MEASUREMENT AND ANALYSIS OF CONDUCTED EMISSIONS IN A THREE-PHASE POWER LINE USING AN EMSCOPE-RX4

Abstract

This application note describes how to correctly design and optimize a three-phase power-line filter (PLF) by decomposing the conducted emissions into their common and differential modes (CM and DM1, DM2 and DM3 respectively). Using an actual test case as an example, the proposed solution is focused on minimizing the total cost and size of the power-line filter and optimizing its performance. This can only be done after measuring and detecting the dominant mode in the coducted emissions of the device under test (DUT).

Scope of the work

Due to the recent exponential growth of three-phase applications, especially linked to the automotive sector, conducted emissions (CE) measurements for three phase systems are becoming an important concern. Different strategies and techniques can be used to design a three phase power-line filter (PLF). The aim of this article is to show how easy the design of a PLF becomes when the information about the common mode (CM) and the differential modes (DM1, DM2 and DM3) is available. The instrument used for the measurements is the EMSCOPE-RX4, an innovate EMI Receiver designed and manufactured by EMZER, that offers the possibility not only to measure the overall conducted emissions as defined inaccording to CISPR-16, but to decompose them into the CM and DMs as well. This information is fundamental to correctly decide which components are needed to implement the optimal power-line filter for specific equipment under test (EUT).

Introduction

EMSCOPE RX4 is a unique receiver which allows to measure the conducted emissions of up to four lines simultaneously. On top, it is the only receiver worlwide capable of directly computing the modal noise of a three phase system. Furthermore, it integrates four Transient Limiters and, optionally, a 16-A single-phase dual-port V network Line Impedance Stabilization Network (LISN), as seen in Figure 1. All these features make the measurement of any EUT and the design and implementation of its suitable power-line filter easier, considerably reducing dozens of hours in test and error practices.

(a) (b)

Figure 1. EMSCOPE-RX4 image with (a) and without (b) a 16-A single-phase dual-port network LISN.

Three-phase measurements

EMSCOPE-RX4 can measure voltages at L1, L2, L3 or N (that is, V_{L1}, V_{L2}, V_{L3} and V_{N}) using the three detectors simultaneously (peak, quasi-peak and average). This is named here EMI measurements.

Alternatively, EMSCOPE-RX4 can also measure the modal emissions, that is, common-mode (CM) and differential-modes (DMs) emissions. In this case, the voltages measured are V_{CM}, V_{DM1}, V_{DM2} and V_{DM3}.

Three-phase systems can dispense with the neutral (N) if the three phases L1, L2 and L3 are well balanced. Accordingly, modal measurements are computed as shown below [1, 2]:

- If Neutral line is not used:

$V_{CM} = \frac{(V_{L1} + V_{L2} + V_{L3})}{3}$,

$V_{DM1} = V_{L1} - V_{CM}$,

$V_{DM2} = V_{L2} - V_{CM}$,

$V_{DM3} = V_{L3} - V_{CM}$.

- If Neutral line is used:

$V_{CM} = \frac{(V_{L1} + V_{L2} + V_{L3} + V_{N})}{4}$,

$V_{DM1} = V_{L1} - V_{CM}$,

$V_{DM2} = V_{L2} - V_{CM}$,

$V_{DM3} = V_{L3} - V_{CM}$.

A practical example using an actual EUT

Figure 2 shows the block diagram of the measurement setup, composed of an EUT, a three-phase LISN and four-port EMI receiver (such as EMSCOPE-RX4).

