Proceedings of the 5th WSEAS Int. Conf. on Power Systems and Electromagnetic Compatibility, Corfu, Greece, August 23-25, 2005 (pp588-590)

Experiment to visualize equipotential lines in a real complex circuitry

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Abstract: - An experiment is proposed to observe equipotential lines in a complex circuitry using a specific probe. The map of equipotential lines is built sweeping the probe across the circuitry. To validate this approach, an experimental ground plane has been analyzed. Measured results have been faced to a rigorous electromagnetic simulation made with a commercial software based on Maxwell's equations. The equipotential lines observed on the ground plane are similar to those calculated numerically.

Key-Words: - visualization of equipotential lines, common-impedance coupling.

1 Introduction

One of the problematic in Electromagnetic Compatibility (EMC) concerns common-impedance coupling [1]. Conventionally, a ground plane is considered like an equipotential surface. The reality is that all conductors have a certain amount of impedance. Consequently a current passing in that ground will cause differences of potential due to the voltage induced through this impedance. This phenomenon is at the origin of coupling that appears sometimes between two systems connected to the ground. One of the challenge of the EMC is to minimize those effects [2]. We propose an experiment to visualize equipotential lines in a complex circuitry moving manually a probe. This phenomenon is delicate to measure because the differences of potential expected are very small and the measuring device can cause interference in the repartition of equipotential lines. Those are the reasons for which the experimental observations have been compared to an electromagnetic numerical simulation with a commercial software based on a rigorous resolution of Maxwell's equations. As it will be shown in this paper, experimental and theoretical results are in good accuracy.

2 Numerical simulation of equipotential lines

Consider a ground plane where slots have been reported to reproduce the irregularities that usually appear in the realization of a printed circuitry. It is fed at two points A and B with a low frequency generator (see Fig.1). A current is induced on the metallic surface and differences of potentials appear on the ground plane since the resistivity of the metal is not null. In particular, the Ohm's law is verified :

$$\vec{J} = \sigma \vec{E} \qquad (1)$$

where *J* is the induced current, *E* the electric field and σ the conductivity of the metal.

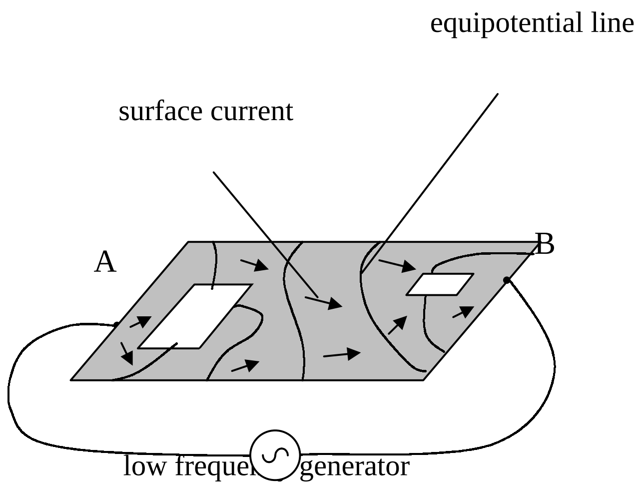

Fig.1 : generation of equipotential lines on a ground plane

From the electric field, the potential at any point M on the ground plane is obtained from the following integral :

$$V(M) = -\int_B^M \vec{E} \cdot d\vec{l} \qquad (2)$$

with V(B) = 0.

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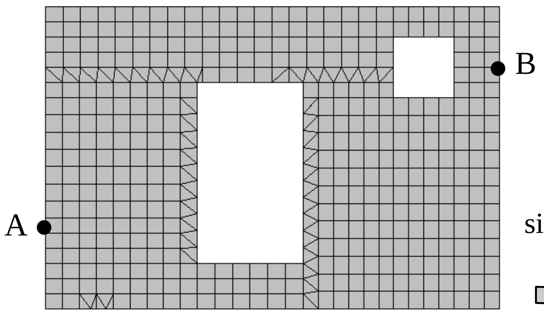
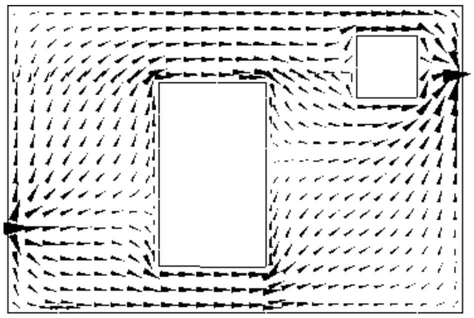
Using an electromagnetic software based on a rigorous resolution of Maxwell's equations, one can determinate numerically the equipotential lines on the ground plane.

