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LaurTec

EMC Testing

Conducted noise - Differential and Common mode noise

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Abstract

On the previous article we have seen what the conducted noise is and how it links with the radiated noise to. CISPR regulations require that you have two tests setup for testing conducted and radiated noise. In regards to the conducted noise, while the standards require that the absolute value should be below a certain threshold, understanding what contributes to the total noise, could be beneficial for the design. Indeed the conducted noise is made of two components, Differential Mode (DM) and Common Mode (CM). The two components summed together is what we measure with the spectrum analyzer or the receiver. In this article we see the details of the DM and CM. Out of the values the designer can better leverage how to dimension the EMI filter, either for the DM or CM noise.

Differential and Common mode noise

Conducted noise has to do with moving charges, while on the other hand, radiated noise can still influence and contribute on it. Thus we would expect that to measure conducted noise we have to attach some cables to measure those current, or if we do it with an isolated technique, we could measure the magnetic field that are generated by those currents. In both scenarios, we are imaging that conducted noise is the energy that flows on our cable. Indeed this is the case, and Figure 1 depicts what that noise is. In particular Figure 1 also shows that the total contribution is made of two components, called Differential Mode (DM) and Commom Mode (CM) currents.

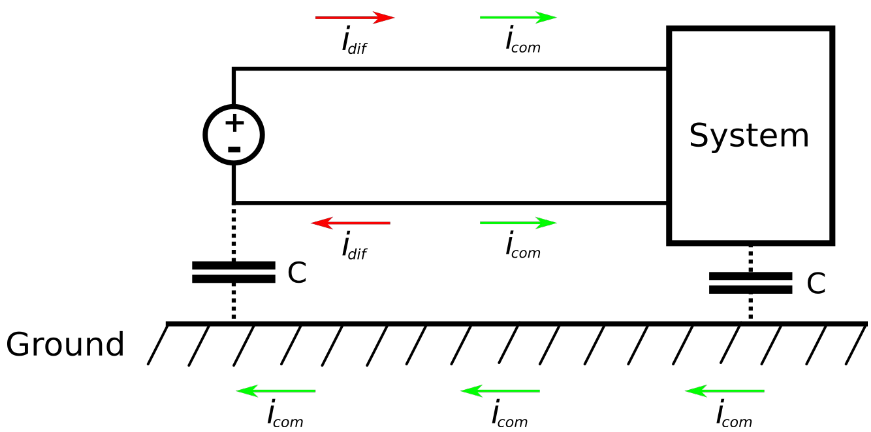

Figure 1: *Conducted noise with the details of DM and CM contributions.*

The relations between the differential current and common mode one are:

$$i_p = i_{dif} + i_{com}$$

$$i_n = i_{com} - i_{dif}$$

$$2 i_{dif} = i_p - i_n$$

$$2 i_{com} = i_p + i_n$$

Where:

i_p: is the total noise current on the positive line
i_n: is the total noise current on the negative line
i_{dif}: is the differential mode current
i_{com}: is the common mode current

By looking the details on Figure 1, we do see that the System is powered by a Generator, and we do have the + and – lines connecting the two. The DM component is the AC noise component that adds to the current sunk by the system, thus it flows from + line to the – line. This means that the phase of the DM current on the + and – lines are shifted 180°, or in other words they are not in phase.

The frequency of interest of our AC noise is related to the specific standard we are taking as reference. CISPR 25 cares about the components in the range from 150KHz up to 108MHz, while CISPR 11 and CISPR 32 do care in the range from 9KHz up to 30MHz.

On top of the differential noise, we do have the CM noise current. In this case, the component is related to the current that flows on both lines + and - without any phase shift, thus in the same direction. This current close the loop back to the generator via the earth connection, which is due to the C coupling you have with the earth. This is highly influenced by PCB layout and system cover, either metallic or plastic one.

The CISPR 11, 25, 32 require measuring the conducted noise that the system generates, but the results can actually be used to understand if the system could be also week in any frequency range. While the system is typically a complex one and the reciprocity theorem may not actually apply, it could be a good indication of what could go wrong and at which frequency the system may be more susceptible to external noise.

Thus a filter that will be used to limit the noise going out from the system, actually also protect from external noise going to the system.

