Wavelet transform – a new tool for electronic product designing in accordance with Electromagnetic Compatibility

Abstract – **For a long time one of major troubles for electronic product designing EMC (Electromagnetic Compatibility) accordance is that we design and process the product according to its voltage waveform, but evaluate the product EMC status according to its frequency spectrum, that makes the EMC status of the product be immeasurable during the design and process. This paper offers a new approach that uses Wavelet to analyse signal in time-frequency domain, and traces out the EMI from EUT both in physical location and in time location.**

Index Terms **–Wavelet, electronic design, EMC, EMI detection.**

1. INTRODUCTION

Up to now we design and produce the electronic product according to its voltage waveform, and evaluate its EMC (Electromagnetic Compatibility) status according to its frequency spectrum. That makes accordant with EMC ruler during the electronic product designing be a difficult thing: When we monitor the voltage waveform during the design and process period, we don't know how the different waveform points in the time domain contribute to the frequency domain. Vice versa, when we evaluate the EMI (Electromagnetic Interference) distribution in frequency domain during EMC test, we don't know a specialized EMI in frequency domain mainly relates to what points of waveform in time domain.

It is intuitive to look for a mathematical tool to bridge time domain and frequency. For a long time, Fourier Transform (FT) has predominated the signal frequency analysis field:

The Fourier transform for $f \in L^2(R)$ is

$$\hat{f}(w) = \int_{-\infty}^{+\infty} f(t) e^{-iwt} dt \qquad (1)$$

But FT has two weaknesses: when it transfers signal from time-domain into frequency-domain, it loses all the signal's time-domain information. Vice versa. Another weakness of FT is that it supposes the signal is stationary and periodical according to function (1), but in many EMC applications, the EMI such as a spark from tram or from switcher, is transient and non-periodical. The best solution should be to observe signal both in time and in frequency domain synchronously, that means, the time-frequency analysis.

2. TIME-FREQUENCY DOMAIN ANALYSIS

There are series mathematical tools for time-frequency domain analysis. Most of them can be catalogued into Short Fourier Transform (STFT) and Wavelet Transform (WT).

Short Time Fourier Transform is developed for $f \in L^2(R)$

$$Sf(u,x) = \int_{-\infty}^{+\infty} f(t) g(t-u) e^{-ixt} dt \qquad (2)$$

It indicates that the signal $f(t)$ is decomposed into the basis functions $g(t-u)$, a shape-fixed-box, on time-frequency domain (Fig 1).

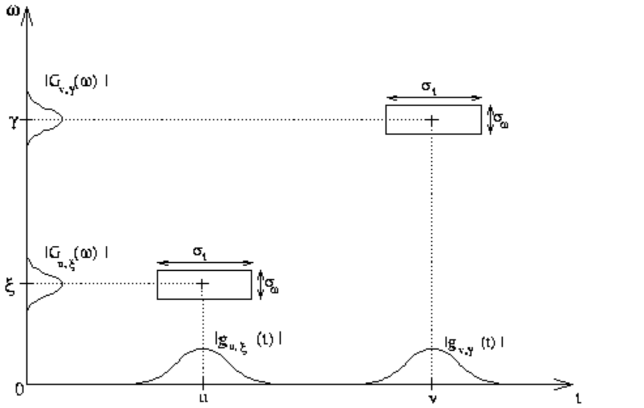

Fig 1. Short Time Fourier Transform on time-frequency domain [1]

The Continuous Wavelet Transform (CWT) of $f \in L^2(R)$ at the time u and scale s is

$$Wf(u,s) = \int_{-\infty}^{+\infty} f(t) \frac{1}{\sqrt{s}} y^{*}\left(\frac{t-u}{s}\right) dt \qquad (3)$$

It indicates that the signal $f(t)$ is decomposed into the basis functions $y_{u,s}(t)$, a shape-variable-box, on so-called "time-scale" domain (Fig 2). Considering that the inverse scale is the frequency, it is easy to be translated into time-frequency domain.

