PARASITIC CAPACITANCE CANCELLATION FOR EMI FILTERS WITH AN EMBEDDED GROUND LAYER

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***Abstract* – Planar structures are often used in the construction of different equipment due to their many advantages like reducing the magnetic profiles, lower leakage inductance, lower HF losses in the windings and improving thermal management. One of the greatest disadvantages is the presence of the equivalent parasitic capacitance (EPC) which is also present in our area of interest, EMI filters.**

In previous researches, the parasitic capacitance was reduced using various methods like increasing the width of the kapton layer, placing an air layer between the windings and shifting the windings. This paper presents the method of EPC cancellation with an embedded ground layer placed so that the electric field energy will be shifted from the unwanted space to ground. The aim of this study, besides eliminating parasitic capacitance, is to maintain the self-capacitances of the windings as close as possible to their original values. Considering the other studies and their results, two different methods of parasitic capacitance reduction are combined to determine if it is possible to have an even lower EPC.

The influence of the embedded ground layer on the whole structure is analyzed, considering the shape, position and thickness of the copper layer and modeling a multitude of structures with varying parameters. The obtained results are compared to ones determined with an energetic parameter method in order to evaluate their accuracy.

Keywords: *parasitic cancellation, embedded ground layer, parameters*

1. INTRODUCTION

The idea of how to cancel the unwanted equivalent parasitic capacitance (EPC) is based on the method used in shifting and redistributing electric field energy for line and high frequency transformers. In order to eliminate or shift structural winding capacitance, additional circuitry or components have to be added. The solution in this case is introducing an electrostatic shield to shift the stored electric field energy from the unwanted space to ground.[1]

Our goal is decreasing EPC for EMI filters. The methods for decreasing EPC were applied on an original structure shown in Figure1.[7]

In previous research the following methods were applied on this structure and an EMI filter structure:

- increasing the thickness of the insulation layer kapton2,
- replacing the insulation layer kapton 2 with an “air layer”
- using the structure with a shifted winding.[6]

Every method studied reduced EPC, but the most effective of them, that we can put into practice, is the one with the shifted winding. The “air layer” would be more effective, but it is not mechanically possible.[7]

2. METHODS AND MATERIALS

The aim of the study was to reduce the parasitic capacitance of a planar structure, also named original structure found in available literature [7]. (Figure 1)

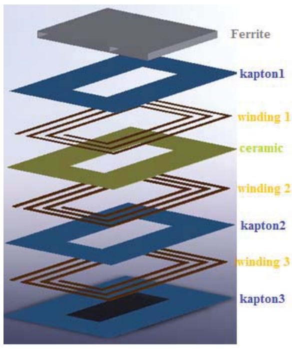


Figure 1.Detailed view of the original structure

This structure is further modeled using the software package Ansoft Maxwell 2D (Figure 2). The original structure consists of an integrated LC structure (made from a thin winding of copper, a ceramic layer, a normal winding) and an auxiliary normal copper winding. It was considered that the parasitic capacitance between windings 2 and 3 must be eliminated.

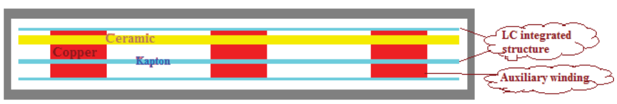


Figure 2. Model created using Ansoft Maxwell 2D to be studied

The new method considered for reducing EPC introduces an electrostatic shield in order to shift the stored electric field energy from the unwanted space to ground. In our case an embedded ground layer between two windings, if optimized, will cancel the parasitic capacitance.

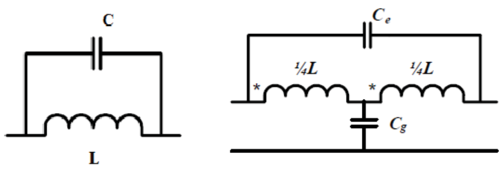
This method was also used in shifting and redistributing electric field energy in: line transformers, HF transformers and other electrical and electronic device.