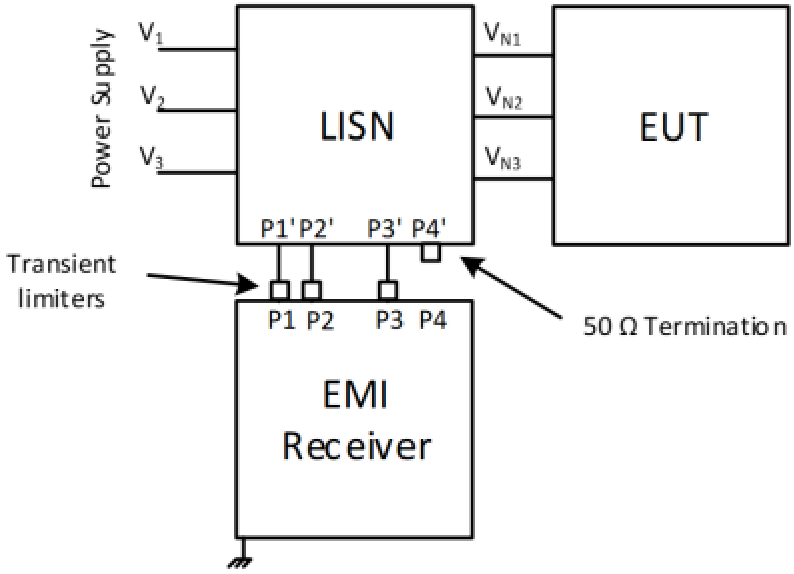


Figure 2. Measurement-setup block diagram: EUT, the three-phase LISN and the EMSCOPE.

This measurement setup has been used to measure the conducted emissions of an actual three-phase EUT. Figure 3 shows the measured conducted emissions registered at the line terminals of the LISN using the quasi-peak detectors, along with the CISPR 32 class A limits. It can be seen that the EUT is not compliant. The quasi-peak trace is above the limit at 630 kHz due to one of the harmonics of the switching power supply, and at 5 MHz.

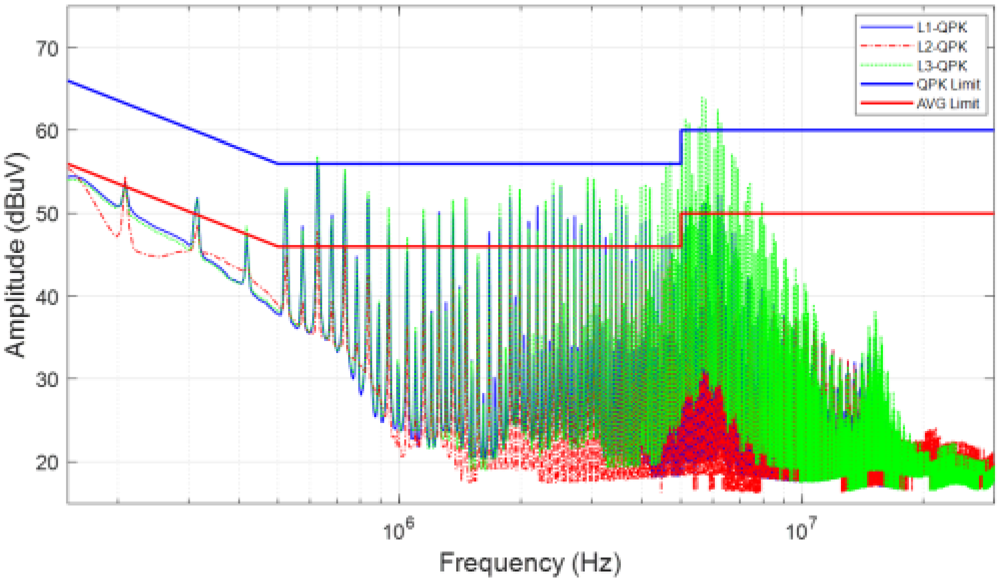


Figure 3. Conducted emissions of the EUT using the quasi-peak detectors at Line terminal.

Therefore, the conducted emissions need to be mitigated to make the product compliant. This can be done inserting a power-line filter in the power-line terminals of the EUT. The best place to mount this filter is where the power-line network terminals enter the enclosure, since it prevents electromagnetic field coupling to the filtered power line. If possible, a metal enclosure helps to block any capacitive coupling from the filter input cable and the filtered power line.

