Some Considerations Concerning Radiated Emissions Produced by a Board Display

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***Abstract* - The paper presents some considerations related to the radiated emissions from automotive area of interest. Firstly the equipment used for tests dedicated to radiated emissions is presented. Afterward some considerations on the test equipment, used in a semianechoic chamber are made. Characteristics of the horn antenna used to accomplish tests dedicated to radiated emissions within the range 0.8…1.6 GHz, along with some aspects related to design and simulation are also presented. The analysis of the electric field in the antenna and respectively of the electric field distribution in the remote field area was performed for three different frequencies (1.2GHz, 1.4GHz, 1.6GHz). Tests conditions are also described. Discussions are made with respect to the recorded data. The results of tests concerning the radiated emissions for a board display are presented, both for the horizontal and respectively vertical polarizations. Tests were made firstly for the initial hardware structure and problems related to the vertical polarization were noticed. Measures to improve the display operation are analyzed. Results of tests after the application of improvement measures are presented. Conclusions related to the improvement of the board display operation are deduced.**

Keywords: *radiated emissions, horn antenna, simulation of horn parameters, tests of board display, anti-disturbance measures.*

I. Introduction

The electric and electronic products designed and conceived to be used in commercial purposes must satisfy specific national and international electromagnetic compatibility (EMC) standards. The tests conceived to certify the compliance with these standards can be grouped in two major categories, as follows:
- tests for radiated and respectively conducted emissions;
- tests for conducted and respectively radiated immunity.

In order to certify the compliance with the norms related to radiated emissions, the Equipment Under Test (EUT) is submitted to the following tests: tests with radiated emissions with antennas, strip line method and current probe.

The tests for radiated emissions (TRE) are defined in order to identify the signals emitted in the surrounding environment by the EUT. These tests are typically developed within the frequency range 30 MHz…1 GHz. Yet some tests for radiated emission which are conceived for the compliance with the American standard FCC extend the upper limit of frequency to 200 GHz [1]. The devices to which these tests are addressed are for example wireless devices for which the carrying frequency is greater than 30 GHz [2].

Sometimes the beneficiaries of some products from the automotive area require additional tests, covering an extended frequency range as compared to the present norms. An improved accuracy of tests is often required for such situations, in order to make sure that the realized products are in compliance with the requirements imposed by norms.

II. Tests for Radiated Emissions

The tests for radiated emissions (TRE) are more difficult than those for conducted emissions. TRE are performed in an open space owing to the additional disturbing signals, already present in the environment, which can be superposed over the signals generated by EUT. Fortunately there are methods to identify and separate the external signals coming from external sources such as mobile phones or digital TV.

A different setup for TRE assumes their accomplishing in semi-anechoic chambers. Inside them a "clean" electromagnetic (EM) environment is provided from the interferences point of view. In this case the external signals cannot disturb the accomplished measures. Even if the costs related to the building of a fully functional semi-anechoic chamber often exceed 1 million Euros, because the environment is more and more crowded by the EM spectrum, the tests performed in semi-anechoic chambers represent more and more often the selected alternative.

Assuming that a test configuration is compatible to the applied standard, the TRE can be achieved considering few basic rules to be followed all over the test procedures.

The TRE described in Fig. 1 uses a test antenna placed 1 m behind the EUT and 1 m over the conducting floor [3].

EUT is placed on a table with metallic plan at a height of 90 cm from the floor. An isolating material (with a permittivity lower than 1.4 F/m, similar to that for air) is placed between EUT and floor.

Placing EUT on the test table is made such as to reproduce the real operating conditions [3].

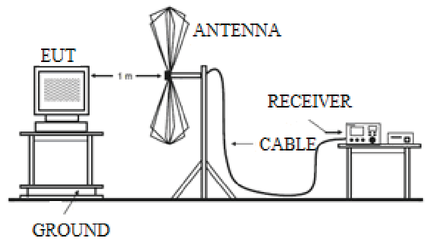


Fig. 1. Setup for TRE

The regulations for the tests concerned with radiated emissions from the automotive area are included in the CISPR 25 standard and, when necessary, are mentioned by the manufacturer's own standards [5], [6]. CISPR 25 mentions that the tested device should be considered as operating in the worst possible conditions, in order to emit the highest disturbances. For these tests, the test received should be set such as to use the appropriate filter (the available options being 9 kHz, 120 kHz or 1 MHz) [5]. Other factors to be considered are the attenuation introduced by the signal cables and respectively the factor of the antenna employed during tests. Fig. 2 depicts a standard configuration of the test equipment for a test concerned with radiated emissions [7].

