Common and Differential Mode Noise Separation: Comparison of two Different Approaches

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***Abstract* - Since the EU Directive 336/89 has been published, the manufacturers of electric and electronic equipment have to face with EMC problems. For this reason the problem of the EMI measurements and the design of a proper filter in order to mitigate the EMI noise have become very important. In the EMI analysis the separation of common mode and differential mode noise is a procedure well known in textbooks. However, separated measurements are only sometimes conducted. Therefore, two different approaches are shown for the diagnosis and reduction of conducted noise emission. Two devices have been realized for determining whether the differential mode or common mode component is dominant and in order to determine whether an anticipated change in a value of an element in the power supply filter will be effective. Experimental results are given to show the validity of these approaches.**

Keywords: EMI and EMC Issues.

I. INTRODUCTION

Electromagnetic interference (EMI) emission is an important matter for any electric and electronic equipment. When the noise emission of an equipment fails to satisfy the Standard limits, it is usually not easy to find the origin of the noise sources. One of the difficulty in dealing with EMI is the lack of diagnostic tools. Measured emissions are a mixture of common mode (CM) and differential mode (DM) noise. The sources of CM and DM noise in the equipment are of different nature and have to be carefully distinguished [1,2]. Furthermore, the design procedure for filters is usually divided in common mode and differential mode filters design [3]. Therefore it is very important to discern the two modes in order to design a good line filter. The basic separation of CM and DM is shown in Fig.1. This scheme represents the equivalent circuit of a Line Impedance Stabilization Network (LISN) in the high frequency behavior and the Equipment under Test (E.u.T.) is shown as an electromagnetic noise source. The differential mode voltage (V_{DM}) and current (I_{DM}), the common mode voltage (V_{CM}) and current (I_{CM}), indicated in Fig.1 are defined as follows:

$$V_{DM} = (V_P - V_N) = 50 \cdot \frac{I_{CM}}{2} = 25 \cdot I_{CM} \qquad (1)$$

$$V_{CM} = \frac{(V_P + V_N)}{2} = 50 \cdot 2I_{DM} = 100 \cdot I_{DM} \qquad (2)$$

$$I_{DM} = \frac{(I_P - I_N)}{2} \qquad (3)$$

$$I_{CM} = (I_P + I_N) \qquad (4)$$

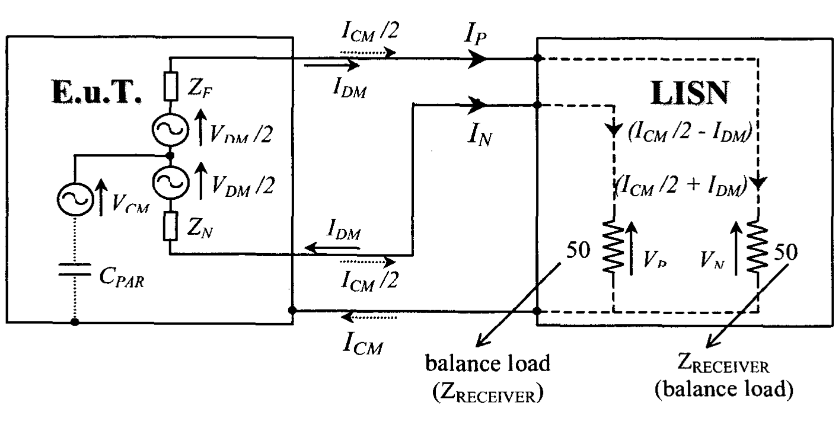

Fig.1: Definition of CM and DM.

In this paper, two different approaches of a noise separator will be presented, which can be used to separate both CM and DM noise from a mixture noise. In the paper, the basic principles of the noise separators will be described and the two devices tests show the good performance and the validity of the two approaches.

II. Requirements for the Common and the Differential Mode Measurements

The main requirements to measure the noise are:

- low damping of the signals;
- high damping of the suppressed signal components;
- linear amplitude response within the requested bandwidth for conducted emissions (150kHz - 30MHz);
- impedance matching (50Ω);
- low distortion;
- no interference with device under test and the LISN.

III. Proposed Solutions: Two Different Approaches

Two different approaches have been studied in order to separate the noise into common and differential mode components: one is based on the sum and difference of the line and neutral voltage and the other is based on the preferred paths of the common and differential components.

