Near Field Measurements to Predict the Electromagnetic Emission of Integrated Circuits

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***Abstract* — Employing electromagnetic emission measurements early in the design process is more and more essential as the high clock speeds of integrated circuits (ICs) lead to increased challenges in meeting the electromagnetic compatibility (EMC) requirements. Due to the shrinking time to market the characterization of the electromagnetic emission during the design cycle according to the chip level standards is often not feasible as special EMC test boards have to be designed, which often takes a long time. Therefore simple measurement techniques that can be applied using every evaluation or demo board are more and more required to give the designers first hints about the electromagnetic emission of an IC. In this paper a simple measurement technique to determine the radiated electromagnetic emissions of ICs is presented. This method is based on the measurement of the near electric and magnetic field components that are emitted out of the surface of an IC package. An advantage of this measurement technique is that it can be used without the need to build a special EMC test board.**

1. INTRODUCTION

The constant growth of microelectronic components in our modern electronic systems makes great demands on the EMC of ICs. With the trend towards higher integration densities as well as integrating more and more radiators like wireless capabilities onto the IC the design for low emission is getting more challenging.

Usually the radiated electromagnetic emission of ICs is measured with the TEM cell method according to the IEC 61967-2 standard as briefly introduced in chapter 3 [1]. For this measurement a special EMC test PCB has to be manufactured according to the requirements of the standard.

Especially if during the design cycles the pining of the IC is not yet fixed and varies together with the arrangement of the external components, multiple designs of such multilayer EMC test PCBs are often too expensive and take too much time to use this method for each prototype. Therefore very often only after the final design of the IC is finished its radiated electromagnetic emission is characterized. This process all too often results in identifying EMC problems when it is nearly too late to perform further re-design steps and often expensive fixes on the design are the only options available. Therefore it becomes more and more essential to include EMC measurements as an integrated part of the design cycle to ensure the EMC compliance of the final product and to minimize the additional re-designs to keep the minimum time to market.

A simple and reliable measurement method, as it is introduced in this paper, can be used during the whole design cycle without the need to design a special EMC test PCB. This method provides a useful alternative to the EMC test methods described in the IEC 61967 standard.

2. HOW DISTURBANCES CAN COUPLE OUT OF AN INTEGRATED CIRCUIT

There are several ways how an IC can produce electromagnetic disturbances and further might cause EMC problems. The three main mechanisms of coupling disturbances out of an IC are by [2]:

- Conducted emission
- Emissions caused by an electric or magnetic near fields
- Direct radiation from an IC

Fig. 1 gives an illustration of these coupling methods. Conducted emissions can be generated at each pin of an IC. In this case for example disturbances such as voltage or current surges are coupled out of the IC and both common mode and differential mode emissions are generated. Often the PCB traces and the cables that are connected to the pins behave as antennas and emit these disturbances into the environment.

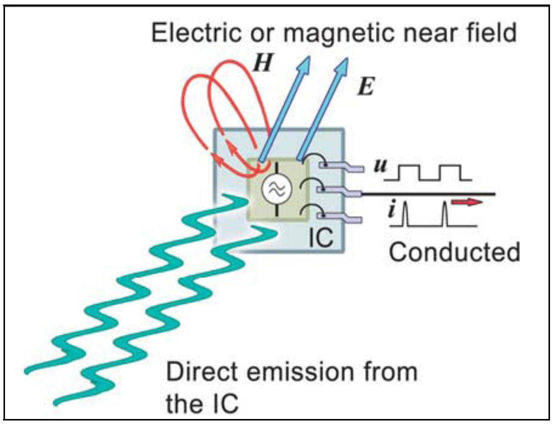

Fig. 1. Ways how an IC generates disturbances

Electric and magnetic near fields are generated by the ICs internal RF voltages and RF currents. Magnetic fields are especially generated in presence of high currents which flow in current loops. Particularly the Vdd-Vss current loops that are closed by the blocking capacitors and the GND plane outside of the IC can produce high magnetic fields. These fields can be divided into two parts, as shown in Fig. 2. The field H2, generated by the currents across the ICs internal conductors, closes in the surrounding area above the ICs surface. Its effective range reaches up to 10-15 cm. If the field reaches for example a surrounding metal system or other metal traces the magnetic field can couple into neighboring loops and induce a disturbing voltage. The magnetic field H2 is significantly stronger than the field H1, which is formed around the ground plane of the PCB. The near field H1 induces a voltage in the GND plane which acts as the supply voltage for parasitic antenna elements such as cables that are connected to the PCB.

