STUDY OF LC INTEGRATED STRUCTURES IN SERIES RESONATOR CONFIGURATION

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REZUMAT. În ultimii ani, tehnologia magnetică planară a devenit de interes major pentru cercetătorii din domeniul proiectării surselor de alimentare cu comutație în înaltă frecvență. Utilizarea frecvenței înalte duce la reducerea dimensiunilor componentelor pasive, ceea ce face ca elementele discrete folosite până în prezent să fie înlocuite de structuri planare . Această lucrare pune în evidență răspunsul în frecvență al structurilor integrate LC, folosind modelului liniilor de transmisie.

Cuvinte cheie: structură LC planară, frecvența, rezonator serie

ABSTRACT. In the last few years, magnetic planar technology has become of great interest for the researchers in the switching mode power supply design at high frequency. Working at high frequency leads to size reduction of passive components, which results in replacing the discrete elements used so far with planar structures. This paper outlines the frequency response of the integrated LC structures, using the transmission line model.

Keywords: LC planar structure, frequency, series resonator

1. INTRODUCTION

In the last 30 years, the electromagnetic modeling of passive components was developed using lumped and also distributed models. In order to understand how these components function, simplified models were created, in order to optimize their design.

A selected hierarchy of electromagnetically integrated structures is presented in Figure 1. The structures are divided into two categories: planar and non-planar structures. Planar structures, the ones that we refer to in this paper, are considered to be constructed from a number of thin layers stacked to form hybrid integrated structures.

The planar integrated structures have numerous advantages. These structures are equivalent to a number of discrete components, but they dont have the same number of conection nodes as them. Their repetability offers the posibility of mass production. Also, reducing the total area of the conductor leads to decreased losses. As a main advantage, the dimensions and volume of the structures are reduced. [1]

The planar structures can have simple and complex geometries. Simple geometries are normally considered to have two conductors with symmetrical current distribution in equal but opposite direction, such as transmission-lines, or multiple conductors and a ground plane, such as micro-strip application.[1]

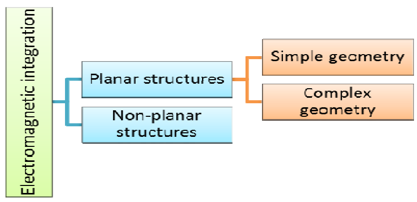
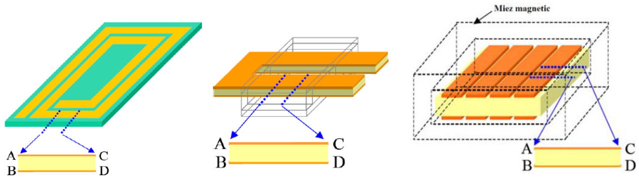


Fig. 1. Classification of electromagnetic integration.

The base for the simple planar structures is the LC cell, so this cell will be analyzed first for a better understanding of integrated LC structures.

2. PREVIOUS WORK ON MODELING OF THE LC STRUCTURE INTEGRATED PASSIVES

The LC cell consists of a dielectric substrate with both sides metalized, with or without a surrounding magnetic core. The traditional model to be analyzed has four terminals A, B, C and D as it can be seen in Fig 2. [2]



(a) **(b)** **(c)**

Fig. 2. Identifying the LC cell as a general functional block for a spiral winding.

Over time, different methods for modeling LC integrated structures have been used, but this study is based on a distributed parameters model proposed by Zhao. Based on his model, Zhao calculated the impedance between terminals A and D of a planar LC cell. [2][3]. Considering different interconnections at the input and output terminals, it was discovered that the LC structure has different characteristics from the frequency point of view for each and every case. In this paper, the frequency response for a planar LC structure in series resonator configuration is presented.(Figure 3)

Fig. 3. Planar integrated LC cell with series resonator configuration

For this configuration, Z_{AD} was calculated and the graphs for the amplitude and phase for a frequency range between 100 kHz – 10 MHz were represented. The results are consistent with results obtained in practice.[3]

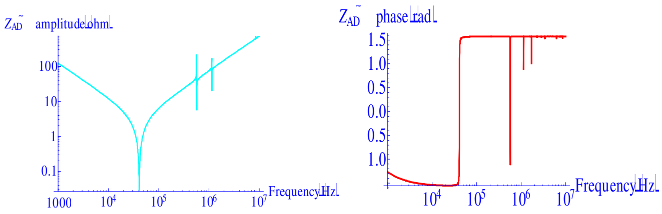


Fig. 4. Z_{AD} for a series resonator configuration of an LC cell.