A First proposed solution

The first proposed solution, shown in Fig.2, allows to separate the common and the differential mode voltage components, respectively by the sum and the difference of the line and neutral voltages.

From the definitions given, it is yield:

$$(V_P + V_N) = 2 \cdot V_{CM} \tag{5}$$

$$(V_P - V_N) = V_{DM} \tag{6}$$

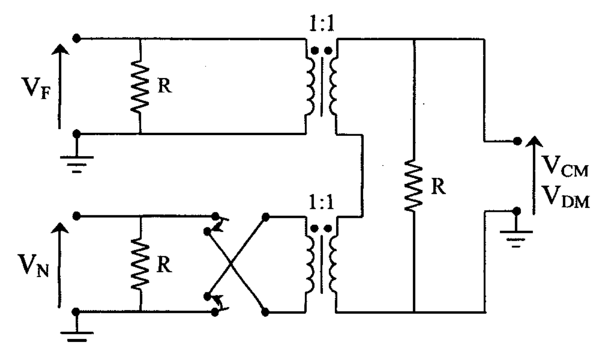

Fig.2: First proposed solution.

The device has to have some essential features to measure each disturbance. Besides the rules given from the Standards, the CISPR document 16-1 recommends that the input and the output impedance must be 50Ω. For this reason, some resistances have been added to the device under consideration.

For practical reasons, two different devices have been realized. The first one makes the sum (CM) and the other makes the difference (DM). The reason of that is due to the high parasitic coupling capacitance among the contacts introduced by the switch, which can produce an undesired unbalance on the two branches of the circuit.

B Second proposed solution

The second proposed solution is shown in Fig.3. The common mode voltage is feed through the primary side of the transformer to the resistor R_{CM}, while the differential voltage is blocked. The differential mode current cannot flow through the coupled inductors used to obtain the common mode noise, because the impedance of it is very high for the differential mode noise. At R_{DM} only the differential mode is obtained.

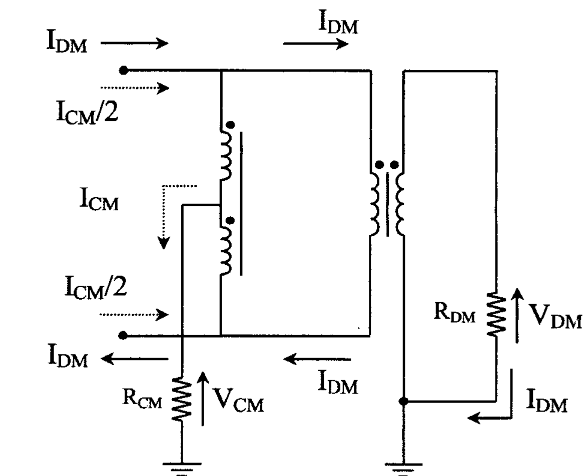

Fig.3: Second proposed solution.

It is also possible simplify the circuit with the construction of a different transformer as shown in Fig.4 [4], [5].

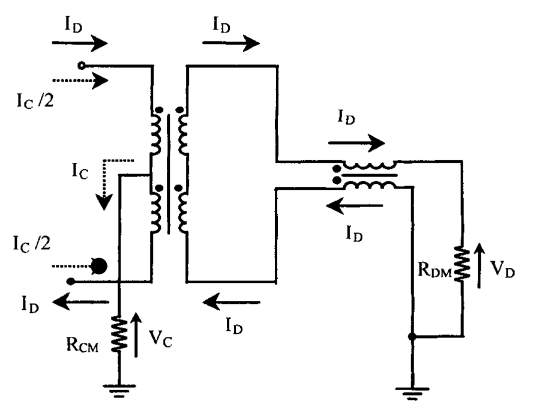

Fig.4: Second proposed solution (modified).

The common mode noise current flows through the primary side of the transformer, but there is not flux transferred to the secondary side, because the two currents are in opposite direction. On the other hand, the differential mode noise current is able to produce flux in the transformer and it is transferred on the secondary side.

The common mode is available on the resistor R_{CM} and at R_{DM} only the differential mode is obtained.

The isolation between primary and secondary side is the main element for the common mode noise rejection in to measure at R_{DM} only the differential mode, but not the only one. Owing to the parasitic capacitors between primary and secondary side, some common mode noise is able to reach the secondary side. For this reason a common mode choke or a second transformer is added to obtain a good common mode rejection at R_{DM} [6].