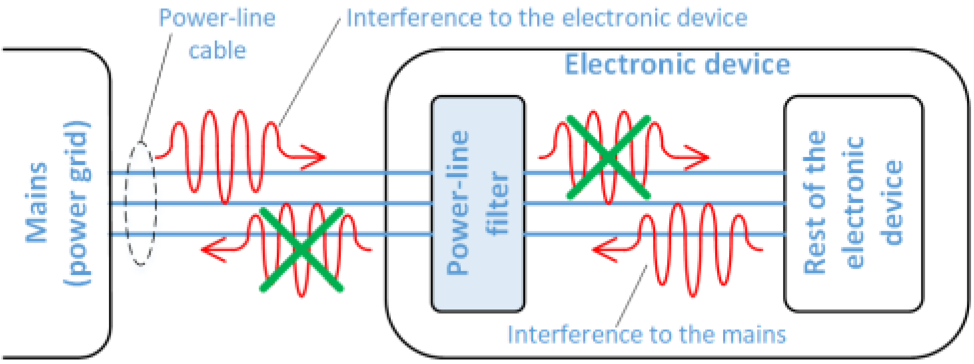
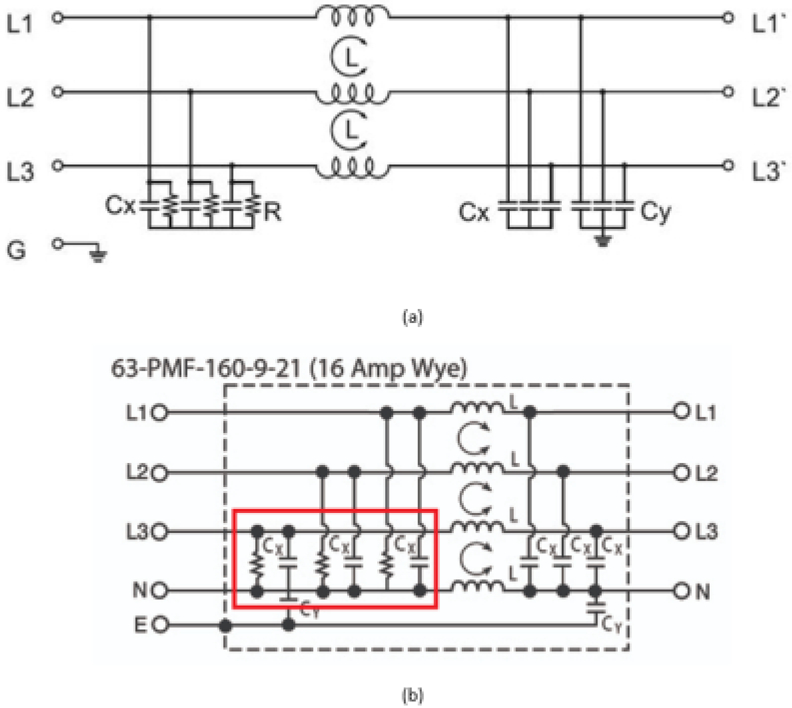


Figure 4. Effect of the power-line filter on the conducted emissions coming from the EUT or the PLN.

The simplest structure of a power-line filter contains X-type capacitors between the three lines and neutral, to mitigate the differential modes, and a common-mode choke and Y-type capacitors from lines and neutral to ground to mitigate the common mode. Figure 5 shows an example of a three-phase power-line filters, without and with neutral, respectively.



(a)

(b)

Figure 5. Basic structure of a three-phase power-line filter. a) Without Neutral. b) With neutral.

Given that each component of a power-line filter primarily affects either the common-mode or the differential-mode component, a thorough understanding of the modal nature of conducted emissions is essential for the proper design of filtering solutions tailored to each Equipment Under Test (EUT). Nonetheless, electromagnetic compatibility (EMC) standards define conducted emission measurements in terms of line-to-ground and neutral-to-ground voltages. Consequently, commercial electromagnetic interference (EMI) receivers are inherently limited, as they do not provide direct separation between common-mode and differential-mode components, being designed to comply with these conventional measurement procedures. As a result, EMC engineers, lacking instrumentation capable of modal decomposition, often rely on commercial off-the-shelf filters—typically selected based on prior experience—or engage in time-consuming trial-and-error processes to identify an appropriate filtering strategy.

EMSCOPE-RX4 allows the measurement of the modal conducted emissions of the EUT. Figure 6 shows the modal decomposition of the conducted emissions generated by the EUT measured with the quasi-peak detectors.

