

CHARACTERIZATION OF FIELDS RADIATED FROM STRUCTURES EXCITED BY ESD USING PASSIVE SENSORS.

Graziano Cerri, Roberto De Leo, Stefano Pennesi,
Valter Mariani Primiani, Paola Russo

Istituto di Elettromagnetismo e Bioingegneria, Università Politecnica delle Marche, Italy
e-mail: graziano.cerri@univpm.it

Abstract: A calibration procedure for the characterization of field sensors is presented. It is based on the use of a simple structure for the generation of a known field, the TEM-horn cell. The achieved sensor transfer function (amplitude and phase) allows the measurement of very fast transient field (e.g. Electrostatic Discharge radiated fields) through the application of a simple deconvolution procedure to the sensor output voltage time history.

Key words: Transient fields, sensor calibration, transfer function, deconvolution procedure.

1. Introduction

The knowledge of the complete ESD phenomenon and coupling mechanism require the measurement of transient electromagnetic fields [1]. This is not an easy task because it requires sensors with flat amplitude response over a wide frequency range (several GHz), a minimum phase distortion, a proper sensibility and reduced dimensions for minimum field perturbation for point measurements. The realization of such sensors requires an accurate design and a considerable technological effort. A way to achieve a flat response is to use capacitively loaded dipoles [2] with a preamplifier: the useful frequency range is upper limited by the resonance of the dipole and can be increased reducing its dimensions and therefore the sensitivity.

In the present paper, the use of sensors not explicitly designed for transient field measurement is proposed. Their main features are: 1) a fully passive construction, 2) dimensions not negligible with respect to the shortest significant wavelength of the measured field, that assure a sensitivity enhancement. In particular, a resonant dipole and a small loop are considered: these are very common devices in an EMC laboratory and used to measure the near field radiated emission from equipments for diagnostic purposes. Such sensors are typically characterized by the standard scalar Antenna Factor and used in the frequency domain. In order to use them for time domain measurements, their frequency responses were numerically compensated by a proper calibration procedure (up to 3 GHz), and the time

history of the impinging fields were recovered from the time history of the output voltage.

The method was adopted for the measurement of the fields produced by Electrostatic Discharges in different conditions, comparing the results with those obtained by a commercially available probe.

2. Sensor characterization

The essential quantity is the transfer function of the used sensor defined as the ratio between the Fourier transform of the output voltage and the Fourier transform of the exciting field:

$$T_E(\omega) = \frac{V(\omega)}{E(\omega)} \quad \text{or} \quad T_H(\omega) = \frac{V(\omega)}{H(\omega)} \quad (1)$$

The determination of this quantity ($T_{E/H}(\omega)$) requires the generation of an electromagnetic field with well known time waveform. Several electromagnetic structures can be used for that purpose (TEM cell, G-TEM cell, Wire-TEM). In the present paper, a very low cost TEM horn cell is used (fig.1), and, due to its characteristics, a time domain procedure is adopted.

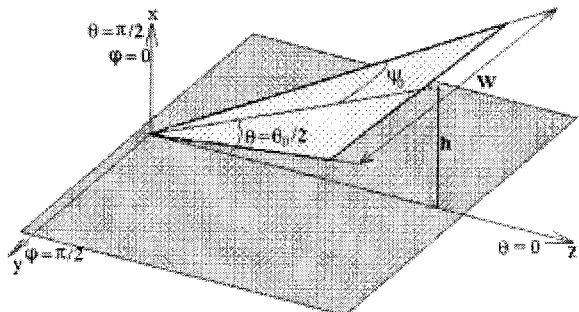


Fig. 1. Definition of the coordinate system in the TEM horn cell.

It is fed by a type N coaxial connector (50Ω), realizing a coax to microstrip transition. The microstrip (designed for a 50 Ω characteristic impedance) feeds the septum of the cell. The

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dimensions are: $w=150$ cm, $h=31$ cm, $\theta_0=20^\circ$, $\psi_0=23^\circ$. It can be noted that the structure is not terminated, and this is the reason for the low cost (<1000\$). The effects produced by the open termination reflection can be eliminated adopting a proper time domain correction in the calibration procedure, as described in the following.

In Fig. 2, the calibration set-up is reported.

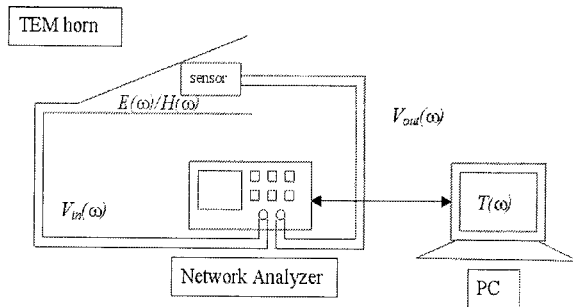


Fig. 2. Calibration set-up.