Differential mode rejection at R_{CM} is obtained thanks to the property of the differential mode that cannot flow through the earth path.

IV. The Realised Devices

In order to respect the specification required, components have to have linear amplitude response within the requested bandwidth for conducted emissions. Therefore, it is necessary reduce the parasitic parameters and control their effects. The devices have to be realized with careful attention: parasitic inductance effects of the connections and parasitic capacitances between the transformer windings have to be kept as low as possible.

For the first proposed solution, two devices, in two different boxes, have been realised: one set is for the CM (sum mode) and the second one is for the DM (difference mode). In this case the impedance matching is provided by the network resistors inside the box.

Particularly attention has to be addressed to the selection of the materials and the realisation of the transformers inside each box. A coil with low reluctance, high flux density, good properties all over the bandwidth, low harmonic distortion, low losses factor at high frequency has been chosen. The two windings have been realised with twisted wires around the coil to get better the magnetic coupling between the primary and the secondary side of the transformer and reduce the parasitic coupling capacitances.

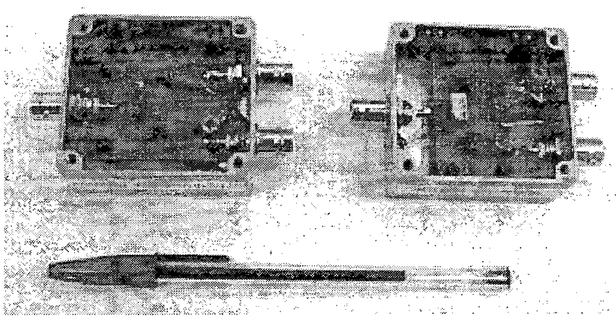

Fig.5: First proposed solution: one set for the CM and one set for the DM.

The second solution is shown in Fig.6. Transformers have been realised with the same technique of the first device. The common mode choke is needed to get better common mode rejection. It must have high impedance for the common mode noise and zero impedance for the differential one. To obtain these constraints, it is necessary to realise two identical windings.

Owing to the asymmetry of the windings, it is not possible to reach the input and the output impedance matching. For this reason, the impedance matching is realised with the BNC external adaptor which provides 50 Ω both for the inputs and for the outputs.

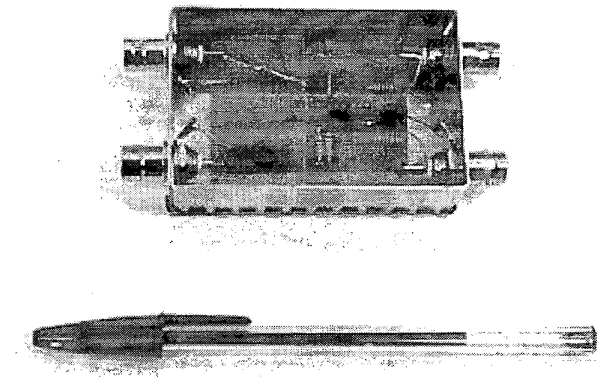

Fig.6: Second proposed solution.

V. Experimental Results

C Set up for the measurements

The setup for the first device is shown in Fig.7. A power splitter connected to the network analyzer provides the signals to the device. For the common mode transfer and the rejection measurements a power splitter 0°/0° is used, while for the differential mode transfer and the rejection measurements a power splitter 0°/180° is necessary to provide the signals phased of 180° between them to the device inputs.

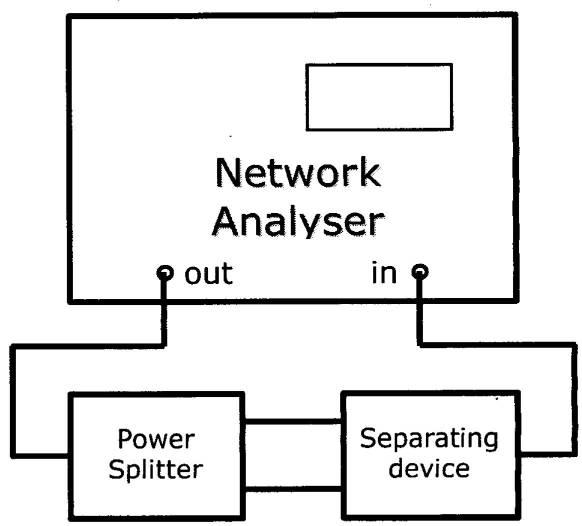

Fig. 7: Set up for the measurements.