The symbols used in Fig. 2 are [3]: 1 - EUT (equipment under test); 2 – cable harness; 3 - Load box (provides the operation in normal conditions of the EUT; 4 - Battery; 5 - Line impedance stabilization network (LISN); 6 - Test table with metallic plan; 7. Non-conductive material; 8 - Antenna; 9 - Metallic floor; 10 – Cable for the signal between the antenna and the test receiver; 11 – Input / Output board for the semi-anechoic chamber; 12 – Test receiver; 13 –Materials absorbing electromagnetic radiations; 14 – System for analysis and control.

III. Equipment Used for Radiated Emissions Tests

In order to test the behavior of the EUT considering the emitted radiations, either tests of pre-compliance with the existing standards for the automotive domain, or tests of compliance with the existing more general standards should be performed.

The most important aspect when accomplishing tests from the domain of electromagnetic compatibility (EMC) is represented by the providing of two characteristics of tests: repeatability and respectively reproducibility. Therefore a special attention must be paid to the connecting of test equipment (receivers, antennas, LISN, current probes etc.), as well as to the EUT.

The connections to ground, the cables and connectors of different test equipment must be considered too.

According to CISPR 25, the cables are put together on a cable harness that is placed on the front of the bench for the tests considering the automotive domain. The problem of cable harness is approached because at lower frequencies the main coupling to radiated fields will occur through the cables feeding the device (the same process is used in MIL STD 461 and in ISO 11452) [5]. A LISN is used to bring power to the device [5].

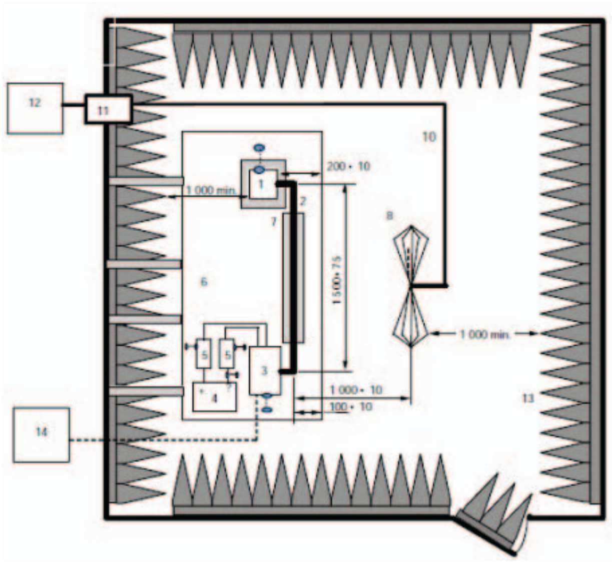


Fig. 2. Standard configuration of the test equipment.

In order to provide correct tests, one should consider all the attenuations introduced in the test procedure by cables and connectors. Therefore the test system (e.g. receiver+antenna+link cables) must be periodically checked. As for the cables, it is required to evaluate the attenuation introduced by them and its compensation during tests.

A series of equipment are required by TRE:

(a) Test receiver (TR). For the cases analyzed in this paper, a receiver Rohde & Schwarz of type ESCI, with range frequency from 9 kHz to 3 GHz was used. It is mainly used for TRE, but it can also be used for various other investigations. The TR performs measurements related to the signal level in a predetermined frequency range.

The new generations of TRs include many blocks used for numerical processing, their operation being fully automated. They allow the operation's control by means of dedicated software packages and interface to a computer [8].

The ordinary operational frequency range of TRs starts from 9 kHz, reaching up to tens of GHz, the new generations of TRs allowing extended frequency ranges [8].

(b) Antennas. At frequencies in the range 30...200 MHz a biconical antenna is used, while for the range 200...1000 MHz, a log periodic dipole array is recommended. From 1 to 2 GHz a pyramidal horn antenna (PHA) is recommended [5].

