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EMI*fix*

An Artificial Mains Network for the Laboratory

Appetizer

If you are designing switching power supplies and struggle with high frequency noise emission, you have been missing this device all the time:

Figure 1

This LISN enables you to separate and view Common Mode and Differential noise.

Introduction

Artificial Mains Networks, also called Line Impedance Stabilization Networks (LISN) are used in EMC test houses for measurement of conducted emission. The LISN is inserted between the device under test (DUT) and the EMI (Electro Magnetic Interference) receiver. The task of the LISN is to supply power to the DUT while conducting the high frequency emission from the DUT's supply cable to the EMI receiver.

Basically the LISN is just a passive filter. A low pass high-current filter from the power source to the DUT and a high pass filter from the DUT to the EMI receiver.

LISNs are made for single phase and three phase AC mains. This article deals only with single phase LISNs.

Figure 2 shows the basic setup for a conducted EMI test. Power is supplied to the DUT through two high-current inductors in the LISN, and the high frequency part of the noise generated by the DUT is directed to the EMI receiver. A dual switch enables us to measure noise on Line and Neutral respectively, as required by noise emission standards.

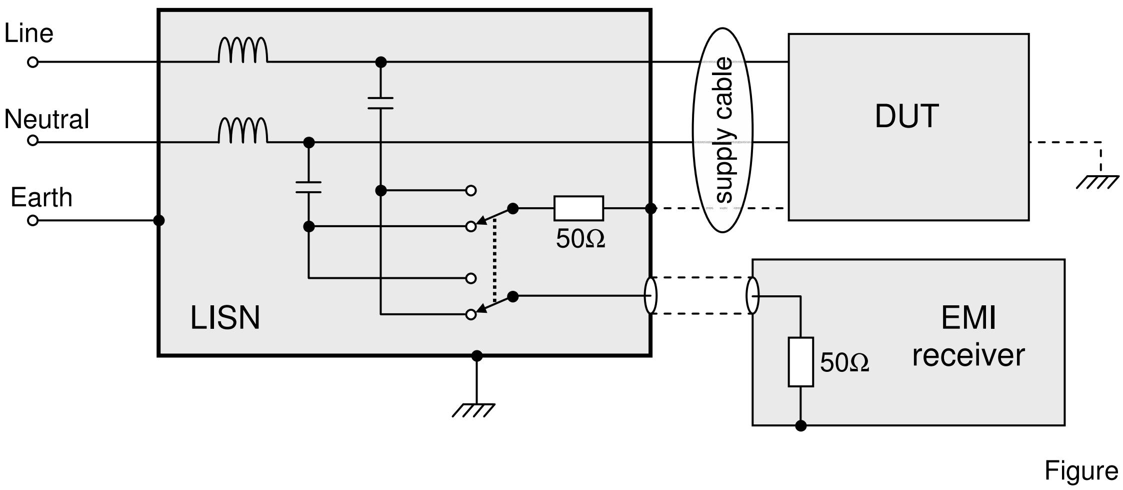


Figure 2

The source impedance seen by the DUT must be stabilized to be 50 Ω at high frequencies for both Line and Neutral.
For correct measurement the LISN must be encapsulated in a metal housing with a short and low impedance connection to an earth plane.
The supply cable to the DUT may or may not contain a safety earth conductor.

Common LISN diagrams

The diagram and component values of a LISN are specified in CISPR16. It is a bit more complicated than figure 2, but still a very simple circuit. Here is how most LISNs on the market are built, with minor variations.

