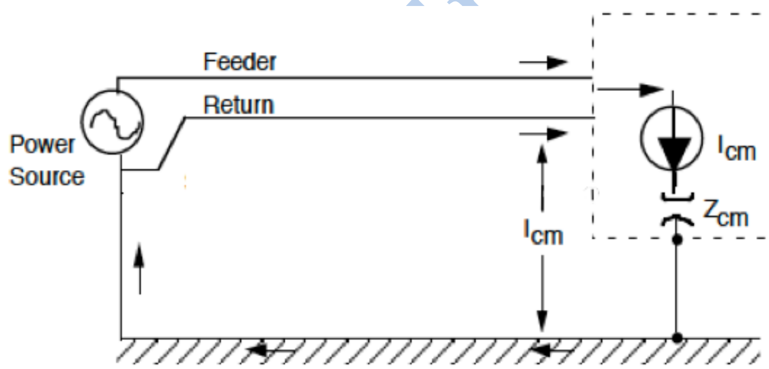

Figure 7b: *Common mode current path*

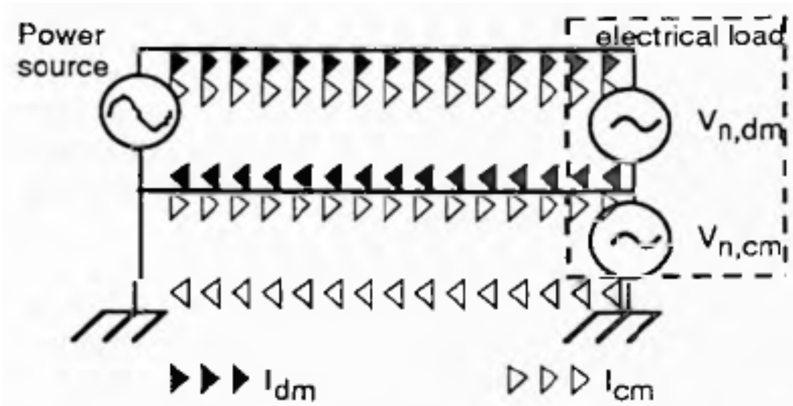

Figure 7c: *CM & DM currents adding and subtracting in feeder and return*

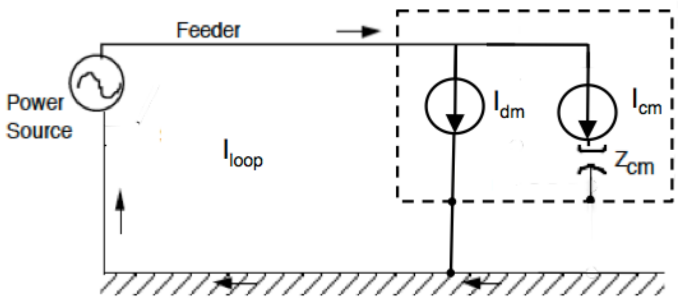

Figure 7d: *All noise currents flow in same path when structure is the return path*.

A concrete and illuminating example of the problem of LISN misuse may be found in a report by the author dating to the late '90s.[24] This report showed that the (now obsolete) FCC Class B 48 dBuV conducted emission limit was in fact 20 dB too stringent for differential mode noise, but was precisely correct for common mode noise. The problem arose because the original work done to establish the 48 dBuV limit was performed using a single 5 uH LISN, but the FCC test method was based on a pair of (50 uH) LISNs.[25] It was not the disparity in the LISN impedance but the mode separation inherent in a pair of LISNs that demonstrated the disparity.

Mode Separation Techniques

Various three-port commercial devices used to separate modes are shown below. These devices all have two input ports for connection to feeder and return LISN EMI ports and a single output port to a spectrum analyzer or EMI receiver. Some mode separators include both modes in one enclosure; these appear to be four-port devices but in all cases only three ports are engaged at anyone time.

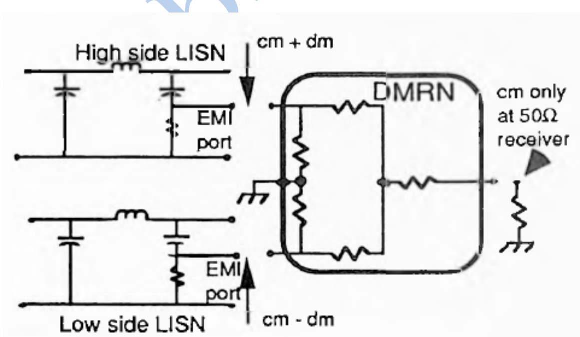

Figure 8: *Differential mode rejection network principle of operation. A CMRN adds a transformer to invert the resistive addition function to subtraction*

