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RESEARCH ARTICLE

DISTRIBUTION OF ELECTRICAL CURRENT DENSITY INTO PLANAR MAGNETIC COMPONENTS ACCORDING TO FREQUENCY

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Abstract

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This article presents a study on influence of frequency and magnetic material on electrical current density distribution and its intensity in a planar inductor.Studied structures are planar inductors without and with a magnetic material. These studies are performed in simulation using HFSS simulator and in experimental measurement using impedance-meter.

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Introduction:-

Magnetic components have no escaped to integration rules in the recent decades. Nowadays, minuatirization subject of magnetic componentincrease more and more. This minuatirization allows them to be integrated into systems operating at high frequencies [1] [2]. Futhermore, when the frequency is high, phenomena such as skin effect, proximity effect or even magnetic fiels effects appear.These phenomena are often source of modification of electrical current density distribution into conductor. The modification of this distribution is due to an increase of losses in the conductors [3]. The studied carried out by [4] and [5]show that when the frequency is high, the current density distribution is not uniform in the width conductor because of losses become high. Other authors were interested in determining by analytical calculation ofDC and AC current distribution into a conductor used in power circuits [6].According to our knowledge, there is work studied the influence of current density on the current intensity into a planar conductor.It is therefore necessary to study this distribution influence on the current intensity value throughturns of an integrated inductors when frequency changes. The aims of this article are to present a study carried out in numerical simulation and by an analytical calculation on the influence of current density distribution on the current intensity flowing through planar inductors at different frequencies. In numerical simulation, we used a 3D electromagnetic simulator. The electrical current intensity is determined analytically using a calculation method that we presented precedently in [7].In this paper, we presently firstly studied structures with there constitution and dimension.Then, we present developed method for our study. In the third section of this document, we present obtained results and discussions.

Studied planar inductors:

The studied structures are planar inductors without (Fig.1. a) called coreless and without (Fig.1. b) magnetic material. These are integrated planar inductors made up from a stack of thin layers.A conductive layer, a mechanical support, an insulating layer and a magnetic layer if it is an inductor with magnetic material.In figure 1 below, we present studied structures' images.

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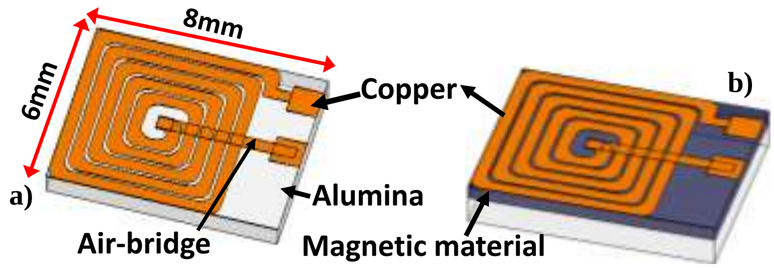

Fig.1:- Studied planar inductors.

The conductive part, shaped as spirale isfabricateddirectly on a dielectricsubstrate for the coreless structure.Or on a magneticsubstrate for structure withmagnetic layer as shown in Fig.1. b.The connexion betweeninner part of the spiral (central pad) and the outer part of the spirale isensured by an Air-bridge.This isseparatedfrom the spirale turns by an insulation layer to avoid short-circuit.The usedmagneticmaterialis YIG (Yttrium Iron Granet) with a thickness of 750µm.Magnetic materialproperties are : constantepermittivity (ε_r) with value of 15and a constante relative permeability (μ_r) of 45 at studiedfrequency. The studied structures are manufacteredusingmicrotechnology technics.Theseallow to fabricate spiral and Air-bridge connectiontroughphotolitography techniques.Deposition of conductive layer by sputtering and etching.The magneticmaterialthicknessisobtained by mechanicalsteps of lapping and polishing the magneticsusbtrate.The spiral conductive part isconsists of 5 turns.The conductive widthis 400µm with a 5µm of thickness. The separating distance of turnsis 100µm. The magnetic layer and the spiral are bonded to a dielectric support whichconstitutes a mechanical support for the component.For the coreless, the conductive part isfabricateddirectly on an alumina mechanical support.

Methodsof Study:-

Twoapproaches are developped for ourstudy.The first one is to determine the electriccurrentdensity by simulation.The second approachis to determine the intensitycurrentintoconductor by using a calculationmethodthatwepresentedpreviously in [7].In thisparagraph, wepresent the developpedapproaches for ourstudy.