meshing of the structure



simulation

calculation of currents



exploitation of the data file

Number Of Cells= 477						
	Length Unit = (mm)		Current Density Unit = (A/m)			
No.	X	Y	ReJx	ImJx	ReJy	ImJy
1	2.885000e+002	2.000000e+002	1.736226e-001	6.671663e-001	1.712397e-015	3.751614e-015
2	2.770000e+002	2.000000e+002	4.507768e-001	1.274358e+000	1.040634e-015	1.818395e-015
3	2.655000e+002	2.000000e+002	7.876320e-001	1.862966e+000	-3.605273e-015	-5.513511e-015
4	2.540000e+002	2.000000e+002	1.176642e+000	2.457867e+000	-2.726060e-015	-3.847825e-015
5	2.425000e+002	2.000000e+002	1.617855e+000	3.080630e+000	1.060276e-014	1.433432e-014
6	2.310000e+002	2.000000e+002	2.108156e+000	3.743482e+000	-4.802091e-015	-6.388472e-015
7	2.195000e+002	2.000000e+002	2.626301e+000	4.432790e+000	-1.539486e-015	-2.047517e-015
8	2.080000e+002	2.000000e+002	3.124631e+000	5.095564e+000	-5.143289e-015	-6.913893e-015
9	1.965000e+002	2.000000e+002	3.540852e+000	5.655064e+000	8.963454e-016	1.228365e-015
10	1.850000e+002	2.000000e+002	3.831001e+000	6.052681e+000	0.000000e+000	0.000000e+000

numerical calculation of potentials

using equations (1) and (2)

Fig.2 : calculation of potentials from the current simulated by the software IE3D

Fig.2 shows the procedure followed with Zeland software IE3D, a simulator designed for planar structures. First, the geometry is described as a metallic surface with the characteristics of the metal. In particular, the Ohm's law is modeled by a surface impedance taking in account the skin effect. The ground plane is meshed in polygons. Moreover, a source is defined by a differential port which sets a voltage drop between the points A et B. Then the simulator calculates the current on each polygon. The solution is stored in a data file from which the potential on the ground plane can be deduced by a numerical integration.

3 Description of the experimental device

To detect equipotential lines, we propose to sweep the surface of the ground plane with a specific probe (see Fig.3).

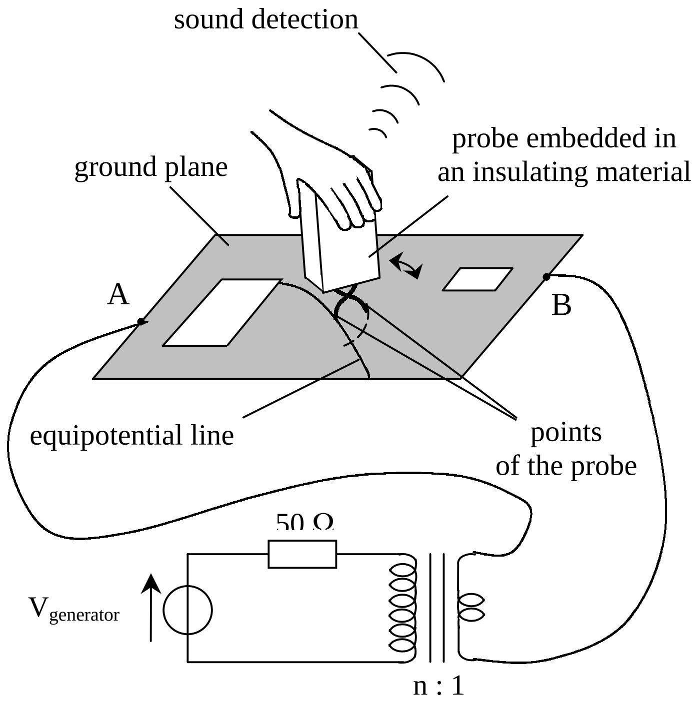


Fig.3 : experimental device to visualize equipotential lines on a ground plane

The probe is designed to collect a difference of potential between two points of the ground plane (see Fig.4). The points of the probe are made with a bunched cable to cancel the voltage that could be induced by the magnetic field present above the ground plane. The difference of potential expected from the ends of the points is very small (< 10 µV). Different electronic modules are necessary to make the signal perceptible. First a transformer amplifies the detected voltage. Then a resonant LC cell filters frequency noise notably the disturbance linked to the electric grid and two modules of amplification bring a gain of 40 to 60 dB. The power supply is provided with batteries for reasons of stability but also to decouple the probe with the circuitry. Finally the operator detects an equipotential line searching a minimum of the sound emitted by a speaker. This measuring device has been chosen because it is necessarily neutral. Indeed, we are sure that the acoustic wave emitted by a speaker does not disturb the electromagnetic phenomenon we want to analyse. The probe is embedded in an insulating material so that the hand of the operator does not cause any interference.