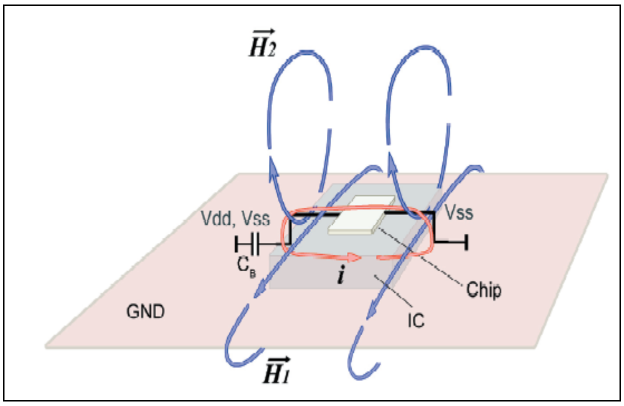

Fig. 2. Mechanism of direct magnetic field emission from an IC.

Electric fields are generated wherever RF voltages exist. For example these voltages are present between the internal metal traces of the IC or between the metal traces and the GND plane. In Fig. 3 an electric field emission caused by the square-wave voltage of the Clk signal is shown. Most flux lines reach the GND system on the shortest way, but a few spread upwards and lead far into the surrounding area. There they can couple into neighboring metal parts and stimulate them as emitting antennas.

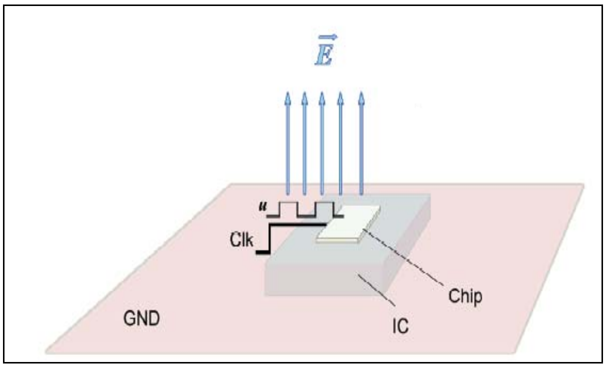

Fig. 3. Mechanism of direct electric field emission from an IC

In the case of direct emission, the IC generates electromagnetic fields that are directly radiated by the IC i.e. mainly by the package lead frame and the bonding interconnections. The direct emissions are generated at frequencies of 1 GHz and above.

The measurement techniques for the characterization of the electromagnetic emission of ICs can be assigned to the ways how disturbances are generated by an IC. One of the commonly used measurement techniques, the so-called TEM cell method (IEC 61967-2) is described in the following chapter.

3. TEM CELL MEASUREMENT METHOD

The TEM cell method as a part of the IEC 61967 standard can be used to measure the radiated electromagnetic emission of ICs in the frequency range from 150 kHz to 1 GHz. The TEM cell measurement is based on the idea of combining the fields generated by an IC in one global measuring quantity. As the electric and magnetic fields are measured together at the same time the TEM cell does not differentiate between these two components.
For characterizations with the TEM cell a special test PCB has to be designed under the conditions of the IEC standard 61967 which dictates both electrical and mechanical properties. For example, the board size has to be 100 mm square; its edges shall be tinned or gold-plated for at least 5 mm in order to make proper contact with the conductive surface of the mating port of the TEM cell. A double layer board is proposed as a minimum requirement, although four layers are recommended. A picture of the TEM cell and the related EMC test PCB can be found in Fig. 4.