Numerical simulation method

The simulation developpedappoachisconsists of determining the electriccurrentdensityflowingthrough structure using a 3D electromagnetic simulator.Used simulator is HFSS (High Frequency Structure Simulation) software. This software uses FiniteElement Method for itscalculation.HFSS cannotdeterminedirectly the electricalcurrentflowingthroughstudied structures.But, itdetermines volume densitycurrent (Jvol) in 3 axes into a conductors. The developpedstudyprinciple for currentdensitydeterminationconsistsfirstly of exciting the structure under test by using a alternative source.Then, to extractcurrentdensityfromstudied structure turns.The component excitation signal is at a variable frequencyfrom10MHz to 200MHz. This bandwithischosenwithidea of remaining on a frequency band where component behavioris more inductive.Fig.2 presentsstudyprinciple for determinationof currentdensity in the structure. The calculationcurrentdensitymethodisdescribed in followingparagraph.

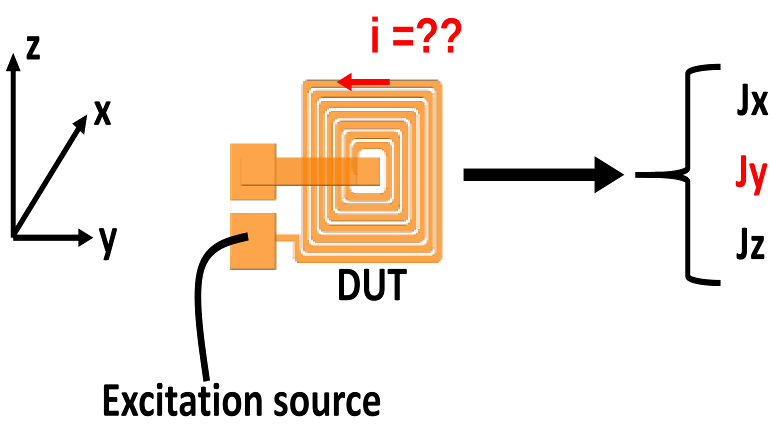

Fig. 2:- Studyprinciple.

This currentdensityisdistributedalong the 3 axes of the conductor (Jv_x, Jv_y and Jv_z).The currentdensityalong y-axis is the highestcomparedothers axes.In our case, we are particularyinterested in the currentdensityalong y-axis becauseitis the conductor axis. It isalso the Jvolwhich has the highest amplitude.Fig.3belowpresentsmoduluscurves ofJv_x, Jv_y et Jv_zaccording to conductorwidthobatined in simulation using HFSS.

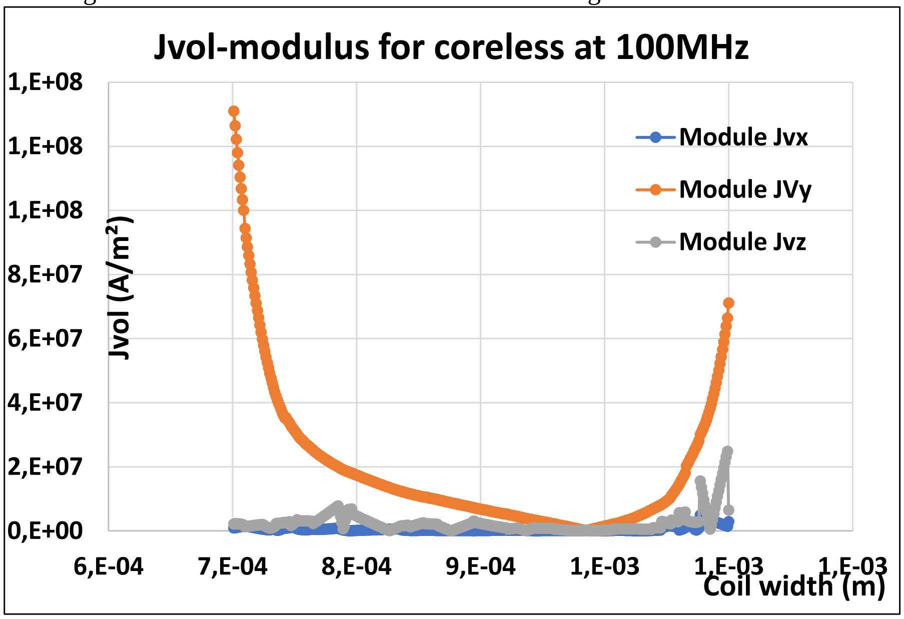

Fig. 2:- Jvx, Jvy and Jvzinto a coil of coreless.