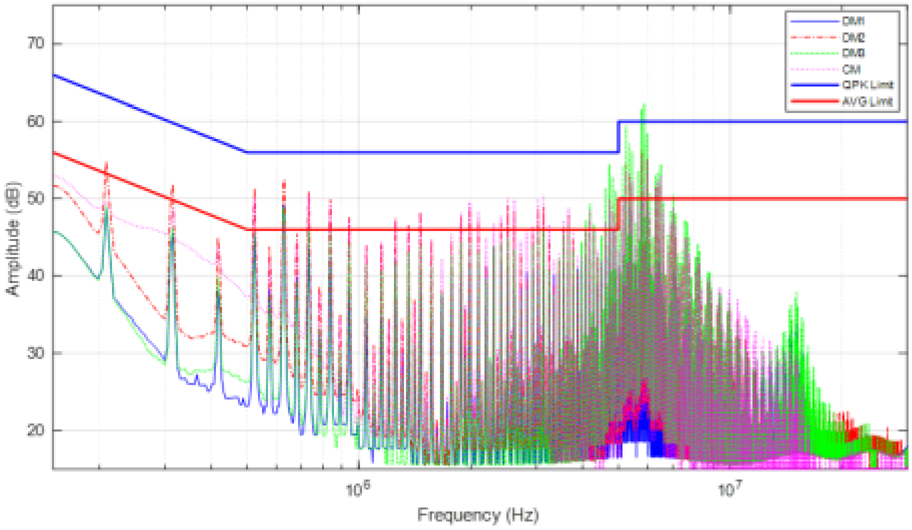


Figure 6. Modal conducted emissions of the EUT using the quasi-peak detectors.

Thanks to the modal decomposition it is possible to determine that the DM3 is the dominant mode. Since the other modal noises are below the limit, they do not require additional mitigation. According to [3], two CX capacitors are the correct elements to filter the differential mode noise DM3. The capacitors must be placed between lines 1-3 and 2-3. In this specific case, the value of the CX capacitors is 0.47 uF (different values could be tested to find the optimal ones). Figure 7 shows the DM3 recorded before and after connecting the two X-type capacitors between line 1-3 and 2-3.

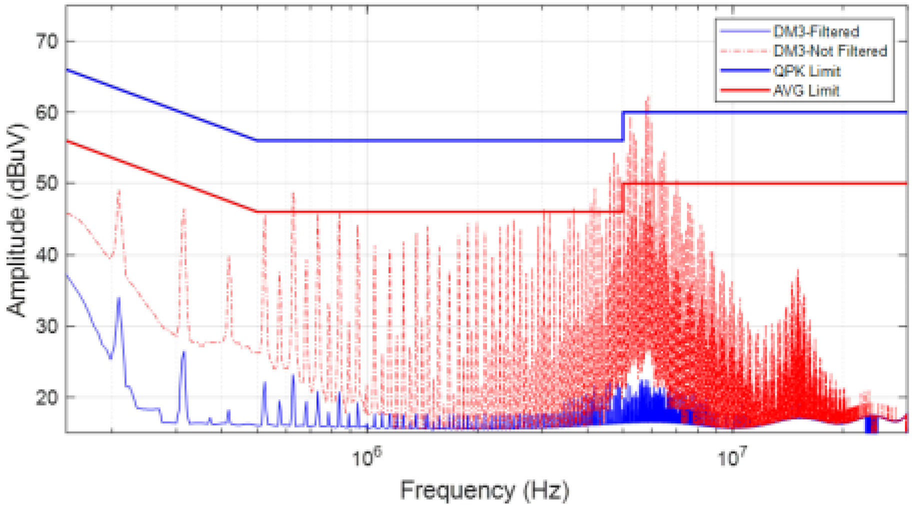


Figure 7. DM3 without (red) and with C_{X} capacitors (blue).

As can be seen, a reduction of 21 dB is achieved at 630 kHz, and above 30 dB at 5 MHz. Besides, the addition of these two capacitors also adds attenuation to the DM1 and DM2 modes, as seen in Figure 8 and Figure 9.

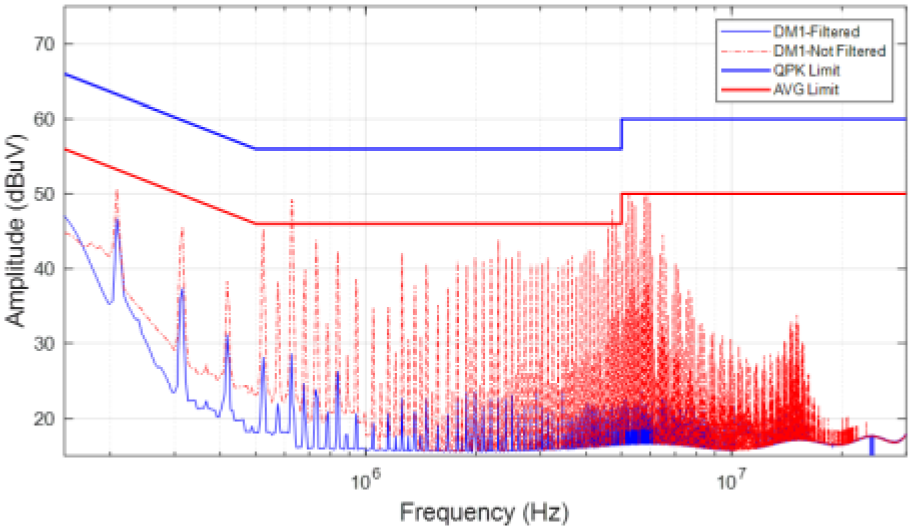


Figure 8. DM1 without (red) and with C_{X} capacitors (blue).