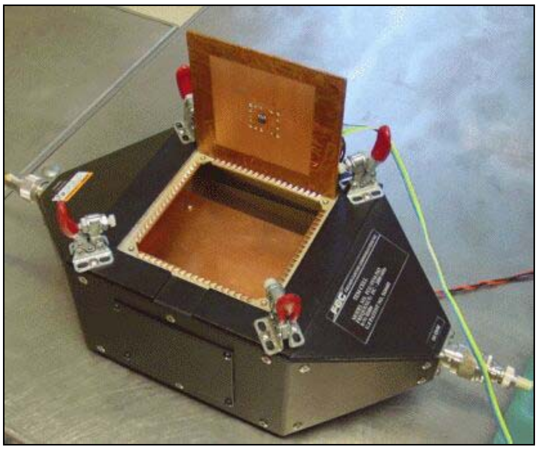

Fig. 4. TEM cell according to IEC 61967-2 to measure the radiated electromagnetic emission of ICs.

The test PCB is clamped to a mating port, which is cut into the top of the TEM cell. Thus, the test board is part of the TEM cell wall. It is absolutely important to design the test PCB in such a way, that all connecting leads within the cell are eliminated. Only the IC as the device under test (DUT) is allowed to be inside the cell (bottom side of the PCB), all other circuitry is located outside on top of the test PCB. Due to the limited available space on the test board this can be a challenging task for complex ICs with many pins. Therefore very often a daughter board has to be designed, which increases the costs of the test board. Moreover I/O and other required pins have to be fed from the top layer to the bottom layer which requires the use of vias. These vias should preferably be centered in the pads used for soldering the IC. Especially for SMD packages this might be difficult, especially if some adjacent pins are concerned.

4. AN ALTERNATIVE MEASUREMENT METHOD (NEAR MAGNETIC AND ELECTRIC FIELD MEASUREMENT)

As ICs generate electric and magnetic near fields it is obvious to characterize the electromagnetic emission of ICs by performing near field measurements. In order to give a prediction on the total electromagnetic emission of the IC (as it is done using the TEM cell method) each measurement of the two field components (i.e. electric and magnetic) should be performed separately. Thereby the near fields should be measured directly at the surface of the ICs package as shown in Fig. 5.
This measurement technique can be used as an alternative to the TEM cell technique.

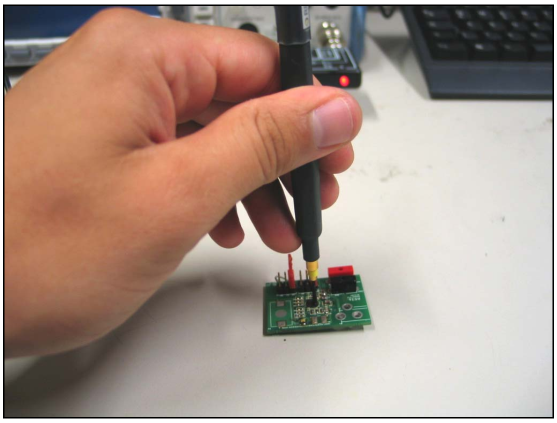

Fig. 5. Near field measurement using electric and magnetic probes. The near fields should be measured directly at the surface of the ICs package.

In order to get almost equivalent measurement results to the TEM cell (as shown in measurement example in the following chapter) we suggest to mathematically combine the electric and the magnetic near field measurement results. For this purpose the electric and the magnetic field probe measurement results (X_E and X_H) given in dBµV are transformed into Volt values, added together, and retransformed into dBµV according to equation (1).

$$x = 20 \cdot \log(10^{\frac{X_E}{20}} + 10^{\frac{X_H}{20}}) \qquad (1)$$

Of course we know that this is a very unconventional way to deal with magnetic and electric field components. Furthermore the E- and H-field strengths are usually given in V/m and A/m respectively and therefore cannot be added without any further transformation. But since the near field probes acquire induced voltage values anyway we decided to use this proceeding as a first approach in order to keep the measurement as well as the calculation as simple as possible. As we will see later on, the results with this approach are quite satisfying.