Electric current calculation method

The principle of thismethod for calculatingcurrentintensityfrom volume currentdensityprovided by HFSS can besummarizedin 3 steps:

- Definecutting plane on the conductor (Figure 5 below) ;
- Determinecurrentdensity volume flowingintoconductor direction ;
- Calcultatecurrentintensity in eachconductorusingmathematics expression (1) below :

$$I = \iint Jv.ds \qquad (1)$$

A studyiscarried out on instensitycurrentaccording to conductorthickness.The objectif is check if intensitycurrent value does not change according to the thickness.Wethereforeremarkthatinstensitycurrent value are the same over the entirethickness of the conductor.Conductorthicknesswerebeing 5µm.Fig.4 presentscurve of calculatedcurrentintensityaccording to conductorthickness (z-axis).So, we can simplify expression (1) by (2).

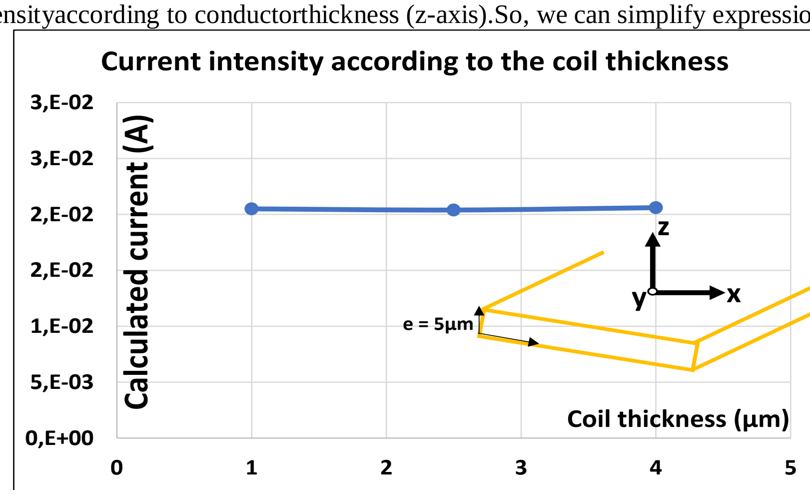

Fig.4:- Calculatedcurrentaccording to the coil'sthickness.

$$I = e.\int_{x=0}^{x=l} J_y(x).dx \qquad (2)$$

The volumiccurrentdensity (Jvol) provided by HFSS is in complexform (real part and imaginary part).Considering simulation frequency, wenotedthatcurrentcirculatealong the 3 axes x,y and z. Currentflowing in both directions (negative and positive).It is the Jvol in the direction of conductorwhichisretained for the rest of ourcalculationbecauseit corresponds to the conductorcurrent direction. For ourstudy case, itisJvolalong y-axis.The others directions correspond to current circulation due to skin effect, proximityeffect or magneticfieldseffect. Fig. 5below, show a cross section of the conductor for determiningJ_{vol}.

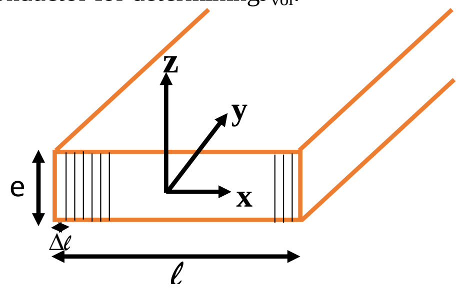

Fig. 5: - Cross section of the conductor.