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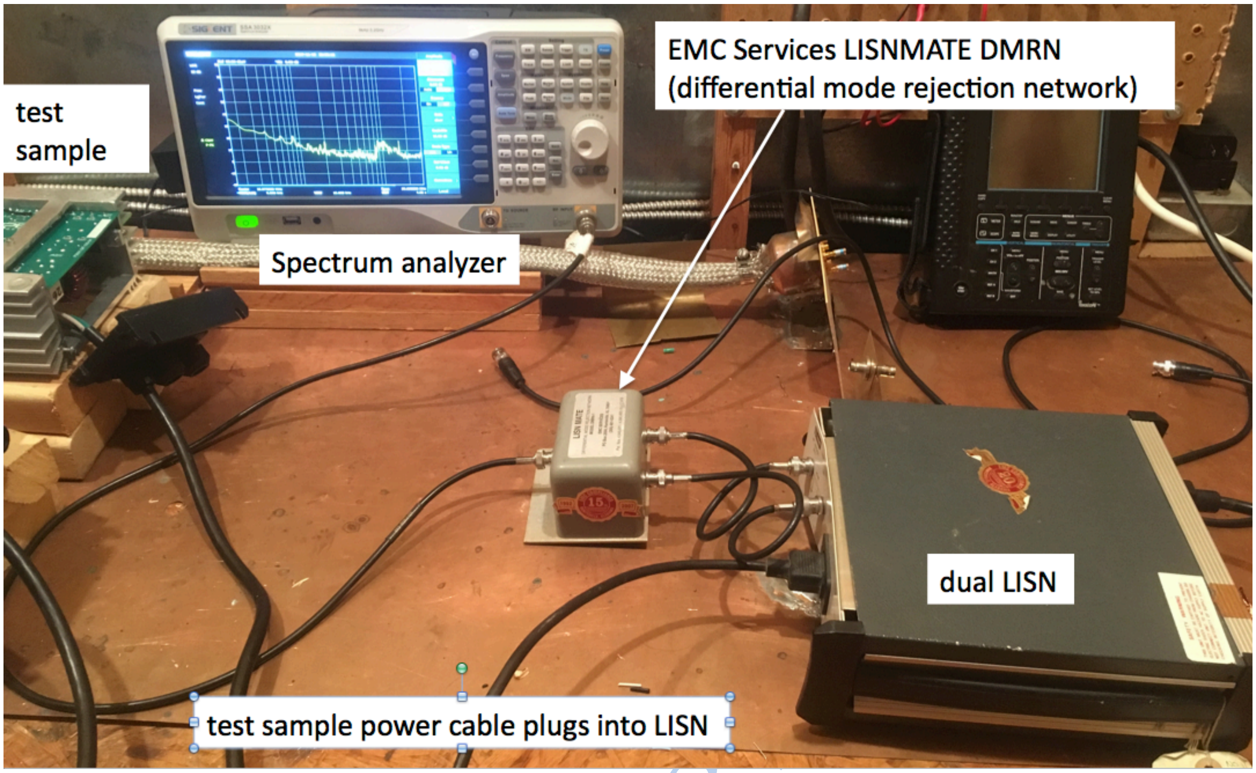

Figure 9: Test *implementation of Figure 8, using an EMC Services LISNMATE (DMRN)*

Figure 10: *The author's well-worn collection of EMC Services LISNMATE (DMRN) and LISNMARK (CMRN) mode separators. At this writing these are not commercially available.*

Figure 11: *Fischer Custom Communications offers the two-in-one CMRN and DMRN in a single unit trade named LISN-UP*

Figure 12: *Tekbox combination cm & dm separators in a single box*[26]

Conclusion

Alan Watton bequeathed us a great gift some seventy years ago. It is up to us to use it wisely, and well. To echo Mr. Parker about the comedy of errors, and intentionally misquote Gall's Law, "A complex system that works poorly is invariably found to have evolved from a simple system that worked well."

Acknowledgments

The author wishes the thank reviewers for their time and effort in making this article useful. Any errors of omission or commission are the author's own.

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[1] All specifications, standards, and other sundry documents cited herein that are not copyrighted by others may be found at http://www.emccompliance.com.

[2]

MIL-I-6181B 29 May 1953	Interference Limits, Tests and Design Requirements, Aircraft Electrical and Electronic Equipment

[3] Ministry of Defence Standard 59-411 and the older 59-41 all use a modification of the 5 uH LISN. The modification extends the frequency range of controlled impedance down to 1 kHz and up to 400 MHz. It is less than obvious why the LISN impedance needs to be controlled to 400 MHz when it is placed several meters from the test sample. The mismatch between power wire transmission line characteristic impedance and the 50 Ω LISN is always going to generate reflections, no matter how well the LISN impedance is controlled. If it is desired to have true impedance control, the LISN needs to be within a tenth-wavelength of the test sample power input. A 10 uF feedthrough capacitor would function admirably so used, at a tenth the cost of the 400 Hz LISN.

