Planar Transformers Improvement in the Conducted Emissions Frequency Range

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***Abstract*—The planar transformer offers many benefits over the traditional transformer in size, weight, thermal management, and manufacturing. But as any other planar device, planar transformers have issues that must be fixed as high parasitic capacitance values between the primary and secondary windings and high high frequency losses. This paper tries to determine the way in which different parameters influence these two aspects and the most efficient values for them considering the dielectric used and its dimensions, the way the primary and secondary winding are placed and the core dimensions which influence their window utilization.**

***Keywords*—conducted emissions range; planar transformer; losses; parasitic capacitance**

I. Introduction

Planar structures are used in the last few years due to their many advantages like repeatability of the components, the reduction of the total conductor area and the fact that using the LC structures in their construction makes inserting of such structures possible in almost any dimension and volume. They also have low profile, efficient cooling, dimensional precision and reduced electromagnetic interferences. The disadvantages are the capacitive coupling between the primary and secondary which must be reduced and the losses in the structure which must be also decreased [1]. A representation of such a transformer can be seen in Fig. 1 and Fig. 2.

Planar transformers are highly used in our days due to their many applications in medical apparatus, hybrid vehicles, electric vehicles, telecom applications, power supplies, battery charging and others. This study focuses on the improvement of such planar structures in the frequency range of the conducted emissions namely 100 kHz- 30 MHz, although these planar transformers can be constructed also to be functional in many other frequency ranges.

In order to determine the means by which the parasitic capacitance and the high frequency losses can be decreased, the structure of the planar transformer was determined for the input parameters presented below and it was constructed with a numerical modeling program of the electromagnetic field, namely Ansoft Maxwell 3D [10].

As a planar structure, the planar transformers are constructed from copper winding layers which represent the primary and secondary windings separated by a dielectric layer, which initially is considered to be FR4 Epoxy.

Considering the input voltage of 230 V and the output voltage of 12 V, and using the formulas given by [2], the number of turns for the primary and secondary windings were determined. Also the core geometry for such a planar transformer was determined considering the application's power, the ambient temperature and the operating efficiency needed to be reached. This step was considered to be the electrical design of the planar transformer.

The second step was the mechanical design where, considering the core window, the dimensions for the primary and secondary layers were determined. The width of the dielectric substrate on which the windings are placed is also calculated at this stage.

The primary and secondary are constructed as it can be observed in Fig. 3 [3], [4], [5].

The whole structure of the planar transformer is then constructed with the help of a numerical modeling program of the electromagnetic field.

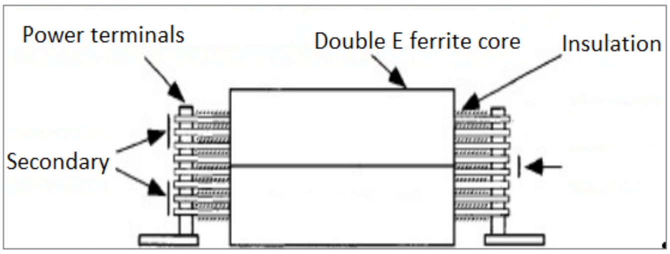


Fig. 1. Lateral view of a planar transformer.