Sinceprovidedcurrentdensityfrom HFSS is in a complexe form, instensitycurrentiscalculatedusing expression(3).

$$I = e * \sqrt{A^2 + B^2} \qquad (3)$$

$$A = \Re\frac{I}{e} = \sum_{i=0}^{i=n-1} \frac{\Re J_{(i)} + \Re J_{(i+1)}}{2} * \Delta l \qquad (4)$$

$$B = \Im\frac{I}{e} = \sum_{i=0}^{i=n-1} \frac{\Im J_{(i)} + \Im J_{(i+1)}}{2} * \Delta l \qquad (5)$$

Avec e : conductorthickness

Δl : variation of widthconductor

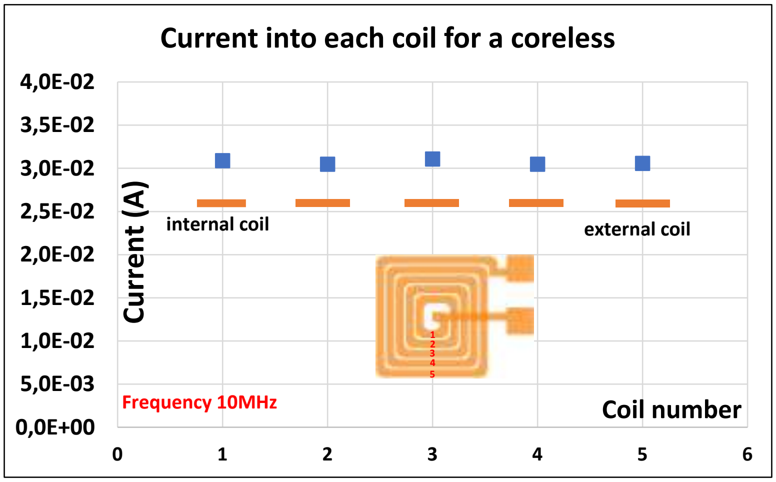

Fig.6:- Current in eachcoil.

We can notice in Fig.6 that the curve of calculatedcurrent I by thismethod in eachturnis quasi-constant.Theseallow us to conclude the thereis no propoagationphenomena. And ensurethatcurrentflowing spiral isidentic.

Obtained Results and Discussions:-

In this section, wepresentobtainedresultsusingdeveloppedapproach. Wefirstlypresent the studycarried out on the influence of the currentdensity on currentintensityflowingintoconductorsconstituting spiral.Thenwepresentstudycarried out on frequency influence on the calculatedcurrentintensity.

Currentdensity influence on the flowingcurrent

Wepresent in figure 7 below, a comparison of currentdensityevolutionalongconductor axis for inductorwith and withoutmagnetic material.

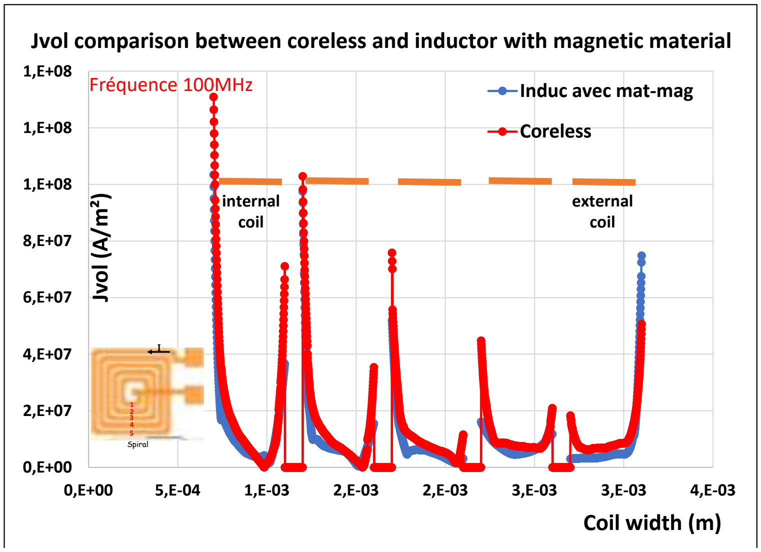

Fig.7:- Currentdensityintocoreless and inductorwithmagneticmaterial.

We can notice herethat for the two structures (coreless and inductorwithmagneticmaterial) currentdensityis not homogeneousover conductorwidth.The currentdensityJvolis maximum at the edge of the conductor and verylow in the center.This illustrates the influence of high frequencyeffects in the conductors.Theseeffects are skin effect and proximityeffects in the conductors. Whatmakescurrentdensitydoes not occupy all conductorwidth but rather in the edgesof the conductors.The lowcurrentdensity in the center of the conductorisclearly visible on the mapping of the conductorshown in figure 8 below.We can alsoremarkthat in the last turn, currentdensityis high in the edgewherethereis no otherconductor in the proximity.This explainthat the external position of thisturn and the absence of the proximityeffect on thisturn.