4.1 The near field probes

To characterize the electromagnetic emission of an IC we suggest to use special near field probes which have screened miniature heads such as the passive E- and H-field probe (RF-E 10 and RF-B 0,3–3) from Langer EMV Technik GmbH [3]. The probes provide a high resolution of less than 1 mm, which is well suitable for scans on the surface of an IC package.
The magnetic field probes loop opening is oriented horizontally to measure the magnetic field components that are vertically emitted out of the ICs surface.
The head of the electrical near field probe is only approx. 0.5 mm. Therefore each individual circuit path under the surface of the IC package can be evaluated.

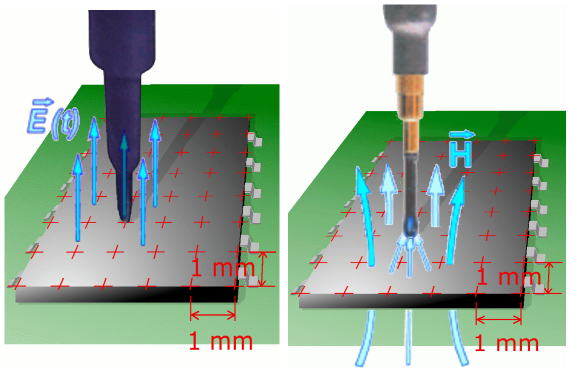

Fig. 6. Near electric and magnetic field probes for the characterization of the electromagnetic emission of integrated circuits.

4.2 The measurement technique

The surface of the IC package should be divided into a 1x1 mm matrix mesh as shown in Fig. 7. At every cross point Mxy of this matrix the near electric and magnetic field components should be measured in the frequency range from 150 kHz to 1 GHz. This ensures that every single spot emitter of the IC is detected.

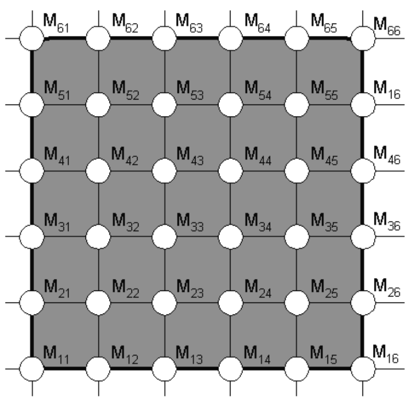

Fig. 7. Setup for near field measurements: the surface of the IC package should be divided into a 1x1 mm matrix mesh.

The probes should be placed in a constant distance of d=0 mm directly onto the surface of the IC package. By using the max hold function of the spectrum analyzer (or EMI receiver), the maximum electromagnetic emission of the IC is given if the final measurement point has been measured. The sweep time should be selected in a manner that the software loop execution time is at least three orders of magnitude faster than the time the spectrum analyzer dwells at one frequency position. To be able to compare the measurement results of the TEM cell with the near field measurements, the same spectrum analyzer settings (i.e. RBW, VBW, etc.) should be used.
A further advantage of this measurement technique is the ability to localize the sources of the emissions from the collection of the measurement results and to get information about the way the IC is generating emissions.

5. MEASUREMENT EXAMPLES AND INTERPRETATION OF RESULTS

In order to compare the measurement results of the alternative near field probe method with the conventional TEM cell method, two simple reference radiators were used. With these two test devices it should be shown that the measurement result of the alternative method can be correlated to the TEM cell result and match in an acceptable manner.

5.1 Measurement using a single loop

For the first emission measurement a digital signal with a frequency of 1 MHz is used. The DUT that was used for this purpose is a radiator build by a simple loop over a ground plane. It consists of a CU-rod of 20 mm length which is mounted in 2 mm distance above a ground plane. An SMB connector was mounted on one side and two 100 Ohm termination SMD-resistors in parallel on the other side. The implementation of this DUT is shown in Fig. 8.

