AN APPROACH FOR NEAR-FIELD MEASUREMENT OF RADIATED EMISSIONS FROM DIGITAL CIRCUITS

Alexandru Salceanu[(1)], Constantin Sarmasanu[(1)] , Mihai Cretu[(2)]

(1) Department of Electrical Measurements, Faculty of Electrical Engineering, Iasi, Bd. Mangeron 53, Romania
Phone (+40)32278683 Fax (+40)32237627 e-mail: asalcean@ee.tuiasi.ro
(2) Rector, Technical University "Gh.Asachi" Iasi , Bd. Mangeron 67, Romania
Phone (+40)32212322 Fax (+40)32211667 e-mail: mcretu@ee.tuiasi.ro

Abstract – *There are presented two E-field and two H-field, versatile, cheap and easy-to-use probes, the effective constructive solutions, the adopted calibration set-up and procedure for measuring their performance factors. As standard reference we used commercial available Agilent and EMCO probes. While trying to improve the EMC characteristics of the prototype of a fluxgate magnetometer, and in consequence near field measuring, problems were encountered. More or less successful attempts are discussed. Some useful techniques and recommendations when dealing with designing PCBs of sensitive equipments are presented.*

Keywords – Close E and H fields, electromagnetic radiation, PCB design.

1. GENERAL FRAMEWORK

In recent times, more and more products are designed with digital circuits, replacing in a decisive manner the linear ones. The ability of a product to operate without interfering with another product's operation and being "immune" to interference from any other source are two principal trends in today's design practices. Very complex devices such as 32-bit or even 64-bit microprocessors, impressive variety of ASICs (application-specific integrated circuits), digital signal processors, represent un-negligible sources of radiated electromagnetic energy. To be blamed for that are their high clock frequencies, greater dynamic current consumption and increased size and complexity. The use of ground planes and stripline reduces trace emission, implying that the elevated (0.1'' usually) wiring within large IC devices as the main radiator. More dangerous is not the intrinsic level of the radiated emission, but the resonant excitation of any structure within electronic equipment [1], [2]. The radiated energy flows from the integrated circuit into printed circuit board (PCB), back-plane structures, into enclosure cavities and onto connectors, apertures and cables, all of this "components" contributing to the total energy radiated from the equipment.

In this context, a suitable EMC/EMI pre-compliance system is developed in order to analyse some fundamental radiating characteristics by calibrating and measuring near-field patterns. The so-called near (close) E(Electric)-field and H (magnetic) field probes, even if they are reliable and cheap indicators of excessive emissions, they are not a substitute for compliance measurements performed with a properly equipped test facility.

The final aim is to obtain clear and objective EMC design rules and recommendations for PCB layout.

2. DESCRIPTION OF THE MANUFACTURED CLOSE FIELD PROBES

Due to some unexpected EMC failures while pre-compliance testing one of our new fluxgate magnetometer, we decided to develop versatile, easy-to-use and affordable tools for extending the capability of a spectrum analyser (or, even of a simpler scope), in order to map the "hot-spots" of magnetic and electric field emissions even where access is limited, so acquiring the desideratum of preventing our products from meeting the EMC regulatory requirements.

Probes (antenna) for EMC close-field measurements have to comply two important, but often contradictory, requirements.

First, the antenna size must be large enough in order to allow a high sensitivity of the near-field probe. On the other hand, the antenna dimensions must be small enough in order to yield a high resolution of the field scans as well as to reduce the disturbance of the electromagnetic field pattern by the presence of the probe. Focusing upon a good compromise between resolution (precise location of the radiating source) and sensitivity, electric near-field probes as well as magnetic near-field probes, were developed and characterized.