3. INFLUENCE OF THE LC INTEGRATED STRUCTURE'S PARAMETERS

The next step is to determine how the structure's frequency response is influenced by the LC cell's parameters.The authors varied the width of the LC cell, thickness of the dielectric substrate and thickness of the copper that covers the dielectric's surfaces.

The lenght of an LC cell is considered to be 5 mm. Because a precise configuration of the LC cell is not available in the scientific literature, in this study it is considered to be constructed from a kapton layer with 0.1 mm thickness with the surfaces metalized with 0.3 mm copper layers.

The impedance for the LC cell is calculated with the formula:

$$Z_{AD} \cong \frac{j\omega(L+M)}{2} l - j\frac{1}{\omega C \cdot l} \qquad (1)$$

Every structure's characteristic values considered in this study are calculated with a 2D numerical modeling program and are then inserted into a computational software. From the simulation with the 2D numerical modeling program, the values for a one meter long structure are calculated. The results are then processed with the computational software to determine the influence of different parameters on the frequency response. It should be noted that the results presented in this paper are the frequency responses of a LC structure with series resonator configuration.

For the first study, the width of the LC cell is varied between 0.4 mm-2 mm, while the other parameters are maintained constant. The values obtained from the 2D simulation are inserted in the computational software where the Z_{AD} value for a series resonator is calculated. The influence of the width of the LC cell is presented in Figure 5.

As it can be seen, the fundamental resonant frequency appears at smaller values of the analyzed frequency range when the LC cell is wider. As the frequency increases, multiple resonances appear.

The amplitude and the phase of Z_{AD} when the dielectric thickness is varied between 0.03 mm -0.2 mm is presented in Figure 6. The dielectric considered for this study is kapton, with a relative permittivity of 3.6.

Figure 7 also represents the frequency response graphs for Z_{AD}, but as a result of the variation of the copper layer's thickness. Maintaining the other parameters constant as in the other cases studied, the copper thickness for the two conductors is varied from 0.005 mm to 0.3 mm.

It can be observed that when the thickness of the dielectric is varied, the fundamental resonant frequency is found at higher values as the thickness of kapton layer increases. The multiple resonances following are present at higher frequency values as the kapton thickness increases, but the shape of the entire graph tends to remain the same.

When the graphs for Z_{AD} were created, considering the variation of the copper layer's thickness, the frequency response of the LC cell did not significantly modify. Only if we consider the multiple resonances, their position may differ in the frequency range considered.

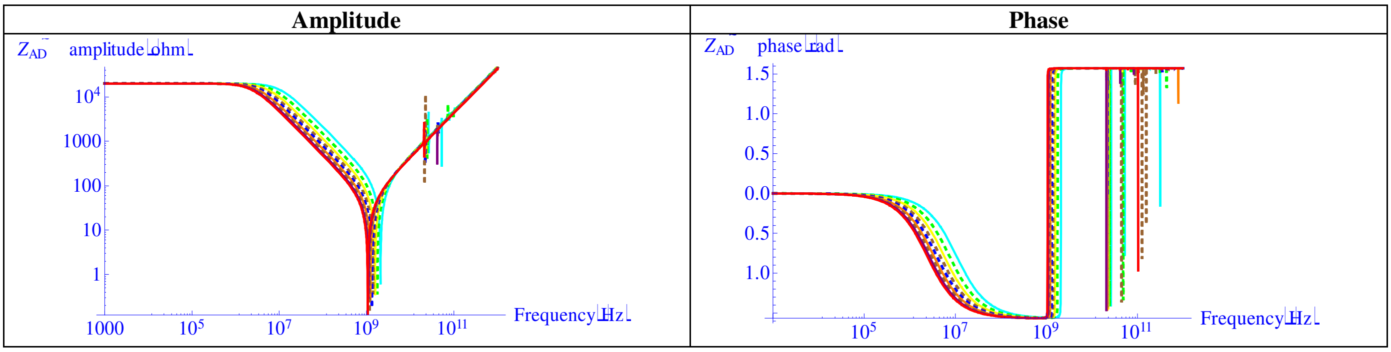


Fig. 5. Z_{AD} with the variation of the LC cell's width (length=0.005m).