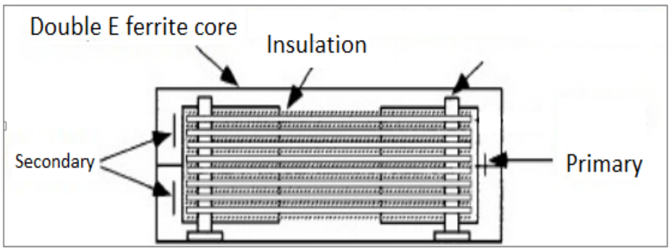
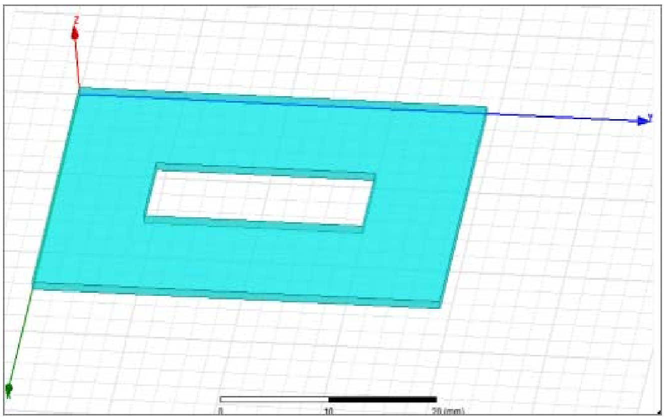
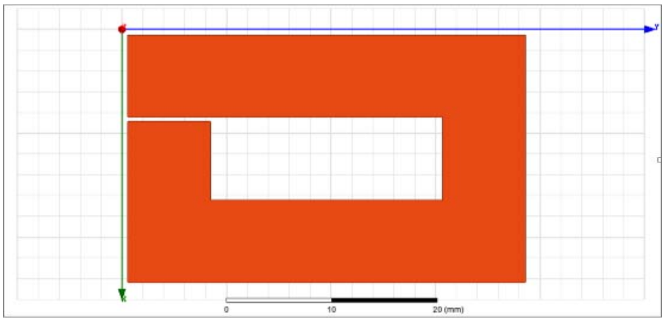


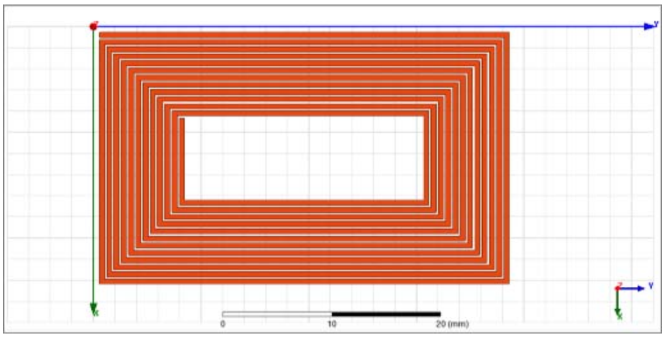
Fig. 2. Frontal view of a planar transformer.



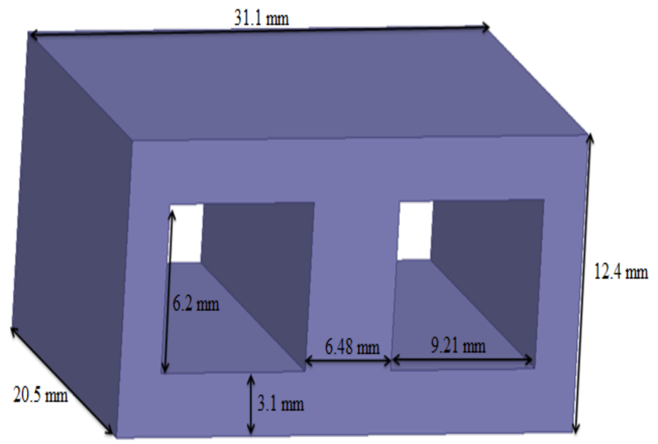
a)Dielectric construction



b)Primary winding construction



c)Secondary winding construction



d)Initial geometry for the ferrite core

Fig. 3. 3D components construction for a planar transformer.

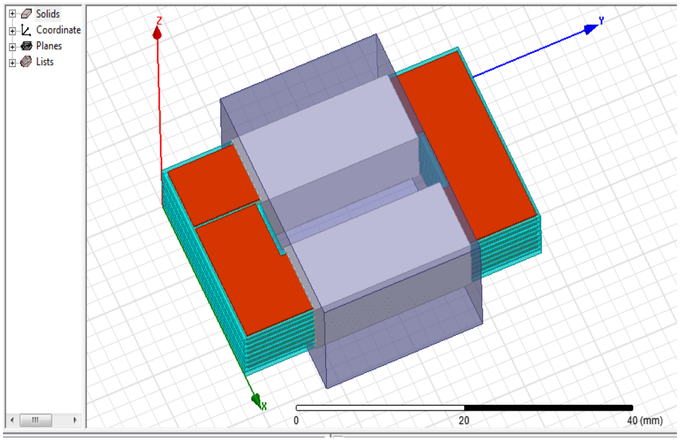


Fig. 4. 3D representation of the planar transformer.