2.1 Two Electric close field probes

The electric near-field probes have no closed loops (no current pickup capacity), preventing current flow and so, rejecting (more than 25dB) the H-field. Two different probes for tracing high-impedance fields were produced:

a) one 3.2 cm copper sphere connected at a rod made from 50Ω coaxial cable. In order to have a conjugate (matched) termination to the 50Ω line, a resistor of the same value was soldered between the sphere and the shield of the "handle";

b) one single semi-rigid coaxial cable of 50Ω ("unfinished"), total length 9 cm, having only 8 mm of the centre conductor as active region (with the shield removed) at its termination. This quite insensitive monopole antenna (also known as "stump or stub probe") allows

ISBN 972-98115-4-7

(possible in addition to a broadband low noise preamplifier), a precise location of the radiation source, for instance when distances between pins of the IC chip are involved.
In order to preserve all frequency information, no diode element is used to rectify the signal.

2.2 Two magnetic close field probes

The magnetic field probes are based upon Faraday's law, containing a single turn, shorted loop inside a balanced E-shield (a gap was cut at the farthest point of the probe, comparing to the connector, for splitting the shield of the coax). The loop antennas are constructed by turning a single piece of semi-rigid 50Ω coax. At the point where the circular loop meets the "rod handle", the centre conductor and its shield are 2π radians soldered to the shield at the shaft, forming a single shorted turn. The greater the diameter of the circular loop, the better the immunity to the E-fields and the sensitivity. Two different probes for tracing low-impedance fields were produced and calibrated:

a) one circular loop, with 5.4 cm diameter, presenting a 38dB rejection of the electric field and 830 MHz upper resonant frequency;

b) one circular loop, with only 1.2 cm diameter, presenting a 13 dB rejection of the E-field and an upper resonant frequency higher than 2 GHz.

3. PERFORMANCE FACTORS AND DIAGNOSE TECHNIQUES

The probe performance factor *PF* (with dimension l/m) is defined as the ratio of the amplitude of the (E)field value at the position of the probe to the amplitude of the actual measured voltage at its BNC connector , (1):

$$PF[1/m] = \frac{E[V/m]}{U[V]} = \frac{H[A/m] \times Z[\Omega]}{U[V]} \qquad (1)$$

Even if loop probes only respond to the H-field, the equivalent E-field response is traced on the graph, assuming that plane wave conditions are met, which means that the amplitudes of the electric field and the magnetic field relate by a factor of $Z = 377\ \Omega$, known as the free space impedance. The advantage of this approach is the easier estimation of the strength of the far field.

Using more familiar dB units (the reference fields are 1μV/m and 1μA/m, while considering the reference voltage 1μV), (1) becomes, after applying decimal logarithm function and multiplying by 20:

$$E[dB\mu V/m] = U_E[dB\mu V] + PF[dB1/m] \qquad (2)$$

$$H[dB\mu A/m] = U_H[dB\mu V] + PF[dB1/m] - 20\log 377 \qquad (3)$$

where the last term has the approximate value of 51.52 .

In this case, the PF must be interpreted as the ratio of the magnetic field normal to and at the centre of the loop to the induced voltage.

In the far field only the electric field is measured and it is not important whether the source is electric or magnetic in nature.

However, in the near field, this is not the case. An electric dipole will create high impedance fields (high rate changes in the voltage) and a magnetic dipole will create low impedance fields (faster changes in the current). Of course, high or low impedance is assumed with respect to the 377 Ω far field wave impedance. Thus, it is not sufficient to measure only the total radiated power. We need also to know the type of field emitting source, mainly because the reducing techniques working in a situation are not suitable for the other.

A small "spy" probe can help diagnose the cause of an electromagnetic interference problem. By determining the nature of the radiating structure, we can quickly select the most appropriate design techniques. Good diagnosis saves time, false starts and random attempts to solve the EMI problem in the early stages of the product development cycle. Primarily, we need to get a rough estimate of the field impedance. The field impedance then is used to diagnose the radiation physics and to select a given solution.

Dealing with an EMC/EMI problem inside the cabin, we need to know two things before efficiently addressing the situation:
-what is radiating inside the unit?
-why and how that component or circuit is radiating?

Radiation is caused either by an instantaneous change in current flow, causing a magnetic field, or by an instantaneous change of a potential difference, causing an electric field,(4):

$$\frac{dU}{dt} = Z \times \frac{dI}{dt} \quad , \qquad (4)$$

Z meaning the total impedance at the radiating frequency, inductance in the physical circuit having major importance.

