A Thin Film Common Mode Noise Filter and Its Evaluation by Wavelet Analysis

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Abstract— With the developments of modern electronic switched mode power supplies, greater attention is being focused on line noise problems. To overcome this difficulty, we have previously proposed a resonant type inductor having a noise filtering capability. In the present paper, we develop a film filter implementation of a resonant type inductor. Also, we employ a wavelet analysis technique to evaluate the noise filtering characteristics of the filter. The thin film shape inductor was designed and was used eliminate the line noise caused by a switched mode power supply.

I. INTRODUCTION

With the development of modern semiconductor devices, greater attention is being focused on electromagnetic compatibility problems because the semiconductor's switching generates a high frequency line noise. Furthermore, some of the modern electronic devices, e.g., notebook computers and cordless telephones, are required to be small and light. Power supplies in such products occupy a significant amount of space and are relatively heavy. In order to minimize the weight and size of the magnetic elements (transformer and inductor), the operating frequency of the switched mode power supplies must be raised to over 1MHz [1,2]. For such high frequency operation, switching noise leads to a serious line noise problem. To overcome this difficulty, we have previously proposed a resonant type inductor having a noise filtering capability [3].

In the present paper, we develop a common mode noise filter employing the resonant type film inductor. Further, we propose a wavelet analysis technique to evaluate the noise filtering characteristics of the filter [4].

II. EXPERIMENTAL

A. Common mode noise filter

We have previously proposed a resonant type inductor [4]. This inductor has been constructed using a copper coated polyimide film. Fabrication was accomplished using chemical etching processes. Figure 1 shows the picture of the film inductor. Figure 2 shows the frequency vs. impedance characteristic of the prototype inductor.

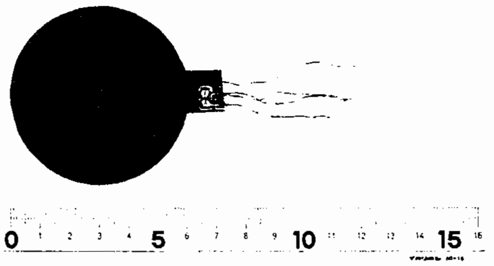

Fig.1. Prototype of film inductor

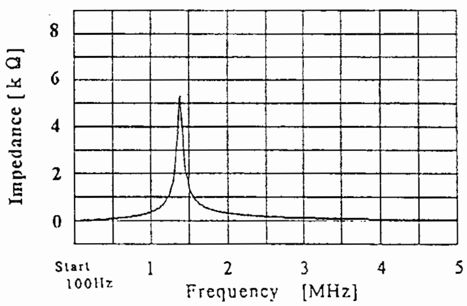

Fig.2. Impedance vs. frequency characteristic of the prototype inductor.

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Figure 3 shows a common mode noise filter circuit employing the resonant type inductor. Figure 4 shows the measurement system which was used to quantify the common mode noise caused by a switched mode power supply. Figures 5(a) shows the common mode noise Fourier spectrum observed at the input terminals of switched mode power supply. As shown in Fig.5(b), attaching the noise filter eliminates the higher harmonic noise spectra.

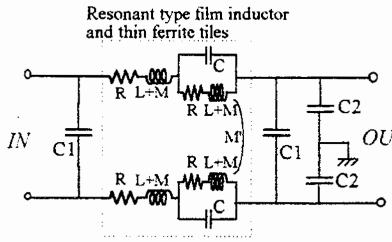


Fig.3. A common mode noise filter circuit employing the resonant type inductors.