Because the frequency range for which the effect of EM radiations had to be evaluated was extended to the range 1...2 GHz at the client request, a PHA was used for the tests presented in this paper.

IV. Horn Antenna Used for Tests

The ratio "front / back" (*RFB*) represents a parameter to appreciate the directivity of an antenna for the angles of 0^0 and 180^0 respectively. According to its definition, this ratio is computed considering the voltages occurring across the antenna's terminals when the antenna is irradiated under these angles [8]:

$$RFB = U_{0^0} / U_{180^0} \tag{1}$$

This ratio is often expressed by using logarithms [8]:

$$RFB = 20\log\left(U_{0^0} / U_{180^0}\right) \tag{2}$$

A pyramidal horn antenna (PHA) was utilized for the analyzed frequency range. Its gain is given by [9]:

$$G = 10\left[1.008 + \log(a/\lambda)\cdot(b/\lambda)\right] - L_e - L_h \quad [dB] \tag{3}$$

where L_e , L_h represent the coefficient used for correction relative to the maximum deviation of the phase of the field from aperture.

If the aperture of the PHA fits to that corresponding to the maximum gain for the sector – type horn antenna, an optimum PHA is obtained. For it, the gain is [9]:

$$G = 10\left[1.008 + \log(a/\lambda)\cdot(b/\lambda)\right] \quad [dB] \tag{4}$$

For slight modifications of the aperture's opening relative to the values given by (4), a significant increase of the antenna's frequency range is noticed, the gain being reduced by 2 dB (as compared to the maximum one).

At first simulations were performed in order to get optimal values for one of the PHA's major parameters (gain, radiation characteristics and input impedance). An extensive study on numerical methods usable for simulation of electromagnetic shields behavior was made in [10]. Our simulations were made with the dedicated software tools "ANTENNA MAGUS", and "CST MICROWAVE STUDIO" which allowed for the selection of the PHA's central resonance frequency. For the analyzed cases, the PHA's gain played the role of the optimized parameter.

Once built by using "ANTENNA MAGUS", the physical model of the PHA was loaded into the software tool "CST MICROWAVE STUDIO" (CST) [11]. CST allows the creation of a mesh within the built antenna mode as well as the setting of a port in order to inject the signal into the antenna, in order to study its behavior at various frequencies. CST is using the finite elements method (FEM) for analysis and mesh creations. It also uses an original FEM, with applicability for EM fields [11].

A tetrahedral mesh was built. The mesh for the entire computation domain is depicted by Fig. 3 (a) whilst Fig. 3 (b) depicts a cross section through this domain.

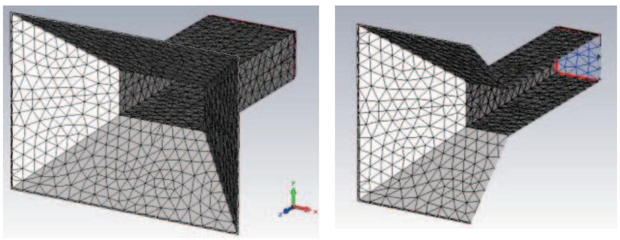
A tetrahedral type of mesh was used because it provides a very good accuracy of results and respectively saves run-time. Considering the spatial symmetry along the central axis (Fig. 3 b), only 34840 tetrahedral were used for computation (half of the number required by the mesh from Fig. 3 a).

In order to evaluate possible reflections of the power inside antenna (caused for example by the poor adaptability between the connection cable and antenna, or between the antenna and the tool used for measurements), the reflection coefficient of the steady wave was analyzed. It is known as "wave standing ratio – VSWR" (Fig. 4) and can be computed with [12]:

$$VSWR = (1+|\Gamma|)/(1-|\Gamma|) \tag{5}$$

where Γ stands for the reflection coefficient.

Fig. 4 reveals small reflections, lower than 1.5. Therefore one could conclude that the antenna was well adapted for the impedance of 50Ω.



(a) (b)

Fig. 3. Mesh (a) of the whole computation domain; (b) in a cross section.

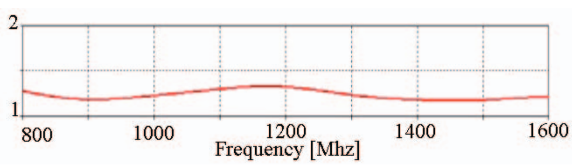


Fig. 4. VSWR as a function of frequency (the range: 0.8…1.6 GHz)

The simulation was made for the frequency range (0.8…1.6) GHz, which matches the range for which the PHA is used during the final tests developed in a semi-anechoic chamber.

