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A RESONANT PHENOMENON BETWEEN ADJACENT SERIES CONNECTED COILS AND ITS APPLICATION TO A NOISE FILTER

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ABSTRACT

In this paper, we propose a new inductor having a noise filtering capability based on a resonant phenomenon between the two adjacent series connected coils. Although the resonant impedance and frequency of our inductor can be controlled by changing the inductance as well as capacitance, simple theoretical and experimental considerations clarify that the resonant impedance takes a larger value at lower frequency when increasing the inductance. This means that it is possible to realize a noise filter without any external capacitors. Thus, we have succeeded in realizing a new inductor having a noise filtering capability.

1. INTRODUCTION

In order to design small and compact electric power supplies, it is essential to reduce the size of the magnetic devices, e.g. inductor and transformer. One way to reduce the size of the magnetic devices is to employ high frequency excitation. Previously, we have exploited a new type coreless high frequency transformer[1]. Further, we have succeeded in realizing a 15W DC to DC converter employining our coreless transformer[2]. Nevertheless, it remains a noise problem which becomes more serious when employing a higher exciting frequency. This means that even if we succeed in realizing a small and compact power supply employing high frequency excitation, it is essential to attach a noise filter.

In this paper, we propose a new inductor having a noise filtering capability based on a resonant phenomenon between two adjacent series connected coils. The principle of this inductor is that any conductors arranged in parallel have a capacitance between them but the capacitive effect depends on the voltage difference between the coils. Furthermore, if the currents of both conductors are flowing in a same direction, then this yields a common magnetic flux between them. Thereby, a parallel resonant phenomenon is evoked at a certain frequency. Although the resonant impedance and frequency of our inductor can be controlled by changing the inductance as well as capacitance, simple theoretical and experimental considerations clarify that the impedance takes a larger value at lower frequency when increasing the inductance. This means that it is possible to realize a noise filter without any external capacitors. Thus, we succeeded in realizing a new inductor having a noise filtering capability.

2. RESONANT TYPE INDUCTOR

2.1. Basic theoretical background

Let us consider the two parallel arranged conductors shown in Fig. 1(a), then the self inductance L and resistance R for each distinct conductor are

$$L = L_i + L_o$$

$$\cong (\mu l/2)\left[(1/k)-(1/64)(1/k^3)\right]+(\mu l/2\pi)\left[\ln(2l/a)-1\right], \quad (1)$$

$$R \cong R_d\left[(1/4)+k+(1/64)(1/k^3)\right], \quad (2)$$

where l , a and μ are the length, diameter of a conductor and permeability, respectively [1]. The parameter k and DC resistance R_d are

$$k = a\sqrt{\omega\mu\pi\rho}, \quad (3)$$

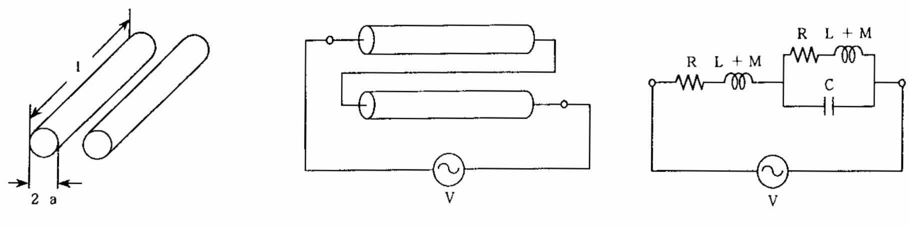
$$R_d = \rho l/(\pi a^2), \quad (4)$$

where ω and ρ are the angular frequency and the resistivity, respectively. Further, Eqs. (1) and (2) have been derived by assuming a symmetrical current distribution to each of the conductor axes. Because of skin effect, the internal inductance L_i in (1) and resistance R in (2) become functions of the frequency $f(=\omega/2\pi)$. Denoting d as a thickness of insulating material having the permitivity ε and permeability μ, the mutual inductance M and capacitance C between the coils are

$$M = (\mu l/2\pi)\left\{\ln\left[2l/(a+d)\right]-1\right\}, \quad (5)$$

$$C = \varepsilon\pi l/\ln\left[(a+d)/a\right]. \quad (6)$$

When we connect these two coils in series as shown in Fig. 1(b), consideration of the circuit connection in Fig. 2 neglecting an impedance of connection wire and representing capacitive effect by the capacitor C connected at a center of each conductor leads to a lumped circuit model shown in Fig. 1(c). Physically, this is because connection of these parallel arranged coils in series yields a voltage difference between them. It becomes a half of entire impressed voltage on the two conductors. Furthermore, the currents of both conductors are flowing in the same direction. This yields a common magnetic flux between them so that a parallel resonant phenomenon is evoked at a certain frequency.



(a) (b) (c)

Fig. 1. (a)Two parallel conductors,(b) the method of circuit connection, and (c)its lumped circuit model.