Typical sources of DM and CM noise

As we have seen, the DM noise is related to currents flowing from + and – lines. The AC DM components are typically related to switching nodes, such as the one from DC-DC converters, digital lines and clock. Switching signals do requires quick energy delivery, which comes from bulk capacitors and bypass capacitors. Capacitors are not ideal, does they have a certain ESR (*Equivalent Serie Resistance*). Once the capacitor delivers current in and out, on the ESR, there is a voltage drop that represent the AC noise component we can see on the DM noise, thus its spectrum is what we see on the conducted noise. Ripple frequency will also show up in the conducted DM noise and is related on how fast the generator can provide energy to the bulk capacitor and how fast the load sink that out.
Also in this case ESR plays an important role, and having low ESR helps to reduce it. The R and L on the power cable and PCB traces, also play an important role since any current change will create a voltage drop on it, that we can measure out as conducted noise. R and L we do have on the traces are also among the root cause that may enable conversion

of CM noise to DM noise.

The CM noise is related to the C coupling we have between the system and the earth. This coupling could be indirectly via the human body, system location (e.g. Table) or due to a physical connection via a capacitor to the earth. In any of the case the difference would be on how big the C would be, but the same considerations would apply. If we have high dV/dt variation on our system, this may better be a cause of coupling with the earth, and be a cause for the CM noise. A typical location that could be source of high dV/dt are the switching node of a DC-DC converter. This is why, often the switching node offers controlled slew rate option to limit the high dV/dt.

While we have analyzed some source of noise that could be the reason behind the DM and CM noise, things are not that easy. The system complexity does not always allow splitting one source from the other. The ground layer play for instance an important role reducing the stray inductance. High impedance of it may also cause conversion from CM to DM, thus while you have done all possible to make a DC-DC converter having low DM noise, you may still and up with high DM noise if the grounds is not properly layout and you get conversion from CM to DM. Figures 2, 3 and 4 show a typical conducted noise spectrum for a buck converter working at 460KHz switching frequency and 500mA load (Vin=12V, Vout 5V). The plots shows the bandwidth between 150KHz-30MHz tested for CISPR 25, the spectrum between 30-108MHz is removed for clarity.

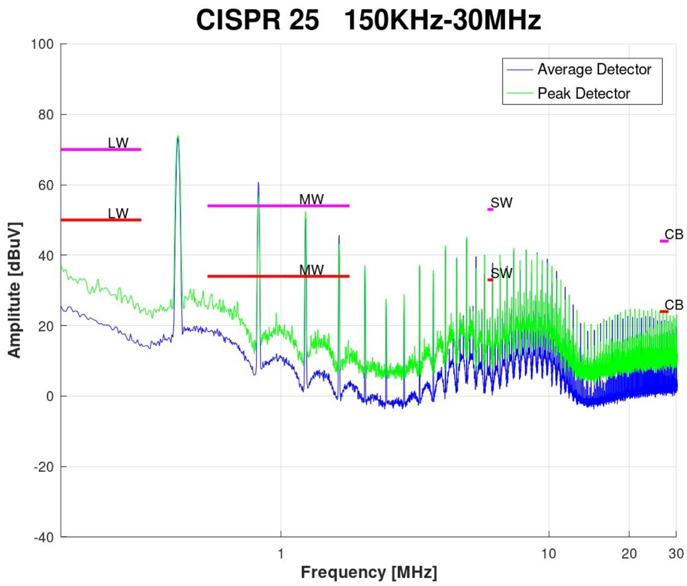

Figure 2: *Total conducted noise for typical buck converter.*

From Figure 2, showing the total noise, it is not possible to know on which filter type we should focus on. Only by measuring the CM and DM contributions, shown on Figures 3 and 4, it is possible to determine on which input filter, either differential or common mode, we should invest more money. Comparing the noise amplitude with the limits, it is also possible to determine how much attenuation we should get. Depending on the filter order, it is than possible to decide the cutoff frequency for the filter.

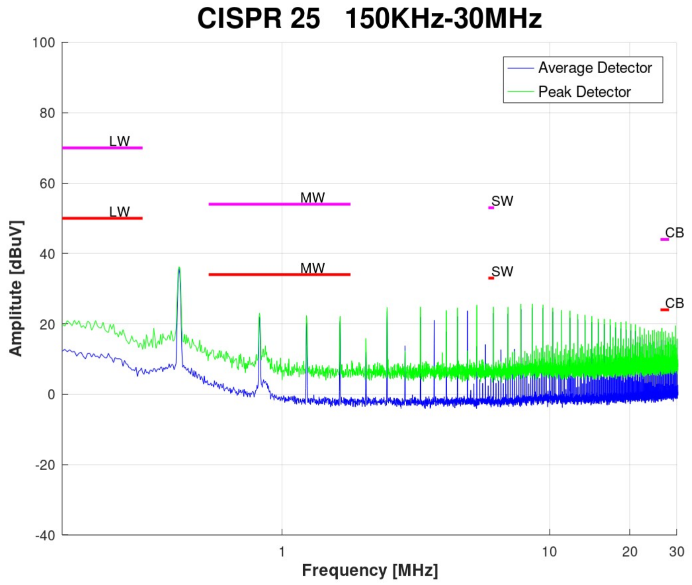

Figure 3: *Conducted noise - CM contributions.*

Comparing Figures 3 and 4, it is possible to see that the majority of the noise contribution comes from the DM. This is a typical situation, and this is why many simple systems only have a simple LC filter for the differential mode.

