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An Original Method for the Measurement of the Radiated Susceptibility of an Electronic System Using Induced Electromagnetic Nonlinear Effects

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Abstract—The objective of this paper is to propose an improved approach based on a novel non-intrusive method for easily assessing the high frequency CW EM radiated susceptibility of an electronic system by characterizing its nonlinear electromagnetic effects. For this purpose, we have developed a specific harmonic frequency detection system coupled with a mode stirrer reverberating chamber. We describe the principles of the method and study a generic device board which is representative of a real electronic system. We evaluate the EM susceptibility of a micro controller in full functional mode and the data exchanges with two types of external 8 Mb SRAM memories. We observe the EM radiated susceptibility of this device by a functional EMC analysis method; then we measure the harmonic frequency content and make a correlation with the EM susceptibility results. We obtain significant differences between the two memory devices, as a consequence of their different managements of internal voltage over stress. We are well aware that this method is currently not validated in industrial environments EMC. In this paper, we only want to show that the appearance of the highest harmonic level occurs only when DUT has the highest functional failure.

1. INTRODUCTION

In the ElectroMagnetic Compatibility (EMC) domain of embedded electronic systems, equipment manufacturers must perform a large number of electrical tests in order to meet EMC standards for their products to be placed on the market [1]. If we take the case of EMC tests in radiated mode, they are often made in a Mode Stirrer Reverberating Chamber (MSRC).

For this, equipment manufacturers are required to implement measures techniques that are tailored not only to their electronic systems to be tested, but also with the normative tests applied in MSRC [2]. In reverberation chamber, measurement techniques EMC calls are statistical methods that are related to the field of the structure applied to the Device Under Test (DUT), but this part is not the subject in this paper.

Instead, we will focus on the techniques used on electronic systems to be tested. To apply these techniques, equipment manufacturers need to conduct hardware and software adaptations on their electronic systems before performing EMC tests. During EMC qualification tests, implementing a temporary control links between the hardware and software is often required. These preliminary intrusive conditioning operations are expensive and time consuming.

To avoid this problem, we propose a measurement technique which is not intrusive for the electronic system under test and based upon a harmonic frequency detection combined with a high frequency Continuous Wave (CW) EM-field stress generated in an MSRC [3, 4].

After the presentation of the measurement principle, we show some results obtained with this method on an electronic printed circuit board and compare them with the results obtained with a classical EM-radiated susceptibility approach.

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2. PRINCIPLE OF HARMONIC DETECTION

Most electronics components contain nonlinear junctions. When they are illuminated by a high power continuous wave, ElectroMagnetic (EM) field harmonic frequencies appear as illustrated in Fig. 1.

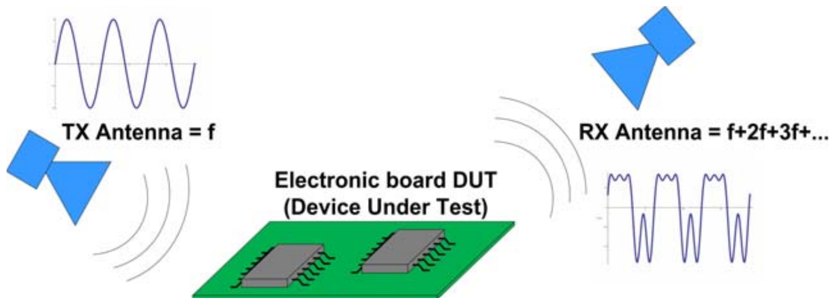

Figure 1. Electronic device submitted to a high level illumination field and generation of harmonic frequencies.

To explain the frequency of appearance of harmonic mechanism analytically, consider the case of an elementary electronic component such as that of a diode illuminated by the radiation of an electromagnetic field type CW [5].