The setup for the second device is the same as the previous one. Only a resistor of 50 Ω has to be connected to the output not used during the measurements, while the other is connected to the network analyzer.

D First device tests

The transfer function and the suppression function for the first proposed solution (one device for CM and one device for DM) are shown in Fig.8 and Fig.9, both for common and differential mode. It can be seen that the transfer functions are constant in a wide frequency range, because of the impedance matching obtained by the resistor network utilized that provides a constant impedance of 50 Ω, as shown in

Fig.10 both for the input and the output.

The impedance matching resistor network introduces an insertion loss of 3 dB; the real loss of the device is less than 0.5 dB and this represents a very good result.

The common and the differential mode rejection functions are quite satisfactory and show a very high attenuation (more than 50 dB) all over the bandwidth.

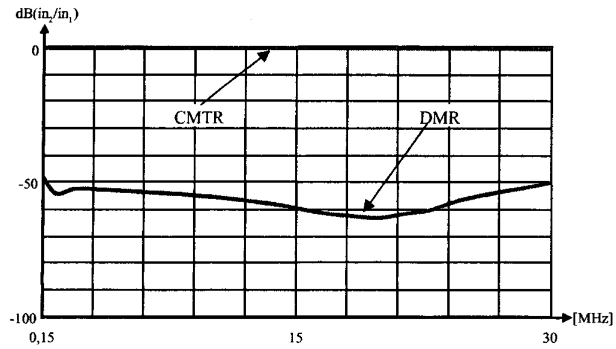

Fig.8: Common mode transfer and differential mode rejection for the CM device (sum mode).

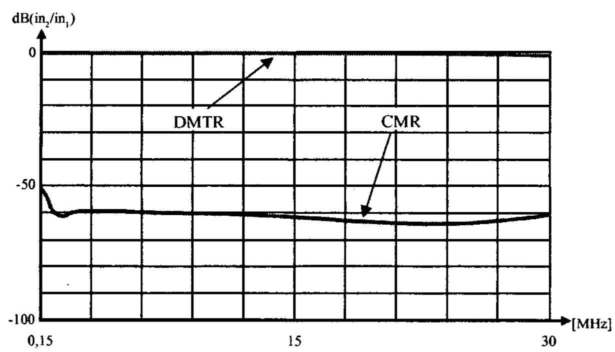

Fig.9: Differential mode transfer and common mode rejection for the DM device (difference mode).

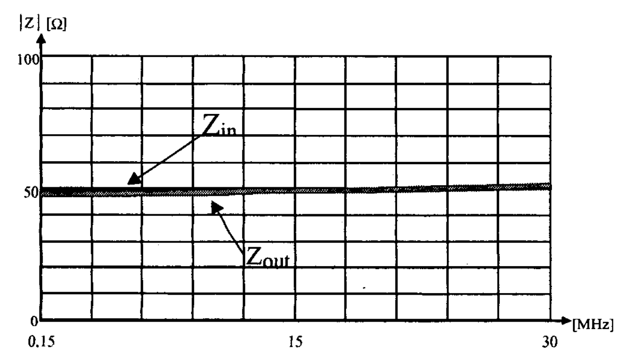

Fig.10: Input and output impedance for the first proposed solution (both CM and DM devices).

E Second device tests

The transfer function and the suppression function for the second device are shown in Fig. 1 and Fig.12, both for common and differential mode.

The common mode and the differential transfer functions are still less than 0.5 dB in a wide frequency, while the differential mode and common mode rejection functions are a little worse, because of the parasitic effects due to the near montage of the two outputs (differential and common).

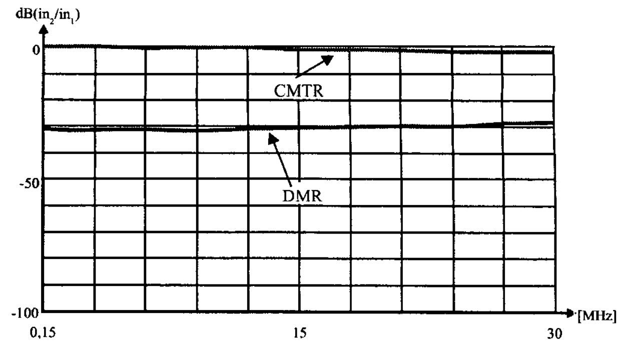

Fig.11: Common mode transfer and differential mode rejection for the second device.

