Science Publications

World Journal of Electrical and Electronic Engineering, 2022, 2, 469
www.scipublications.org/journal/index.php/wjeee
DOI: 10.31586/wjeee.2022.469

Review Article

Experimental Study of Winding Topology Effect on Coils Electrical Behavior

Safer Omar Adib [1, *], Bensaid Samir [2]

[1] Algerian Space Agency; Operation Center of Space Telecommunications, Medea 26000, Algeria
[2] University of Bouira, Electrical Engineering Department, Bouira 1000, Algeria

*Correspondence: Safer Omar Adib (omar.safer@gmail.com)

Abstract: The main goal of this paper is to study the effect of winding topology on coils electrical behavior in experimental way to take into account the self capacitance of coils, several coils are fabricated using copper wire with changing the number of winding layers and fixing the spiral numbers, in addition two coils was fabricated to study the effect of the winding wire diameter, the measured reactance and resistance of eddy current coils are done using precision LCR-meter with a frequency range from 0Hz to 5 MHz, the experimental results shows very remarkable interactions of resonator due to the changing of winding topology and his effect on self capacitance of coils.

Keywords: Winding Topology, Coil, Self Resonator Frequency, Self Capacitance, Experimental

How to cite this paper:

Adib, S. O., & Samir, B. (2022). Experimental Study of Winding Topology Effect on Coils Electrical Behavior. *World Journal of Electrical and Electronic Engineering*, 2(1), 15–21. Retrieved from https://www.scipublications.com/journal/index.php/wjeee/article/view/469

Received: September 1, 2022
Accepted: October 27, 2022
Published: October 29, 2022

1. Introduction

Coil inductors are indiponsable composnentes in the filed of fabrication technologies at high and low frequencies, such as power electronics [1], radio transmitters [2], wireless power transfert[3], and eddy current sensors [4], for that the coils need to be well design deapnds on the application. The electrical behavior of coils inductors are very different at high frequencies compared with low frequencies [5], due to the skin depth and proximity effects which they induce the increasing of resistance losses and reactance but acting linearly fot low frequencies[6].

At high frequency a self resonance phenomenan will apear due to the self capacitance effect, the electrical behivior of coil inductor than show a non linear behavior with increasing of frequency, for that the self capacitance effect must be considred which depands on the winding toplogy and sprial raprachement[5, 6].

In this papaer proposed an expiremntal study based on fabrication of coil inductor with changing of winding layers by a copper wire with fixing the spiral numbers, add to two coils with changing of wire diameter, the measured reactance and resistance of coils are done using precision LCR-meter with a frequency range from 20Hz to 5 MHz, the experimental results shows very remarkable interactions of resonator due to the changing of winding topology and his effect on self capacitance of coils.

2. Coils Inductors winding topology

To understand the influence of the geometric structure of the coils on the capacitive effect, we started a purely experimental study in which we first made several solenoid coils with different numbers of turns and different configurations, Figure 1. Then we measured the impedance of all of these coils in the frequency range from 20Hz to 5MHz.

Figure 1. Fabricated coils with diffirent winding topology

The dimensions of each coil are mentioned in the following table, knowing that we symbolize the coils in the form "AxB" such that "A" is the number of layers and "B" the number of turns per layer.

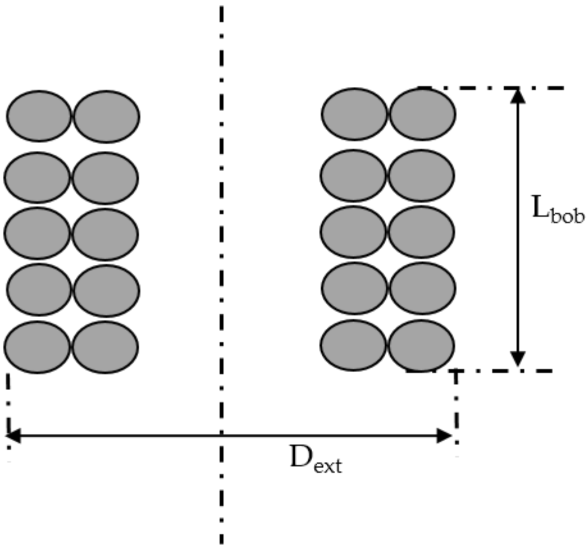

Figure 2. Coil geometry

Dextb, Lbob and Ns are respectively the outer diameter of the coil, the length of the coil and the number of turns as shwon in Figure 2.