The next step consisted in the analysis of results and of PHA behavior at different frequencies. Fig. 5 depicts:
- in the upper part - the electric field in PHA, for the type of analysis "peak". For the analyzed frequencies (1.2 GHz, 1.4 GHz and respectively 1.6 GHz), the maximum 2D values were 213.32 V/n, 284.15 V/n and respectively 207.48 V/n, whilst the phases were 0^0 for 1.2 GHz and respectively 158.5^0 for the other 2 frequencies.
- in the bottom part, the electric far field and directivity are represented, the associated numerical results being depicted by Table I.

The polar representations of the radiation characteristics, for different frequencies are depicted by Fig. 6: (a) 1.2 GHz, main lobe magnitude = 12.9 dB, angular width = 34.20 side lobe level=-16.9 dB; (b) 1.4 GHz, main lobe magnitude = 13.5 dB, angular width = 28.90 side lobe level= -18.1 dB; (c) 1.6 GHz, main lobe magnitude = 11.6 dB, angular width = 690 side lobe level=-13.4 dB.

A board display (Fig. 7) was used as the EUT submitted to TRE. The EUT's placing on the test table was done such as to reproduce the conditions from the car, the final goal being to provide test conditions as close as possible to the natural ones.

V. Radiated Emissions Measurement

The test setup was accomplished according to the standards for emissions CISPR 2 and its placement is depicted in Fig. 2.

After putting the equipment in the test semi-anechoic chamber and preparing the test software, the appropriate horn antenna was prepared. It was used to make measurements for the frequency range (1…1.6) GHz, the same with that used for simulations, as described in Section V. The horn antenna is of type SCHWARZBECK BBHA 9120 D.

The tests were accomplished for both types of antenna's polarizations: horizontal and respectively vertical.

A. The Initial Experimental Determination Concerning the Radiated Disturbances

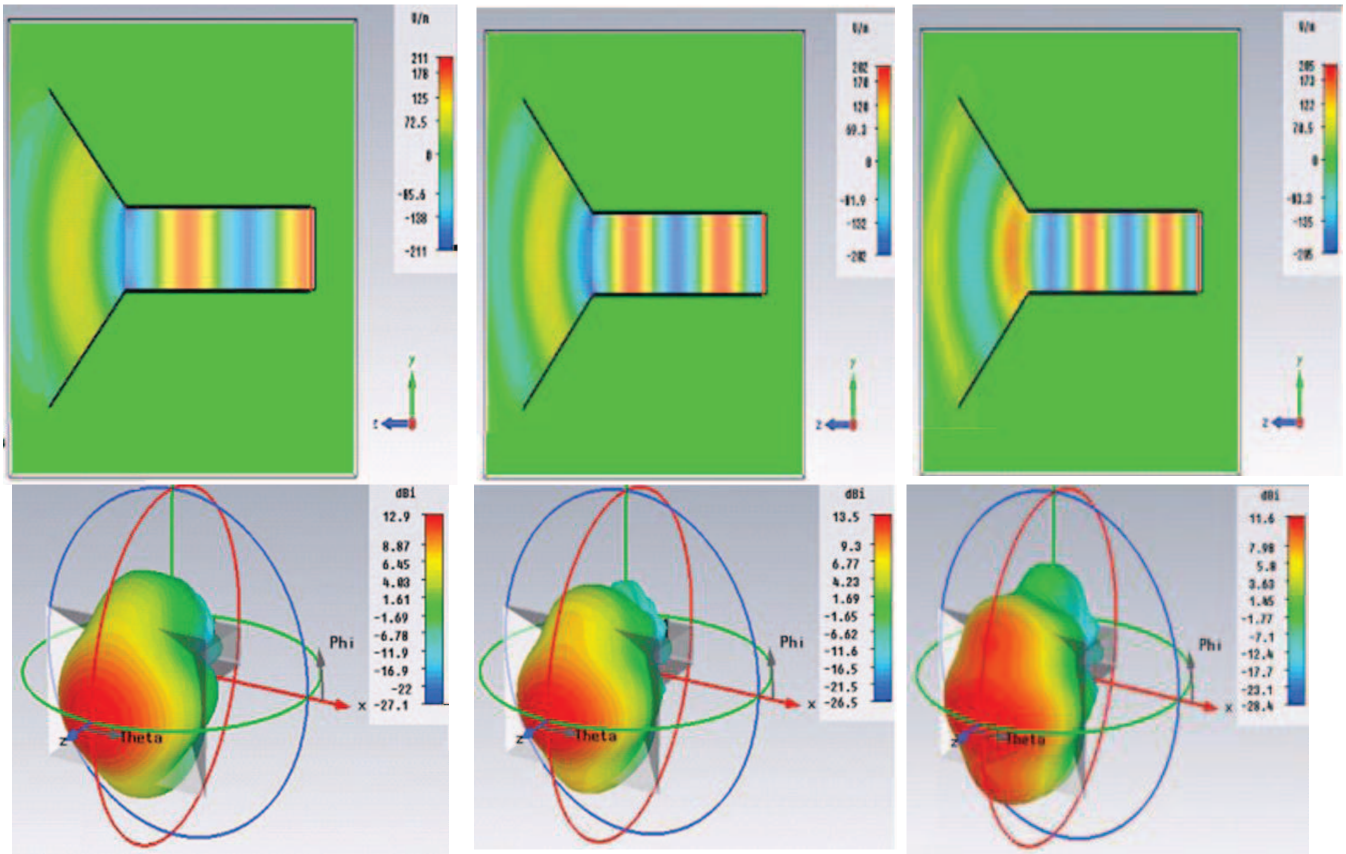
The EUT equipment must be compliant with the limits imposed to the disturbances transmitted through radiation according to CISPR 25 [5].