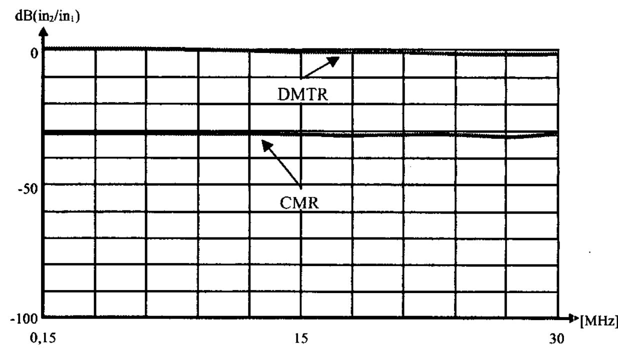

Fig.12: Differential mode transfer and common mode rejection for the second device.

The input impedance, the common mode output impedance and the differential mode output impedance are shown in Fig.13, 14, 15. Both values with the impedance adaptors and without the adaptors are shown.

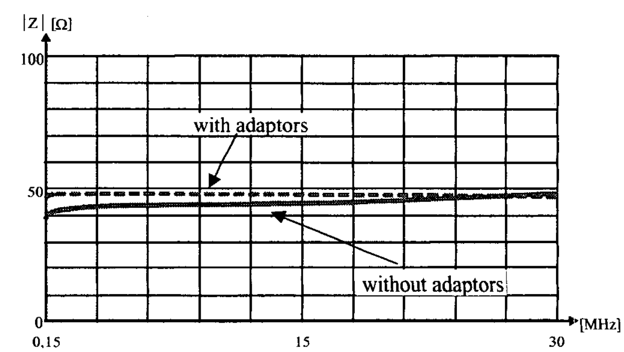

Fig.13: Input impedance for the second device.

The common mode output impedance is very low, because it is given only by the parallel of the half primary side transformer impedance and the internal impedance of the generator.

On the other hand, the differential mode output impedance is pretty high, because the common mode choke windings are not perfectly coupled.

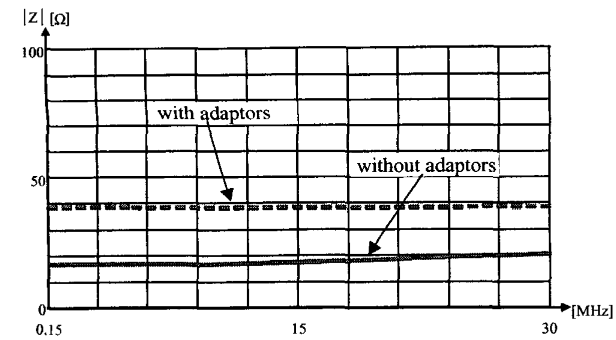

Fig.14: Common mode output impedance for the second device.

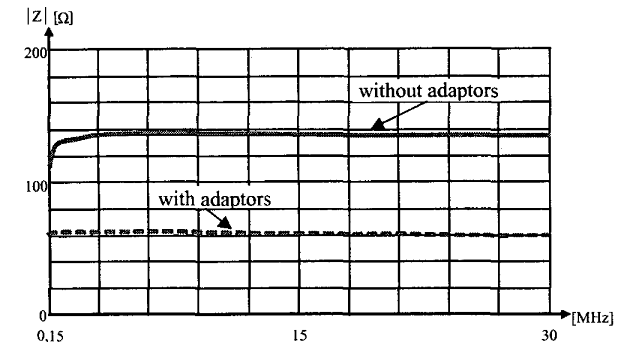

Fig.15: Differential mode output impedance for the second device.

F Use of the devices for the filter design

The devices realised have been used to separate the conducted disturbances into the differential and common mode components. In this way it is possible to have a deeply analysis of the disturbances nature and to find an easier and more economic method to suppress the noise.

For this reason a video game has been used as equipment under test. This equipment is a great source of noise and does not satisfy the compliance with the European EMC Standards EN 50081-1 both for the quasi peak and the average emission values, as shown in Fig.16.