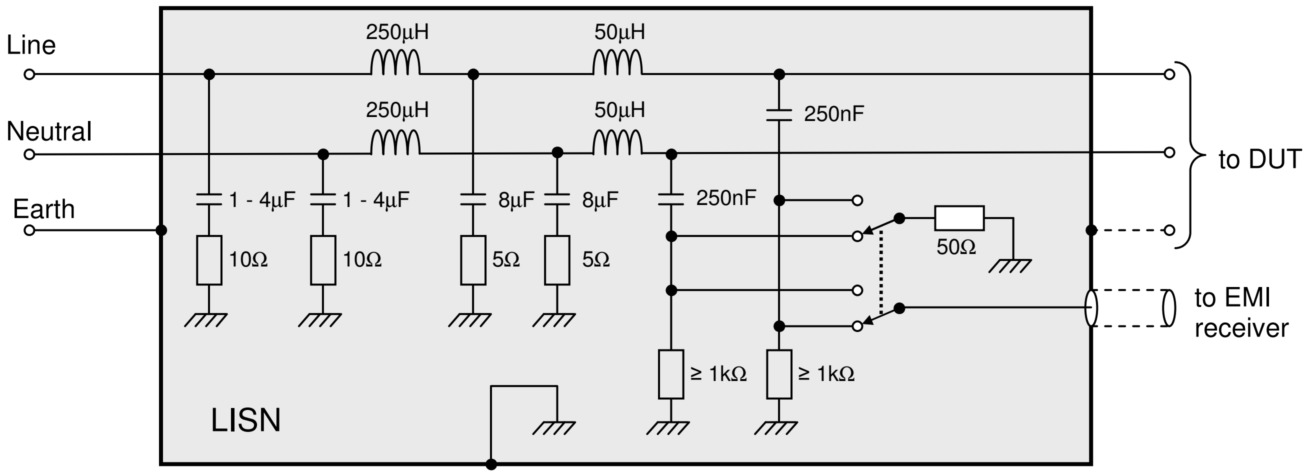


Figure 3 LISN for 10 kHz - 30 MHz

The inductors can become large and heavy. They must sustain any rms current and peak current that the DUT might want to draw.

Why measure Common Mode and Differential noise?

The LISN in figure 3 can do what EMC standards require: measure the noise on Line and Neutral respectively. All LISNs that I have seen, have only this functionality.

For the power supply designer this information is of limited value when a power supply comes back from the EMC test house with a FAIL mark on it. For the power supply designer it is essential to know how much of the noise is common to Line and Neutral with respect to earth (Common Mode) and how much comes out as a Differential voltage between Line and Neutral. In other words - to make a sweep over all frequencies showing a CM spectrum and a DIFF spectrum respectively.

Why is that?
Because the useful remedies against noise depend a lot on which of the two types of noise we are dealing with. The noise sources and the noise paths are fundamentally different for CM and DIFF noise, as well as the measures to suppress it.

Surprisingly, no-one seems to have seen a market for a LISN with the ability to pick out the CM and DIFF parts, even though an idea for the realization of such a LISN has been published long ago (ref. 1).

Now there is a solution: the EMIfix - figure 1.

Picking up the CM and DIFF parts of the noise can be done by adding an ideal transformer comprising four identical parts, according to ref. 1.
The next four figures show how this can be accomplished for the four modes Line, Neutral, CM, and DIFF.
The two ≥1 kΩ resistors are not shown.
The challenge is to design the transformer so that it does not change the basic characteristics of the LISN (50Ω || 50µH etc.). Also, in the CM and DIFF setting it must transmit the whole frequency band 10kHz - 30MHz to the

EMI receiver with no loss of gain at any frequency. Therefore the transformer must have a high main inductance compared to 50 µH, and it must have low enough leakage inductances.

In all four modes the EMIfix represents a high frequency impedance of 25 Ω to common mode signals (50 Ω pr. phase) and 100 Ω to differential signals, as it does in a standard LISN.

The connections needed in Line and Neutral mode are represented by the switches in figure 2 and 3.