We used for the tests an electromagnetic disturbances receiver of type ESCI with the frequency range 9 kHz…3 GHz, a LISN and a horn antenna [3].

The receiver's test parameters for all the determinations presented below were: (a) The test range: 1 ÷ 1.6 GHz; (b) Bandwidth: 9 kHz.

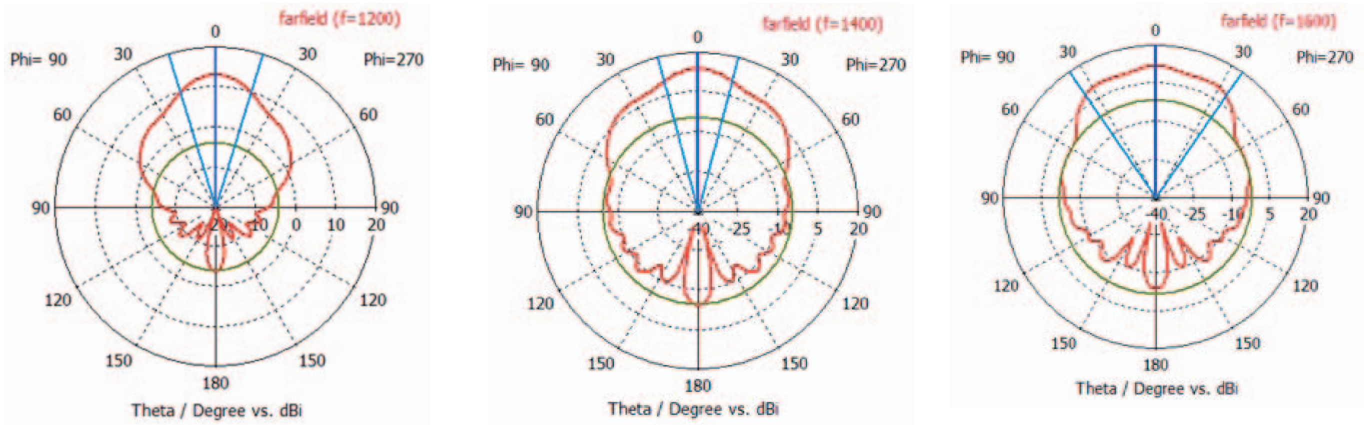
TABLE I.
Results of Analysis on Electric Far Field and Directivity

	Frequency [GHz]		
	1.2	1.4	1.6
Radiation efficiency [dB]	-0.033	-0.054	-0.06
Total efficiency [dB]	-0.114	-0.082	-0.098
Directivity [dBi]	12.9	13.53	11.61



(a) (b) (c)

Fig. 5. Electric field in PHA (top) and electric far field and directivity (bottom), at different frequencies: (a) 1.2 GHz; (b) 1.4 GHz; (c) 1.6 GHz.