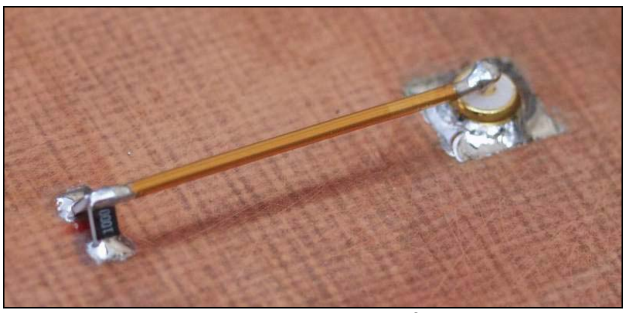

Fig. 8. Single loop test board used as reference radiator

The loop is placed in the middle of a 100x100 mm PCB, which was designed according to the requirements of the IEC 61967-2 standard. The connector was attached to a signal generator which provided the 1 MHz rectangle digital signal with 5 Vpp and a duty cycle of 50%.
The TEM cell measurement was performed with the loop oriented in four directions (0°, 90°, 180°, and 270°) inside the TEM cell. The maximum emission of these four measurement results was used as the reference measurement and is shown in Fig. 9.
The measurement results using the near field probes of course depend on the distance and the orientation of the probe to the loop. In order to obtain reproducible results the probes were placed in a way that a maximum value was measured. In the case of the electric field measurement the probes head was placed directly onto the rod and in case of the magnetic field the H-field probe was placed right next to it.

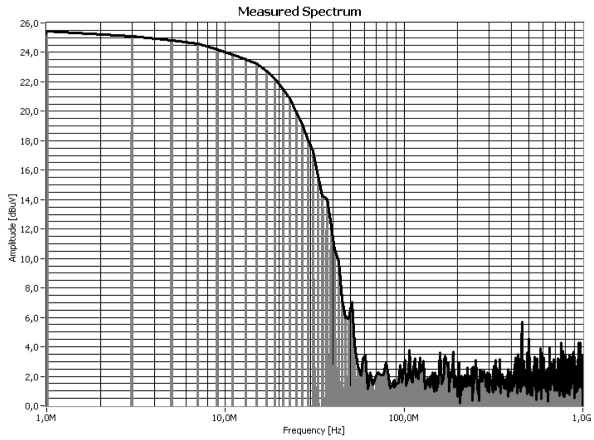

Fig. 9. Loop measurement result with the TEM cell (reference)

The result of the magnetic near field probe measurement can be seen in Fig. 10. The black trace is the envelope of the measured spectrum. For better visualization the area under the trace was filled grey. To compare the measurement result with the reference the diagram also shows the TEM cell results as the dotted line.

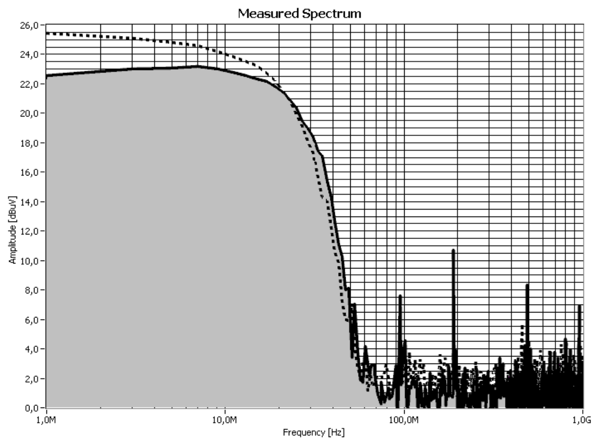

Fig. 10. Loop measurement with the RFB 0,3-3 magnetic field probe vs. reference

We can observe that the magnetic field probe retrieves less emission than the TEM cell below 20 MHz and the difference grows with lower frequencies. The probe measures slightly more between 20 MHz and 70 MHz. For higher frequencies, however, the results are quite similar, although the near field probes results are a little below the reference.

Due to the fact that the measurements were not performed in a shielded room, several external disturbances resulting in single peaks at about 100 MHz, 190 MHz, 500 MHz, 800 MHz, and 950 MHz can be found. These peaks are mainly interferences from radio-, TV-, and telecommunication broadcast stations and should not be considered.