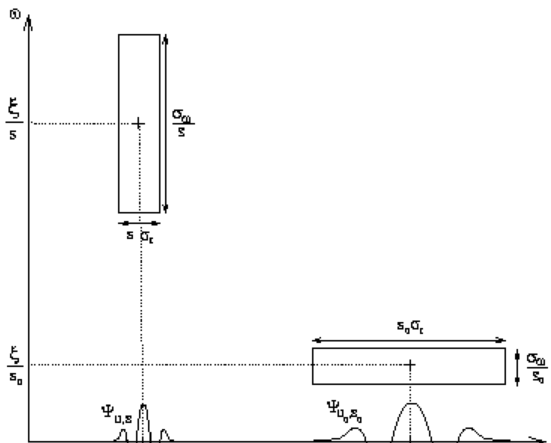

Fig 2 Wavelet Transform on time-frequency domain [1]

Both STFT and WT can evaluate the signal $f(t)$ in Time-Frequency domain. Considering that comparing Fig 1 and Fig 2, WT has more advantage in frequency analysis than STFT due to the fact that WT can automatically adjust the frequency resolution to meet different resolution requirement when analysing in high frequency (require lower frequency resolution) or in low frequency (require higher frequency resolution), we use wavelet as the time-frequency domain analysis tool in EMC applications.

3. ADVANTAGES OF WAVELET APPLICATION IN EMC

3.1 Testing non-stationary or transitory EMI

Don't like FT that decomposes signal $f(t)$ into the periodical base e^{-iwt} that extends in the time from zero to infinite (function (1)), WT decomposes signal $f(t)$ into the transitory basis functions $y_{u,s}(t)$ that only covers a very small time period (function (3)) so that can be used to measure transitory and non-periodical EMI.

3.2 Indicating EMI's position in time domain

Because WT decomposes signal $f(t)$ into the transitory basis functions $y_{u,s}(t)$ that has corresponding location in both time and frequency, it not only transfers signal into frequency, but also indicates where the frequency is located in time. For most electronic product design engineers, if they know the exact time domain location of specialized EMI frequency, they will be able to trace out the components that generate the waveform corresponding to that time point, so that can reduce the EMI by modifying the waveform by replacing the components with different ones [2].

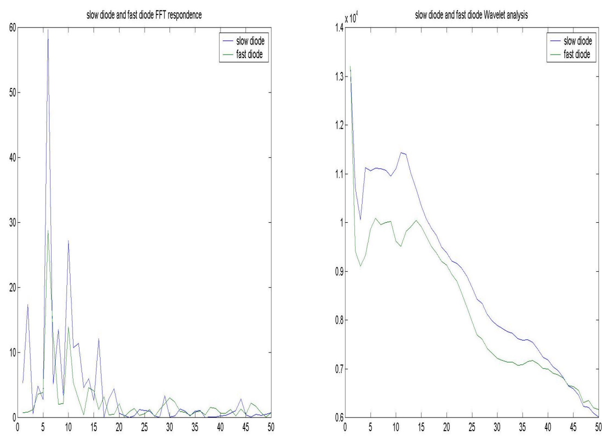

Fig 3 FT (left) and WT (right) results comparison of a DC-DC converter before and after changing component

3.3 Faster than FFT when checking single frequency EMI

During EMC application, if we know EMI of a EUT over EMC limitation in a specialized frequency and want to calculate EMI of the specialized frequency, WT is faster than FT because WT can only calculates one point of frequency meanwhile FT has to calculate all frequencies cover the frequency spectrum.

Fig 3 shows that when comparing the difference of the frequency distribution on a DC-DC converter before and after changing component, WT properly indicates the difference and FT fails to apply.

4. DISADVANTAGES OF WAVELET APPLICATION IN EMC [3]

- When calculating full frequency spectrum, WT is time consuming.
- WT has lower frequency resolution than FT due to WT calculating frequency with band so that the calculating result indicates the frequency with the average value of the band.
- Frequency identification accuracy depends on wavelet and estimating rule.

Wavelet transform coefficients also vary on different wavelet mother functions.

5. STRATEGY OF WAVELET APPLICATION IN EMC

5.1 Using Wavelet as an analysis tool rather than a measurement tool

If our purpose were EMC analysis, we usually hope in high frequency have higher time resolution and in low frequency have higher frequency resolution, then the multi-resolution analysis property of WT would be an asset. If our purpose were EMC measurement to retrieve EMI amplitude and power directly from the spectral magnitudes, the multi-resolution property of WT would be a drawback because the multi-resolution effect also reduces the magnitude of higher frequency component from its real magnitude.