The sensor under characterization is placed inside the cell, along the longitudinal axis, and a Network Analyser (HP 8753D in the present case) with a Time Domain (TD) facility is used to relate the sensor output voltage $V_{out}(\omega)$ to the cell input voltage $V_{in}(\omega)$, by the measurement of the S_{21} parameter, and therefore in the frequency domain. The evaluation of the sensor transfer function according to eq. (1) requires the computation of the electric (in the case of a dipole) or magnetic (in the case of a loop) field impinging on the antenna and the corresponding sensor output voltage $V(\omega)$. Both these quantities can be separately evaluated starting from the cell input voltage $V_{in}(\omega)$. In particular, the cell's field in the point where the sensor is placed, must be considered:

$$E_\theta(r, \theta, \phi) = K(r, \theta, \phi)V_{in} \quad ; \quad H_\phi = \frac{E_\theta}{\eta} \quad (2)$$

where the cell factor K is frequency independent, due to the absence of dispersion [3] and V_{in} is constant in frequency because the incident voltage produced by the NWA port is constant. The calculation of the factor K as function of the sensor position is analytical and allows to recover the incident field. We want to highlight that the field calculated from $V_{in}(\omega)$ is the field of an infinitely long cell only. Therefore, also $V(\omega)$ in eq. (1) must be the sensor output for an infinitely long cell.

The network analyzer provides $V_{out}(\omega)$ i.e. the $S_{21}(\omega)$ parameter of the sensor, but this quantity is affected by the open termination of the cell. By using the TD facility of the NWA, $V_{out}(\omega)$ is transformed in the time domain, $v_{out}(t)$, and a proper gating function is applied to eliminate the pulse reflected by the termination. In this way, $v(t)$ represents the signal of an infinitely long cell.

Finally, performing the ratio between the gated sensor output voltage $V(\omega)$ and the electric/magnetic field, the sensor transfer function $T_{E/H}(\omega)$ is recovered. The use of a time gating procedure to eliminate the unwanted sensor response, due to the cell's open termination reflection, may cause problems in the low frequency range of the recovered sensor transfer function [4]. To overcome the problem, a precise measurement is performed in the low frequency range (up to 120 MHz) using a standard TEM cell. The final sensor transfer function is obtained combining the two technique results.

3. Calibration results

The same set-up of fig. 2 can be used to characterize the cell itself in terms of its reflection signature, performing a S_{11} measurement at its input and transforming the result in the time domain, fig. 3. For this measurement, the network analyzer was calibrated in the full two-port configuration from 1.8 MHz to 3 GHz using 1601 frequency points.

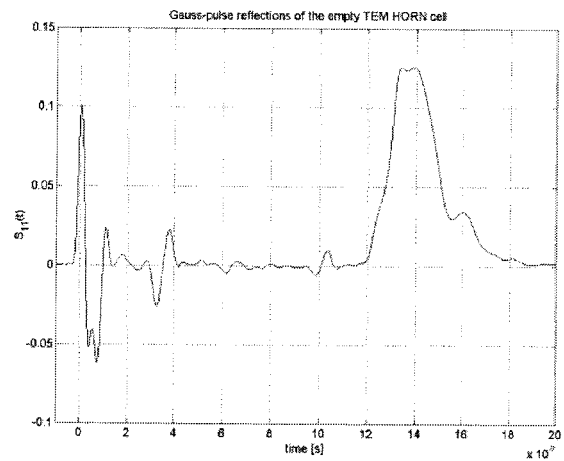


Fig. 3. Cell reflection signature in the time domain.

The first peak is related to the transition between the coax connector and the microstrip, whereas the last peak is due to the open termination of the cell.

The small peaks are due small cell imperfections. However, from a practical point of view, they can be neglected due to their very low level. So, a sensor inserted in the middle of the cell will be excited firstly by the well known incident field pulse and, after a time delay, by the reflected pulse. Its response to this second field pulse must be removed.

In the present paper the calibration of a dipole HZ-13 (from Rohde & Schwarz) up to 3 GHz is presented. Following the same procedure, any passive sensor could be calibrated, in particular a loop for the magnetic field measurement. In the next sections measurements done both with a dipole and with a loop are presented.

