COMSOL simulation of an attenuated magnetic field through a metallic plate

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Abstract: This paper presents the evaluation, by COMSOL software simulations, of the magnetic fields due to a circular coil [1-3] when a 0.7 mm metallic plate is placed near the coil. We have analysed the variation of this magnetic field $B_e$ as function of the frequency as well of $z$ (perpendicular to the circular coil). We show that a clear evanescent magnetic field $B_e$, near the metallic plate, appears due to the skin effect related to the "Plasmon current". We analyse also the particular effect near the metallic plate concerning the increasing value of frequency. The comparison of the results shows that the developed model and the performed experimental measurements are accurate and effective.

1. Introduction
Metal plates are generally used as electromagnetic shielding against sources of disturbance. The electrical and magnetic properties favor more or less the passage of the electromagnetic field through the plate. In the following and for the purpose of determining the optimum parameters which allow the passage of the magnetic field, a modeling followed by an experimental confirmation was made.

2. Theoretical considerations
The exact resolution of this system amounts to solving the differential equation of the magnetic vector potential.

$$\nabla^2 \vec{A} + k_D^2 \vec{A} = 0$$  (1)

Where

$$k_D^2 = \mu_0 \varepsilon_0 \omega^2$$  (2)

The analytical solution of equation (1) is difficult. The problem was dealt with, many years ago, by Schelkunoff [1] taking the following considerations

- It considers an incident wave on an infinite metal plane.
- It considers the most constraining case that is for a normal incidence wave.
- It evaluates the attenuation by the sum of the three phenomena (Absorption, reflection, multiple reflections) depending on the permeability, the permittivity and the conductivity of the material and the frequency of the wave.
- In our application, the coil is placed near the plate and a near-field considerations are studied.
The results indicate that the efficacy of a magnetic shield decrease when the frequency increase [2][3]. The model gives good results for high frequencies; to study the phenomenon at low frequencies a numerical resolution is necessary.

![Graph](image)

**Figure 1** Amplitude of the magnetic induction in % crossing the plate with respect to the amplitude of the incident wave by the near-field theory

3. Resolution by finite elements

Under COMSOL, for a two-dimensional model the equation (1) becomes

\[(j \omega \sigma - \omega^2 \varepsilon_0 \varepsilon_r)A + \nabla \times (\mu_0^{-1} \mu_r^{-1} B) - \sigma v \times B = J_e\]  

Where \(\omega\) the pulsation, \(\sigma\) conductivity, \(\varepsilon_r\) relative permittivity, \(\mu_r\) relative permeability, \(v\) velocity of the phenomenon in the medium or of the medium and \(J_e\) Charge density.

The coil used in the tests was modeled on COMSOL in two dimensions to optimize the calculation time. The field of study is composed of four regions represented in Figure 2 Table 1 summarizes the parameters for different regions.

In the area (3) \(J_e\) is calculated directly from the winding's parameters (number of turns and current) given in the model.

The low electrical conductivity value of the area will not affect the results, and it is necessary for convergence of the solver [4]. The parameters of region (4) were taken from [5]. The metal plate at a thickness of 0.7 mm, its relative permeability was determined empirically. The dimensions of the coil regions (3) and (4) are in agreement with the dimensions of the test coils.
Figure 2 Finite element resolution model

Table 1 Finite Element Resolution Parameter

| Region     | (1) | (2)     | (3)     | (4)      |
|------------|-----|---------|---------|----------|
| Description| Air | Metal plate (steel) | Flat coil (copper) | Ferrite |
| Conductivity (S/m) | 0.1 | 1.12 $10^7$ | 5.998 $10^7$ | 0        |
| Relative permeability | 1   | 240     | 1       | 2300     |

4. Simulation results

Figure 3 Variation of the magnetic induction amplitude (B) as a function of z for the frequencies 50 - 2000 Hz for a coil with ferrite
With the presence of the plate, it can be seen in Figure 3 that the magnitude of the magnetic induction varies as a function of the frequency on both sides of the plate. The plate is positioned at \( z = 0 \) and the coil at 4 mm in the negative part.

The increase in magnitude of the magnetic induction under the plate is due to the field created in the plate by the eddy currents which themselves were induced by the magnetic field emanating from the coil. This additional field is all the more important as the thickness of the skin can be. Hence inversely proportional to the frequency from which the magnitude increase of the magnetic induction.

![Image](image.png)

**Figure 4** Variation of the magnetic induction amplitude (B) as a function of z for the frequencies 50 - 2000 Hz for a coil without ferrite

In the figure 4 it can be seen that without the presence of the ferrites the amplitude of the magnetic induction is lower on both sides of the plate.

![Image](image.png)

**Figure 5** Mapping magnetic field lines

In the figure 5 the lines of the magnetic field pass easily through the plate for 50 Hz without large dispersion. On the other hand, the higher the frequency, the more the lines of the field concentrate under the plate and close more quickly to the surface of the latter. The increase in frequency affects not only the amplitude of the field on the plate but also the mapping.

5. **Experimental confirmation**

Throughout the experiments, the electric current flowing in the coil remained constant and equal to 0.5 A. The amplitude of the magnetic induction was measured with and without the presence of the plate. The figure (6) contains the values of yields, experimentally measured and theoretically taken from the COMSOL model.
6. Conclusion

The approximate Schelkunoff model applied to our system indicates the need for working at low frequencies. The resolution per finite elements under the COMSOL environment gives us the yields for several frequencies. The obtained experimental results confirmed the model and the finite element resolution.

The values of the obtained yields encouraged us to study in detail the transfer of power by induction through a metal plate in another work.

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