For a better understanding of this phenomenon, a practical inductor is considered (Figure 2). To achieve our purpose, the inductor must become an ideal inductor, which means the parasitic winding capacitance being completely cancelled. To achieve this goal, the inductor is split into two halves and the center point is tapped. A capacitor is then connected from the center point to ground. By doing so, the mutual inductance of the two halves of the inductor is utilized to generate a second resonance, as shown in Figure 3. The distributed structural winding capacitance is represented by a lumped capacitor C_e. Performing the Y/Δ transformation, the circuit can be simplified to its π- equivalent circuit, shown in Fig. 4. The equivalent parameters are given by[2][3]:

$$Y_1 = Y_2 = \frac{1}{2} j\omega C_g \tag{1}$$

$$Y_{12} = \frac{1 + \frac{\omega^2 L C_g}{4} - \omega^2 L C_e}{j\omega L} \tag{2}$$

The parasitic winding capacitance is cancelled when Cg = 4Ce, Z12 = jωL is the impedance of an ideal inductor.[4][5]



a)A practical inductor with EPC   b)Realization of winding capacitance cancellation

Figure 3. EPC cancellation

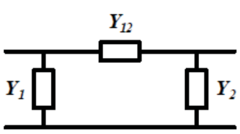


Figure 4. π- equivalent circuit of the circuit analyzed

Based on the above, the new method is applied to the original structure. To create the new capacitance needed to reduce the parasitic capacitance, an embedded ground layer with a thickness of 0.02 mm and the same length and width as the kapton layers is inserted in the middle of the kapton2 layer.

The new model created, with the copper layer, is presented in Figure 5.

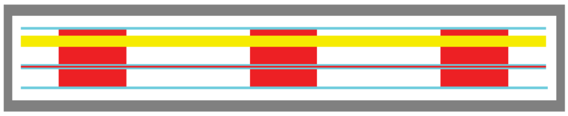
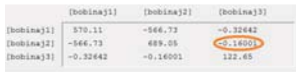


Figure 5. Model with embedded ground layer

The original structure and the structure with embedded ground layer were modeled with the software package Ansoft Maxwell 2D and the results show that introducing the embedded ground layer in the original structure reduces the parasitic capacitance between winding 2 and winding 3, almost eliminating it. But analyzing the entire capacitance matrix, the self-capacitance of winding 3 is three times greater.(Figure 6).

	[bobinaj1]	[bobinaj2]	[bobinaj3]
[bobinaj1]	569.37	-567.94	-1.4332
[bobinaj2]	-567.94	617.15	-49.214
[bobinaj3]	-1.4332	-49.214	50.647

a)original structure



	[bobinaj1]	[bobinaj2]	[bobinaj3]
[bobinaj1]	570.11	-566.73	-0.32642
[bobinaj2]	-566.73	689.05	-0.16001
[bobinaj3]	-0.32642	-0.16001	122.65

b)structure with copper layer

Figure 6.Comparison between the resultant capacitance matrices

Because the object of the study is decreasing the parasitic capacitances, but also maintaining the other parameters as close as possible to their initial values, the following analyses are justified.[8]

2.1. 2D study of the influence of the shape, position and thickness of the embedded ground layer[8]

The next step of the study presented in this paper was to determine how the thickness of the embedded layer affects the parasitic and self-capacitances. For this step, the kapton2 layer was split in two equal parts and the embedded ground layer was placed in the middle. The thickness of the copper layer was varied between 0.01-0.09 mm with a step of 0.01mm. The distance between windings 2 and 3 was maintained constant.

This indicated that the parasitic capacitance decreases with the increase of the thickness of the embedded ground layer, but the self-capacitance of the windings increases with a higher percentage, so a thinner layer is appropriate. The variation of the self- and parasitic capacitances with the increase of the copper layer thickness cam be observed in Figure 7 and 8.

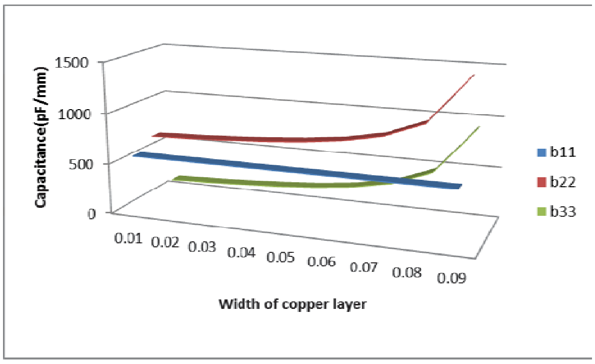
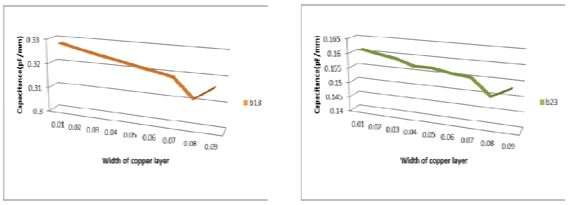