Regarding the calibration, the dipole is placed in the cell center at a distance of 0.9 m from the open

termination. The total dipole height is 14 cm. The chosen dipole position assures a suitable observation time window ($0.9 \text{ m} \times 2/c = 6 \text{ ns}$). In this position, the K factor of eq. (2) is 6.753 m^{-1} .

In fig. 4 the S_{21} parameter, measured according to the set-up of fig. 2 is reported in the time domain.

The effect of the cell termination reflection is well evident: the time history highlights a secondary dipole response at about 13 ns. If a time gate from $t_1 = 5.8$ to $t_2 = 11.8 \text{ ns}$ is applied, the response due to the incidence pulse only is acquired. The sought sensor transfer function $T_E(\omega)$ is recovered turning back into the frequency domain, using eq. (1), where $E(\omega)$ is given analytically by eq. (2). The low frequency correction is achieved according to the considerations reported in section 2.

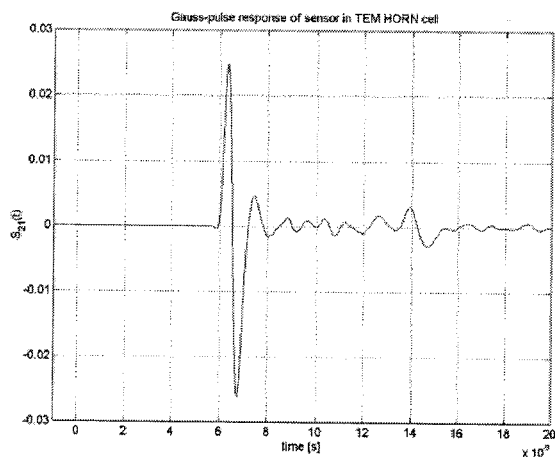


Fig. 4. S_{21} in the time domain measured according to the set-up of fig.2.

The final transfer function of the dipole is obtained substituting the horn cell results with the TEM cell results below 120 MHz, fig. 5. Following the same procedure also the loop transfer function is recovered: in fig. 6 results for two loops of different dimension are reported.

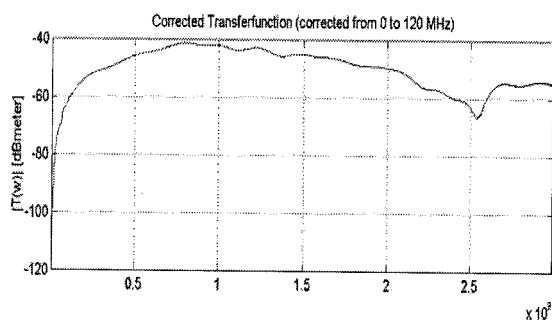


Fig. 5. Final dipole transfer function up to 3 GHz.

4. Applications

The recovered dipole transfer function can now be

used to measure transient fields. The first example consists in the measurement of the magnetic field radiated during an ESD test. For a typical EMC situation, we compare the results obtained by two commercial magnetic sensors (EMCO 901-902), S3, S6, and results obtained by a wide band active probe (Thomson HT 1052), on purpose designed for transient magnetic field measurements.

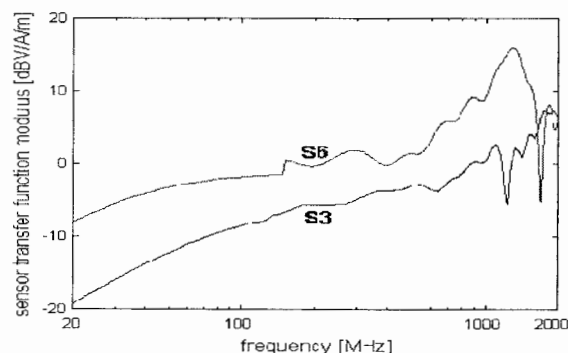


Fig. 6. Amplitude of the estimated transfer functions of the two analyzed loop sensors (S3 with 3 cm diameter, S6 with 6 cm diameter)

Fig. 7 shows the considered set-up that is very similar to the set-up specified by the norm IEC 1000-4-2 concerning ESD immunity tests for indirect discharge application in the situation of horizontal coupling plane (HCP). The signal detected by the sensors is delivered to the oscilloscope and then to a computer for the reconstruction of the incident field.

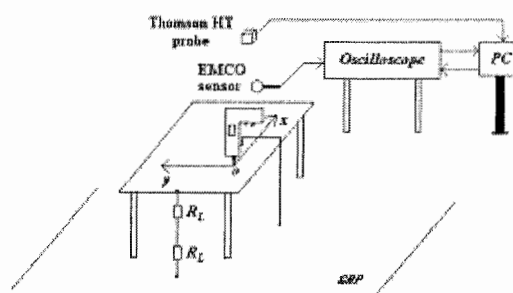


Fig. 7. Set-up used to measure magnetic field radiated during ESD test.