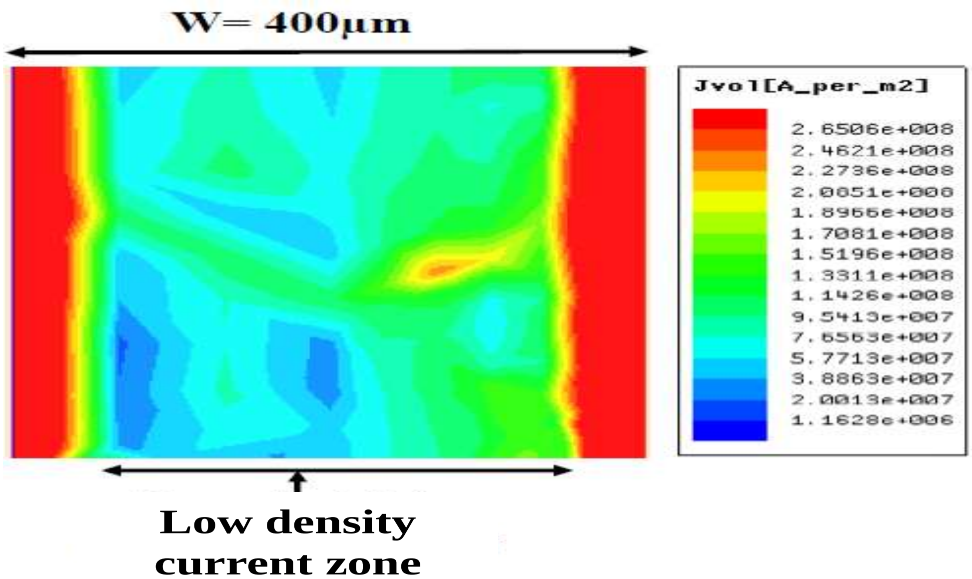

Fig 8:- Currentdensityintoconductor.

The I currentiscalculated in eachturn to check whetherthere are propagation phenomena or a high frequencyeffectwhichcouldmodifycurrent I in theseturns.The figures 9.a and9.b belowpresentcurves of currentintensity in eachconductor for the two structures (coreless and inductorwithmagneticmaterial).Intensitycurrentiscalculatedusing expression (3) for differentsfrequencies values from 10MHz to 200MHz.It isindeed the frequency range where the structures behaviorispurely inductive.

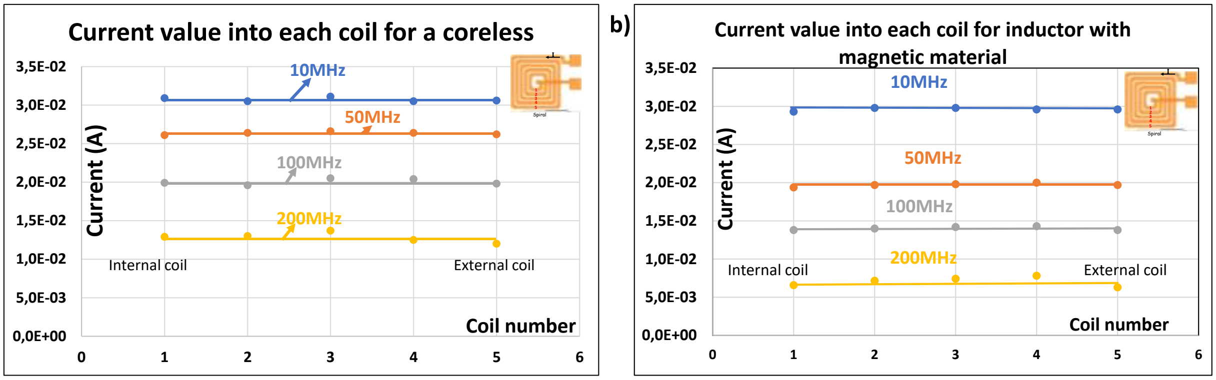

Fig9:- Currentaccording to frequency for inductor : a) coreless and b) withmagneticmaterial.

