Source Diagnosis Method for Radiated EMI Noise Based on Wavelet and ICA Strategy

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Abstract. In this paper, the independent component analysis (ICA) algorithm, combined with wavelet algorithm, are introduced to diagnose the radiation noise source, also to segregate various radiation noise components. The nonlinear time domain signals of superposed radiation noises are measured using multi-channel high-speed digital oscilloscope. Double frequency domain analysis of radiation noise are conducted with the proposed method. Furtherly, time-frequency joint graph of excessive radiation noise are accessed, according to overclock points. The radiation noise component is determined by employing signal separation algorithm. The effective diagnosis of common frequency radiation noise is thus realized, which contributes to reducing the radiated noise electronic device emitted.

1. Introduction

THE rapid development of high-speed digital circuit brings out seriously radiation noise [1-5]. In order to effectively suppress the radiated noise of electronic equipment, it is necessary to determine the radiation noise source which caused the excessive radiation noise. However, there are a large number of nonlinear devices in electronic equipment, and all of them could emit radiation noise. Therefore, it is difficult to diagnosis the characteristics of radiation noise. On the basis of the occurrence mechanism of radiation noise, it can be divided into the common and uncommon frequency radiation noise source. For one thing, the common frequency radiation noise source refers to the high-frequency noise caused by 2 or more electronic device superposed in the same frequency. For another, the uncommon frequency radiation noise source refers to the high-frequency noise caused by electronic device superposed in the different frequency. To be more specific, common frequency radiation means high frequency noise emitted by several electronic devices superposed in a certain frequency while the uncommon frequency noise emitted by only one single device.

Domestic and foreign experts and scholars have done a research on the diagnosis of radiated noise source. Wei discusses the application effects of the two numerical simulation methods of linear filtering and Fourier inverse transform [6]. Miroshnichenko describes a synchronous two-frequency oscillation regime characterized by cooperative interaction of the excited modes in the DRO [7]. Yang researches on the detection and direction finding (DF) algorithm of mixed signals under the background of interference [8]. Liu uses the SVM method to analyze training data set, build and test the classification model, gets higher classification accuracy in noise environment [9]. Sfavi-Naini S proposes a technique for analyzing the problem of radiation from a point electromagnetic source located on a perfectly conducting cylinder of finite length [10]. S. Saidi uses the Artificial Neural Network (ANN) and the Pseudo Zernike Moment Invariant (PZMI) to search and identify the radiation sources [11]. Shi D proposed a new method to identify EM radiated noise sources by using their
spatial characteristics as unique parameters for the ANN [12]. Dan S presents a new approach to improve Electromagnetic Radiation Source Identification by adopting support vector machines [13].

Traditional wavelet and ICA algorithms have been widely applied in various subjects [14-16], while are not very effective in case of multiple sources noise. In this paper, a novel method by combing wavelet and ICA is proposed, which can analyze the common frequency radiation source more accurate and quicker in comparison with other popular method of multi-radiation source analysis. Furthermore, it is simple to operate and complete in real application.

2. Theoretical analysis

Modern electronic equipment usually includes ARM, microcontroller, crystal oscillator and many other devices can emit high frequency noise. These kinds of noise would arouse radiant electromagnetic field in the space and caused serious radiation noise by overlay each other. The present method of diagnosis and test radiation sources is to adopt EMI receiver, anechoic chamber and far field antenna to determine the uncommon frequency radiation noise. However, this existing method cannot diagnose the common radiation noise.

There are a number of noise sources in the actual circuit board. The multiple sources noise model of the actual circuit board is shown in Figure 1, wherein different sources are contained in the circuit board. The radiation noise caused by each source includes common and different mode, which are expressed as $E_{CM1}, E_{CM2}, \ldots E_{CMi}(i=1,2,\ldots n); E_{DM1}, E_{DM2}, \ldots E_{DMj}(j=1,2,\ldots n)$ respectively. The total noise in certain frequency of this board is formed by all of these noises overlay each other in the same frequency.

On the basis of Maxwell equation and the electric dipole radiation theory, common mode radiation field intensity in the far field refers to:

$$E_{CMi} = 12.6 \times 10^{-12} \frac{fI_{CMi}}{r}$$  \hspace{1cm} (1)

In Eq. (1), $I_{CMi}$ is common mode radiation current. $L$ is the radiation length of cable, $r$ is test distance. The electric field intensity of different mode radiation field in the far field is:

$$E_{DMj} = 2.632 \times 10^{-14} \frac{f^2A_{DMj}}{r}$$  \hspace{1cm} (2)

In Eq. (2), $f$ refers to the frequency of the signal, $A$ is the loop area of the signal current. $I_{DMj}$ is the different current while $r$ is the test distance.

Therefore, in this paper, radiation noise component is determined by combining wavelet and ICA algorithms. The common radiation noise is diagnosed effectively, which contributes to reduce the radiated noise of electronic devices.

![Figure 1. Multiple Sources Noise Model of Circuit Board](image-url)
3. Source diagnosis method

The flow chart of the source diagnosis method was shown in Figure 2, which includes four steps.