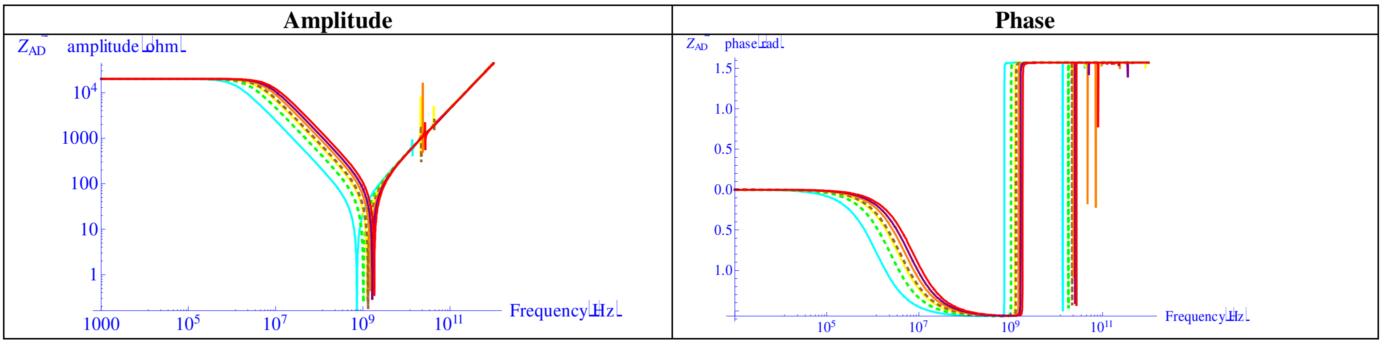


Fig. 6. Z_{AD} with the variation of the LC cell's dielectric thickness .

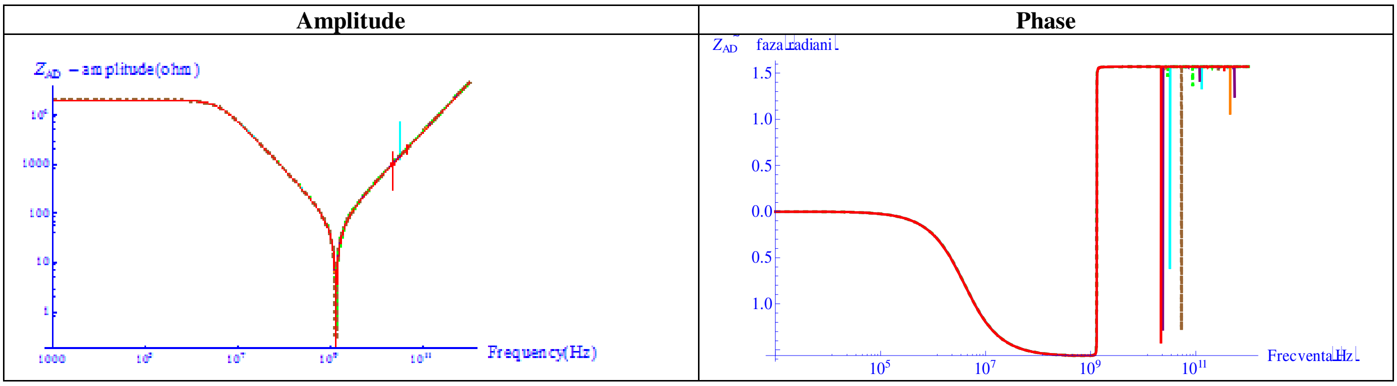


Fig. 7. Z_{AD} with the variation of the LC cell's copper thickness .