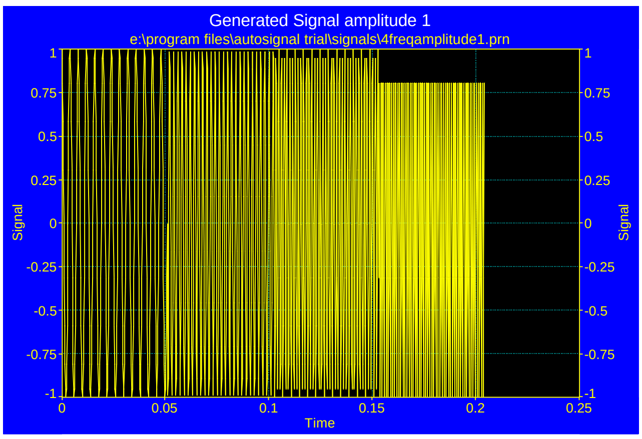

Fig 4 Sine wave successive in 250 Hz, 500Hz, 750Hz, 1000Hz

Above discussion can be well illustrated by transferring Fig 4 signal that connects four different frequency's sine waves successive in time with the same amplitude, by Morlet CWT, into Fig 5. Fig 5 well indicates the different frequency component locations in time but fails to indicate correctly the amplitude. It is because that the CWT magnitude is a property of the smearing in both the time and frequency dimensions so that varies with frequency. Further, the smearing in time and frequency is a product of the wavelet and its adjustable parameter (for example, N in dbN).

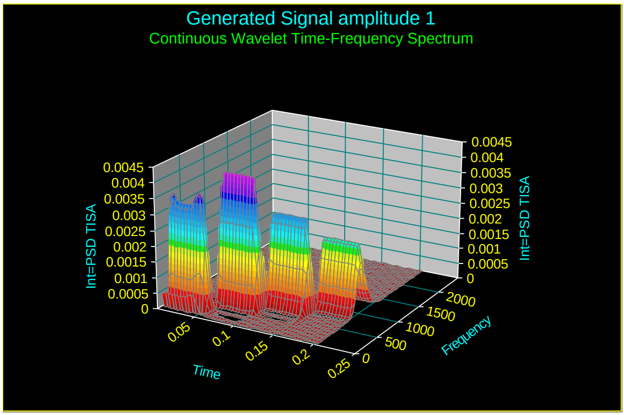

Fig 5 CWT 3D transform of Fig 4 signal

5.2 Select Wavelet arithmetic function and wavelet mother function according to EMC application requirement

The first step to initiate a wavelet application in EMC issues is to choose Continual Wavelet Transform (CWT) or Discrete Wavelet Transform (DWT) as a WT tool. CWT can continually transfer signal from time domain into time-frequency domain and in most EMC issues EMI may occur in any frequency, so that for EMC analysis, CWT should be a right choice. DWT decomposes the signal into discrete frequency bands with less redundancy and is fast than CWT, so that if our purpose is signal de-noise, then DWT will be a right choice because signal de-noise only focuses on the signal decompose and reconstruction arithmetic regardless of the frequency distribution.

The second step should be choosing a suitable Wavelet mother function according to different application. According to CWT function (3), it is clear that the wavelet transform results not only depend on signal $f(t)$, but also depend on wavelet mother function y . The former dependence is what we are looking for, the latter dependence is what we never required and should be avoided.

If our purpose were to analysis a group of data by comparing their WT coefficients, or were to continually modify and test an EUT to see if the modifications are in right direction, the best way to avoid the errors caused by the multiformity of y is to sure the same y is used for all data. In this case, any wavelet under CWT catalogue can be considered.

If our purpose were to de-noise signal, a process of signal decompose and reconstruction with specific wavelet, any wavelet under DWT catalogue can be considered.

However, if our purpose were to evaluate or measure EMI quantitatively, we should choose carefully a wavelet mother function y that has better frequency resolution.

Let's generate a 10 MHZ sine wave with MATLAB and evaluate its "global wavelet spectrum" using "Summed-coefficient rule"(5) and "Maximum-coefficient rule"(6). By means of db1 and Morlet wavelets, we obtain Fig 6 and Fig 7 results respectively:

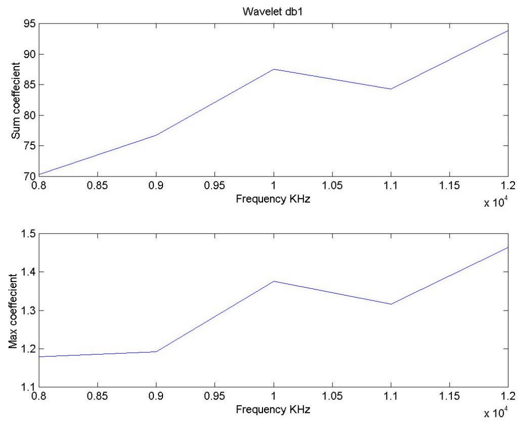

Fig 6 db1 Wavelet "global wavelet spectrum" analysis

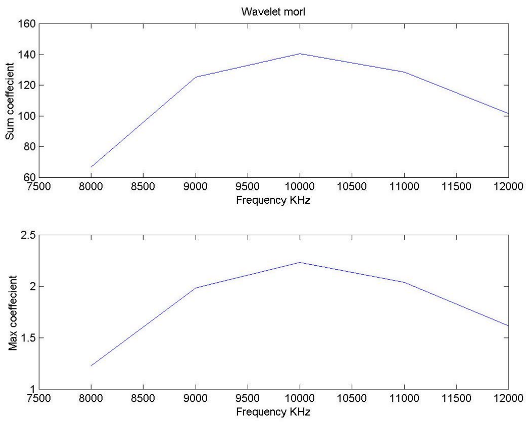

Fig 7 Morlet wavelet "global wavelet spectrum" analysis

It is clear that both db1 and Morlet wavelets indicate a top value in 10 MHZ but db1 results a fake top in 13 MHZ that may raise errors if there were some higher frequency components near by. The same simulation and comparison are made to compare Morlet with other wavelets and result that the Morlet has the best property of frequency resolution comparing with others.

5.3 "Sum-coefficient rule" and "Max-coefficient rule"

To evaluate the signals that last T time in m frequency points and obtain a "global wavelet spectrum", we can use "Sum-coefficient rule" or "Max-coefficient rule". The "sum-coefficient rule" is described in the following arithmetic:

$$Wf_{sum} = \left[\frac{1}{T} \sum_{u=u_1}^{T} Wf_{s,u} \right]_{s=s_1,s_2,\ldots,m} \quad (4)$$

and the "Max-coefficient rule" is described in the following arithmetic:

$$Wf_{\max} = \left\{ \max\left[Wf_{s,u} \Big|_{u=u_1,u_2,\ldots,T} \right] \right\}_{s=s_1,s_2,\ldots,m} \qquad (5)$$

Both result in m points frequency value (m is arbitrary, depending on frequency resolution requirement). In most situations, both arithmetic result in similar curve shape, but sometimes can be variable as Fig 8 shows:

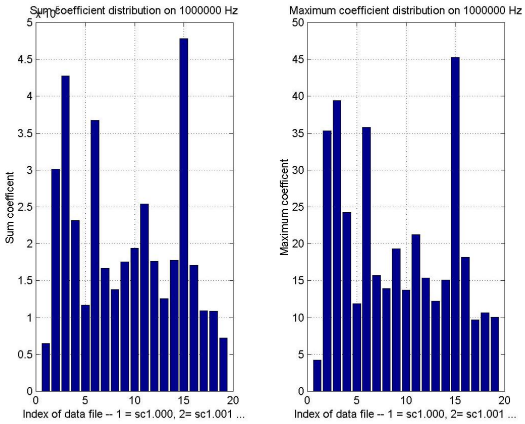

Fig 8 Morlet wavelet transform according to "Sum-coefficient rule" and "Max-coefficient rule"

6. APPLICATION OF WAVELET IN EMC

6.1 locating EMI in layout

We first select several points in EUT layout as the test points. Then, we measure the voltage of the points with a digital oscilloscope, save the waveforms into the data files with different file name, one data file for one test point. The data files are analysed by the software programmed according to the arithmetic introduced above. If we know in which frequency the EMI is above the limit, analysing all of the data files under such a specialized frequency yields Fig 9 results. Fig 9 clearly indicates that the data file named sc1.003 has the highest EMI value in the frequency 13 MHz. Because all the test points are named relating to the different test points, we can quickly locate the test point corresponding to sc1.003 where the EMI source in frequency 13 MHz possibly resides.

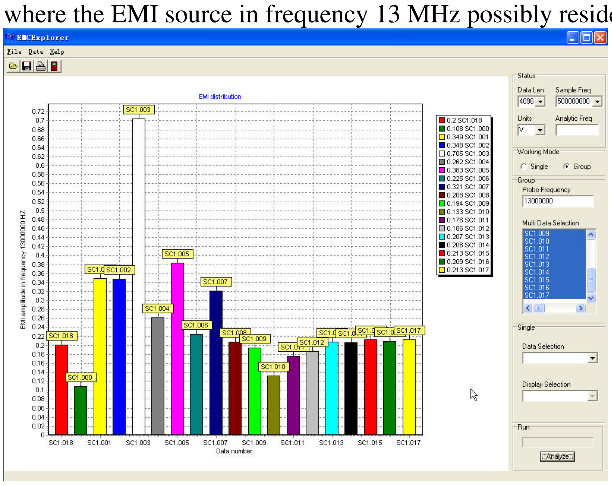

Fig 9 comparison of the specialized-frequency-EMI among the test points.