The signal detected by the commercial active probe is directly acquired by the computer that automatically manages the measurements, and then is sent to the oscilloscope to display the waveform.

Measurements were carried out placing the center of each loop at a distance of $x=10\text{cm}$ from the discharge point, and at the height of 4cm from the HCP; referring to Fig. 7, the ESD current is directed along the z-axis and therefore sensors and probe are oriented to sense H_y , the maximum field component.

The result is shown in fig. 8.

It is noticeable that the reconstructed waveforms are quite similar, and in particular the initial sharp peak

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is perfectly described, even if the two sensors have quite different transfer functions and different sensitivities.

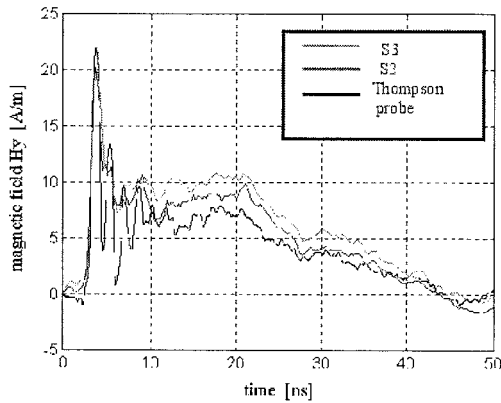


Fig. 8. Time history of the magnetic field radiated by an ESD at the distance of 10 cm recovered by 3 different probe.

This is an indirect validation of the sensor calibration and of the reconstruction procedure described in the previous sections and confirms again the reliability of the proposed method.

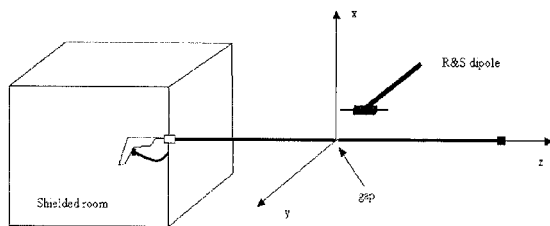


Fig. 9. Set-up for the measurement of the aperture radiated field.

A second example is the measurement of the transient electric field radiated by an aperture; this condition is obtained realizing an annular slot in the screen of a coaxial cable and injecting an ESD pulse along the cable itself.

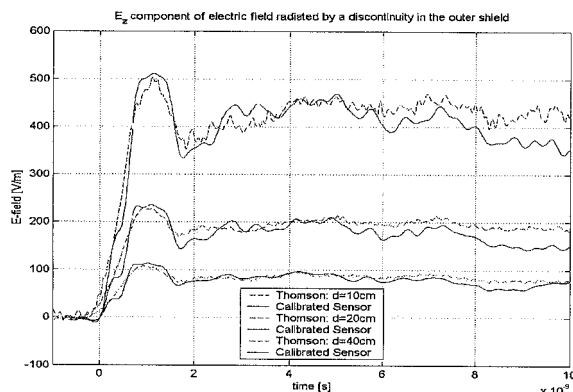


Fig. 10. Field radiated by a cable aperture under ESD excitation.

In particular the situation shown in fig. 9 is considered: a coax cable type RG 213 is fed by a 2 kV discharge, performed inside a shielded room to avoid unwanted radiation components, and lies along the z axis at a height of 1.5 m above the laboratory floor. The cable is matched at its end.

The gap width is 3 mm and the dipole is oriented along the cable axis. The measurements are performed at a distance of $d = 10, 20, 40$ cm from the gap, and a height of 1,5 m above the laboratory floor.

The results are reported in fig. 10, where the dipole measured field is compared to that one measured by the Thomson sensor, showing a good agreement for all measurement positions.

5. Conclusions

A procedure is presented for the characterization of passive E-field and H-field sensors: the calibration is used for the measurement of the transient field produced by an electrostatic discharge exciting two different structures.

The obtained results demonstrate the possibility to use a common commercial sensor for the measurement of transient fields even though it is not specifically designed for this purpose. Typically, the manufacturer provides the Antenna Factor, a scalar quantity that allows frequency domain measurement only. If the manufacturer provided the "complete" Antenna Factor (amplitude and phase), the sensor could be also used for time domain measurement. According to the shown procedure. The method highlights that no particular frequency behaviour of the sensor response is required (for instance flatness or purely derivative), because also deep resonances are accounted for. Therefore, the sensor dimensions can be increased to enhance the sensitivity.

References

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