II. Determination of the Parameters Influence on the Parasitic Capacitances and HF Losses

In this paper, the influence of the thickness of the dielectric layer, the type of material used as dielectric and the core used for this device are considered for the planar transformer improvement.

The study from the parasitic capacitance point of view will consider the values of parasitic capacitances between different layers from the planar transformer. In order to better understand, the numbering of these layers is explained in Fig. 5 where a half of the transversal section of the constructed planar transformer is presented.

The primary and secondary windings are considered to be interleaved because in previous researches it was determined that the interleaving decreases the losses from the structure [6].

A. *Dielectric material influence*

In order to determine the influence of the dielectric material on the parasitic capacitances values a large range of dielectric materials is considered [8][9][12].

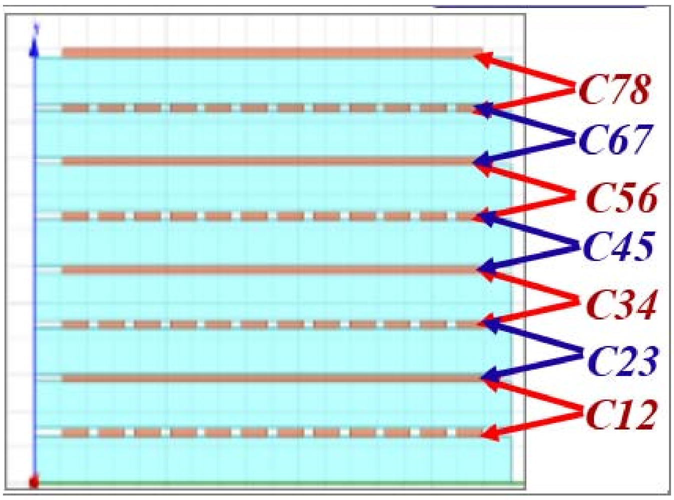


Fig. 5. 2D representation of half of the transversal section of the planar transformer with the numbering of the considered layers.

After researching the market, it was determined that the dielectric materials are of two types: woven glass reinforced laminates and nonwoven glass reinforced laminates. Woven glass reinforced laminates are lower in cost than non-oven laminates and are cheaper to produce and process.

Six woven glass materials were considered for the study, with relative permittivity values between 2.2 and 4.4. The materials were FR4 Epoxy, Multifunctional FR4, Tetrafunctional FR4, Nelco N4000-13, Getek, Cyanate easter, Teflon. For the nonwoven materials four different materials were considered and represented in Fig. 7.

The considered structure for this study was the initial structure presented in Fig. 4 with the dielectric thickness of 0.55 mm. The parasitic capacitance values differ a lot from the woven glass reinforced laminates to the nonwoven reinforced laminates, the difference being of approximately 50%. This is the reason for which the results are represented on two different graphs in order to better analyze them. The results can be observed in Fig. 6 and 7.

The conclusions are that the woven reinforced laminates are the better solution for the construction of the planar structures analyzed because of their lower costs and due to the fact that the structures where they are used have smaller parasitic capacitances.

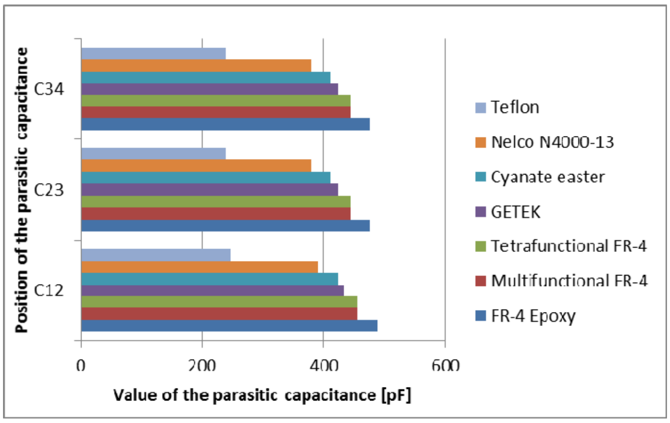


Fig. 6. Parasitic capacitances values for the woven glass reinforced materials.