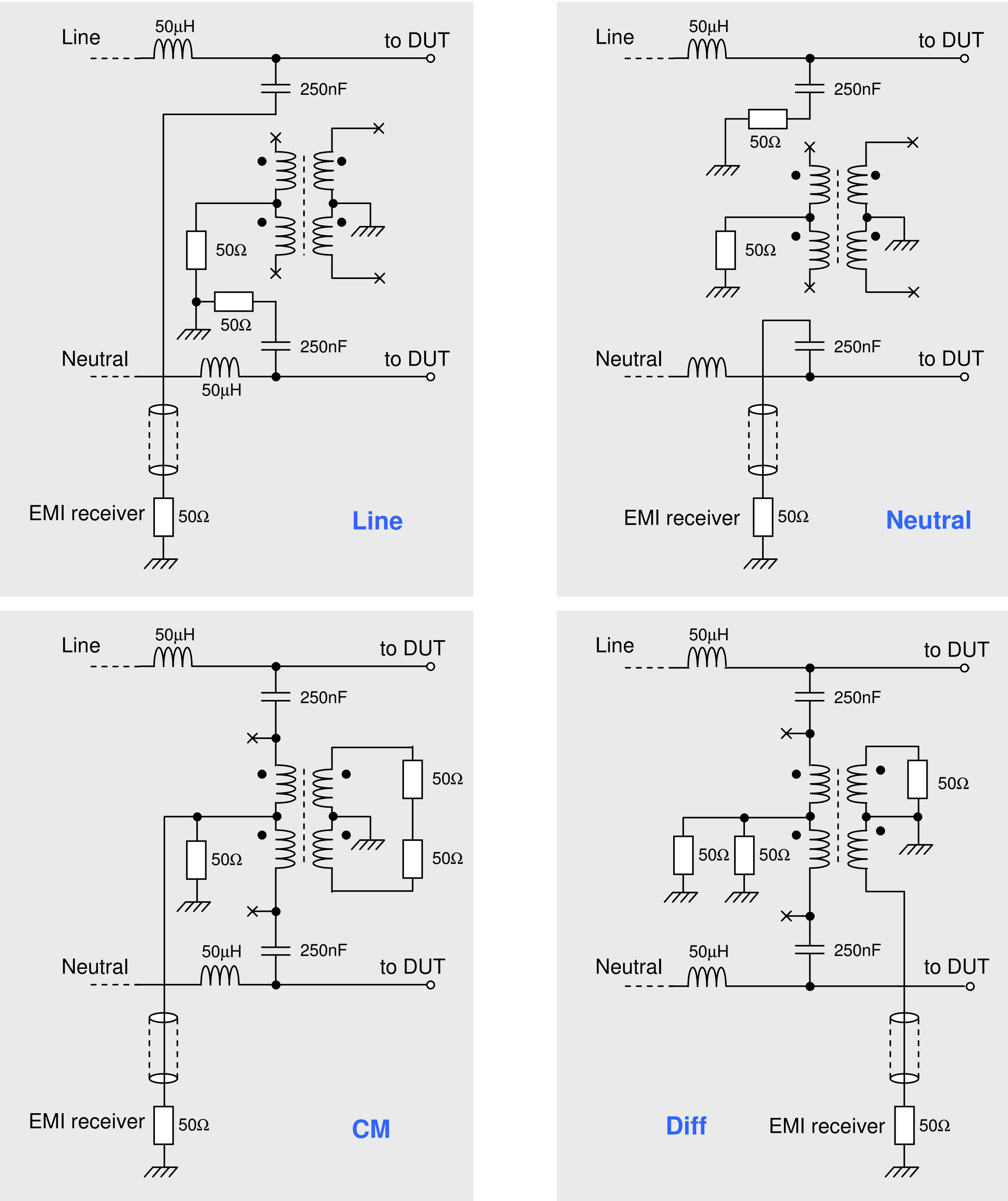


Figure 4

To add CM and DIFF modes a more complex switch bank is needed. It can be handled by a four row interlock pushbotton switch, which will be familiar to many older electronics engineers.

The EMI receiver will see the voltage (Line + Neutral)/2 in CM and (Line - Neutral)/2 in DIFF mode. If the noise is pure common mode, CM will display same result as Line and Neutral while DIFF will display zero. If it is purely differential noise, CM will display zero, and DIFF will display same result as Line and Neutral.

Features and components in EMIfix

The EMIfix was developed and designed during a period in 2019 with free time available in my company. The first ones are home made. What comes next will depend on the demand from the world.

The EMIfix is primarily intended as a tool for the design engineer, but can be used in the EMC laboratory as well.
Additional to the CM and DIFF features it comprises an internal **transient limiter /10dB attenuator** to protect an EMI receiver or a spectrum analyzer. It covers the frequency range 9 kHz – 30 MHz. It has a selectable 5th order Butterworth **high-pass filter** with a corner frequency at **130 kHz** to suppress low frequency noise that may cause overdrive of a spectrum analyzer. This filter can be used in most cases where you do not need to measure below 150 kHz. The filter is beneficial if you want to study a clean noise picture on your oscilloscope which can provide much useful information during noise mitigation.

The EMIfix also contains the standardized "**artificial hand**" terminal on the front panel. It is used when testing hand held tools to emulate the noise current path through a human hand.

The earth conductor to the DUT can be disconnected with a separate switch, replacing it with an inductor. I don't believe this is required by any standard, but some commercial LISNs have this feature. For the experienced engineer this switch can be a nice feature to quickly reveal certain properties of the noise generator in a "class I" device.