**Step 1:** Supposed $x_1(t)$ and $x_2(t)$ as two measured signals in time domain. Based on the energy limited function, it satisfied $x_1(t), x_2(t) \in L^1(R)$ and the continuous wavelet refers to:

$$W_{x(t)}(a,b) = \{x(t), \psi_{a,b}(t)\} = \frac{1}{\sqrt{|a|}} \int_{-\infty}^{\infty} x(t)\psi(t-b/a)dt$$  \hspace{1cm} (3)

In the above equation, $a$ means scale factor while $b$ means shift factor, $a, b \in R$ and $a \neq 0$. $\psi(t)$ on behalf of the basic wavelet or mother wavelet, and it can turn into wavelet function $\psi_{a,b}(t)$ by scale expansion and time shift:

$$\psi_{a,b}(t) = \frac{1}{\sqrt{|a|}}\psi(t-b/a)$$  \hspace{1cm} (4)

And meet the condition:

$$C_{\psi} = \int_{-\infty}^{\infty} \left| \mathcal{F}_\psi(\omega) \right|^2 d\omega < \omega$$  \hspace{1cm} (5)

In the above type, $\mathcal{F}_\psi(\omega)$ is the Fourier transform of $\psi(t)$. Eq. (3) decomposed the function $x_1(t)$ into a number of wavelet coefficients $W_{x_1(t)}(a,b)$, and these coefficients can refactor the function $x_1(t)$:

$$x_1(t) = \frac{1}{C_{\psi}} \int_{-\infty}^{\infty} \int_{\infty}^{\infty} W_{x_1}(a,b)\psi(t-b/a)\frac{1}{a}dadb$$  \hspace{1cm} (6)

$x_2(t)$ adopt the same algorithm with $x_1(t)$. We could get $W_{x_2}$ after wavelet algorithm.

**Step 2:** Take $x'_1(t)$, $x'_2(t)$ when $f=f_1$ ($f_1$ is the frequency of radiation noise exceed the standard point), and define the matrix $A = [x'_1(t), x'_2(t)]$.

**Step 3:** Define the initial value of random weight vector $W$ is $W_0$. $W_0$ is a normal distribution matrix, the mean value is 0 and variance value is 1. And supposed the non quadratic function $G(x)$

$$G(x) = \frac{1}{a_i} \lg \cosh a_i x$$  \hspace{1cm} (7)
Where, \( 1 \leq a_i \leq 2 \) (\( a_1 \) is a constant). \( \cosh \) is hyperbolic cosine function.

And \( g(x) \) is the derivative of \( G(x) \):

\[
g(x) = G'(x) = \tanh(a,x) \tag{8}
\]

The \( n \)th iteration random weight vector \( W_n \) is:

\[
W_n = E(Ag(W_{n-1}^T) - E(Ag'(W_{n-1}^T))W_{n-1} \tag{9}
\]

Where, \( E \) is the mean value function, while \( g' \) is the derivative of \( g \).

\[
g(W_{n-1}^T,A) = \tanh(a,W_{n-1}^T,A)
\]

\[
g'(W_{n-1}^T,A) = \sec^2(a,W_{n-1}^T,A) \tag{10}
\]

Where, \( \sec \) is the secant function.

Repeat the above calculations until the random weight vector \( W \) is convergence.

**Step 4:** The components of the radiated noise source are \( y_1(t) \) and \( y_2(t) \),

\[
Y = (y_1(t), y_2(t)) = W \cdot A \tag{11}
\]

4. **Experimental verification**

4.1. **Experimental platform**

The experimental schematic diagram and physical layout are shown in Figure 3 and Figure 4. Noise source circuit is consist of two oscillators: 5MHz crystals and 12MHz crystals. The Tektronix DPO5204B multi-channel high-speed oscilloscope and Rohde&Schwarz HZ-11 near field probe were used in the experiment. The DPO5204 sampling rate is set to 2.5GS/s, can meet the needs of the experiment.

![Figure 3. Schematic Diagram](image)

![Figure 4. Physical Layout and Noise Source Circuit](image)

4.2. **The analysis of experimental results**

Oscilloscope DPO5204B and magnetic probe HZ-11 are used to measure the intensity of radiation magnetic field of 5MHz and 12MHz crystals emitted in different location of the working circuit. The measured results are \( x_1(t) \), \( x_2(t) \) respectively. Then, \( x_1(t) \), \( x_2(t) \) are analyzed by Wavelet algorithm and the time frequency results are obtained. The results are shown in Figure 5. Obviously, both of \( x_1(t) \) and \( x_2(t) \) contain complicated distributed noises.
When selecting two groups signal of $f=20$MHz, the time domain waveform of $x_{1f=20$MHz$}(t)$, $x_{2f=20$MHz$}(t)$ is shown in Figure 6.

$x_{1f=20$MHz$}(t)$, $x_{2f=20$MHz$}(t)$ are analyzed and separated by ICA algorithm, and the signals after separated is $x_{1'f=20$MHz$}(t)$, $x_{2'f=20$MHz$}(t)$.

The specific results of these two groups of the signal are shown in Figure 7. The amplitude is significantly lower than before.

After the separation of ICA algorithm, we can get the data $x_{1'f=20$MHz$}(t)$, $x_{2'f=20$MHz$}(t)$. Additionally, we use the wavelet algorithm to analyze the data. It is clearly that the main ingredients of the signal are around 12.21MHz and 19.53MHz, as shown in Figure 8. As 19.53MHz is about 4 times than the 5MHz radiation source in the original noise source circuit, while 12.21MHz close to the 12MHz...
radiation source in the original circuit. Consequently, by comparing with Figure 6, the method proposed in this paper can analyze the common frequency radiation noise effectively.

Figure 8. Wavelet results

5. Conclusion
Noise superposed signals are first measured by multi-channel high-speed digital oscilloscope, which caused by noise sources in different locations. The wavelet is then employed to acquire double frequency domain signals. Combined with ICA algorithm, the radiation noise source is further diagnosed. In addition, each radiation noise components are segregated. Finally, the component causing radiation noise is defined by using nonlinear signal separation algorithm. The proposed algorithm contributes to reducing the radiated noise emitted by electronic device.

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