With the realized devices, the total conducted disturbances have been separate in its two components: the common mode and the differential mode as shown in Fig.17.

It can be seen, that the common mode components has higher influence than the differential one.

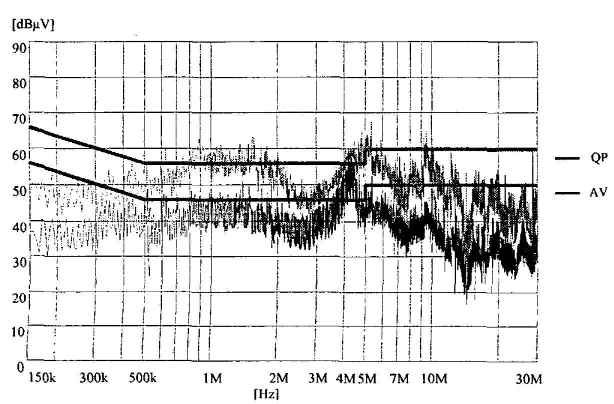

Fig.16: Total conducted emission of the device under test.

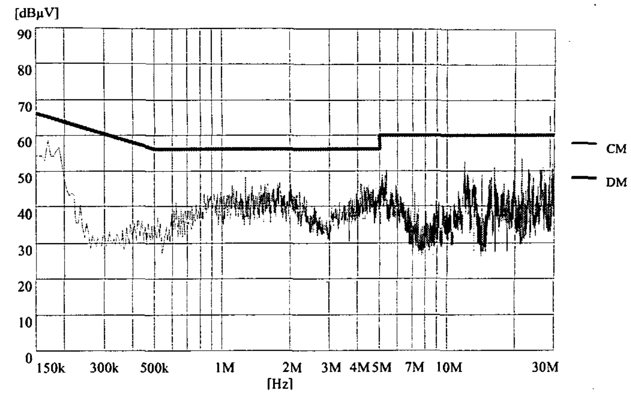

Fig.17: Differential and common mode conducted emission of the device under test.

To reduce the noise is sufficient to minimize the common mode component using capacitors between the line phases and the ground or using a choke transformer, instead of using a generic expensive filter.

Two film capacitors of 12 nF have been used in order to reduce the common mode noise and to have very small leakage current through the ground wire.

The results are shown in Fig.18. At low frequency, the influence of the capacitors in negligible, because of their high impedance, but at high frequency the reduction of the common mode noise is pretty good.

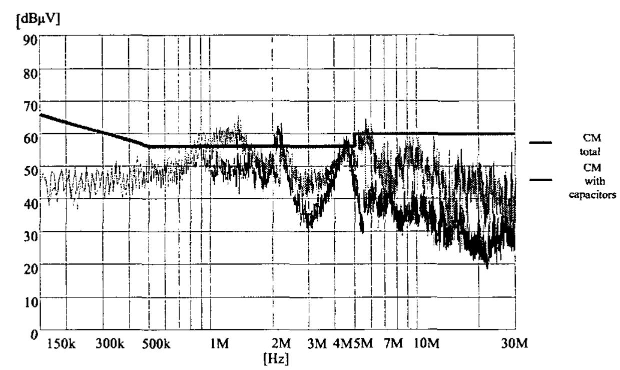

Fig.18: Common mode conducted emission before and after the insertion of the film capacitors.

Nevertheless, this method is not sufficient to reduce the total conducted disturbances under the Standard limits, as shown in Fig.19.

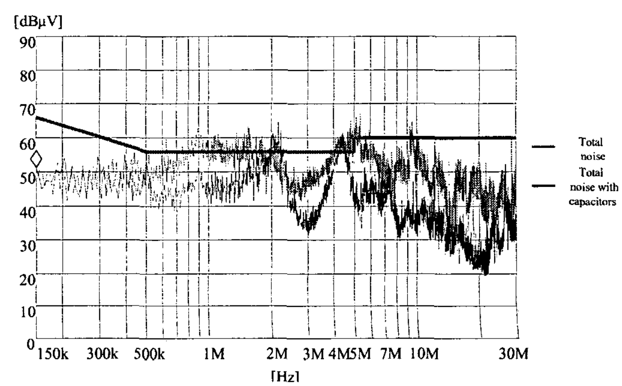

Fig.19: Total conducted emission before and after the insertion of the film capacitors.