Inductors:
The instructions in CISPR16 suggest us to use air core inductors, at least for the 50 µH. The EMIfix does not follow this instruction, most of all to keep it small and handy. For the 50 µH an ETD54 ferrite inductor was designed, and for the 250 µH an inductor made with laminated iron was used. However, care has been taken to assure that they will show the same results as well designed air-cored inductors. Saturation current is 55 A which should be more than enough for a 16 A rms LISN. Furthermore they are one-layer-like inductors, minimizing parallel capacitance and parasitic resonances.
The 50 µH has a parasitic parallel capacitance of < 4 pF, and |Z| of the 50 µH is still > 1 kΩ @ 30 MHz. As long as |Z| of 50 µH >> 50 Ω, the parasitics will not affect the measurement.

Similarly for the iron core inductors 250 µH. Iron is not at all perfect for high frequency, however |Z| of 250 µH just needs to match an ideal inductor at 10 kHz and must be >> 5 Ω at high frequency to form a reasonable LCR filter. For the 250 µH I measure |Z| = 300 Ω @ 1 MHz and 1,2 kΩ @ 10 MHz. So it does not at all work as a high-Q inductor, but in this application it works just fine.

EMIfix is a purely passive network. It contains no relays or LEDs, and it is not remotely controllable. Therefore it does not need an aux. supply voltage as many other LISNs do. Unlike many others, it can therefore handle AC as well as any **DC voltage between 0V and 400V**.

It has been seen that the contacts of signal relays in LISNs can wear out or oxidize, leading to unreliable readings. EMIfix does not contain signal relays. All switches are manually operated "slide contact" types, and all are doubled with two switches in parallel. Hence a **good reliability and a high life time** is anticipated.

Measured properties

Figure 5 shows the impedance that must be measured into Line and Neutral of the LISN when the RF output is terminated into 50 Ω. At >1 MHz the impedance is 50 Ω. Below 1 MHz it drops because 50 Ω is in parallel with 50µH + 5Ω. CISPR16 allows the impedance to deviate ±20% (±10 Ω). This deviation would affect a measurement with an error of up to +1,6 dB / -1,9 dB.

Also during CM or DIFF measurements the impedance into Line and Neutral should agree with figure 5, regardless of the source impedance feeding the opposite terminal.

Calculated and specified impedance

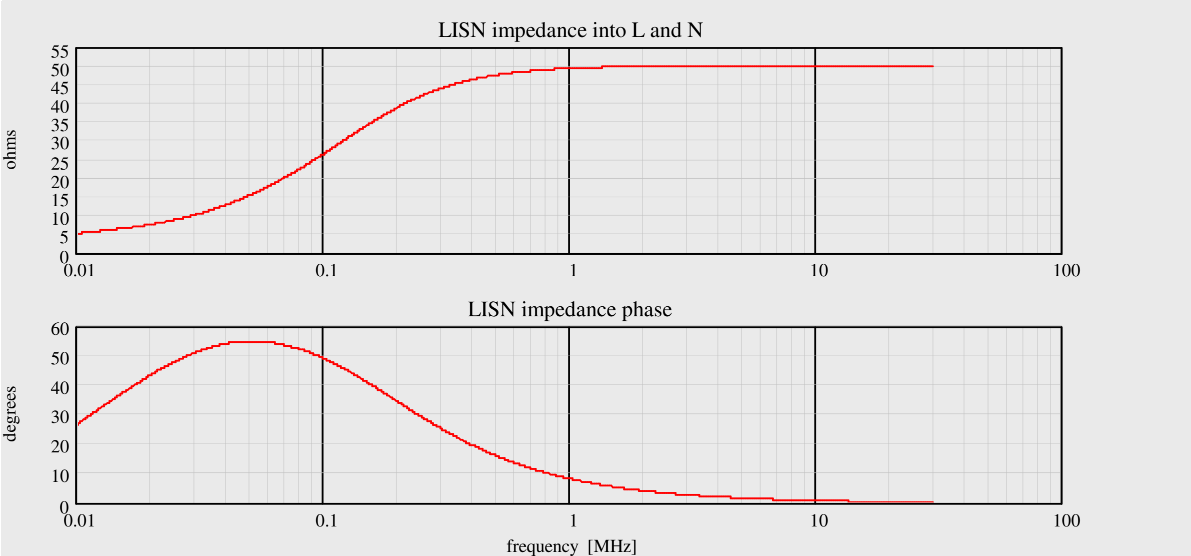
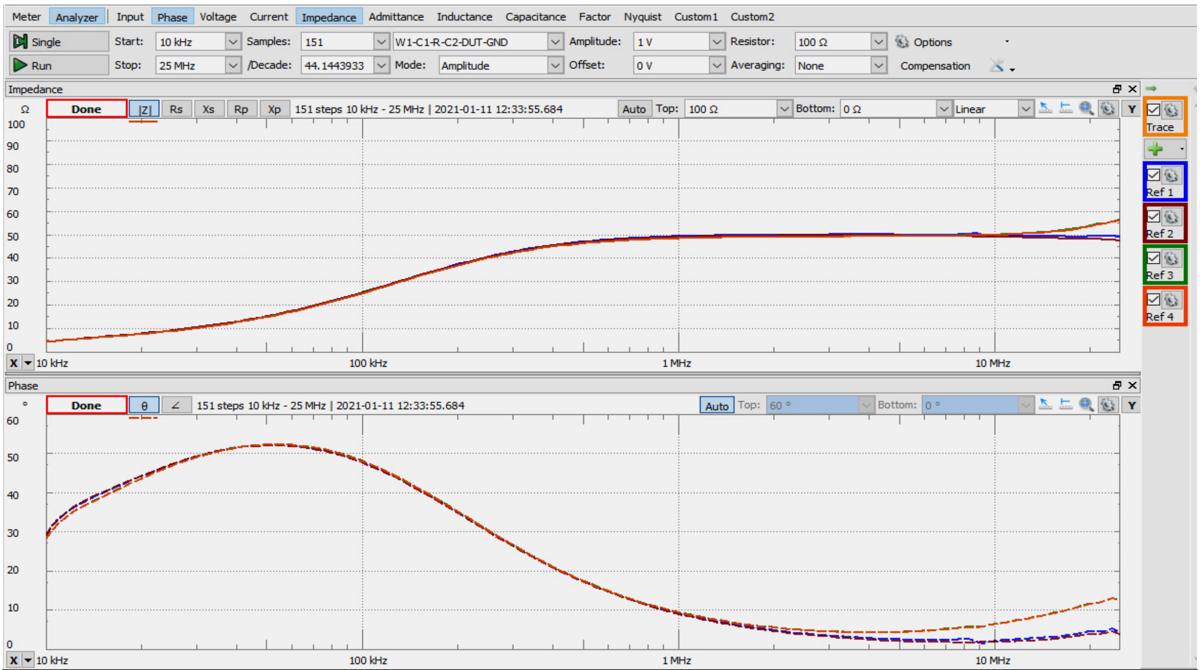