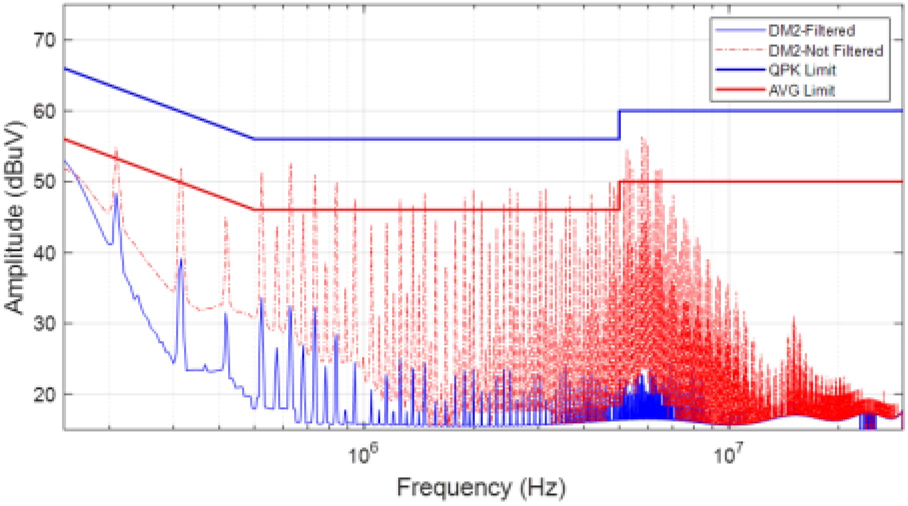


Figure 9. DM2 without (red) and with C_{X} capacitors (blue).

As expected, these capacitors do not introduce any effect on the CM noise, as seen in Figure 10.

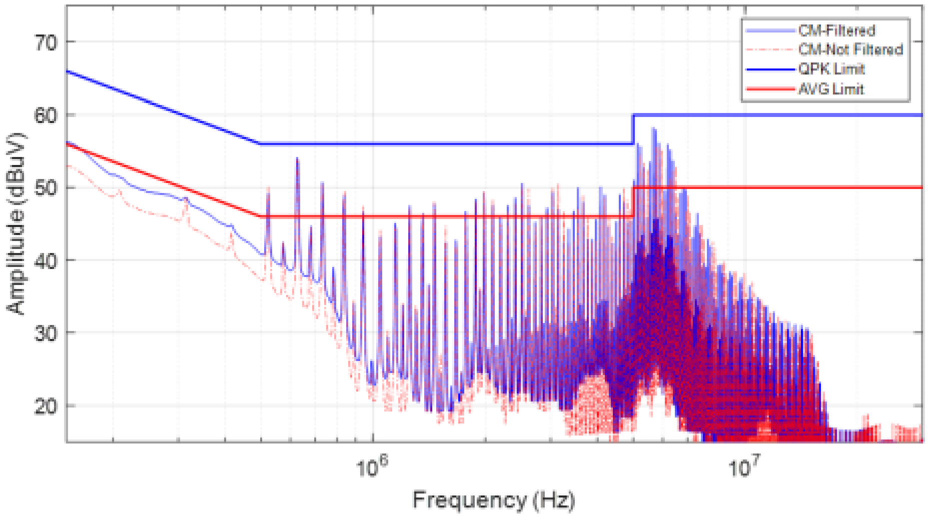


Figure 9. CM without (red) and with C_{X} capacitors (blue).

It can be seen that, in order to design the optimal power-line filter for a specific EUT, it is needed to measure the modal noise separately. In this particular case, a power-line filter composed by two CX capacitors was found to be the optimal configuration. Hence, every other component, as a CX capacitor placed between lines 1-2 or a common-mode choke, would have been redundant, and only contributing at increasing the size and cost of the PLF.

This example shows how using EMSCOPE, the only commercial instrument able to provide the measurement of modal emissions, the design of an optimal filter is obtained easily, saving time in the designdesign, and obtaining a cheaper final product.

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