(a) (b) (c)

Fig. 6. Polar representation of the radiation characteristics at: (a) 1.2 GHz; (b) 1.4 GHz; (c) 1.6 GHz.

Fig. 7. The board display submitted to TRE

The mean and quasi-peak values of the disturbances transmitted through radiation must not exceed the limits imposed by CISPR 25.

EUT was supplied through an artificial network LISN – in order to provide a constant impedance of 50 Ω at the EUT supplying and to be able to filter the signals from its supplying cables. Fig. 8 depicts the ensemble used to measure the disturbances transmitted through radiation.

The experimental determinations of the radiated disturbances generated by EUT, before the implementation of anti-disturbances measures are depicted by Fig. 9 (horizontal polarization) and by Fig. 10 (vertical polarization).

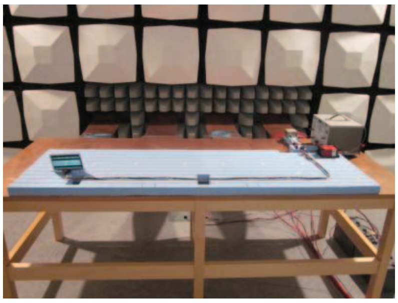


Fig. 8. Setup for the determination of disturbances transmitted through radiation for EUT

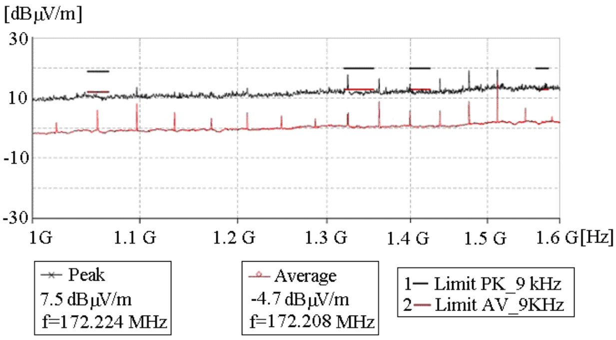


Fig. 9. Disturbances radiated by EUT in horizontal polarization, before the implementation of anti-disturbances measures.

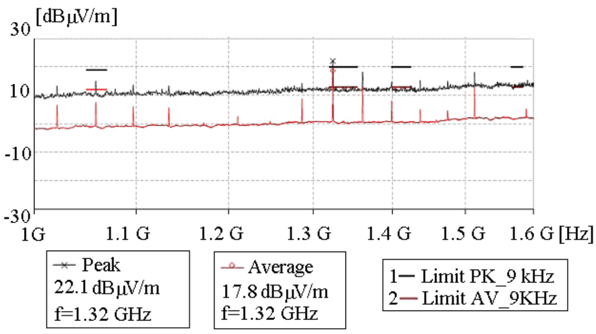


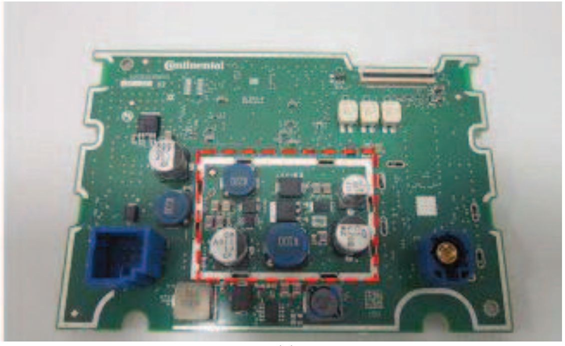
Fig. 10. Disturbances radiated by EUT in vertical polarization, before the implementation of anti-disturbances measures.

The tests revealed that the limits imposed for the peak and average values are under the limits for tests in horizontal polarization Fig. 9), whilst the limits imposed by CISPR 25 [5], [6] are exceeded for vertical polarization.