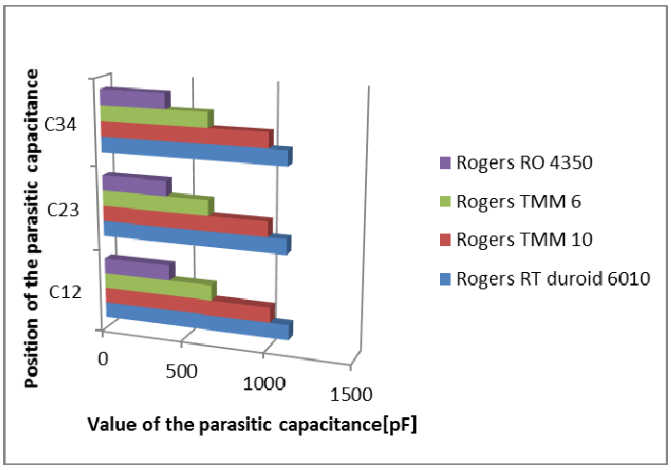


Fig. 7. Parasitic capacitances values for the non-woven glass reinforced materials.

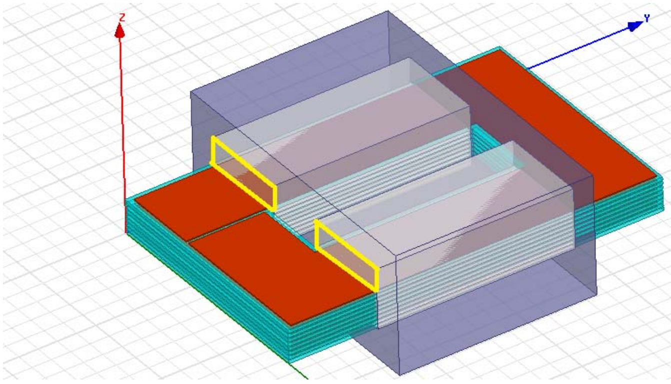
In the study presented, the losses for the structures with different dielectric materials was also considered. It was discovered that the type of dielectric used does not influence the losses from the structure.

B. Dielectric thickness influence

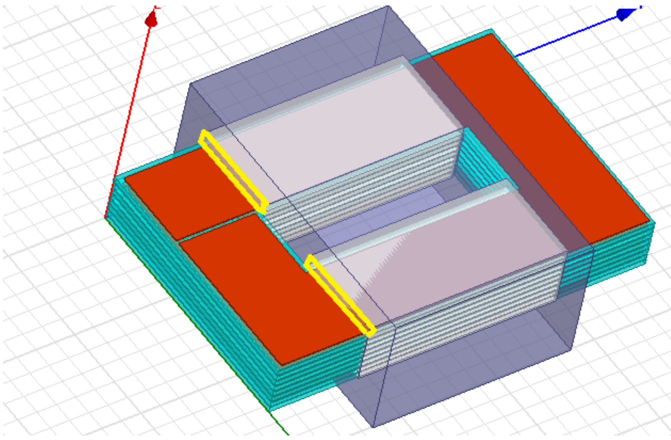
Considering the fact that in the previous section it was determined that the better structures are constructed using the woven glass reinforced laminates, the study aiming at determining the dielectric thickness influence was based on the initial structure having as dielectric FR4 Epoxy, a woven glass reinforced laminate. The mechanical possibility of constructing such a structure must be also taken into account, considering the small window of such a planar structure.

There were four studied structures, with the thickness of the dielectric varying between 0.35 mm and 0.65 mm. Two of them, with the free space of the window highlighted, are presented in Fig. 8.

After analyzing the parasitic capacitances values, it can be stated that the parasitic capacitances values decreases with the increase of the dielectric substrate vales. The results can also be observed in Fig. 9. Also the values are not influenced by the position of the windings inside the ferrite core, so only the parasitic capacitances values for three of the winding layers are represented.



a)



b)

Fig. 8. 3D structures with dielectric thickness of a)0.35 mm and b)0.55 mm.