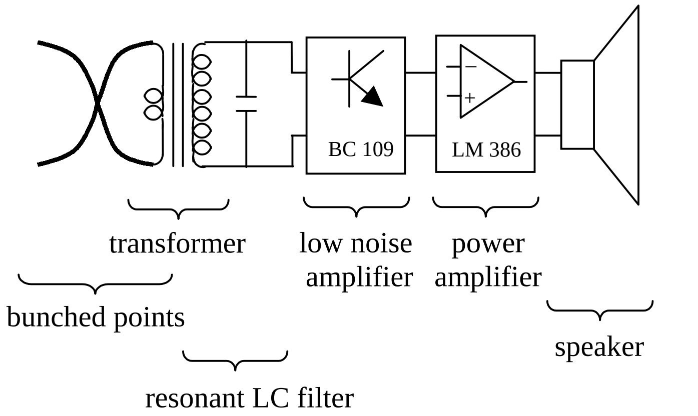


Fig.4 : electronic modules of the probe

Moreover, the excitation of the ground plane can be improved. Indeed, the load that represents the ground plane has an impedance near zero. When we feed directly the ground plane, the voltage induced between the points A and B is very small :

$$v_{AB} = \frac{z_{ground}}{z_{ground} + 50\,\Omega} V_{generator} \approx \frac{z_{ground}}{50\,\Omega} V_{generator} \qquad (3)$$

with $z_{ground} << 1\ \Omega$

A better matching is obtained adding a transformer with a ratio primary to secondary equal to n. The dynamic is increased by a factor n^2 :

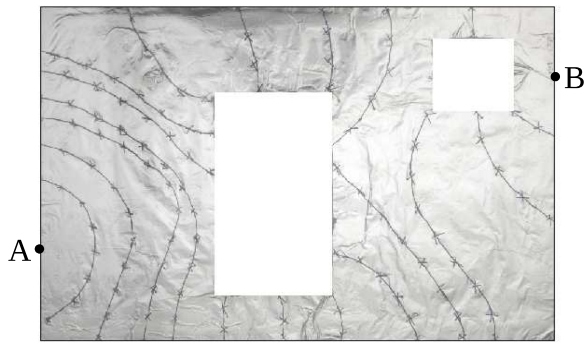
$$v'_{AB} = \frac{n^2 z_{ground}}{n^2 z_{ground} + 50\,\Omega} V_{generator} \approx n^2 v_{AB} \qquad (4)$$

A transformer has been designed with n equal to 30. Consequently, a gain of 60 dB is obtained without adding any noise.

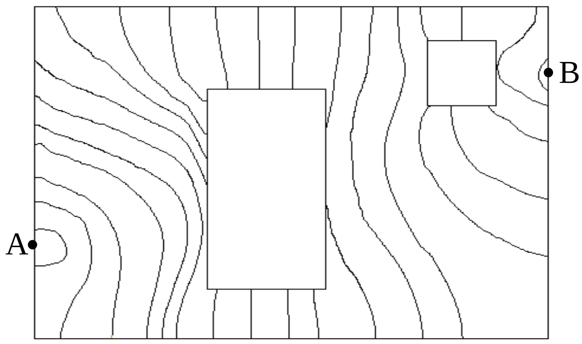
4 Comparison between simulated and measured equipotential lines

A ground plane has been realized with a sheet of aluminum. The dimensions are 30 cm x 20 cm and the thickness is 12 μm. The electrical conductivity σ of aluminum is 2/3 the one of copper that is to say about $3{,}7 \times 10^7$ S/m. With a low frequency generator, we apply a sinusoidal voltage of 5 kHz.

At the top of Fig. 5 are reported the equipotential lines measured moving the probe step by step on the ground plane. Otherwise, the problem has been simulated with the commercial software IE3D. Numerical results are given at the bottom of Fig. 5. The simulated equipotential lines are in good correlation with those measured.



measure



simulation

Fig. 5 : simulated equipotential lines using the software IE3D and measured equipotential lines using the probe

5 Conclusion

An experiment is proposed to observe equipotential lines in a complex circuitry. The measure realized with a sheet of aluminum is in a good accuracy with the result simulated by a commercial software based on a rigorous resolution of Maxwell's equations. This experiment enables to better apprehend the problem of common-impedance coupling and can be used to minimize its effects in any circuitry.

References:

[1] R. Paul Clayton, "*Introduction to Electromagnetic Compatibility*", John Willey & Sons Inc, 1992.

[2] E. L. Bronauch, W. S. Lambdin, "*Electromagnetic interference test methodology and procedures*", Gainesvillee, 1988.