Physically is established a high degree of correlation between magnetic fields with differential mode current flow and electric fields with common mode current flow. Although a change in voltage will cause a change in current and vice versa, one of these vectors will predominate. The impedance of the radiating source will determine whether a predominately magnetic or predominately electric field is produced.

Magnetic fields typically are produced by local current loops within a unit. These loops may be analysed as differential mode.

Electric fields require high-impedance sources. Since the changing potential is isolated by substantial impedance on all lines into the circuit, all lines will carry just the forward current.

Essentially, EMC/EMI problems may be classified principally as current-related or voltage-related. Current-related problems normally will be associated with differential mode situations. Likewise, voltage problems normally will be associated with common mode circuit situations. Approximation of the field impedance is important if many fruitless attempts are to be avoided, solutions effective for differential mod problem seldom work against a common mode one. As we probe in close to the equipment, we have to switch between an E-field probe and an H-field probe. By noting the rate of change of the field strength versus distance from the source and the relative amplitude measured by the probes, the relative field impedance may be determined.

In summary the algorithm of locating the source of a disturbing signal is the following: first, time domain representation on oscilloscope, then using the set of "spy" probes to identify the signal path and the signal source. Using the least sensitive but smallest probes, often in conjunction with regular scope probes, we can identify the particular component or circuit causing the problem.

4. TEM CELL CALIBRATION

In order to obtain quantitative radiated emission results, the electric and magnetic near-field probes have to be calibrated accurately. For complying this, we need an accurate field to be generated. For our frequencies of interest, (100 KHz-400 MHz), we used a transverse electromagnetic transmission cell (TEM) [3], with the calibration set-up presented in Fig.1. The size (also setting the superior limit of the frequency of the TEM cell and the dimensions of the probes) is 16 x 16 x 21 cm. The strength of the electric field inside the TEM cell could be calculated with the relation (5):

$$E = \frac{\sqrt{Z(P_{inc} - P_{ref})}}{l} \qquad (5)$$

where Z is the impedance of the load and of the transmission line, P_{inc} is the incident power at the input of the cell, P_{ref} being the reflected one and l is the separation distance between the dividing and the bottom wall of the cell.

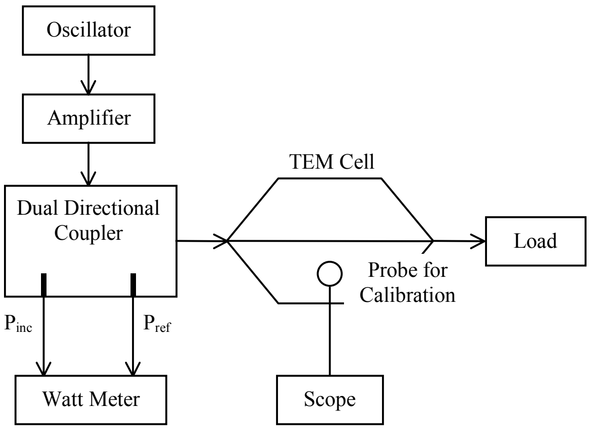

Fig.1 – Experimental calibration set-up using TEM cell

The probe element has to produce its maximum response to the electric field, so it is oriented within the field with its length parallel to the direction of the E-field vector. The probes were placed in the centre of the lower half of the cell, with their length normal to the dividing wall. Using equation (5) is advisable, for greater accuracy, not to have probes longer than one third of the distance between the dividing wall and the floor of the cell. The probes have to be characterised in the dynamic range of 2-100V/m (the frequency varying in discrete steps) and in the frequency range (this time, the field strength level is generated at selected discrete frequencies across the bandwidth of 100KHz-400MHz).