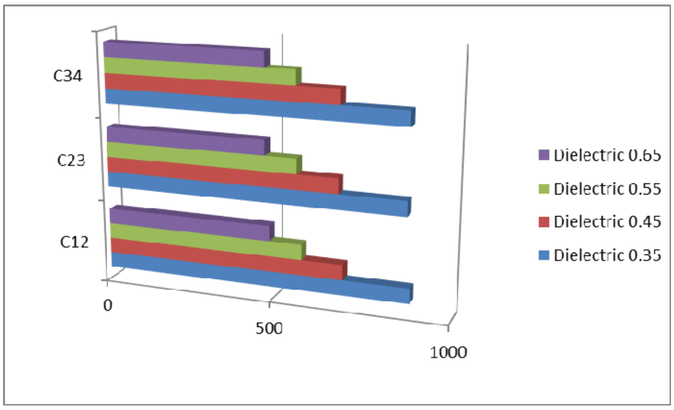


Fig. 9. Variation of the parasitic capacitances values with the diectric width.

From the HF losses point of view, it can be stated that the thickness of the dielectric influences the losses in the conductors [6], [7].

The study was conducted only for a structure in 2D with four windings, 2 primary and 2 secondary, because of the repeatability of the results. As it can be seen in Fig. 10, the value of the losses for the winding layers increases with the decrease of the thickness of the dielectric. Also it was determined for this frequency range that the losses for the windings are the same weather the windings are primary or secondary.

C. Ferrite core influence

In the mechanical design process is was determined that for this structure an EE ferrite core will be used. After consulting the products catalogues from the market, three types of cores were considered, namely EE26, EE33, EE33A along with the initial one, EE34 [11].

All this core types have similar geometries and dimensions in order to better understand their influence on the parasitic capacitances values. Also, between the EE33 and the EE33A structure only one dimension differs, namely the height of the core. The structures for EE26 and EE33 are presented in Fig.11 and Fig. 12.

It can be seen that the position and shape of the core influences the parasitic capacitances, so the value of the capacitances is higher when the windings are closer to the core as it can be seen in the case of the parasitic capacitance C12.

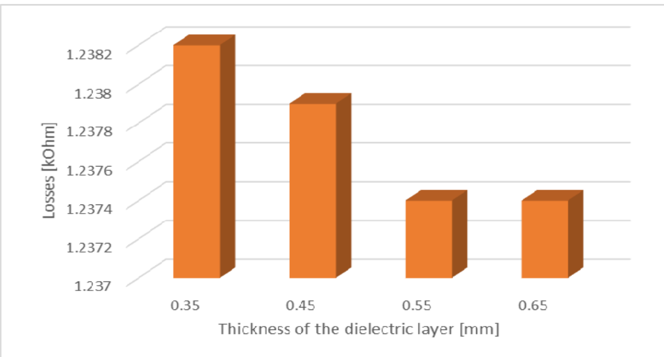


Fig. 10. Variation of the lossesvalues with the diectric width.

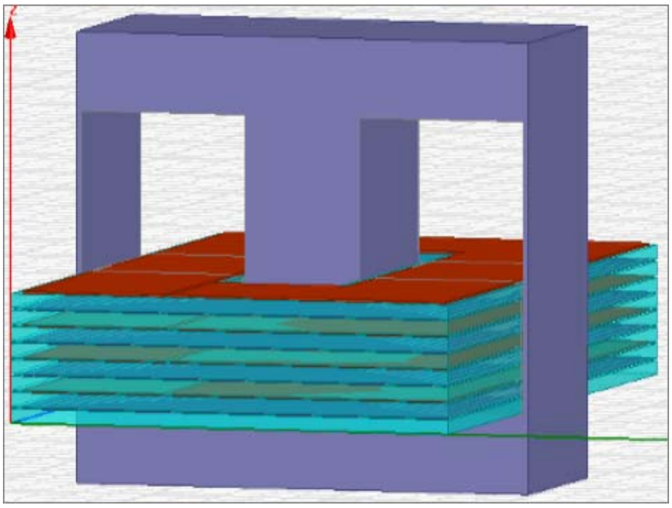


Fig. 11. Structure embedded in a EE26 ferrite core.