Fig. 11 shows the envelope of the measured emission spectrum acquired with the electric field probe (black trace with grey area) along with the reference (dotted line).

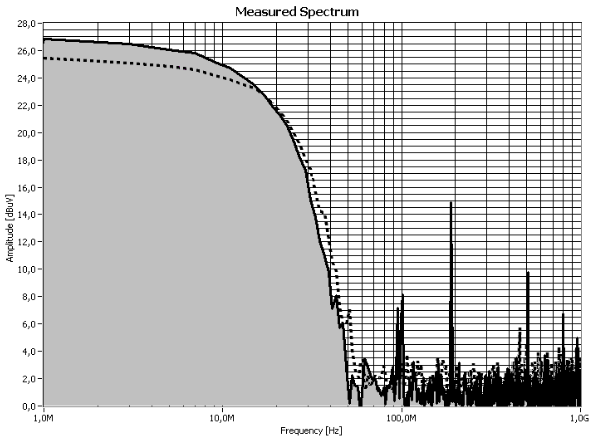

Fig. 11. Loop measurement with the RFE 10 electric field probe vs. reference

In contrast to the magnetic field probe the electric field probe retrieves more emission below 20 MHz. Again the difference grows with lower frequencies. In the frequency range between 20 MHz and 70 MHz lower results than the reference were received. Above 70 MHz the two near field probes behave akin: similar though a little lower than the reference.

If we combine the results according to equation (1) we get the black plot in Fig. 12. The TEM cell measurement result is again shown as the reference by the dotted line.

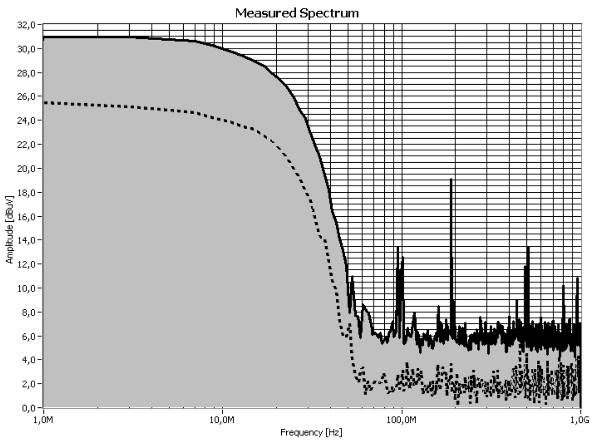

Fig. 12. Sum of probe measurements vs. reference

The shapes of the two plots look very similar, which confirms our assumption that near field measurement results are comparable to the TEM cell measurements. However, they show an almost constant offset of about 4 dB over the whole measured frequency range. This offset is mainly caused by the orientation and the distance of the probe to the rod.

In the case of a simple loop radiator the two measurement methods show a good match. As a next step the methods were evaluated with a real IC to investigate if our theory is still valid.

5.2 Measurement using an IC

The IC that has been used for this investigation is a simple bus driver IC realized in a CMOS 0,35um technology. It operates eight inputs on one site of a plastic DIP 24 package, which are directly connected to eight outputs on the other site of the package. In order to generate high electromagnetic emissions all inputs are externally connected together and are driven by a signal generator providing a 1 MHz square wave signal. In this case also all the output buffers are switching simultaneously with the same frequency resulting in high ground bounce amplitudes and emissions.
Again, the reference was measured with the TEM cell method using an appropriate PCB. Fig. 13 shows the TEM cell measurement result.