[4]

JAN-I-225 14 June 1945	Interference Measurement, Radio, Methods Of, 150 Kilocycles To 20 Megacycle (For Components And Complete Assemblies)

[5] RTCA/DO-160 original through C revision: Environmental Conditions and Test Procedures for Airborne Equipment

[6]

MIL-I-6181C 06 June 1957	Interference Control Requirements, Aeronautical Equipment

[7]

MIL-I-6181D 25 November 1959	Interference Control Requirements, Aircraft Equipment

[8] CISPR 25 all editions, various titles. "Limits and methods of measurement of radio disturbance characteristics for the protection of receivers used on board vehicles" is the 1995 title.

[9] Parker, A. T. "A Brief History of EMI Specifications," presented at the 1992 IEEE EMC Symposium.

[10] Some exceptions that prove the rule are many spacecraft line impedance *simulation* networks that appear to be designed to include the dedicated wiring to the test sample itself. See the line impedance *simulation* section of older print Solar catalogs (they no longer supply spacecraft LISNs so the on-line catalog is of no value here). Pay special attention to the series resistance value. Values above a few tens of milliohms mean they are simulating the entire power distribution network, not the main bus. As Mr. Parker said in his

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catalogs, in his gentlemanly way, " Spacecraft designers do not always agree on the characteristics of the d.c. power source aboard the vehicle. The inductance in series with the load, the resistance across the inductor, and the series resistance in each leg of the unit are variables specified by different spacecraft engineers."

[11]

MIL-I-16910A 30 August 1954	Interference Measurement, Radio, Methods and Limits; 14 kilocycles to 1000 Megacycles

[12]

MIL-STD-461 31 July 1967	Electromagnetic Interference Characteristics, Requirements, Electrical for Equipment

[13]

MIL-STD-462 31 July 1967	Electromagnetic Interference Characteristics, Measurement of

[14]

MIL-STD-826 20 January 1964	Electromagnetic Interference Test Requirements and Test Methods

[15]

MIL-STD-461D 31 January 1993	Requirements for the Control of Electromagnetic Interference Emissions and Susceptibility

[16]

MIL-STD-462D 31 January 1993	Measurement of Electromagnetic Interference Characteristics

[17] Solar Electronics Application Note AN622001, "Using the Type 6220-1A Transformer for the Measurement of Low Frequency EMI Currents." The application note used to be included in Solar Electronics catalogs. The excerpted portion is still found on their website under "Audio Isolation Transformers" under "History." https://www.solar-emc.com/6220-1B.html

[18] Author's comment about the 1947 date in this paragraph. No way to know for certain, but 1947 seems too early. That is before MIL-I-6181, which used JAN-I-225, which didn't include the 5 uH LISN. The date 1957 would fit better, but there is no way to know for certain if this was a typo, or bad memory or some other explanation.

[19] For much more on the topic of conducted emission mode separation, see the expanded version of this article on the author's website, and other articles by this author and those listed as references on this topic.

[20] A. A. Toppeto, "Test Method to Differentiate Common Mode and Differential Mode Noise," *Proc. 3rd Symposium on Electromagnetic Compatibility,* Rotterdam pp. 497-502, May 1979.

[21] M. J. Nave, "A Novel Differential Mode Rejection Network," *IEEE International Symposium on Electromagnetic Compatibility,* Denver, May 1989.

[22] LISN UP Application Note, Fischer Custom Communications, 2005.

[23] Two spacecraft specifications follow this approach, where it is known that no current of any sort returns on structure. These spacecraft don't operate radios in the bands where conducted emissions are controlled; the imposition of a common mode limit is based purely on controlling crosstalk. The resulting common mode limit is sufficient to the task, and represents a large relaxation relative to typical radiated emission limits that protect against radio frequency interference.

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GSFC-STD-7000B 29 April 2021	General Environmental Verification Standard (GEVS) for Goddard Space Flight Center Flight Programs and Projects
GP 11461 06 November 2019	Gateway Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment

[24] Javor, Ken. *"Investigation Into the Susceptibility of Radio Receivers to Power-Line Conducted Noise"* EMC Compliance, 1998. Technical committee presentation and demonstration at 1998 IEEE EMC Symposium, Denver

[25]

CBEMA/ESC5/77-29 20 May 1977	Limits and Methods of Measurement of Electromagnetic Emanations from Electronic Data Processing and Office Equipment

[26] https://www.tekbox.com/product/tblm1-lisn-mate/

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