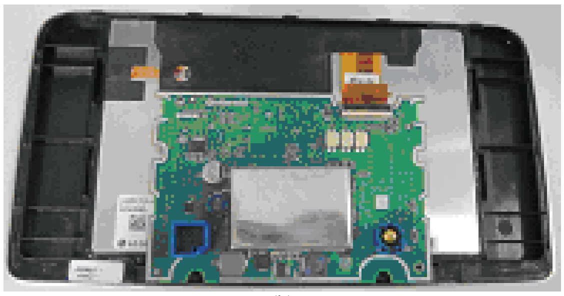
B. The Anti-disturbances Measures

In order to improve the performances of EUT with respect to its radiated emissions and to provide conformity with the limits imposed by CISPR 25, a shield was added on the supplying side of the display, on its source (Fig. 11 (a)). The EUT's source consists of two dc-dc converters of types boost and buck. Although operating at low frequency, these two converters (of step-up and step-down type) generate all high order harmonics. These latter ones are over the limits imposed by the client.

The shield placed in front of the supplying source behaves like a Faraday cage (Fig. 11(b)). It is made of Aluminum and is 2 mm thick. The connections toward the board were made by clipping and melting.



(a)



(b)

Fig. 11. PCB of the board display: (a) without shield, and (b) with shield, for the supplying source.

The practice of shielding as a solution to reduce the EM radiations is widely used because it is highly efficient and the implementing costs are reasonable. It often represents the "last solution" (it is applied when nothing else can be done to modify the electronic board from the EMC point of view).

C. Experimental Determination Concerning the Radiated Disturbances after the Implementation Measures

By adding a shield over the supplying source of the EUT, all the harmonics generated by the converters were removed.

The shield is designed and manufactured such as to let unaffected the normal functionality of the board display. The novelty of this solution consists in extending the frequency range beyond 1 GHz, as the client requested.

The accomplishing of another set of tests revealed that the emissions are now under the imposed limits - Fig. 12.

VI. Conclusions

The EMC tests, including the TRE, are very important during the process of designing and realization of a new electronic product [13]. When the limits imposed by the client and current standards are disobeyed, the withdrawal of the EUT from production can be imposed, resulting in waste of money and time.

In order to have the guarantee of some correct measurements of emissions, the results of the simulation concerned with the operation of a horn antenna, used to evaluate the radiated emissions in the semi-anechoic chamber were analyzed.

Several horn antennas were analyzed. The conclusion was that the PHA represents the best option for the case analyzed in this paper.

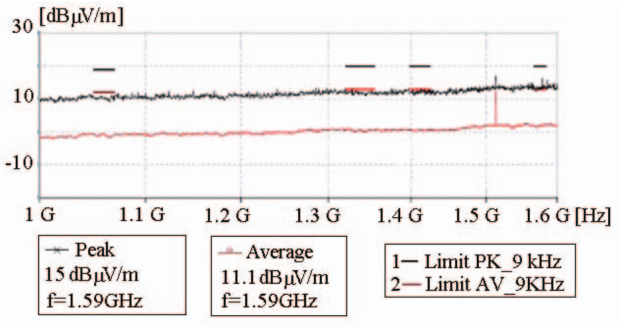


Fig. 12. Disturbances radiated by equipment in vertical polarization, after the implementation of anti-disturbances measures.

For this type of antenna, firstly numerical simulations concerned with the PHA parameters were performed in order to determine the optimum configuration (from the geometrical point of view).

The simulation was performed with the dedicated software CST MICROWAVE STUDIO which used a physical model built with ANTENNA MAGUS.

The simulated horn antenna presents characteristics that are similar to the real horn antenna used for measurements of radiated emissions (gain, directivity and aperture) [14], [15]. Although the simulated antenna proved its efficiency up to frequencies of 20 GHz, the simulations were made only for the frequency range from 1 GHz ... 1.6 GHz, because in this limited range problems were noticed during the tests made in the semi-anechoic chamber.

The FEM analysis revealed that the antenna proposed for the tests accomplishing is compliant with the imposed requirements.

The initial TRE considering the analyzed EUT revealed that the disturbances radiated by exceeded the limits imposed by norms. By adding a shield on the supplying side of EUT, the level of radiated emissions was decreases and consequently the limits imposed by CISPR 25 were no longer exceeded [5], [6].

Therefore the EUT could be certified for the series production.

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