We can reallyremark on thesetwo figures(Fig.9.a and Fig.9.b) that the calculatedcurrentcurves in eachturn are quasi-constante. Although, the non-homogneity of the currentdensityalong the conductors and the high frequencyeffects.The currentintensityremainsidenticinto all turnsconstituting the component. This can beexplained by the absence of propagation phenomena in the spiral.At the frequency of 10MHz, currentintensity for structure withmagnetic layer isalmostequal to that of the coreless.This explainthat, at thisfrequency, the high frequencieseffects are almostnegligible on the components.So, losses at negligible in the conductors at the frequency of 10MHz.From 50MHz frequency up to 200MHz, losses due to high frequencyeffectsincrease and currentintensityalongconductorvaryaccording to frequency and structure.For structure withmagnetic layer, currentintensityissmallcompared to that of corelessbecause of the magneticmaterial.Presence of magneticmaterial in the component increasesmagneticfieldlinesquantity [8] and changes impedance component.

Frequency influence on currentintensity

Figure 10 below presents a comparison between intensity current evolution according to frequency for the two structures.First of all, we note that current instensity value for structure with magnetic material is low compared to that of the coreless.This decrease is due to the impedance component change.The current value for structure with magnetic layer divides by 2 that of structure without magnetic material.This translates the increasing inductance L value when magnetic material is presence in the component. Thus, changes impedance component.Figure10.b below shows inductance L value evolution according to the frequency for structure with and without magnetic material obtained in measurement.Measurment is carried out using an impedancemeter.Applied measurement method is the one that we developed and presented previously in [9].

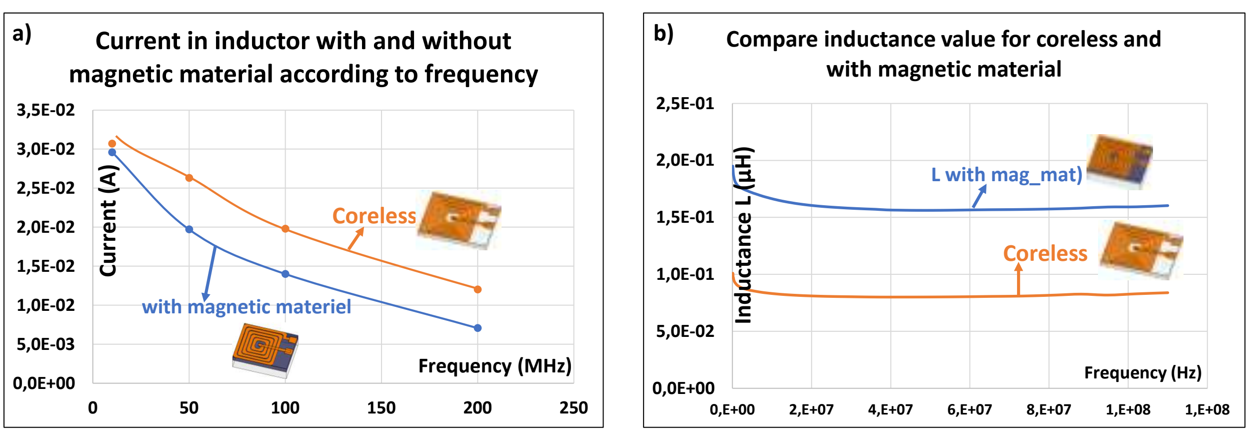

Fig.10:- Compariasonbetween : a) Currentevolutionand b) inductance evolutionaccording to frequency.

We can also notice thatcurrentintensity for the two structures (coreless and inductorwithmagneticmaterial)decreaseaccordingto the frequency. This decreaseis due to conductorlosses augmentation whenfrequencyincrease.

Conclusion:-

In this article, wepresentedfrequency influence on the distribution of electriccurrentdensity in a planarconductor.Weparticularypresented the currentdensity distribution influence on currentintensitywhenfrequencyis variable.Wenoticedthatwhenfrequency variation over studied band, currentintensityremainsidentical in all turnsconstituting components.Wealsopresented a study on magneticmaterial influence on the current value according to the frequency.Wealsofoundobviouslythatwith the presence of magneticmaterial in the inductor, currentintensitybecomeslowcompared to the coreless structure.This isexplained by the component impedancechangedwith the presence of magneticmaterial.Measurements on real components as well as numerical simulations using HFSS are carried out duringthesestudies.Measurement of inductance L value carried out usingimpedancemetrershow thatinductance L value of structure withmagnetic layer istwo time biggerthan one of the coreless.

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