Figure 7.Self capacitance variation with the increase of the copper layer thickness

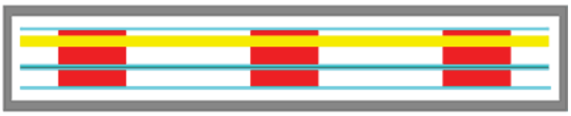


a) b)

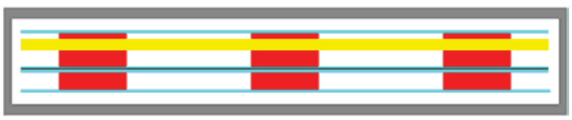
Figure 8. Parasitic capacitance variation with the increase of the copper layer thickness

The case when the copper layer was not positioned in the middle of the kapton layer, but higher or lower was also considered. The study indicated that this doesn't affect the parasitic capacitance, it affects only the self-capacitance of each winding, which increases if the embedded copper layer is closer to it or decreases if the embedded ground layer is placed further away.

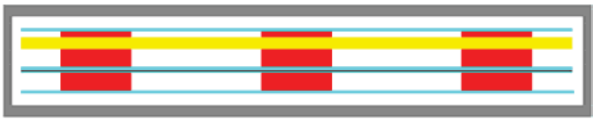
Table 1 contains the values for the self-capacitances of winding 2 (b22) and winding 3 (b33) and the parasitic capacitance between windings 2 and 3 (b23) and the conclusions above are based on these values.



a)with copper layer placed in the middle of the kapton2 layer



b) with copper layer placed higher in the kapton2 layer



c) with copper layer placed lower in the kapton2 layer

Figure 9.Influence of the position of the copper layer in the kapton2 layer

Capacitance [pF/mm] / Position of the copper layer	b22	b33	b23
in the middle	699.09	122.64	0.16005
Higher	803.47	84.437	0.16082
Lower	650.8	236.71	0.15942

Table 1. Self- and parasitic capacitances for different positions of the copper layer in the kapton 2 layer

The shape of the embedded ground layer also affects the capacitances of the structure. Seven different models with different shapes of the embedded ground layer were analyzed.

Considering the conductors numbered as shown in Figure 10, the embedded layer was placed:

- Between all the conductors, as a continuous layer (a)
- Between conductors 1 and 4, 3 and 6 (b)
- Between conductors 1 and 4, 2 and 5, as a continous layer (c)
- Between conductors 2 and 5, 3 and 6, as a continuous layer (d)
- Between conductors 2 and 5 (e)
- Between conductors 1 and 4, 2 and 5,3 and 6 in the shape of the winding (f)
- Between conductors 1 and 4, 2 and 5, 3 and 6, in the shape of the winding with a width of 1.4mm (g)

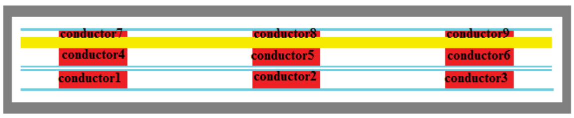


Figure 10. Explanatory figure for the study

The results show that the best models when it comes to reducing EPC are the last two (f), (g) and the one with a complete embedded ground layer positioned on the entire surface of the kapton layer (a). The graphics presenting the fluctuations of the self-capacitance and the parasitic capacitance in the 7 cases mentioned before (Figure 11, Figure 12). The conductors from Figure 10 are grouped into 3 windings.

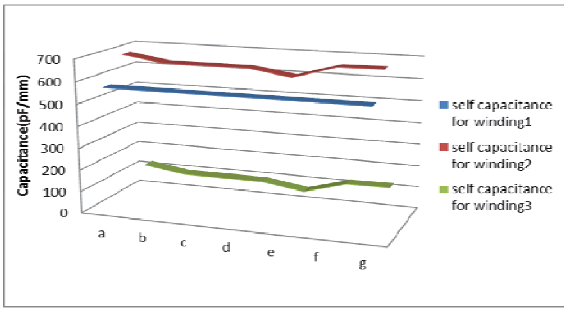


Figure 11.Variation of self-capacitance with various shapes of the embedded ground layer