In the direct electrical characteristic of a diode, we can use the following equation:

$$i = i_0 \left[e^{\alpha v} - 1 \right] \tag{1}$$

In which:

i is the direct current (A)

i_0 is the saturation current (A)

v is the forward voltage across the diode (V)

and $\alpha = \frac{q}{\eta k_B T}$

In this last term α:

q is the electron charge in Coulomb (c)

η is the ideality factor of the diode

k_B is the Boltzmann constant (JK^{-1})

T is the absolute temperature in degrees Kelvin (K)

In response to our calculation, we consider the ideal diode and neglect the reverse current which is close to the value of the saturation current i_0, and we do not take into account that the reverse voltage can induce a breakdown and destroy the diode.

In the case of aggression by a harmonic frequency f_1 as $\omega_1 = 2\pi f_1$, we can express $v(t)$ as follows:

$$v(t) = v_0 + v_1 \cos(\omega_1 t) \text{ avec } t \in [0,\, T/2] \tag{2}$$

So using Equation (1) we express $i(t)$:

$$i(t) = i_0 e^{\alpha v_0} e^{\alpha v_1 \cos(\omega_1 t)} - i_0 \tag{3}$$

Using the expression of expansion following Sonine:

$$e^{v \cos(\omega t)} = I_0(v) + 2 \sum_{k=1}^{\infty} I_k(v) \cos(k\omega t) \tag{4}$$

With symbol I_k denotes the modified Bessel function of order k, we get to Equation (3):

$$i(t) = i_0 e^{\alpha v_0} \left[I_0(\alpha v_1) + 2 \sum_{k=1}^{\infty} I_k(\alpha v_1) \cos(k\omega_1 t) \right] - i_0 \tag{5}$$

By developing this expression we get:

$$i(t) = i_0 e^{\alpha v_0} \left[I_0(\alpha v_1) + 2I_1(\alpha v_1)\cos(\omega_1 t) + 2I_2(\alpha v_1)\cos(2\omega_1 t) + 2I_3(\alpha v_1)\cos(3\omega_1 t) + \ldots \right] - i_0 \quad (6)$$

We see, appear in this expression, a term harmonic 2, which corresponds to a frequency $f_2 = 2f_1$:

$$i_2(t) = i_0 e^{\alpha v_0} 2I_2(\alpha v_1)\cos(2\omega_1 t) \quad (7)$$

And also a term in harmonic 3 with frequency $f_3 = 3f_1$:

$$i_3(t) = i_0 e^{\alpha v_0} 2I_3(\alpha v_1)\cos(3\omega_1 t) \quad (8)$$

The presence of the aggression of a field frequency of the diode will have the effect of changing the shape of its characteristic as shown in Figure 2. This impact on the shape of the feature may increase the nonlinearity of the function of the diode and affect the bias region that degrades these functional performances. This is reflected by the appearance of harmonic levels $(2f_1, 3f_1, \ldots)$ as presented in Figure 3.

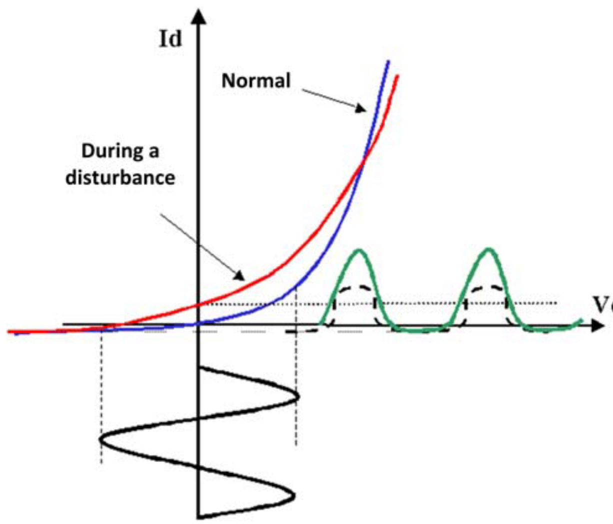

Figure 2. Electrical characteristic of diode under EM illumination in CW mode.