figure 5 Impedance characteristics

Impedance measured with Digilent's Analog Discovery



Blue: Input under test (Line with L pressed or Neutral with N pressed)
Brown: Input not under test (Line with N pressed or Neutral with L pressed)
Green: Line or Neutral with CM pressed (behind orange curve)
Orange: Line or Neutral with DIFF pressed

Figure 6 Measured impedance

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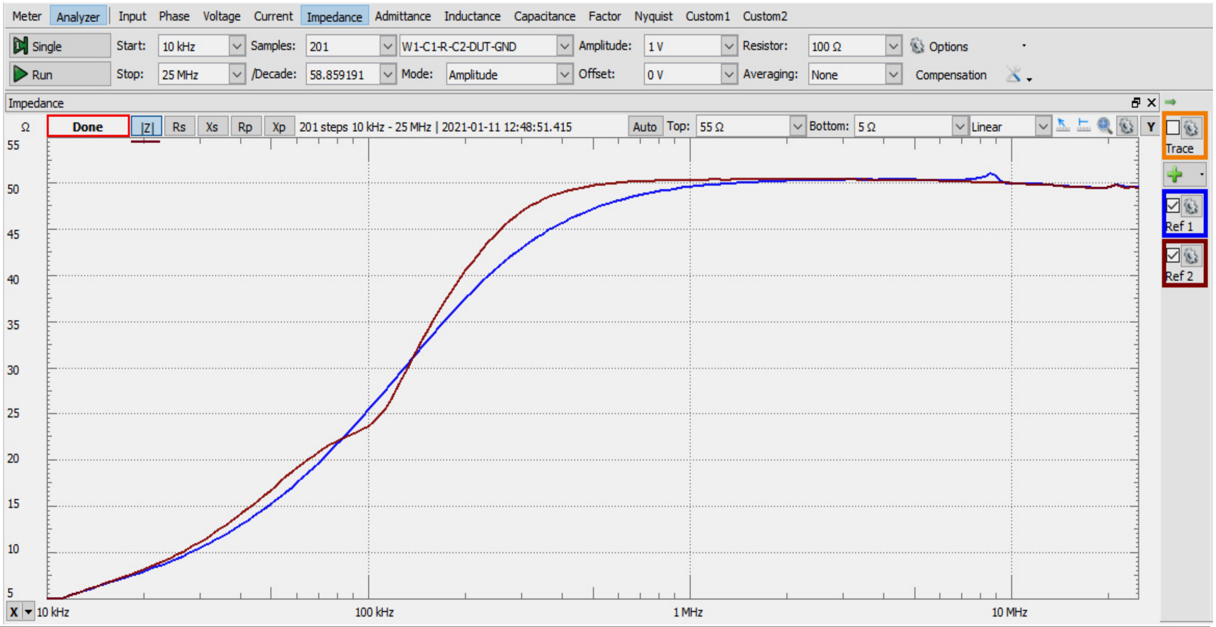
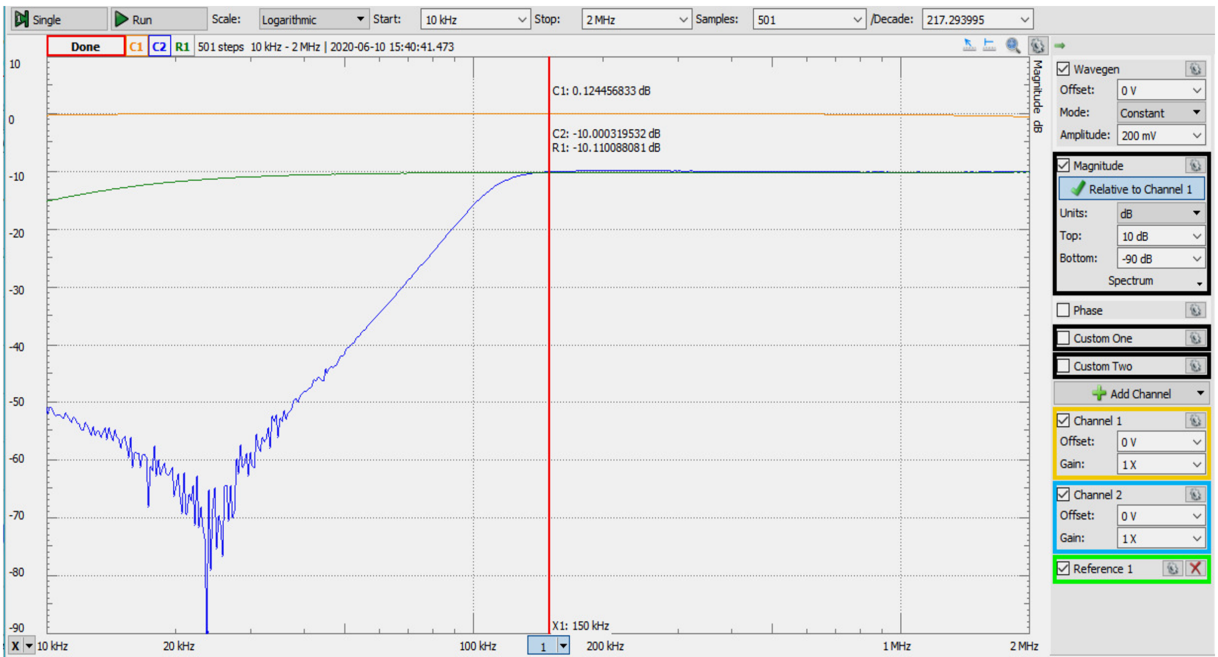
Measured impedance without and with HP filter



Blue: Input under test (Line with L pressed or Neutral with N pressed). No HP filter
Brown: Same but with HP filter active

Figure 7 Measured impedance

High pass filter characteristics



Yellow: Input to LINE (reference). Generator impedance = 0 Ω
Green: Output into 50 Ω with L pressed, no HP filter
Blue: Output into 50 Ω with L pressed, HP filter active

