A Multi-Resonant Type Inductor Having Notch Filtering Capability

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Abstract—In order to realize a compact size DC to DC converter power supply, the operating must be in the mega hertz region. Operation at higher frequencies introduces a harmonic noise problem. This problem can be overcome by proposing a new multi-resonant type inductor which exhibits a notch filtering characteristic. This multi-resonant type inductor can be used to reduce a problematic harmonic frequency.

I. INTRODUCTION

Recently, people have been using modern electronic devices, such as notebook computers and cordless telephones. These devices are required to be small and light. The power supplies in such electronic devices occupy a large amount of space and are heavy. In order to design small and compact electronic power supplies, the operating frequency of DC to DC converters is being raised into the mega hertz region [1-2]. At these frequencies, a serious noise problem arises. To overcome this difficulty, we have previously proposed a new inductor having a noise filtering capability [3].

In the present paper, we develop a new multi-resonant type inductor which exhibits a notch filtering characteristic. This means that our multi-resonant type inductor can be used to reduce a problematic harmonic frequency.

II. EXPERIMENTAL

A. Principle of a single resonant inductor

Let us consider the two parallel arranged conductors shown in Fig.1(a). Consideration of the connection in Fig.1 (b) leads to an equivalent circuit shown in Fig.1 (c) [3]. As compared with length of conductors, the lead wire between the two conductors is very short length, therefore the impedance of lead wire can be neglected. By means of the equivalent circuit shown in Fig.1 (c), the resonant frequency f_r and resonant impedance Z_r are obtained by

$$f_r = \frac{1}{2\pi\sqrt{C(L+M)}}, \tag{1}$$

$$Z_r = R + \frac{L+M}{RC}, \tag{2}$$

where the parameters in (1) and (2) are shown in Fig. 1.

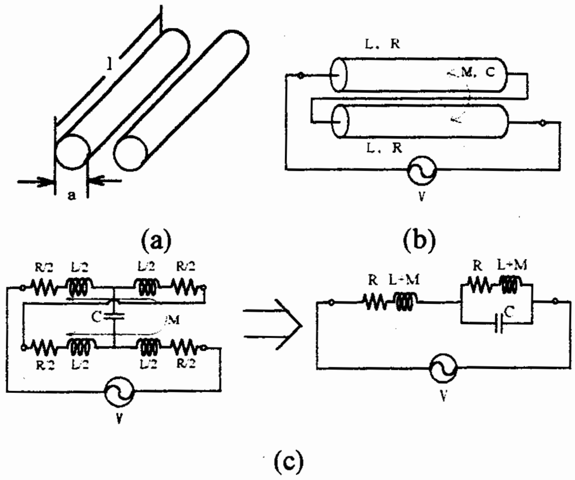

Fig.1. Principle of resonant inductor. (a) Two parallel conductors, (b) method of circuit connection, and (c) lumped circuit model.

Equations (1) and (2) reveal that the resonant frequency f_r can be reduced by increasing the inductance $L+M$ or capacitance C however increasing capacitance C reduces the resonant impedance Z_r.

B. Principle of the multi-resonant inductor

Two parallel conductors are connected as shown in Fig.2(a). The equivalent circuit for this arrangement is shown in Fig.2(b) and follows from the equivalent circuit of Fig.1(c). Arrangement of similar resonant inductors as shown in Fig.3(a) yields a multi-resonant circuit. Figure 3(b) shows the equivalent circuit of the multi-resonant type inductor, where each of the single resonant circuits is magnetically coupled.

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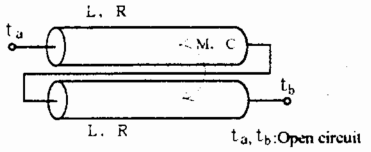
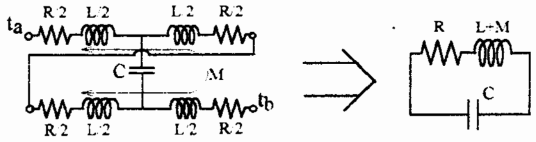
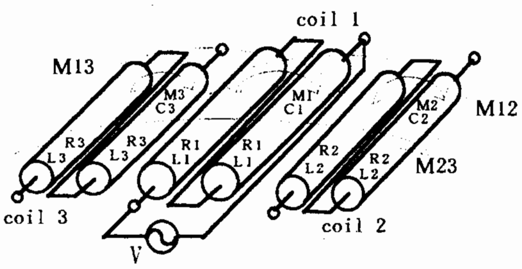


(a)

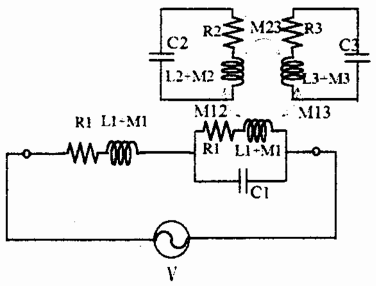


(b)

Fig.2 Principle of a resonant circuit. (a) Method of circuit connection, and (b) Equivalent circuit.



(a)



(b)

Fig.3 Principle of multi-resonant type inductor. (a) Basic structure, and (b) Equivalent circuit.

C. Frequency characteristics

Based on the structure shown in Fig.3(a), we designed an inductor to have three resonant frequencies. Figure 4 shows its construction and Table 1 lists its dimensions.

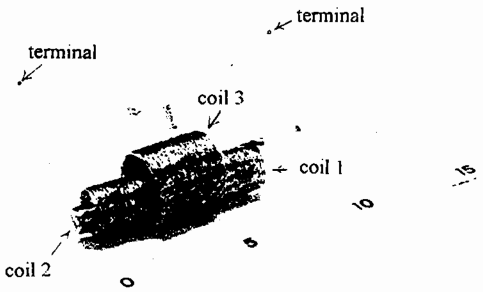


Fig.4 Exterior view of a multi-resonant inductor. (3 resonant)

Table 1.
Various constants of a multi-resonant inductor.