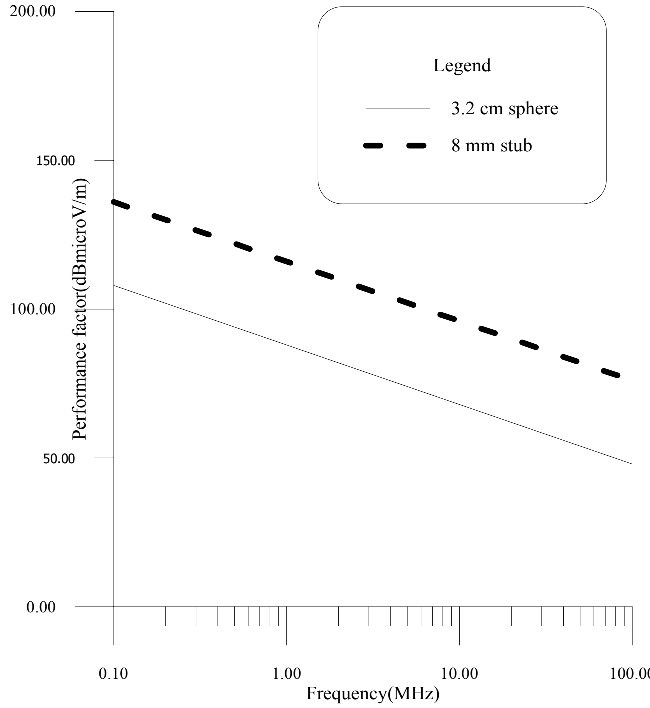

Fig.2 – Performance Factor [dB1/m] versus frequency, E-field probes

The measured performance factors as function of frequency, determined in the TEM cell are shown in Fig. 2 for the E-field probes and in Fig. 3 for the H-field probes.

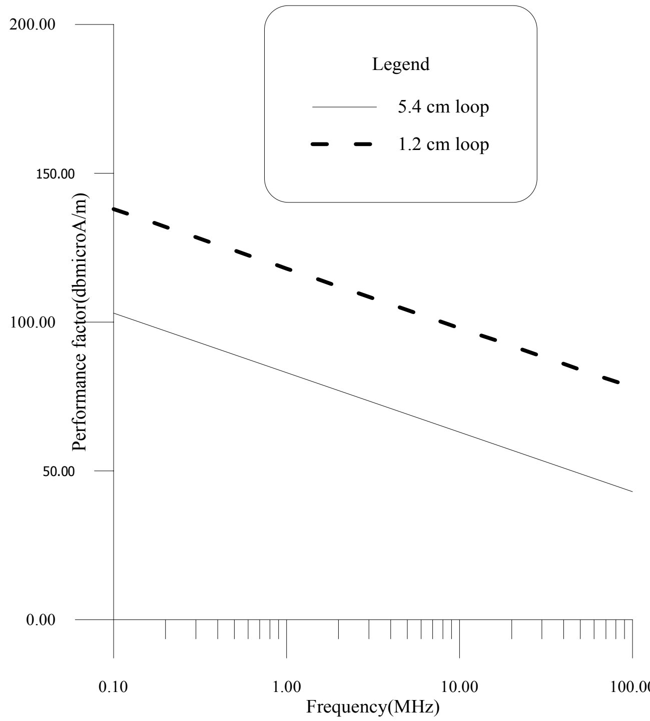

Fig.3 – Performance Factor [dB1/m] versus frequency, H-field probes

5. MINIMAL MEASUREMENT CONFIGURATION

The most rigorous methods for certifying radiated emissions and susceptibility are those using sophisticated and very expensive anechoic chambers [4]. We tested and proposed a quasi-alternative, more affordable method, implying test equipment that is typically included in an electronics laboratory [5], presented in the minimal configuration of Fig.4. For signal modulation we used the video output of the spectrum analyser supplying an oscilloscope for capturing the time domain representation of the received signal.

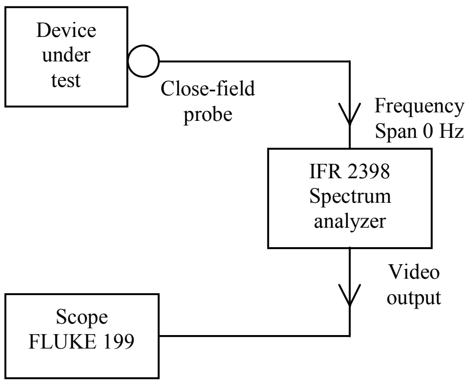

Fig.4 – Minimal configuration for close field measurement

6. RESULTS ACHIEVED AND APPLICABILITY

The paper proposes an approach for the measurement of radiated emissions potential at the component level, with the objective of quantitatively specifying the level of device emission, ensuring compliance at the equipment level.