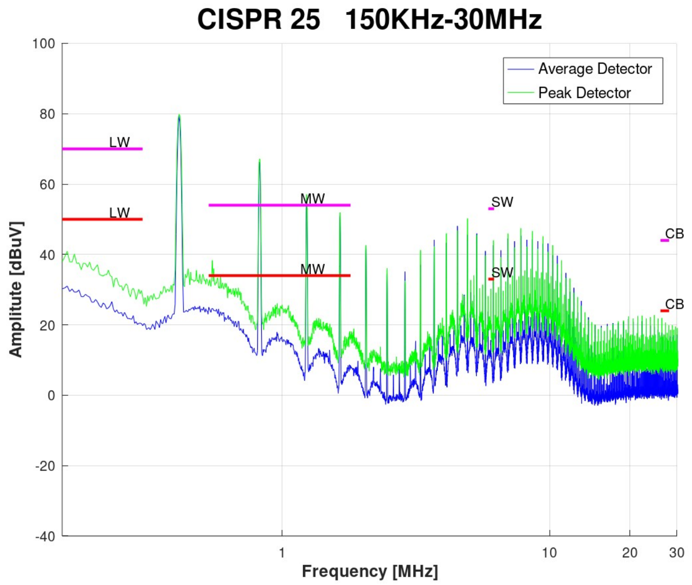

Figure 4: *Conducted noise - DM contributions..*

While the differential filter is very important, it is relevant to recall that the power cords, of few meters, may have resonance frequency of 30-100MHz, thus if the CM noise is not filtered out, it may be source of radiations. Thus if we pass Conducted test, and the CM noise is too high, we may fail radiated test because of it. By adding a PI LC filter on the input of the DC-DC converter, the total noise can get easily reduced below the stringent CISPR Class 5 limits, but CM noise will stay there.

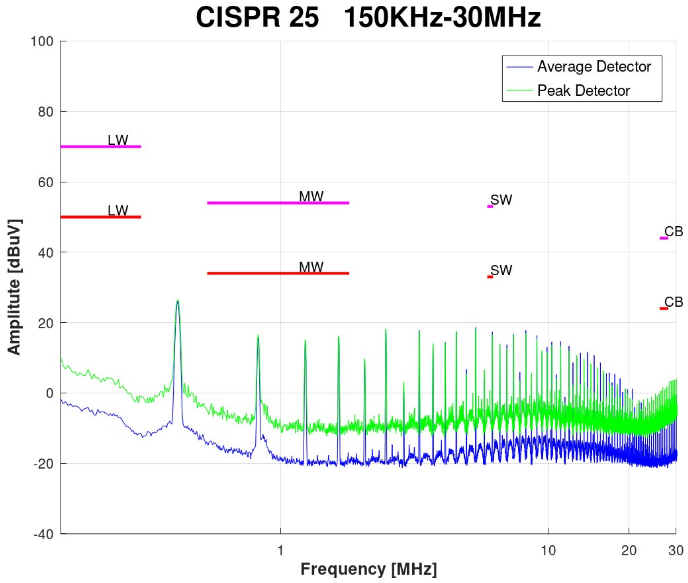

Figure 5: *Conducted noise after applying an EMI filter.*

Conclusions

In this article we have seen the details of the conducted noise and the differential and common mode components that are part of it. Details have been shown in regards to what may cause DM and CM noise, showing a typical use case of a DC-DC converter. The measures taken on the DC-DC converter have shown how important it is to identify the magnitude of each component to properly design the input EMI filter for the differential and common mode noise. Indeed, only by doing that measures, it is possible to properly dimension the filter with the right attenuation and cutoff frequency. This avoids making it too big or not effective at all.

Bibliography

[1] www.LaurTec.it: official site where you can download the "EMC Testing" series.

History

Date	Version	Author	Revision	Description
14. July 2020	1.0	Mauro Laurenti	Mauro Laurenti	Original version.