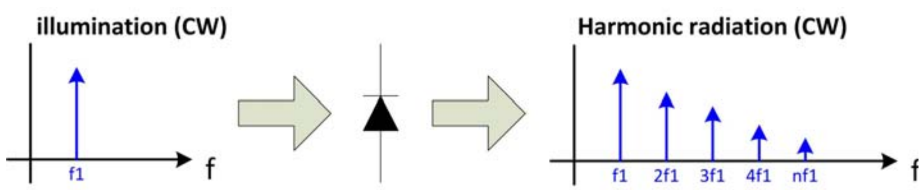

Figure 3. Principle of harmonics generated by a diode under illumination EM.

In the presence of a more complex electronic component or integrated transistor circuit, we will observe the same phenomenon. In an EM CW illumination of an electronic card equipped with more or less complex components, functional anomalies may occur causing radiation of harmonics of order 2 or 3 levels higher or lower. For digital integrated circuits type of standard components of Complementary MetalOxideSemiconductor (CMOS) type, the harmonic order 2 levels are generally strongly marked when there is occurrence of malfunctions.

3. EXPERIMENTAL SETUP

To illustrate a practical point of view, the phenomenon of harmonic frequency radiation from electronic maps in radiated susceptibility test mode, we will look at an experimental setup to highlight this phenomenon.

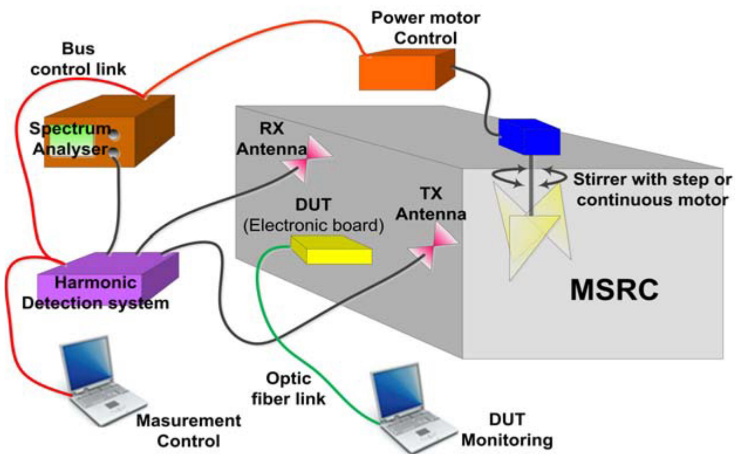

Figure 4. Block diagram of MSRC in configuration for testing radiated immunity devices.

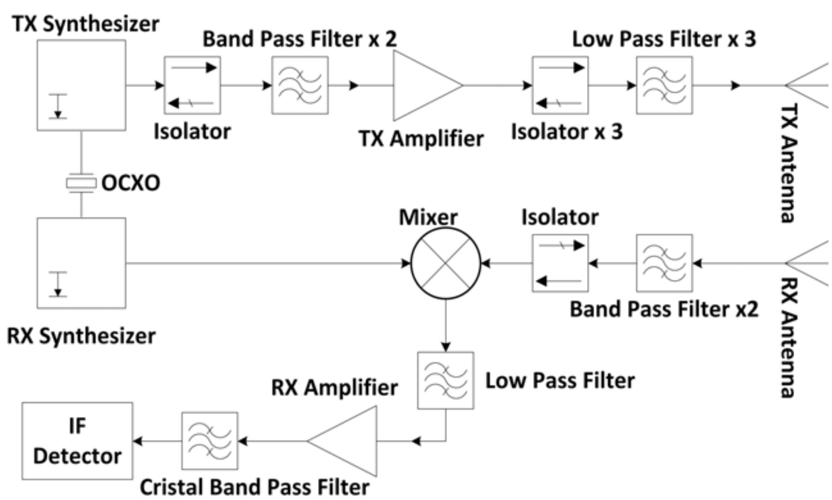

Figure 5. Schematic diagram of detection system of harmonic frequencies.