Any device could be represented by a small loop antenna (magnetic dipole) and/or by a small dipole antenna (electric dipole) [5]. But the measure of the potential for radiated emission and coupling might be provided only in correlation with the current flowing through the loop or the "stub" (multiplying loop area, or stub length, by the passing current we evaluate the "dipole moment").

We also compared the results with those supplied by a high-impedance FET probe (in connection with a metallic lid, capacitively coupled to the die and lead frame beneath). The energized lid is modelled as an annular slot antenna, with the approximated area and measured voltage. The electric dipole moment is proportional to $1/\lambda$. FET probe is suitable as E-fields are high potential (more susceptible to perturbations). For measuring magnetic field radiation from surface currents, slots, cable and ICs for EMC diagnostic and troubleshooting, we used (as previously calibrated and certified), an Agilent 11941A Close H-Field probe and, for measuring electric field radiation, an EMCO (EMC TEST SYSTEMS) 905 E-field stub probe [6].

We measured magnetic and electric field coupling in the close vicinity of the digital circuits, using and comparing various types of probes. We recorded 4 points, at 0.2 m (reference), 0.4, 0.6 and 0.8 meters from the source, along two radials, using for each point two probes: one which is highly selective of the H-field and the other highly selective of the E-field. The propagating selected field decreased with about –6dB, –9dB and –12 dB, while the reactive field has a more greater rate of fall-off about –18, –27 and finally, respective –36dB. We concluded that relative amplitude between the probes is a good indicator of the nature of the dominating field.

7. CONCLUSIONS

The near-field experienced probes provide self-contained means of accurately detecting dominating electric or magnetic field emissions even where, due to narrow places, access is limited. The purposes of using near-field probes and previously presented minimal configuration are:

1. To acquire information about the source, its type and location of the radiating element.
2. To reduce test expense, just using relatively inexpensive equipment.
3. To reduce test time by quickly pre-screening various solutions and alternate implementations of the same solution.

Treating adequately an EMI problem just from the beginning, by tailoring it to a differential mode situation or a common mode situation is very advantageous.

When constrained to its proper place, the near-field probe is an essential tool for quick, efficient EMC/EMI engineering. These measurements are particularly useful for PCB designers, identifying what RF radiation is caused and what part of the device under test is most "emissive". Plots of the emission could be traced for correcting the problems at each step.

ACKNOWLEDGMENTS

This work was financed and developed in the framework of the Leonardo da Vinci Pilot Project with the Contract number: RO/98/83550/PI.

REFERENCES

[1] Criel,S., Haelvoet K., Martens L., "Theoretical and Experimental Quantitative Characterization of the Near-Fields of Printed Circuit Board Interconnections Structures*", IEEE International Symposium on Electromagnetic Compatibility*, Atlanta, 14-18 August 1995, pp.471-474

[2] Simpson, J.P., Goulette,R.R., "Radiation from Microstrip Transmission Lines*", IEEE International Symposium on EMC*, Seattle, Aug. 199,p29.

[3] Kourosh Matloubi "A Method for Calibration of isotropic E-field probes", *IEEE International Symposium on Electromagnetic Compatibility*, Cherry Hill, 12-16 August 1991, pp.277-278.

[4] Bronaugh,E.L., Osburn,J.D.M., "Radiated Emissions Test Performance of the GHz TEM Cell", *IEEE International Symposium on EMC*, Cherry Hill, N.J., Aug 1991,pp.235-238

[5] Goulette R.R., "The measurement of Radiated Emissions from Integrated Circuits*", IEEE International Symposium on Electromagnetic Compatibility*, Anaheim, 17-21 August 1992, pp.340-346.

[6] EMC Test Systems^{TM}, *Near-Field Probe Set*, User's Manual, Austin, Texas, 1999,pp.15-28.