Table 1. shows the dimensions of the coils such as D_{extb} , L_{bob} , and N_s, however the inside diameter of the coils is the same, D_{int}=15.44 mm and likewise for the diameter of the coil conductors is constant and it is D_c=0.25mm.

Table 1. Coils dimensions.

	1x48	2x24	4x12	1x96	4x24	2x48	6x24	3x48	3x24	5x24/ Dc=0.5	5x24	2x12
Dextb	17.16	18.38	19.10	17.23	20.24	18.08	21.53	19.11	18.96	22.69	20.73	17.67
Lbob	13.72	8.90	5.10	26.06	9.90	14.9	9.35	13.79	8.03	14.84	10.57	5.02
Ns	48	48	48	96	96	96	144	144	72	120	120	24

The impedance meter used (Figure 3) is a precise device that allows us to scan a wide range of frequencies ranging from 20Hz to 5MHz. The frequency range and accuracy of the device meet our expectations with respect to the measurement of the impedance of the system studied.

Figure 3. precision LCR-Meter

This impedance meter is connected to a PC through an RS232 link and completely controlled using a commercial application for manipulation and test management. This application makes it possible to analyze several parameters at the same time with a wide range of frequencies and reinforced by a display system (variation curves).

3. Results and Discussions

To show the influence of the coil winding topology configuration on the self-resonance phenomenon, we made three series of coils with the same total number of turns for each series.

The first series with a total number of turns equal to 48 is: 1x48; 2x24; 4x12, the second series with a total number of turns equal to 96 is: 1x96; 2x48; 4x24, the third series with a total number of turns equal to 144 is: 3x48; 6x24.

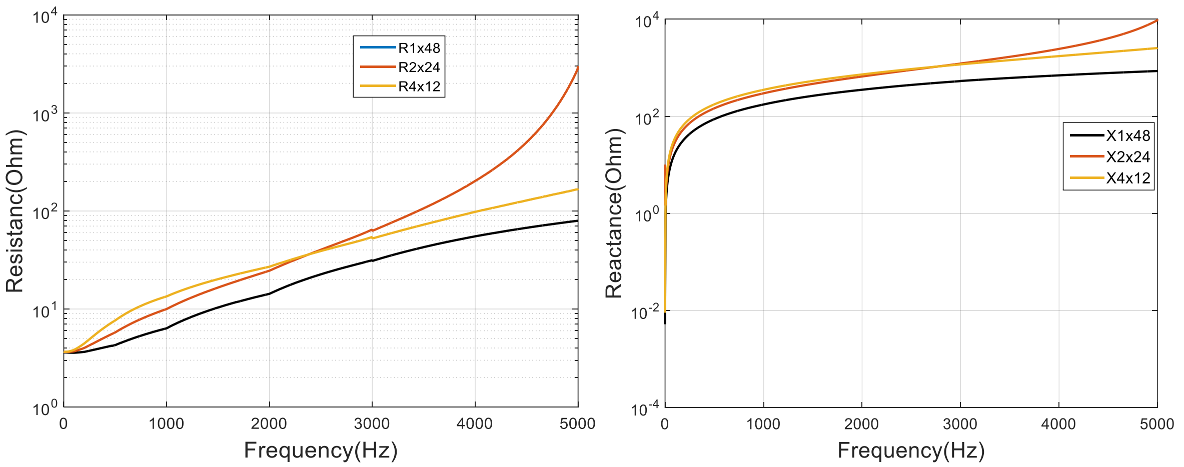

Figure 4. First series (a) Resistance (b) Reactance.

Figure 4 shown the coils resistance and reactance development in a frequency range from 20Hz to 5MHz ,the electrical characteristics (resistance and reactance) of 1x48 and 2x24 coils behaving linearly for all frequency range from 20Hz to 5MHz, other than a resonance phenomenon is appear in 2x24 coil above 3MHz due to the number of self capacitance between spiral coil.