To achieve high frequency and high level EM radiated susceptibility tests on electronic cards and electronic systems, EMC laboratories have now adopted the reverberating chamber as an adequate facility (IEC 61 967-7 in emission and IEC 62 132-7 in immunity).

This measurement system can apply an illumination on the DUT with a high level of EM field by using a small power generator source. The homogeneous field illumination on the DUT is provided by turning a mechanical stirrer powered by a controlled motor as illustrated in Figure 4 which represents the entire measurement system.

The reverberation chamber that we present in the following dimensions: length 2.5 m, height 1.25 m and depth 1.25 m, a volume of about 3.9 m^3. With these geometric dimensions, the room has a Lowest Usable Frequency (LUF), a 400 MHz signal, minimum frequency for which we are reverberating mode, and this behavior can be likened to that of a high-pass filter. The high frequency of use of our room is around 20 GHz for which the energy losses caused by the metal walls that form the room are acceptable in our measurements. With this value of chamber volume about 3.9 m^3, the maximum permissible size DUT should be that of a cube with an edge about 30 cm in length to ensure correct measurements.

To monitor the levels of harmonic frequencies radiated by the DUT positioned in the MSRC, we have developed a harmonic detection system represented by a part in Figure 4 in a purple color. The diagram in Figure 5 presents the various parts of this harmonic detection system. It is composed of a transmission chain (TX) and a reception chain (RX).

The TX chain generates the incident field on the DUT at an as-pure-as-possible frequency; it is composed of a frequency synthesizer, a power amplifier and a transmitting antenna. To improve the TX chain performance, low-pass filters are added to reduce the levels of unwanted harmonic frequencies on the transmission chain. Insulators are also inserted in this chain to achieve wide-band impedance matching.

The RX chain measures the levels of harmonics frequencies generated inside the chamber; it is composed of a receiving antenna, a mixer and a synthesized local oscillator. To increase the RX chain performance, high-pass filters are used to suppress the leaks at the fundamental frequency likely coming from the TX chain. This will keep only the harmonics frequencies generated by the DUT.

The measurement of the levels of the harmonic frequencies is thereby performed by a very sensitive heterodyne detection. In particular, the mixer has been selected to be efficient in terms of linear signal conversion. Finally, a low noise amplifier with a sharp filter is connected to the IF output (see Figure 5) of the mixer in order to adapt to the dynamics of the useful signal. Note that the use of a standard spectrum analyzer could replace the receiving device, but it would be much less effective in terms of sensitivity [6] and [8].

Figure 6 displays the electronic board (DUT) located in the MSRC and to be characterized in terms of radiated EM susceptibility.

The top face of the Printed-Circuit-Board (PCB) contains a micro-controller (dsPIC33FJ128GP706) and a Static Random Access Memory (SRAM) memory. A metallic box is used to protect the bottom face of the board from the incident field. This bottom face contains the peripheral components for the connection of an optic-fiber link with the outside of the chamber. The EMC test procedure applied on this board is in agreement with the Aeronautic DO160 standard test [1]. For each frequency, we perform a complete rotation of the stirrer, record the functional failures of the electronic board, and measure the levels of the generated harmonic frequencies. Two types of boards with two types of SRAM components provided by two different manufacturers have been tested with this process (configuration n^{o}1 BS62LV8001 and configuration n^{o}2 AS6C8008).

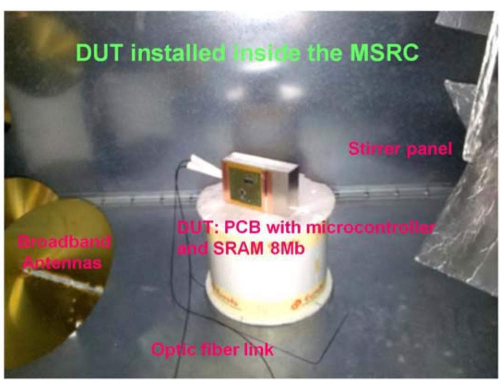

Figure 6. DUT located inside MSRC.