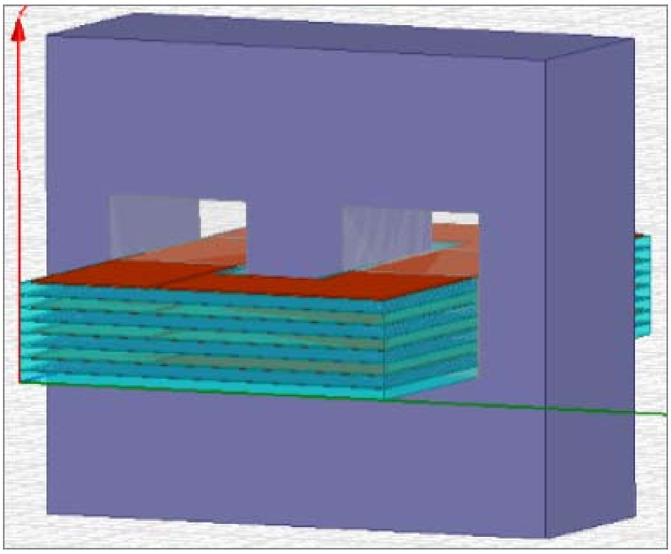


Fig. 12. Structure embedded in a EE33 ferrite core.

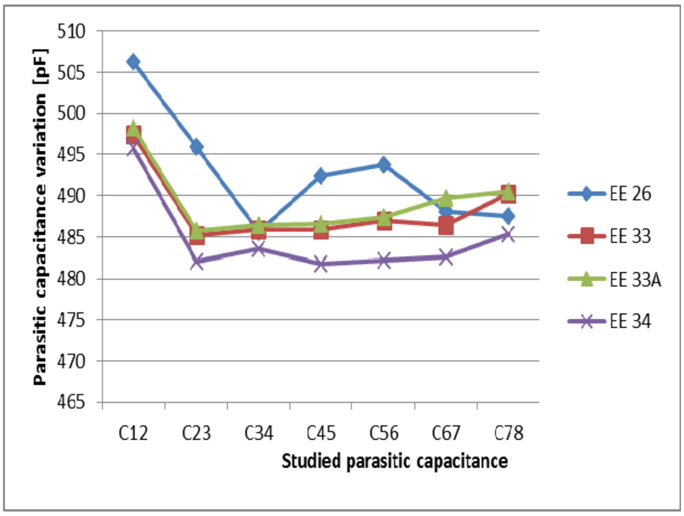


Fig. 13. Variation of the parasitic capacitance with the geometry of the ferrite core.

The thickness of the ferrite core also influences the values of the parasitic and self-capacitance from the structure.

Also, considering all the analyzed structures, it can be observed in Fig. 13 that the best solution regarding the ferrite core used is the initial one.

Although it is barely noticed, there is a difference also between the parasitic capacitances values for the ferrite cores EE33 and EE33A although there is only a small difference between them.

The study from the HF losses point of view for different cores of the planar transformer is still to be made.

III. CONCLUSIONS

The constructed structure is one of a planar transformer with the input voltage of 230 V and the output voltage of 12 V. The structure was modeled with a numerical modeling program of the electromagnetic field, namely Ansoft Maxwell.

Some of the construction parameters were varied in order to determine their influence on the parasitic capacitances and high frequency losses values. Also, the primary and secondary windings were interleaved from the beginning in order to decrease the structure's losses.

For this study two types of dielectric materials were considered, namely woven glass reinforced laminates and non-woven glass reinforced laminates. It was observed after modeling the resulting structures that the ones constructed with woven glass reinforced laminates have smaller parasitic capacitances. Also, the fact that the price of these materials is smaller than the price for the other type materials, leads to the conclusion that this type of materials is suited for the planar transformer point of view. Also, the fact that the type of dielectric used does not influence the losses from the structure makes us suggest it even more for the structure's construction.

If the dielectric thickness is varied, it was determined that the parasitic capacitances values decreases with the increase of the dielectric thickness. Also the fact that the value of the losses for the winding layers increases with the decrease of the thickness of the dielectric thickness was observed. It was also determined for this frequency range that the losses for the windings are the same weather the windings are primary or secondary. Considering both results, it can be concluded that a thicker dielectric layer is better to be used in the construction of planar transformers. The designer must also keep into account the fact that the window of the planar transformer is small and the construction must be mechanically possible.

For this study the EE type core was considered, with four different geometries: EE26, EE33, EE33A, EE 34.

It can be seen that the position and shape of the core influences the parasitic capacitances, so the value of the capacitances is higher when the windings are closer to the core.

The thickness of the ferrite core also influences the values of the parasitic and self-capacitance from the structure.

As a final conclusion, the initial ferrite core considered is the best solution for the studied structure.

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