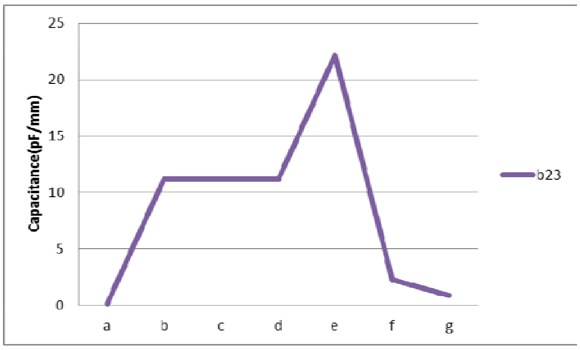


Figure 12.Variation of the parasitic capacitance between windings 2 and 3 with various shapes of the embedded ground layer

2.2. Combining two methods of EPC reduction

In previous studies it was proven that the most effective way to reduce EPC is shifting winding 3 in the original structure. The authors considered using this method and also inserting the embedded ground layer in the structure.

In order to study the influence of the shifted winding, new models were constructed with the help of Ansoft Maxwell 2D for the initial structure (Figure 13a) and for the structure with shifted winding (Figure 13b). In the new models constructed the embedded ground layer was introduced (Figure 13c, 13d) and the results were compared.

	[BOBINAJ1]	[BOBINAJ2]	[BOBINAJ3]
[BOBINAJ1]	572.64	-571.21	-1.4286
[BOBINAJ2]	-571.21	620.84	-49.624
[BOBINAJ3]	-1.4286	-49.624	51.053

	[bobinaj1]	[bobinaj2]	[bobinaj3]
[bobinaj1]	571.34	-568.67	-2.6674
[bobinaj2]	-568.67	574.24	-5.5682
[bobinaj3]	-2.6674	-5.5682	8.2356

a)original structure b)shifted winding structure

	[bobinaj1]	[bobinaj2]	[bobinaj3]
[bobinaj1]	571.44	-567.54	-0.21708
[bobinaj2]	-567.54	691.04	-0.11223
[bobinaj3]	-0.21708	-0.11223	122.92

	[bobinaj1]	[bobinaj2]	[bobinaj3]
[bobinaj1]	571.54	-567.65	-0.19154
[bobinaj2]	-567.65	691.06	-0.10266
[bobinaj3]	-0.19154	-0.10266	122.97

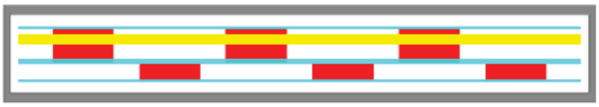
c)embedded layer structure d)shifted winding and embedded layer

Figure 13. Comparison between structures with and without the methods of EPC cancellation

When the embedded ground layer is introduced (Figure 13c), the self-capacitance of the windings increases to approximately three times the initial value. If the winding is also shifted (Figure 13d), the self-capacitance and EPC decrease, but the self-capacitance is much higher in value when compared to the original structure where only the shifted winding was used to reduce EPC (Figure 13b).

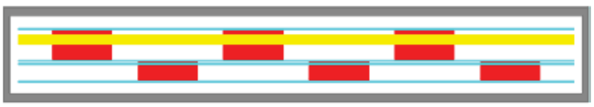
Other ways to shift the winding when the embedded ground layer is as large as the kapton layer do not help.

The next step is to change the shape of the embedded ground layer. The cases when the embedded ground layer is in the shape of the windings and aligned with winding 2 (Figure 14) or aligned with winding 3 (Figure 15) were analyzed.



	[bobinaj1]	[bobinaj2]	[bobinaj3]
[bobinaj1]	570.92	-567.91	-2.5498
[bobinaj2]	-567.91	687.71	-2.9396
[bobinaj3]	-2.5498	-2.9396	7.9886

Figure 14.Embedded ground layer and shifted winding2



	[bobinaj1]	[bobinaj2]	[bobinaj3]
[bobinaj1]	571.05	-568.24	-0.58101
[bobinaj2]	-568.24	573.8	-2.7582
[bobinaj3]	-0.58101	-2.7582	120.2

Figure 15. Embedded ground layer and shifted winding 3

As a conclusion, the most efficient solution is aligning the embedded ground layer with the upper winding where the self-capacitances are similar with the initial values, and the EPC is reduced. Although, if we only consider the parasitic capacitance, the model with the embedded layer aligned with the lower winding is more effective. Because of this, the next case is studied, where the width of the copper layer is greater and is aligned with the upper winding. The results are improved, but are not yet optimal. This subject will be presented in the next subchapter.