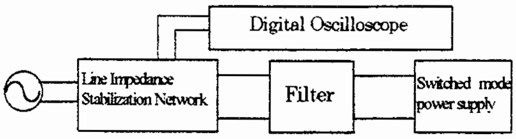
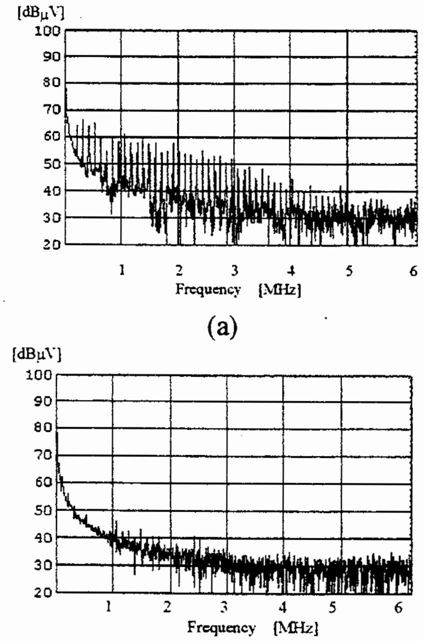


Fig.4. Measurement system



(b)

Fig. 5. Common mode noise Fourier spectrum caused by a switched mode power supply. (a) Original common mode noise Fourier spectrum, (b) common mode noise Fourier spectrum after attaching the noise filter employing the inductor sandwiched between two thin ferrite tiles.

B. Discrete wavelet transform

The Fourier spectrum reveals only the frequency information. Therefore, it is difficult to obtain the noise waveforms from the Fourier spectrum. To overcome this difficulty, we employed the wavelet analysis technique. Wavelet analysis makes it possible to get the time as well as frequency domain information [4].

Let us consider the following linear transformation.

$$X' = CX, \tag{1}$$

where X is a data vector with order n (n must be a power of 2). Matrix C is given by

$$C = \begin{vmatrix} C_0 & C_1 & 0 & 0 & \cdots & 0 & 0 \\ C_1 & -C_0 & 0 & 0 & \cdots & 0 & 0 \\ 0 & 0 & C_0 & C_1 & \cdots & 0 & 0 \\ 0 & 0 & C_1 & -C_0 & \cdots & 0 & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & 0 & 0 & \cdots & C_0 & C_1 \\ 0 & 0 & 0 & 0 & \cdots & C_1 & -C_0 \end{vmatrix}, \tag{2}$$

where

$$C_0 = C_1 = 1/\sqrt{2}. \tag{3}$$

For simplicity, let us consider a data vector X with order 8,

$$X = \begin{bmatrix} x_1 & x_2 & x_3 & x_4 & x_5 & x_6 & x_7 & x_8 \end{bmatrix}^T, \tag{4}$$

then X' becomes

$$X' = C_8 X = \begin{bmatrix} s_1 & d_1 & s_2 & d_2 & s_3 & d_3 & s_4 & d_4 \end{bmatrix}^T. \tag{5}$$

The elements in vector X' are sorted by means of the following matrix.

$$P_8 = \begin{vmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{vmatrix}. \tag{6}$$

Thus, we have

$$\begin{aligned} P_8 X' &= P_8 C_8 X = W_8^{(1)} X \\ &= \begin{bmatrix} s_1 & s_2 & s_3 & s_4 & d_1 & d_2 & d_3 & d_4 \end{bmatrix}^T. \end{aligned} \tag{7}$$

Further transformation to the elements s_1, s_2, s_3, s_4 in Eq.(7) yields

$$W_8^{(2)} X = \begin{bmatrix} S_1 & S_2 & D_1 & D_2 & d_1 & d_2 & d_3 & d_4 \end{bmatrix}^T. \tag{8}$$

Similar transformations to S_1, S_2 in (8) yields

$$W_8^{(3)} X = \begin{bmatrix} S_1 & D_1 & D_1 & D_2 & d_1 & d_2 & d_3 & d_4 \end{bmatrix}^T, \tag{9}$$

where $W_8^{(2)}$ and $W_8^{(3)}$ are

$$W_8^{(2)} = (P'_8 C'_8)(P_8 C_8), \quad W_8^{(3)} = (P''_8 C''_8)(P'_8 C'_8)(P_8 C_8), \tag{10}$$