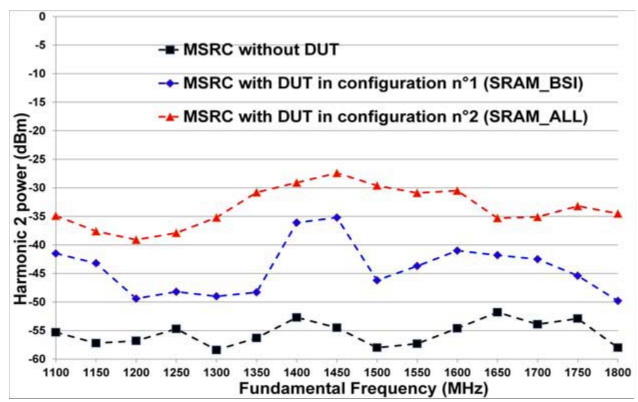

Figure 7. Measurement of second-order harmonic frequency levels.

4. EXPERIMENTAL RESULTS

The measurements shown in Figure 7 are second-order harmonics levels. The EM susceptibility level of the DUT is set when functional errors occur and depends on a level field in the associated chamber of aggression frequency value. In our measurements, the average level of field in the chamber varies around 400 V/m to 1000 V/m for an injected power from 1 W to 10 W in the transmitting antenna. Our system of harmonic frequencies detection measures allows us for the moment to inject aggression frequencies ranging from 1 to 2 GHz. In Figure 7, the curve labeled "MSRC without DUT" corresponds to the reference noise level.

In particular, this curve represents the "spurious" signal level due to the entire measurement system. In the same figure, the curves denoted "MSRC with DUT ... (SRAM-BSI)" and "MSRC with DUT ... (SRAM ALL)" give the levels of the second-order harmonic frequencies for both circuit boards equipped with the two specific SRAM components. In these curves we can notice that the levels of the second harmonic are different for both SRAM configurations [7].

In the same configuration, Figure 8 shows EM susceptibility measurements. Indeed, in this figure, we have monitored in real-time the functional failures on both board configurations illuminated by the same source used to operate for harmonic frequencies measurements. To achieve these EMC tests, a specific software code has been developed and loaded into the flash memory of the micro-controller board. This allowed real time control of the data streams between the micro-controller and the SRAM. The fiber-optic link provides access to the board from the outside of the MSRC through the software interface.

The curves in Figure 8 present the EM-radiated susceptibility measured for both board configurations. On these curves, we also clearly note the difference between the EM susceptibility levels obtained for both SRAM configurations. In fact, we can observe the same behavior of the EM susceptibility levels as the second harmonics levels [7]. The difference in the level of EM susceptibility between the two boards can be explained by the fact that both SRAM components have different protection circuits at their inputs and outputs pins.

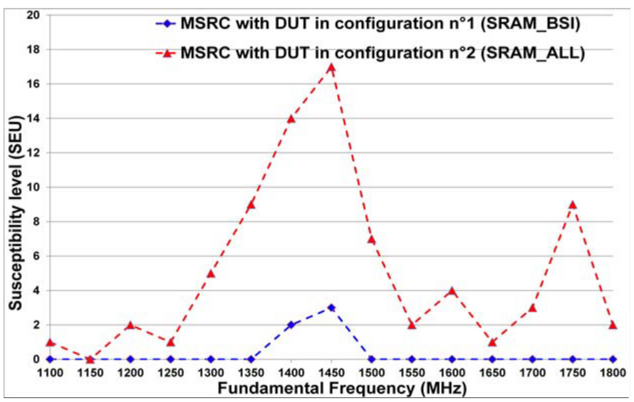

Figure 8. Measurement of functional failure levels.