Figure 8 HP filter

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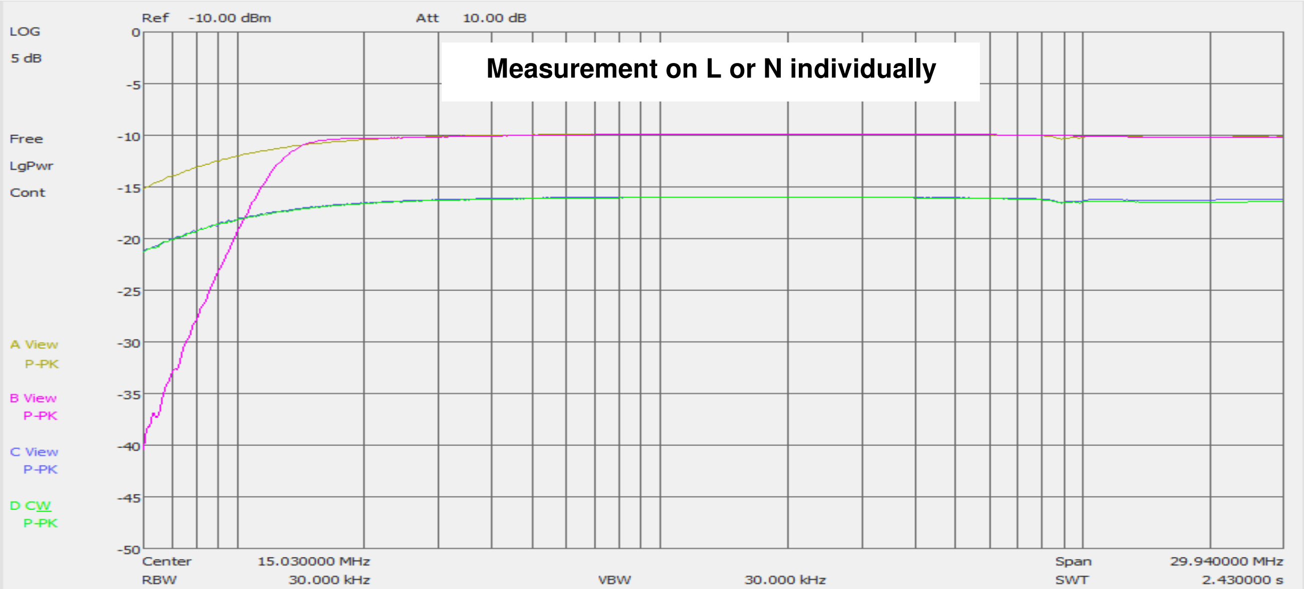
Transmission gain measurements with Siglent SSA3032X spectrum analyzer / tracking generator

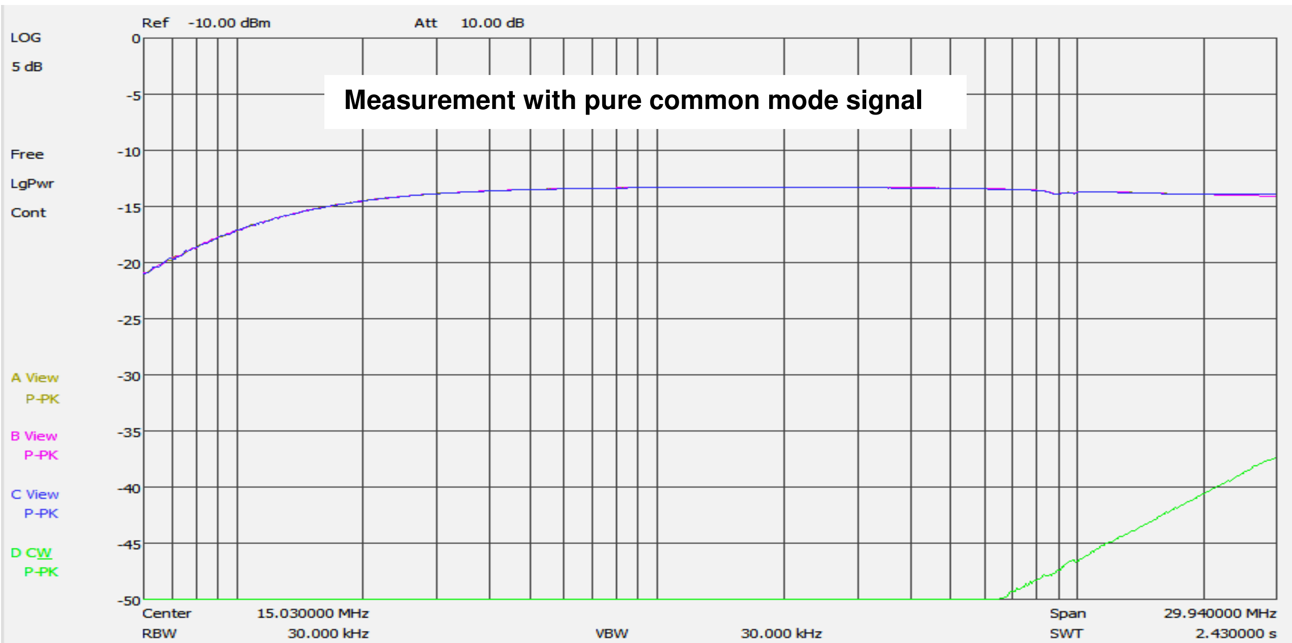


Transmission gain from Line to RF OUT. 60 kHz – 30 MHz. Tracking generator to Line. 50 Ω from Neutral to earth.