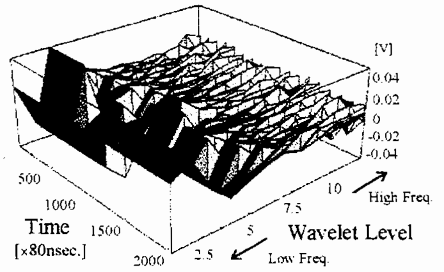
$$P'_8=\begin{bmatrix}P_4 & 0\\ 0 & I_4\end{bmatrix},\quad C_8'=\begin{bmatrix}C_4 & 0\\ 0 & I_4\end{bmatrix},\quad P''_8=\begin{bmatrix}P_2 & 0\\ 0 & I_6\end{bmatrix},\quad C_8''=\begin{bmatrix}C_2 & 0\\ 0 & I_6\end{bmatrix} \tag{11}$$

where I_n is a n-th order unit matrix.

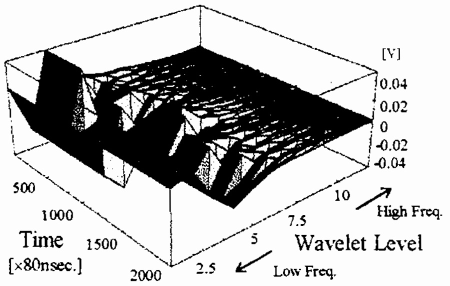
Equation (9) represents the wavelet spectrum. The elements $\mathbf{S}_1$ in (9) are called the mother wavelet coefficient, and the others are called the wavelet coefficients at each level.

C. Evaluation of noise filtering characteristic by wavelet analysis

Figure 6 shows the absolute value of the wavelet spectrum. The horizontal axis corresponds to the frequency. Figure 6 is similar to the Fourier spectrum in Fig.5. Figure 7 shows the three dimensional representation of the common mode noise characteristics using the wavelet approach. In this figure, vertical and horizontal axes correspond to the noise amplitude and frequency, respectively. Large horizontal values correspond to higher frequencies. From Fig.7(b), it is obvious that the higher frequency noise components are substantially reduced by the filter. Also, it is demonstrated that an application of the wavelet analysis to the high frequency noise problem is a useful approach for evaluating the filter characteristics in the time as well as frequency domains.

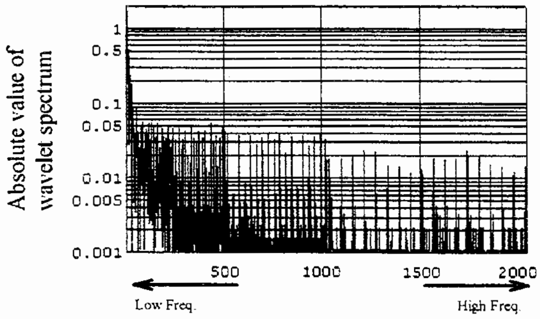


(a) Without filter

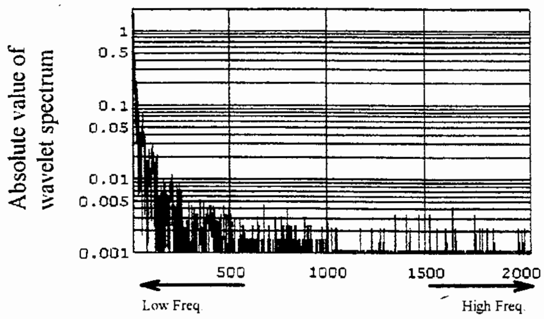


(b) With film filter

Fig.7 Multi dimensional analysis of the common mode noise. The vertical and level axes correspond to the noise amplitude and frequency, respectively. Higher values for level correspond to the higher frequencies.



(a) Without filter



(b) With film filter

Fig.6 Wavelet spectrum of the common mode noise.

III. CONCLUSION

In this paper, we have described the construction of a resonant type film inductor. This inductor has been designed for use as a common mode noise filter. A wavelet analysis technique was used to evaluate the high frequency noise characteristics of the filter. The experimental results demonstrate that the common mode noise was eliminated by the film shape filters. Further, it was shown that the wavelet analysis was one of the promising methodologies for filter characteristic evaluation.

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