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Validation of a 3D decoupled magnetodynamic –electric model by determining the impedance of microcoils

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Abstract ***– This paper presents a model for calculating a posteriori electric field in non conducting regions in steady state AC magnetic application. The computation method used is the finite elements method in 3 dimensions. The approach is validated by calculating the equivalent impedance of a coil on which the resolution of the full Maxwell's equations can be performed.***

Introduction

The steady state AC magnetic problems allow considering inductive and resistive effects of devices studied, such as coils or transformers. Under certain conditions, the capacitive effects can be ignored. These effects are not negligible in other conditions, particularly for microcoils in high frequency, of the order of magnitude of 1 MHz.

A general solution is to solve the full Maxwell's equations (MC), by using AV formulation that gives the magnetic and electric fields at every point of space. This solution, if it does not present particular difficulties for implementation, has two drawbacks however: on the one hand it leads to very large problems; on the other hand it can lead to poor conditioned problems related to the relative order of magnitude of terms of permittivity and conductivity.

Another possibility is to follow the approach described in [1] and [2], which consist in performing two successive resolutions. This is a decoupled model that we call MH3DE. Our work consists in validating this model and trying to find its application limits by taking the general model - full Maxwell model (MC) – as reference. All the developments have been made with the Flux ® software.

Decoupled model approach

The decoupled MH3DE model consists of two successive resolutions: Steady state AC magnetic resolution and then computation of electric field in non conducting regions by solving the equation div D = 0. For the 1st resolution, we use electromagnetic field formulations of type $T_0\phi/T\phi$ [3], often preferred for reduced computational time compared to AV type formulations. They allow in particular to easily take into account the surface impedance condition. For the 2nd resolution, the AV formulation is used because it requires no current loop cut.

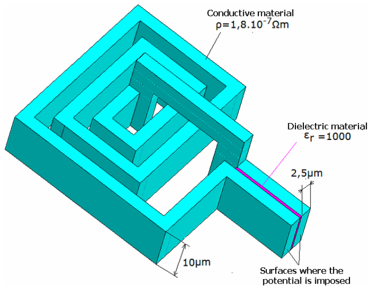
The final approach of model is: - Steady state AC magnetic resolution with $T_0\phi/T\phi$ formulations; - Calculation of A (in the whole space) and V (in conducting regions) from the solution in $T_0\phi/T\phi$; - Computation of electric field in the non conducting regions with the previous solution in AV [1], [2].

Global quantities of a coil

After the resolution with the MH3DE and MC models, the powers are calculated by the following formulas (we have split the power reactive - Q into 2 parts: Q_L - magnetic reactive power and Q_C - electric reactive power, with $Q = Q_L - Q_C$): $P = \int_{Conductor} \frac{1}{2} E.\overset{*}{J} d\Omega$; $Q_L = \int_{\Omega} \frac{1}{2} \omega.B.\overset{*}{H} d\Omega$; $Q_C = \int_{\Omega} \frac{1}{2} \omega.E.\overset{*}{D} d\Omega$

With the help of these powers, the module and the argument of the equivalent impedance of the coil are calculated by: $|Z| = \frac{|U|^2}{\sqrt{P^2+Q^2}}$, $\mathrm{Arg}(Z) = \mathrm{arctg}(\frac{Q}{P})$,

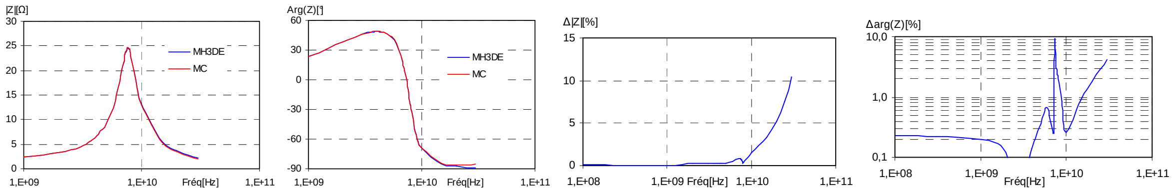
Results of validation



We have defined a coil, and calculated its impedance at different frequencies to validate the decoupled model. The calculation has been performed using two conductivities for coil (σ=1.8 $10^{-7}\Omega$m and then $\sigma=10^{-8}\Omega$m) to have different conditions on the relative importance of resistive, capacitive and inductive effects.

A. *Cas 1*

For this first case, σ=1.8 $10^{-7}\Omega$m.

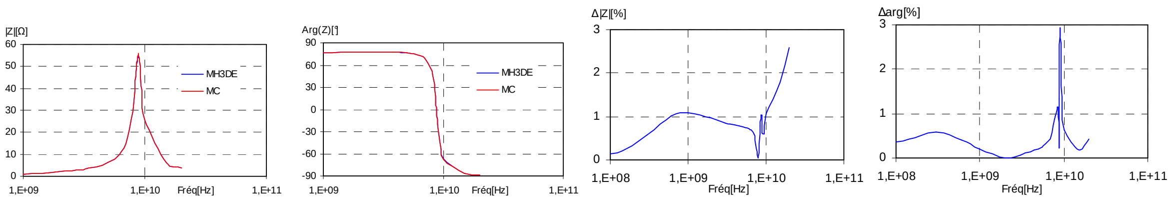


To find the limit of validity of the MH3DE model, we define a validity criterion using the ratio Q_L/Q_C as function of frequency. The higher this ratio, the more the calculation by the MH3DE model is valid.

Fréq [Hz]	Q_L/Q_C	Δ|Z| [%]	Δarg(Z) [%]
1.0 10^{10}	0.57	1.54	0.26
1.5 10^{10}	0.26	3.25	0.91
2.0 10^{10}	0.15	5.17	1.84

B. *Cas 2*

In this case, $\sigma=10^{-8}\Omega$m



As we can see on the two tables, we find that MH3DE model remains valid even if Q_L/Q_C <1. The limit validity of this model appears to be Q_L/Q_C=0.3 to obtain an accuracy of less than 2% on the impedance Z.

Fréq [Hz]	Q_L/Q_C	Δ|Z| [%]	Δarg(Z) [%]
1.0 10^{10}	0.78	1.055	0.621
1.5 10^{10}	0.36	1.795	0.177
2.0 10^{10}	0.20	2.594	0.425

Conclusion

We have validated a decoupled model for the computation of electric field in non conducting regions after steady state AC magnetic application in 3D. We found that this model is valid over a wide frequency range and especially when the ratio Q_L/Q_C > = 0.3.

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