Electromagnetic Field Analysis on Resonance Phenomenon of Inductor Taking Account of Stray Capacitance

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Abstract

In inductors driven by the inverter using GaN devices, the ringing phenomenon, which occurs due to the multi-resonances during the short rising and falling time, increases noise and loss. To clarify the mechanism of the multi-resonances, the high frequency behaviors of a ring core inductor in frequency domain are simulated by using the 2D electromagnetic field finite element analysis taking account of the stray capacitance. Moreover, to explain this phenomenon, a distributed-element circuit model including the stray capacitance is proposed based on the simulated results. It is shown that the proposed finite element and circuit models can represent the measured HF behaviors of the ring core inductor.

1 Introduction

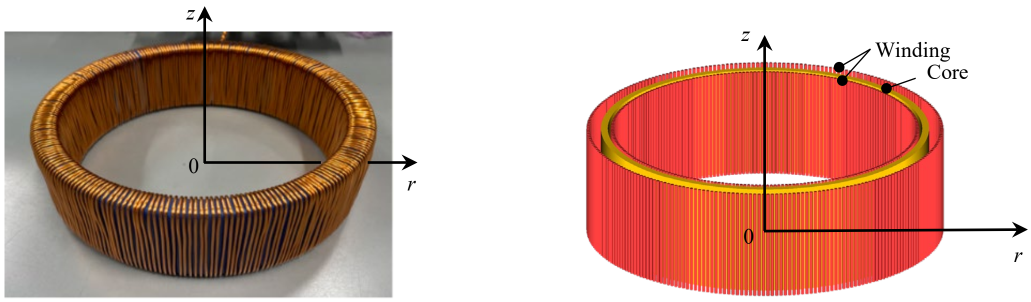
Recently, to make power electronics equipment more compact and higher efficiency, the carrier frequency is increasing by applying the Gallium Nitride - Field Effect Transistor (GaN-FET), etc. [1]. In inductors driven by the inverter using GaN devices, the ringing phenomenon [2], which is the oscillation in the waveform of current, occurs due to the multi-resonances during the short rising and falling time of input voltage, and it increases the noise and iron loss of the core. The resonance phenomenon of the inductors at the high frequency (HF) can be simulated by the behavioral circuit model including the stray capacitance [3]. However, the physical mechanism of the multi-resonant frequencies of the inductors seems to be not explained well by the behavioral circuit, and a physical circuit model for inductors at the HF needs to be developed.

In this paper, to clarify the physical mechanism of the multi-resonances, the HF characteristics of the input admittance $\dot{Y}$ of a ring core inductor are simulated by the 2D electromagnetic field finite element analysis (FEA) in the frequency domain taking account of the displacement current. Moreover, it is founded and verified that the inductors at the HF should be modeled by the distributed-element circuit.

2 Finite Element Analysis Model

A ring core inductor shown in Fig. 1 (a), which consists of a core with an inner diameter of 100 mm, an outer diameter of 120 mm, and a height of 35 mm, and a winding with 254 turns, is simplified into the 2D FEA model shown in Fig. 1 (b). The subdivision is only one layer at *z* direction. A winding is simplified as the straight conductive bars, which are connected into winding by using the numerical connection. To consider the top and bottom parts of the winding in the 2D FEA model, the height of the FEA model is enlarged. Moreover, to keep the sectional area of the core the width of the core is reduced.

The electromagnetic field FEA with the $\boldsymbol{A}$-ϕ method ($\boldsymbol{A}$: magnetic vector potential, ϕ: electric scalar potential) in frequency domain taking account of the displacement current which leads to the stray capacitance is performed with a voltage applied to the winding. Then, the admittance $\dot{Y}$ of the ring core inductor is calculated.



(a) measurement model (b) FEA model

Figure 1: Ring core inductor

3 Distributed-Element Circuit Model

It is founded by the results obtained from FEA that the ring core inductor at the HF should be modeled by the distributed-element circuit shown in Fig. 2 because the wave length becomes shorter than wire length. $\dot{L}_s$ is the self-inductance of the winding in each turn and $\dot{M}_{nm}$ is the mutual inductance between the n^{th} and the m^{th} turns of the winding. C_w is the stray capacitance between each turn of the winding and C_c is the stray capacitance between the winding and the core. These circuit parameters can be obtained by using the FEA model shown in Fig. 1 (b).

4 Results and Discussion

The frequency characteristics of $\dot{Y}$ obtained from the FEA and distributed-element circuit models are compared with that obtained from measurement in Fig. 3. Both simulation models can represent the measured multi-resonances. And it is concluded that the multi-resonances of inductors at the HF can be explained by the wave propagation in the distributed-element circuit.

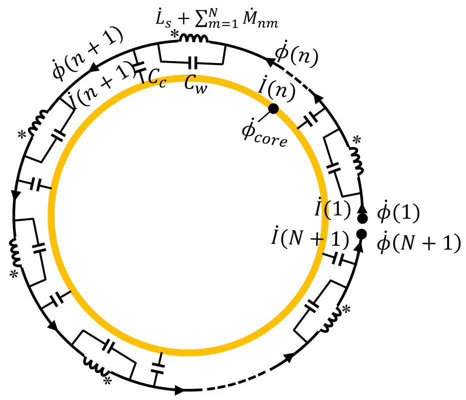


Figure 2: Circuit Model

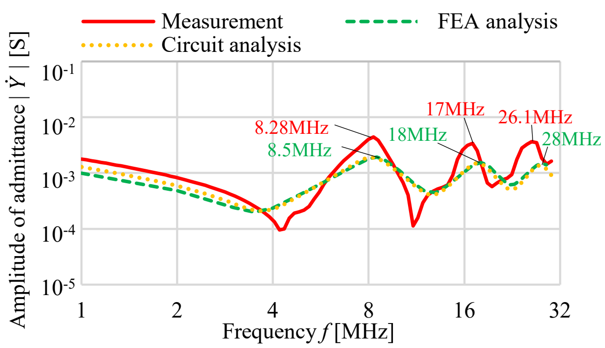


Figure 3: Frequency characteristics of admittance $\dot{Y}$

5 References

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