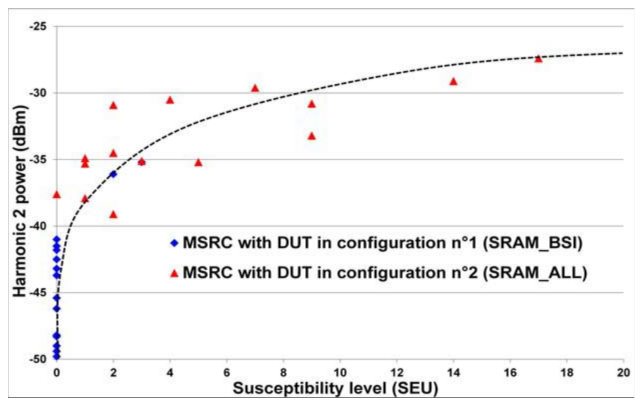

Figure 9. Comparison between measurement of harmonics levels and functional failure levels.

Figure 9 compares the measurements of EM susceptibility levels and the harmonic levels 2. For each value of fundamental frequency and with the same power applied on the transmitting antenna, we have associated the EM-radiated susceptibility levels with the second-order harmonic frequency levels. This figure confirms the same trend in the harmonic levels and the susceptibility levels; from this observation we deduce that the second-order harmonic frequency is correlated to the EM-radiated susceptibility and could therefore be a good parameter to identify the EM susceptibility of an electronic system without any intrusion in its hardware and software.

5. CONCLUSION

The developed and assessed method of measurement of levels of radiated harmonic frequencies in a MSRC has many advantages.

First, this measurement method is non-intrusive in the DUT; consequently, it certainly results in being less expensive than the intrusive measurement susceptibility methods currently used since the whole EM illumination process is made from the outside together with the measurement process.

Second, this method may also be useful for managing electronic equipment obsolescence during their operating life. For all these reasons, measurement of harmonic-frequency levels appears to be a promising approach in the field of EMC qualification of aeronautic and automotive equipment.

REFERENCES

1. "Environmental conditions and test procedures for airborne equipment," RTCA DO-160F, Dec. 6, 2007.
2. "Testing and measurement techniques, reverberation chamber test methods," International Standard IEC 61000-4-21, 2011.
3. Chen, J., A. C. Marvin, I. D. Flintoft, and J. F. Dawson, "A statistical approach to radiated immunity testing of digital hardware in a reverberation chamber," *EMC Europe 2010*, Department of Electronics University of York, Heslington, York, UK, YO10 5DD, 2010.
4. Marvin, A. C., J. Chen, I. D. Flintoft, and J. F. Dawson, "A describing function method for evaluating the statistics of harmonics scattered from a non-linear device in a reverberation chamber," *2009 IEEE International Symposium on Electromagnetic Compatibility*, 165–170, Austin, Aug. 17–21, 2009.
5. Gretsch, W. R., "The spectrum of intermodulation generated in a semiconductor diode junction," *IEEE*, Vol. 54, Nov. 1966.
6. Guibert, L. and J. P. Parmantier, "EMC study of an embedded electronic system placed in a hostile electromagnetic environment," *EMC Compo'09*, 78, Nov. 17–19, 2009.
7. Guibert, L., P. Millot, X. Ferrières, and E. Sicard, "Study of radiated immunity of an electronic system in a reverberating chamber," *2013 9th International Workshop Electromagnetic Compatibility of Integrated Circuits (EMC Compo)*, 2013.
8. Psychoudakis, D., W. Moulder, C.-C. Chen, H. Zhu, and J. L. Volakis, "A portable low-power harmonic radar system and conformal tag for insect tracking," *IEEE Antennas and Wireless Propagation Letters*, Vol. 7, 444–447, 2008.