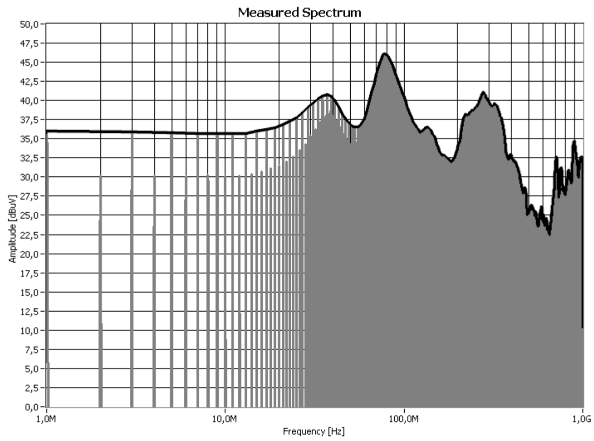

Fig. 13. Measurement result of an IC – TEM cell method (reference)

Next, the electric and the magnetic field at the surface of the ICs package were measured separately. The near field probe measurements were performed as described in chapter 4.2 and combined together by using equation (1). The resulting spectrum and its envelope are shown in Fig. 14.

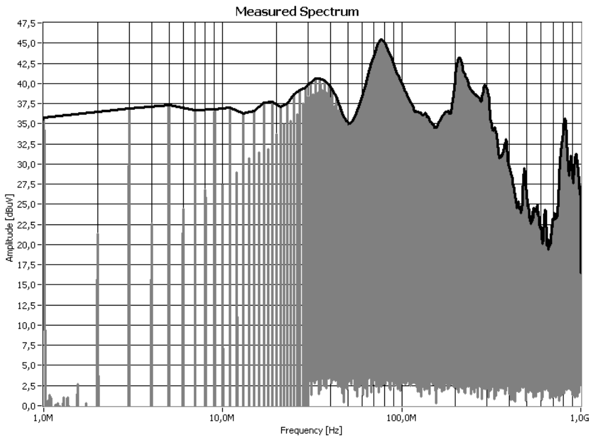

Fig. 14. Measurement result of an IC – Alternative near field probe method

The measurement result of the TEM cell together with the near field probe measurement result can be seen in Fig. 15. The dotted line shows the reference (TEM cell) measurement and the solid plot gives the result of the presented alternative near field probe method.

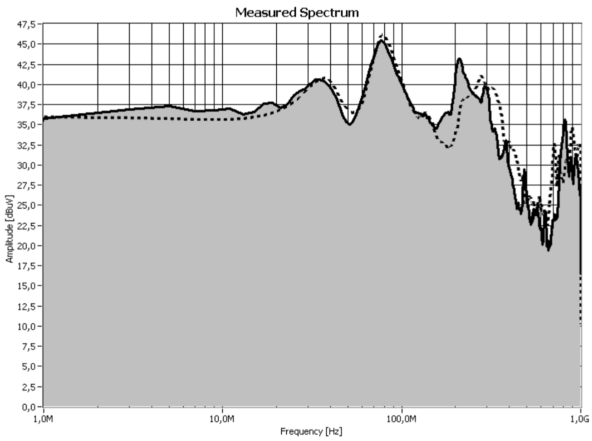

Fig. 15. Measurement result of an IC – Alternative near field probe method / Sum of the two probe measurements vs. the TEM cell measurement

As can be seen, the two measurement methods retrieve quite similar results even if a real IC is used.

Users of the alternative method have to be aware of the fact, that a near field probe measurement and a TEM cell measurement will never give exactly the same results. Nevertheless, the near field probe method gives important additional information to the designers. Knowing in which way an IC is emitting electromagnetic energy (i.e. does the IC produce more electric or more magnetic fields) is very important for the proper placement of the components on the PCB in order to reduce interferences to other circuit parts. For example in the presence of magnetic field radiations of an IC the PCB designer is good advised not to route signal traces in loops close to the IC, whereas in the presence of high electric field emissions metal parts should be located further away from the IC to avoid capacitive coupling.

6. CONCLUSION

In this paper an alternative measurement method to the conventional TEM cell measurement method for the characterization of the radiated electromagnetic emission of ICs is given. We have shown that the near field measurement result using a special electric and a magnetic field probe can be correlated to the measurement result of the TEM cell method so that both results match in an acceptable manner. This allows applying the near field probe method as a cheap and easy to use alternative to the TEM cell measurement without the need to build a special PCB.

7. REFERENCES

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