2.3. EPC analysis with the help of energetic parameters for various structures

The method of EPC analysis with energetic parameters is based on the fact that EPC reduction is coupled with the reduction of electrostatic energy (W_E) of the structure, so EPC reduction is directly proportional with the reduction of W_E.

The image in Figure 16 represents the distribution of potential through the winding.

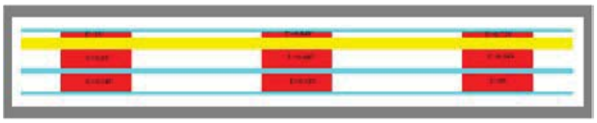


Figure 16. Distribution of potential through the winding.

The models considered in the energetic analysis are listed below and in brackets is the name of the case it presents in Tab. 2.

- original structure (A)
- structure with embedded ground layer from Figure 5 (B)
- structure with embedded ground layer between conductors 1 and 4, 2 and 5, 3 and 6 (C)
- structure with embedded ground layer between conductors 1 and 4, 2 and 5, 3 and 6 but with the length of 1.4mm (D)
- structure from Figure 15 (E)
- structure with embedded ground layer between conductors 2 and 5 (F)
- structure with embedded ground layer between conductors 1 and 4, 2 and 5 (G)
- structure from Figure 17. a) (H)
- structure from Figure 17 b) (I)
- structure from Figure17.c) (J)

As it was previously mentioned, in the case where the embedded ground layer and shifted winding are present in the same structure, the width of the embedded ground layer was varied in different ways. In Figure 17 some of the constructions taken into account are presented.

The value of parasitic capacitance was calculated based on the reduction of electrostatic energy using the post process option of the software package Ansoft Maxwell 2D.

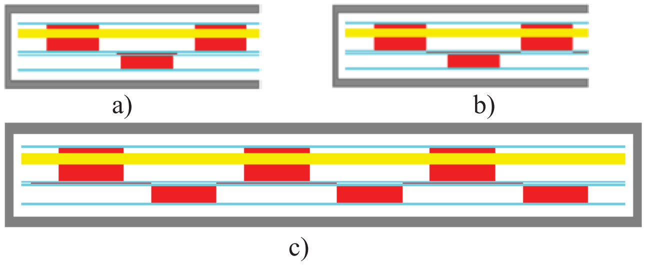


Figure 17. Different positioning of the embedded ground layer

Case	$2W_E$ Total	$2\ W_E$ Ceramic	parasitic capacitance $*10^{12}$
A	2203.487	2015.625	187.862
B	2033.188	2014.883	18.305
C	2048.5746	2015.071	33.5036
D	2061.1582	2016.668	44.49027
E	2048.0107	2014.861	33.1497
F	2111.66	2014.797	96.863
G	2071.9888	2014.596	57.3933
H	2043.146	2014.251	28.895
I	2037.311	2015.585	21.7264
J	2058.644	2017.928	40.716

Table 2. Parasitic capacitance calculated with the energetic method

The results show that the model with a total embedded layer, the one with the same width as the kapton layer, is the best, but because the self-capacitance is highly increased, additional models considered. It can be seen that the models in case I) are better because only the parasitic capacitance is considered in the study with energetic parameters.

3. CONCLUSIONS

The method of reducing EPC with an embedded ground layer is efficient. The shape and size of the embedded layer affects the parasitic and self-capacitance of the structure. A thinner and winding-shaped embedded ground layer gives the most effective EPC reduction when trying to maintain the self-capacitances as close as possible to their original values.

Combined use of an embedded ground layer with the shifted winding results in the cancellation of the parasitic capacitance but it also increases the self-capacitances, so a proper shape for the embedded layer is necessary. The conclusion is that if we consider an embedded ground layer that does not have the shape of the kapton layer, the better solution is aligning the embedded ground layer with the upper winding where the self-capacitances are similar with the initial values, and EPC is reduced. If considering only the parasitic capacitance, the model with the embedded layer aligned with the lower winding is better, but in both cases the parasitic capacitance is highly decreased.

The next step would be optimizing the shape, size and positioning of the embedded ground layer and see how the other parameters of interest vary.

Acknowledgments

This paper was supported by the project "Doctoral studies in engineering sciences for developing the knowledge based society-SIDOC" contract no. POSDRU/88/1.5/S/60078, project co-funded from European Social Fund through Sectorial Operational Program Human Resources 2007-2013.

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