It is necessary to use another method to reduce the common mode noise, for example using a choke transformer. For this purpose a toroidal choke transformer of 3,2mH ± 20% has been inserted with each winding in series to each line wire, to obtain the sum of the fluxes inside the coil core.

This method gives better results than the previous one, as shown in Fig. 20.

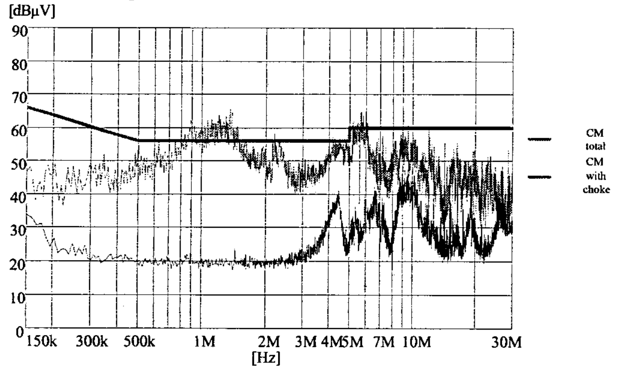

Fig.20: Common mode conducted emission before and after the insertion of the choke transformer for the device under test.

Fig.20 shows that the common mode component after using the choke transformer is under the limits specified by the Standard.

In Fig. 21, it can be noticed, that also the differential mode is reduced, because of the non ideal behavior of the choke transformer.

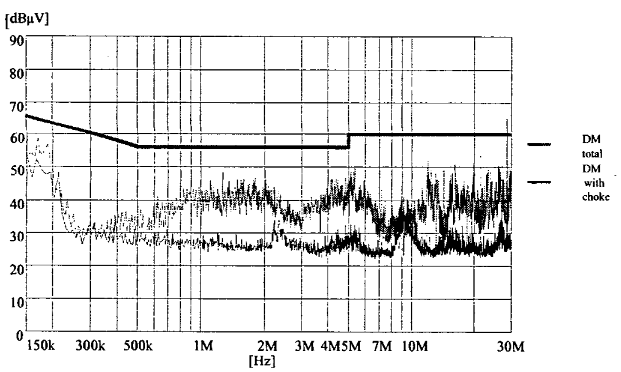

Fig.21: Differential mode conducted emission before and after the insertion of the choke transformer for the device under test.

After using the common mode choke, both the common mode and the differential mode are under the limits specified by the Standard. Also the total conducted noise in reduced under the limits imposed by the Standard, both for the quasi peak and the average values, as shown in Fig.22.

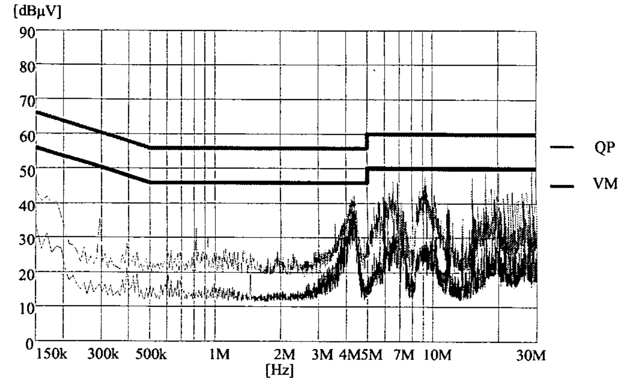

Fig.22: Total conducted emission of the device under test after the insertion of the choke transformer.

Thanks to the analysis of the noise components it can be find a faster, easier and more economical way to suppress the noise.

For the case under test only a small choke transformer has been used to suppress drastically the noise and the large and expensive generic filter has been avoided.

VI. Conclusions

Two methods for the separation of the common and the differential mode components have been presented. The first device shows better performance of the transfer and the rejection functions than the second one. This is obtained thanks to two different circuits for the common and the differential mode. On the other hand, the second device allows to have in the same case common and differential mode outputs, but this introduces some parasitic effects and, as a consequence, the performance of this device are worse than the previous one.

By using this measurement technique, the interference sources of electric and electronic equipment can be found in an easy way. Furthermore filters design can be done straightforward by directly measuring the necessary common mode and differential mode attenuation.

VII. References

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