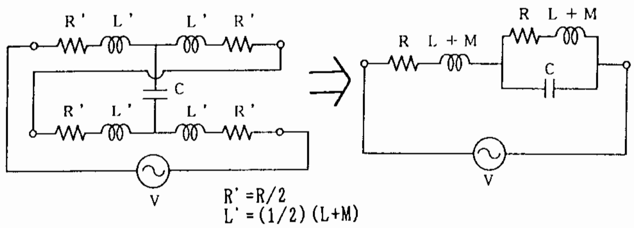


Fig. 2. Derivation of a lumped circuit model neglecting the impedance of connection wires and representing the capacitive effect by the capacitance C connected at the centers of both conductors.

By means of the lumped circuit model shown in Fig. 1(c), the resonant frequency ω_r and resonant impedance Z_r are given by

$$\omega_r = 1/\sqrt{(L+M)C} \,. \tag{7}$$

$$\begin{aligned} Z_r &= R + [(L+M)/(RC)] \\ &= R + [1/(R\omega_r^2 C^2)] \,. \end{aligned} \tag{8}$$

Equation (7) means that the resonant frequency ω_r can be reduced by increasing the inductance L+M or capacitance C. However, Eq. (8) reveals that a larger inductance increases the resonant impedance Z_r at a lower resonant frequency ω_r.

2.2. Experimental

In order to verify our new inductor, we have carried out the frequency vs. impedance measurements for the conventional coreless inductor and our proposed inductor having same specification. As shown in Fig. 3(a), it is obvious that our new inductor exhibits a clear and sharp parallel resonant between the 1MHz and 3MHz. On the other hand, conventional inductor never exhibit any resonant untill 10MHz.

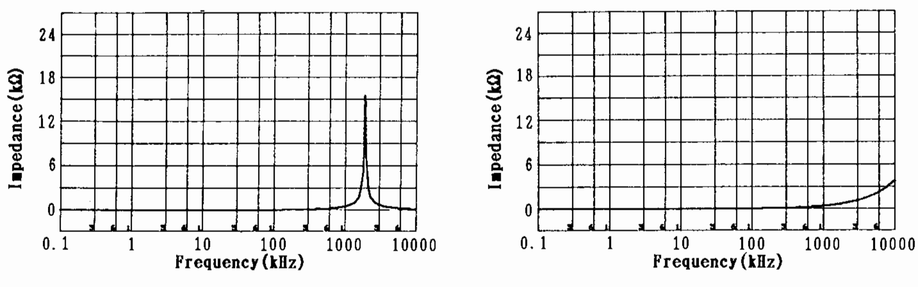
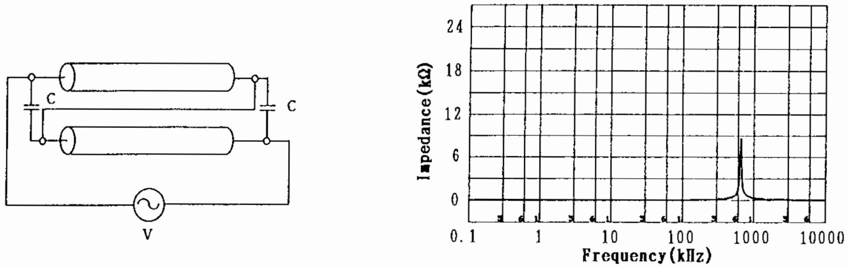


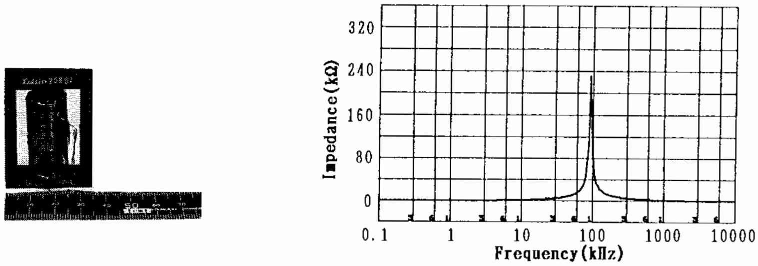
Figure 3. Impedance vs. frequency characteristics. (a) Proposed inductor, and (b) conventional inductor. Both inductors are the finite length solenoidal shape made of 5m length cupper wire with 0.3mm diameter.

In order to reduce the resonant frequency, we attached the capacitor as shown in Fig. 4(a). Consideration of the impedance vs. frequency characteristic in Fig. 4(b) reveals that the resonant frequency is considerably reduced. However, the resonant impedance is also reduced to a small value comparing with the result in Fig.3(a). Figure 5 shows the inductor attacted to the EE ferrite core and its impedance vs. frequenccy characteristic. From Fig. 5(b), it is found that the resonant impedance becomes larger at lower resonant frequency. Thus, it verifies the relationships (7) and (8).



(a) (b)

Figure 4. Reduction of the resonant frequency by attaching the capacitors. (a) Circuit diagram, and (b) its impedance vs. frequency characteristic.



(a) (b)

Figure 5. Reduction of the resonant frequency by increasing the inductance. (a) Picture of the resonant type inductor attached to the EE ferrite core, and (b) its impedance vs. frequency characteristic.

3. CONCLUSION

As shown above, we have proposed a new inductor having a noise filtering capability. Our proposed inductor is based on the circuit connection so that it may have many applications for electronic as well as electrical circuits. In the present paper, we have demonstrated the noise filtering capability of our inductor as a typical application.

REFERENCES

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