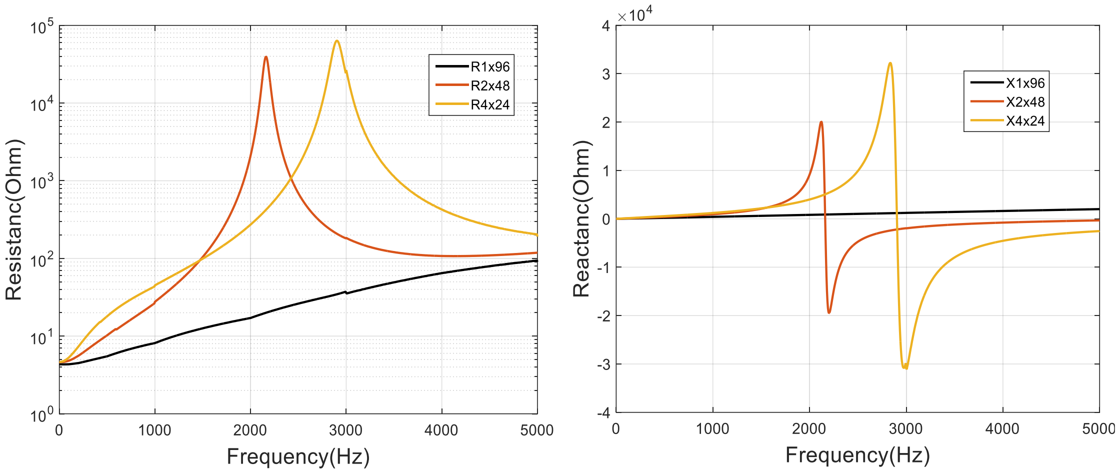

Figure 5. Second series (a) Resistance (b) Reactance.

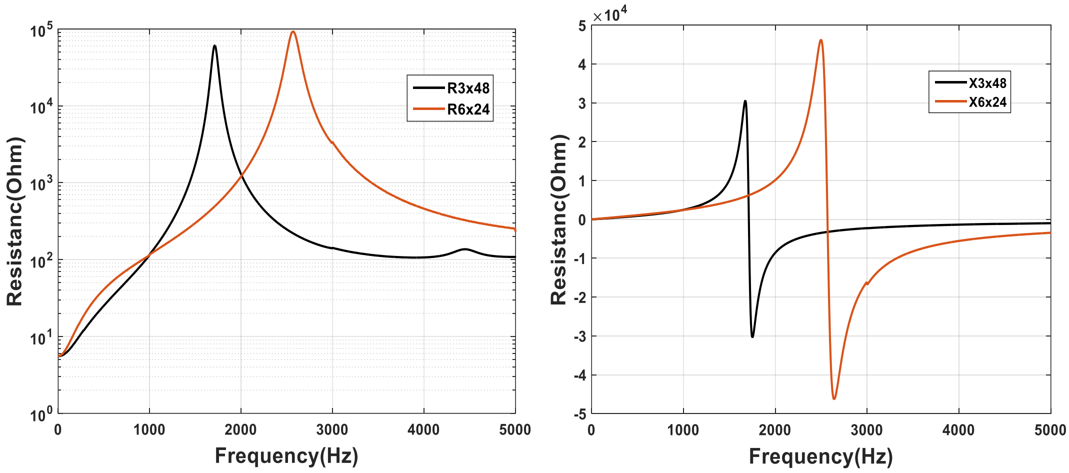

Figure 6. Second series (a) Resistance (b) Reactance.

As shown in Figure 6. the coil resonator appear in 3x48 coil at a resonator frequency of 17MHz before 6x24 coil which resonate at 2500MHz due to the high numbers of neighboring turns numbers which increase the self capacitance value.

For frequencies below 5MHz, we notice that in each of the series of coils made, the resonance frequency for the two-layer configuration is the smallest and it is greater in the case of the single-layer topology. For the other winding topology, this frequency is between the two previous extremism, Figure 4, 5 and 6.

Several factors influence the phenomenon of self-resonance or more simply the point of resonance. Among these factors are:

- Capacitances between turns which depend directly on the surface between neighboring turns, Figure 6: in the case of mono-layer (for example 1x96, Figure 5) the resonance frequency is the highest (beyond 5MHz), it decreases rapidly as soon as the coil is made with the same number of turns as the monolayer on a number of layers greater than or equal to 2 (2x48 or 4x24). For the mono-layer, each turn has either one or two neighboring turns. For the bi-layer, each turn has two or three neighboring turns. For a number of layers greater than 2, each turn has two or three or four neighboring turns.

- Mutual inductance between turns which strongly depends on the chosen winding topology: the total magnetic flux created in each turn depends strongly on the flux created in the neighboring turns. This influence strongly depends on the geometric distance where this turn is located in relation to the other neighboring turns.
- The skin effect at high frequencies: as known that in each conductor traversed by a variable current, a variable magnetic field is created. This magnetic field induces currents which flow inside this conductor which in turn creates an induced field which combines with the source field. At high frequencies, the resulting field repels the currents on the periphery of the conductors, this is called the skin effect.