No.	wire diameter [mm]	entire wire length [m]	solenoidal coil diameter [mm]	turns [turns]
coil 1	0.6	6	15.5	108
coil 2	0.3	6	8.2	216
coil 3	0.4	6	28.2	66

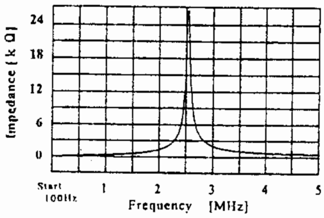
In order to verify the frequency characteristics of this inductor, we carried out experiments under three different conditions, i.e., single, two and three resonant conditions. Frequency characteristics of the multi-resonant type inductor were measured by means of an HP4194A impedance analyzer.

Figure 5(a) shows a single resonant frequency characteristic, where the coil 1 has been connected in the way shown in Fig.1(b), but the remaining two coils 2 and 3 have been removed.

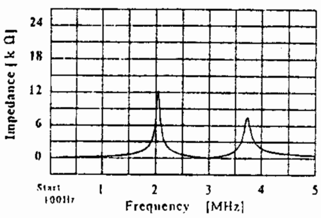
Figure 5(b) shows the characteristic exhibiting two resonant frequences, where the coil 1 has been connected in the way shown in Fig.1(b), and coil 2 have been connected in the way shown in Fig.2 (a), but the remaining coils 3 have been removed.

Figure 5(c) shows the characteristic exhibiting three resonant frequencies, where the coil 1 has been connected in the way shown in Fig.1(b), where remaining two coils 2 and 3 have been connected in the way shown in Fig.2(a).

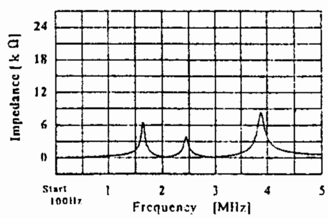
According to the results in Fig.5, the impedance at the resonant frequency decreases as the number of coil increases, because the resonant circuits are parallel circuit. Also, it is obvious that the multi-resonant inductor can be constructed using the simple coil arrangement and connection method shown in Fig.2(a).



(a) 1 resonant mode



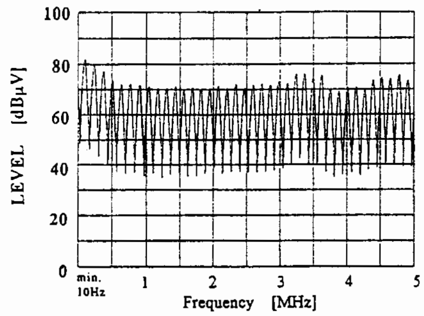
(b) 2 resonant mode



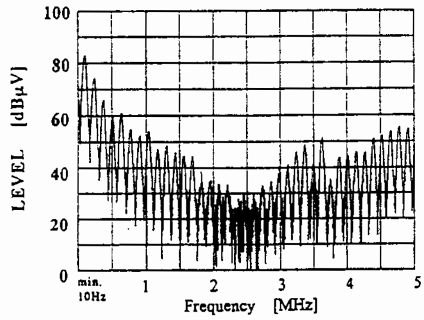
(c) 3 resonant mode

Fig. 5 Frequency characteristics of the multi-resonant inductor. (a) 1 resonant mode, (b) 2 resonant mode, and (c) 3 resonant mode.

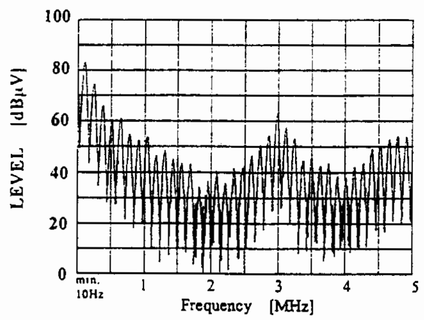
D. Noise filtering characteristics



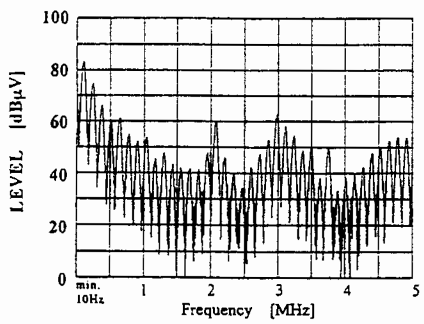
(a) Without filters



(b) With 1 resonant coils



(c) With 2 resonant coils



(d) With 3 resonant coils

Fig.6 Frequency spectra at the load terminal of a DC to DC converter. (Switching frequency is 125kHz.) (a) Without a resonant type inductor, (b) with the inductor having a single resonant frequency, (c) with the inductor having two resonant frequencies, and (d) with the inductor having three resonant frequencies.

As an application of our multi-resonant type inductor, we connected our inductor in series with the output line of a DC to DC converter connected to a 50 Ω resistive load. Higher harmonics spectra were measured at the load terminal using a spectrum analyzer.

Figure 6 shows the noise filtering characteristics of the multi-resonant type inductor. The experimental results demonstlate that the multi-resonant type inductor exhibits a notch filtering capability. Thus, simple replacement of a conventional smoothing inductor by our new multi-resonant type inductor makes it possible to eliminate the selected undesirable frequencies.

III. CONCLUSION

In this paper, we have succeeded in extending our concept of a resonant type inductor into a multi-resonant type inductor. It was shown that a multi-resonant type inductor can be used as one of the notch filters.

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