Considering the length of the LC cell as it was presented in the special literature [2], 0.25 mm, another set of graphs were represented. The conclusions are the same as for the graphs above, with the difference that the fundamental resonant frequency is found at lower frequencies as the LC cell is considered to be longer. For example, in Figure 8 the graphs for Z_{AD} when the width of the LC cell is varied are represented for the 0.25 m structure. As it can be seen, the fundamental resonant frequency is found at 10 MHz for the 0.25 m LC structure and at 1GHz for the 0.005 m LC structure.

The next step in this study was modelling an LC linear structure , like the one presented in Figure 9, as a cascaded structure, with a number of LC cells connected. The thickness of the dielectric is considered to be 0.1 mm, and the copper layers are 0.3mm thick. The width of the structure is 1.2 mm.

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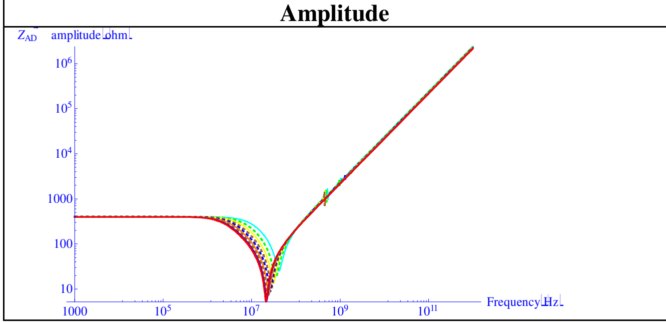
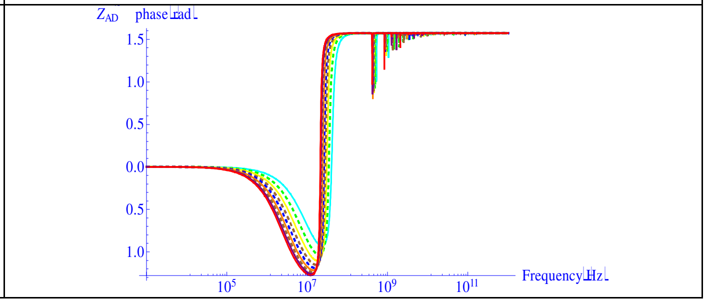
Amplitude	Phase
	

Fig. 8. Z_{AD} with the variation of the LC cell's width (length=0.25m) .

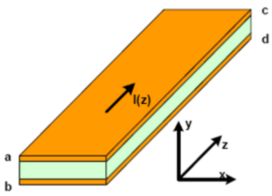


Fig. 9. Linear LC structure.

The impedance Z_{AD} can be calculated with the formula:

$$Z_{AD}=\frac{V_{AD}}{I}=\left(\sum_{i=1}^{n}\frac{R_i+j\omega(L_i+M_i)}{2}l_i\right)+\sum_{i=1}^{n}\frac{1}{2I}\left[V_{ai}(1-e^{-\gamma_i l_i})+V_{bi}(1-e^{\gamma_i l_i})\right]+\frac{2V_{bn}}{I}e^{\gamma_n l_n}-\frac{Z_{0n}}{2} \quad (2)$$

The first concern of the authors was how the length of the LC structure is affecting the frequency response if we consider it as a number of LC cells connected in cascade. In Figure 10 the frequency response for 2 and 3 connected LC cells is presented to be compared. The LC cells are considered to have a length of 0.25 mm.

Comparing the results, it was discovered that the fundamental resonant frequency is found at lower frequencies as the number of LC cells increases.The same thing was observed when the LC cell was considered longer in the previous study.