The curves in figure .7 show the influence of the winding wire diameter on the capacitive effect.

To see the effect of the winding wire diameter on the self-resonance phenomenon, two coils of the same configuration (5x24) but of different wire diameters were made. The results obtained are shown in Figure 7.

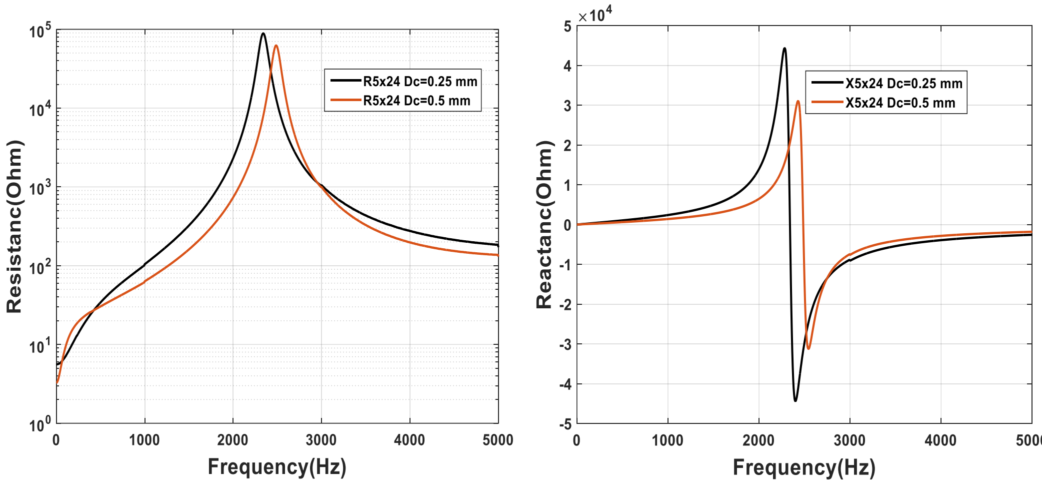

Figure 7. Influence of the winding wire diameter on the self-resonance phenomenon

Note that the amplitude of the impedance of the coil, at the resonance peak of the 5x24 Dc=0.25mm variant, is greater than that of the 5x24 Dc=0.5mm coil because the diameter of the winding wire is different in the two variants.

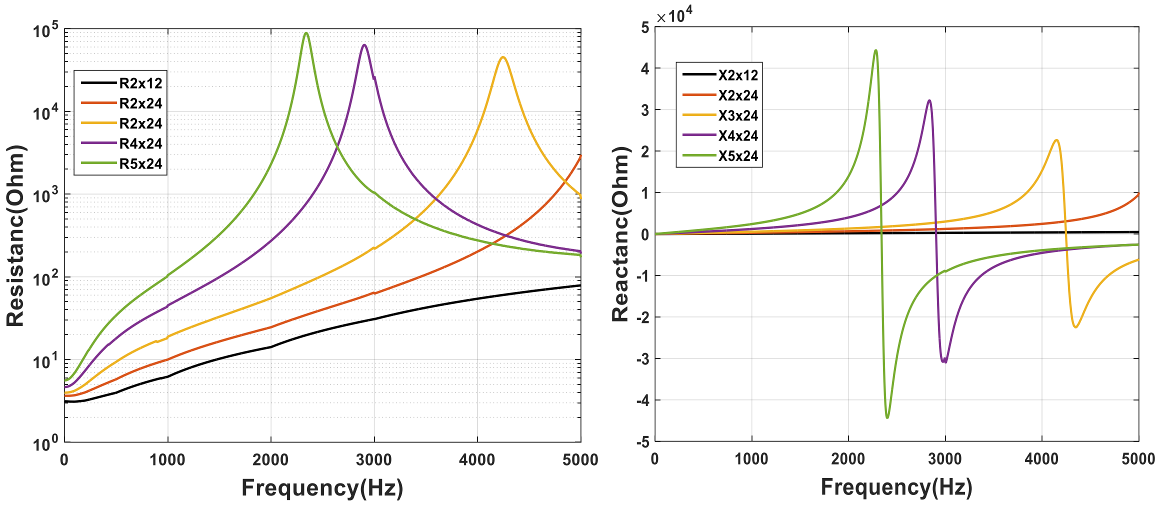

Figure 8. Influence of the number of layers on the self-resonance phenomenon.