6.2 Locating EMI in time

After the test point with the maximum EIM is traced out, further analysing the data file of the test point by means of the software's single-signal-analysis can locate EMI position in time (Fig 10). The top window in Fig 10 indicates the original signal in the time domain; and the middle window transform top window signal into Time-Frequency domain and indicates that in signal's fall side there is higher frequency EMI than in rise side. The bottom window shows the analytic frequency component in 20 MHz. If our problem is that the EMI over limitation in 20 MHz, modifying the fall side of the waveform (if the fall side is generated by a component switching off, replacing the component with new one with lower switch-off-speed) will be the correct solution.

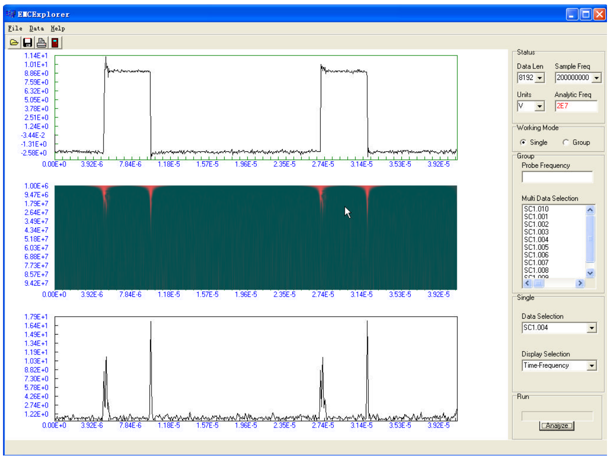

Fig 10 Time-Frequency domain analysis

In most situations, the EMI happens in transient or non-periodical form that the traditional Fourier transform fails to deal with. The Time-Frequency analysis can process the transient and non-periodical signal very well (Fig 11). Fig 11 clearly indicates the transient EMI happens in time 4.7 us, raises the electronic noises around the frequency 20 MHz and 35 MHz. In this way, we can trace out which point of the signal raises the noise that pushes the EMI over the limit.

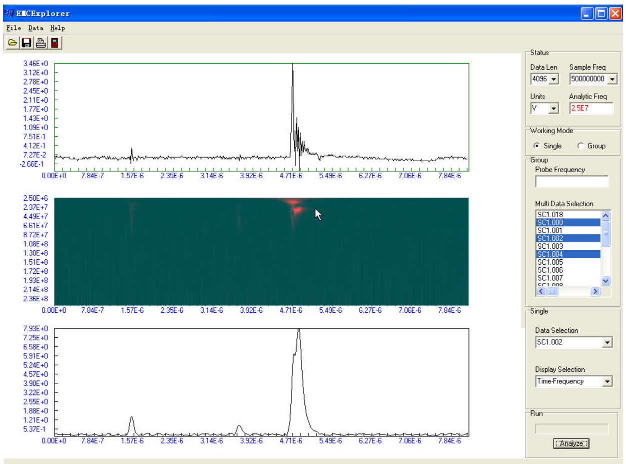

Fig 11 Time-Frequency analysis processes transient EMI signal well

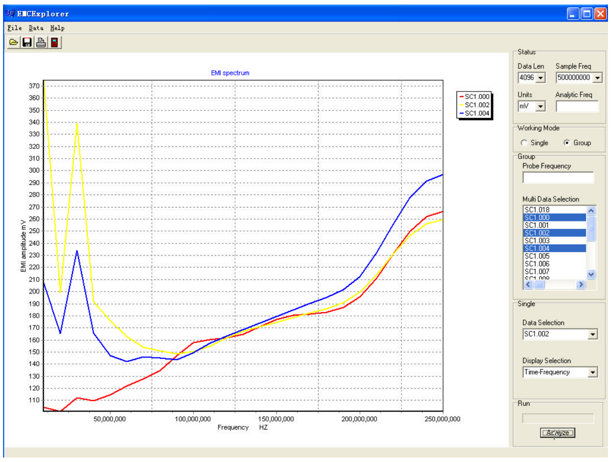

Fig 12 Spectrum comparisons ensure EUT modification in the right direction

6.3 Evaluating EUT modification results

The waveform in a test point can also be transformed into the frequency spectrum by means of the Wavelet. Comparing the different spectrums of the same test point before and after the modifications (Fig 11) can indicate if the modifications relating to the test point are in the right direction.

7. CONCLUTION

Wavelet is a powerful tool for EMC application with some Fourier Transform incomparable merits. It is an analysis tool rather than a measurement tool and has great application potentials in EMC field. The advantages and disadvantages of applying Wavelet in electronic product designing in accordance with EMC are discussed in this paper and a series of strategies for successful application are offered.

8. REFERENCES

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