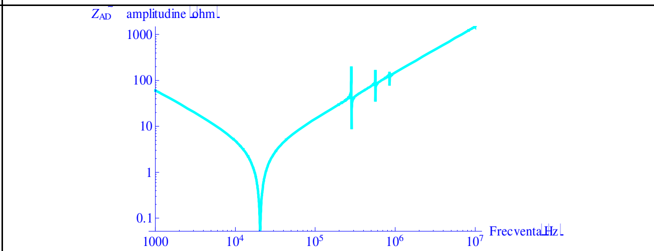
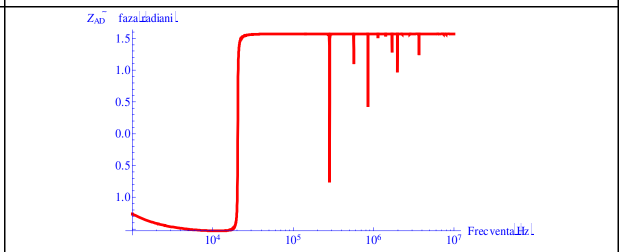
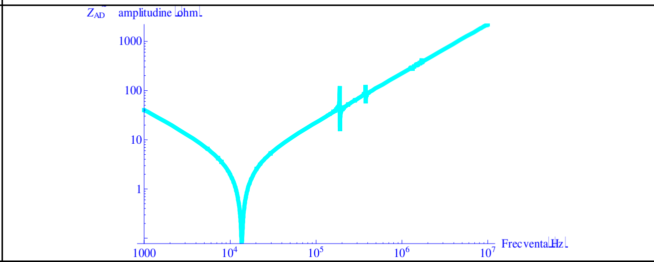
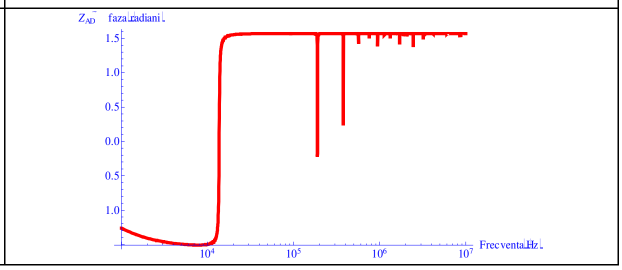
Number of LC cells	Amplitude	Phase
2 LC cells		
3 LC cells		

Fig. 10. The frequency response for cascaded LC cells.

Because available literature does not specify an LC cell length, different ways to split a linear LC structure into LC cells were considered. It was observed that the frequency response for a linear structure considered to be an LC cell with the length of 0.75 m is the same as for a linear LC structure considered to be created from three LC cells, each having a length of 0.25 m.

The importance of dividing the linear structures into LC cells can be noticed when the LC structures pass through a ferrite core, as in Figure 11. The parameters of the area embedded in the core change, the inductance increasing by an order of magnitude.

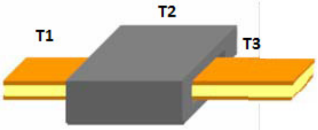


Fig. 11. Linear LC structure considered as 3 cascaded LC cells.

The graph for a linear structure with the length of 49.6 mm was constructed, considering the middle of this structure embedded in a core with the length of 29.2 mm. The structure was considered to be created from 3 cascaded LC cells, T1(10.2 mm), T2(29.2 mm) and T3(10.2 mm), where T2 is an LC cell embedded in a magnetic core. The characteristic parameters of this structure are presented in Table 1.

The frequency response for the structure from Figure 11 and the same structure without the core are compared in Figure 12. The conclusion is that when part of the structure is embedded in a ferrite core, the fundamental resonant frequency is determined to be at lower frequency values from the analyzed frequency domain., considering the three cells having the same length in each of the two cases.

Table 1

Characteristic parameters of the linear LC structure

Parameters	Without sorrounding core(T1,T2,T3)	With sorrounding core(T2)
L [μH/m]	1.4814	15.874
C [μF/m]	0.00040621	0.00040847
M [μH/m]	1.3776	15.75
R [Ω/m]	0.047814	0.047893
G [Ωm]	0.01	0.01