Figure 8 and Figure 9 shows the influence of the number of layers and turns with different winding topologies on the self-resonance phenomena. It clearly shows the decrease in frequency and the increase in the amplitude of the resonance peak with the increase in the number of turns and layers of the coil, in addition the resonator frequency become smaller with the augmentation of the spiral layer number.

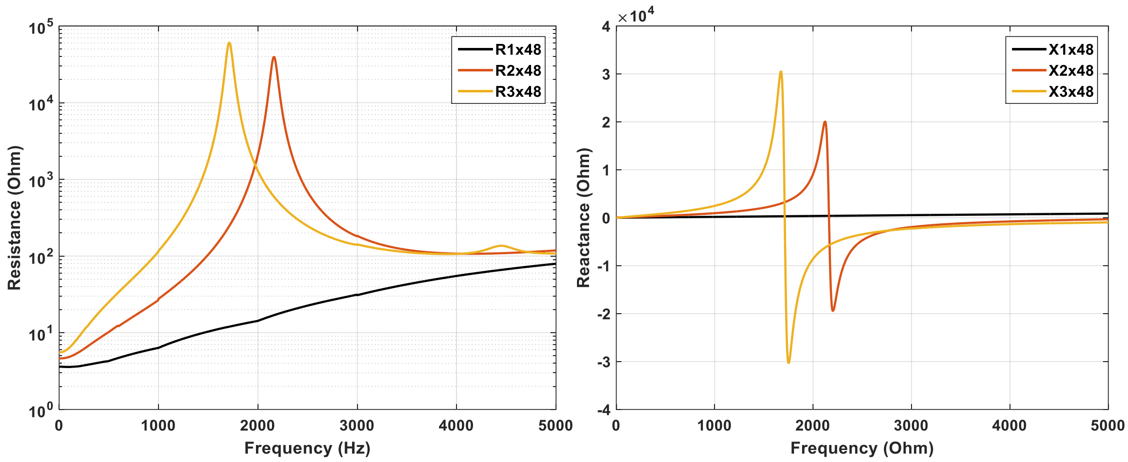

Figure 9. Influence of the number of turns on the self-resonance phenomenon

4. Conclusion

The self-resonant frequency of single-layer and multi-layer solenoid coil is different, the value of self-resonant frequency is influenced by the dimensions of the coils, which means that each coil has its own resonant frequency.

Since the number of turns of the multilayer coil is the most influential factor on the self-resonance phenomenon, we have proposed to classify these coils in relation to our application into two categories:

- coils with a low number of turns: does not require a model with a capacitive effect.
- coils with a high number of turns: requires a model that takes into account the capacitive effect.

References

[1] A. B. Arsoy, Zhenyuan Wang, Yilu Liu and P. F. Ribeiro, "Transient modeling and simulation of a SMES coil and the power electronics interface," in *IEEE Transactions on Applied Supercond*uctivity, vol. 9, no. 4, pp. 4715-4724, Dec. 1999, doi: 10.1109/77.819343.
[2] Y. Cho, A. Basir and H. Yoo, "Adjustable RF Transmitter Head Coil: Improving Transmit Efficiency With SAR Management for 7-T Magnetic Resonance Imaging," in *IEEE Transactions on Microwave Theory and Techniques*, vol. 69, no. 5, pp. 2686-2696, May 2021, doi: 10.1109/TMTT.2021.3057620.
[3] R. Bhujade, R. Mujavar, P. Singh, B. Joshi and R. Oruganti, "Modeling and analysis of coupled coils for Wireless Power Transfer," *2016 IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES)*, 2016, pp. 1-6, doi: 10.1109/PEDES.2016.7914502.
[4] O. A. Safer, S. Bensaid, D. Trichet and G. Wasselynck, "Transverse Electrical Resistivity Evaluation of Rod Unidirectional Carbon Fiber-Reinforced Composite Using Eddy Current Method," in *IEEE Transactions on Magnetics*, vol. 54, no. 3, pp. 1-4, March 2018, Art no. 6200404, doi: 10.1109/TMAG.2017.2751962.
[5] A. Ayachit and M. K. Kazimierczuk, "Self-Capacitance of Single-Layer Inductors With Separation Between Conductor Turns," in *IEEE Transactions on Electromagnetic Compatibility*, vol. 59, no. 5, pp. 1642-1645, Oct. 2017, doi: 10.1109/TEMC.2017.2681578.
[6] A. Massarini and M. K. Kazimierczuk, "Self-capacitance of inductors," in *IEEE Transactions on Power Electronics*, vol. 12, no. 4, pp. 671-676, July 1997, doi: 10.1109/63.602562.