Yellow	L pressed.	
Purple	Same but with HP filter on.	
Blue	CM pressed.	same display
Green	DIFF pressed.	

Figure 9

Gain reduction below 200kHz is due to reduction in impedance of 50Ω || (50µH + 5Ω) at low frequency.
With CM and DIFF pressed, gain = -16 dB because CM and DIFF takes the average of Line and Neutral.

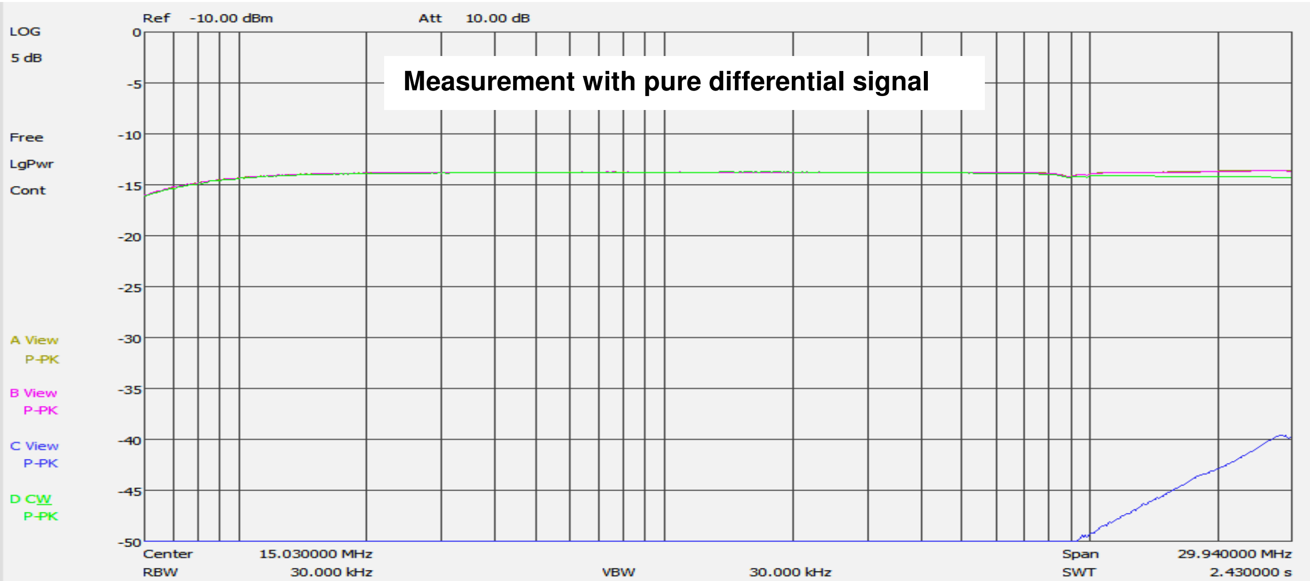


Transmission gain for CM. 60 kHz – 30 MHz. Tracking generator to Line and Neutral (pure CM signal)

Yellow	L pressed.	
Purple	N pressed.	same display
Blue	CM pressed.	
Green	DIFF pressed (unwanted cross talk).	

Figure 10

Output 13,5dB attenuated (TG is now loaded with 25Ω).



Transmission gain for DIFF. 60 kHz – 30 MHz. Tracking generator between Line and Neutral via 50 Ω →50 Ω CM → DIFF balun.			
Yellow	L pressed.	same display	
Purple	N pressed.		
Green	DIFF pressed.		
Blue	CM pressed. (unwanted cross talk).		Figure 11

Output 13,5dB attenuated (TG is now loaded with 100Ω, then voltage divided by 2).

References

Ref. 1:

A. Nagel and R. W. de Doncker:
Separating Common Mode and Differential Mode Noise in EMI Measurement
EPE Journal vol. 10, no 2, August 2000