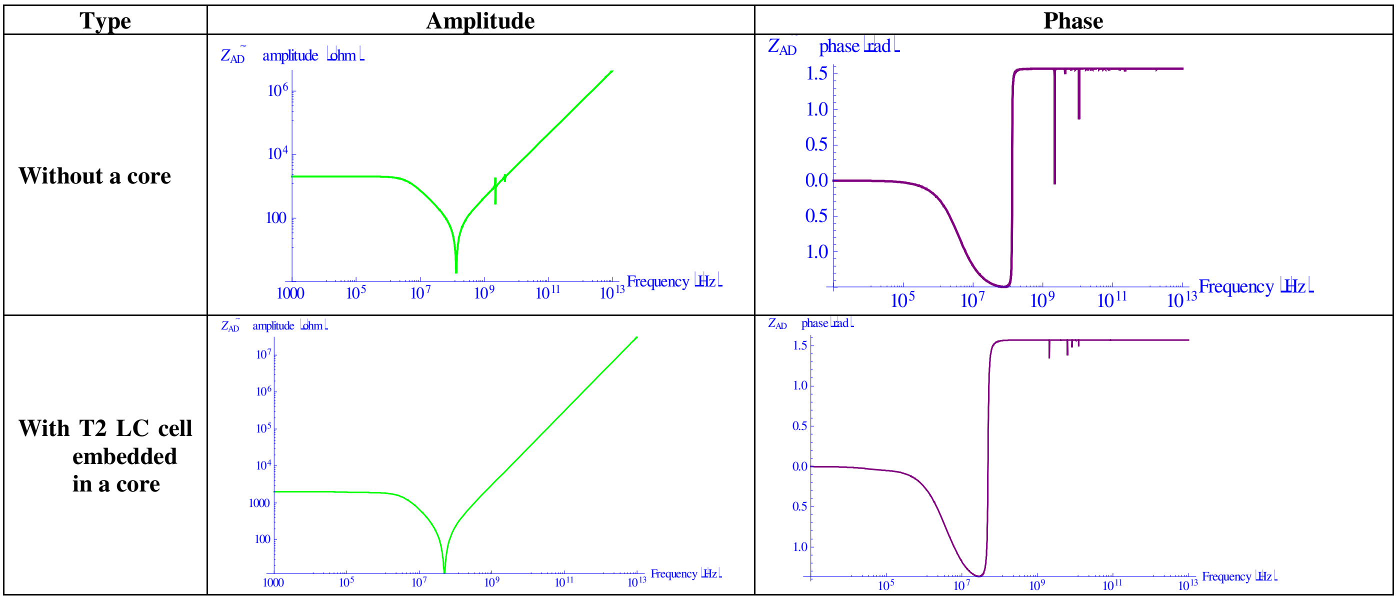


Fig. 12. The frequency response of 3 cascaded LC cells with and without a surrounding core

The spiral integrated structure with one turn can be represented as shown in Figure 13.

In previous researches, the fact that the spiral winding LC structure with one turn can be modeled as a liniar LC structure was demonstrated [4]. That is why the structure was modeled as a liniar structure composed of five LC cells.

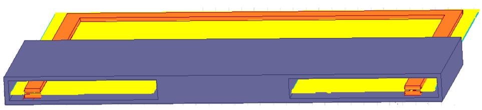


Fig. 13. Front view of the spiral LC structure.

The results for this structure have the same conclusion as the previous ones.

5. CONCLUSIONS

This study highlights the influence of the parameters of integrated LC structures from the frequency point of view, beginning with the influence of parameters on LC cells and continuing with more complex LC structures like linear and one turn spiral LC structures.

The authors determined the parameters of different structures with the help of a 2D numerical modeling program and obtained characteristic impedances inserting their values into a computational software.By varying the LC structure's parameters, they determined what and how it influences the impedance for a series resonator structure.

It was observed that, if we refer to the LC cells, the frequency response does not depend on the thickness of the copper layers.The fundamental resonant frequency appears at smaller values of the analyzed frequency range when the width of the LC cell is greater. Also it can be observed that when the thickness of the dielectric is varied, the fundamental resonant frequency is found at higher values as the thickness of kapton layer increases.

The importance of splitting LC structures with different characteristics along their surfaces in LC cells was also evidentiated,considering the case of LC structures embedded in a ferrite core.

Further invastigations will lead to the study of more complex spiral planar LC structures.

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