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Time Synchronized Near-field and Far-field for EMI Source Identification

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***Abstract*—The evaluation of a product in terms of radiated emissions involves identifying the noise sources. Spectrum analyzer (SA) measurements alone are unable to identify noise sources when multiple sources are responsible for emissions at a particular frequency. In this paper, an approach using combined near-field and far-field measurements is proposed. This method consists of recording signals from a near field probe and from an antenna in the far-field using a high speed oscilloscope and analyzing the relationship between them via different post processing methods. The noise source can be identified by varying the location of near-field probe and searching for the probe signal that best correlates to the far field signal. A variety of post processing methods have been employed in this work. The Short Term Fast Fourier Transform (STFFT) is used to visualize the time dependence of the frequency content. Envelope correlation, coherence factor, and cross-correlation methods are further explained and tested for their ability to identify possible sources of emission problems.**

***Keywords*— EMI, source identification, far field and near field, STFFT, coherence, cross-correlation.**

I. INTRODUCTION

Locating the EMI source and identifying the coupling path are the most challenging problems in EMI failure analysis. A spectrum analyzer (SA) is often used first. Besides the amplitude spectrum, it is also able to analyze steady signals' sideband patterns and phase noise and time varying signals' repetition rates and AM modulation signatures. These signatures can be helpful when using near-field measurements to identify sources with similar modulation or sideband characteristics. This approach may not be sufficient for highly complex emission signals that do not have unique spectral characteristics. In such cases, a time synchronized near- and far-field measurement will provide more information. However, most SAs have only one channel, and phase information is not easy to obtain.

The signal timing is quite useful for locating the source of a radiated signal. Hardin et al. [1] successfully identified the causes of the emissions from switched mode power applications by utilizing the video out signal of SA to trigger an oscilloscope, which was used to acquire the near-field probe signal. However, the method will fail if the trigger signal cannot be extracted from the emission signals. Li and Pommerenke [2][3] have used the STFFT to analyze EMI signals. Displaying the signal in both time and frequency domains can help illustrate the composition of complex signals, but the relationship of some compound signals still cannot be determined directly via the STFFT analysis. In the proposed method, far-field and near-field signals are recorded simultaneously by a high speed oscilloscope. Post-processing techniques are applied to determine the relationship between near-field and far-field signals, regardless of whether or not the trigger information exists. The STFFT analysis is carried out first. If the STFFT results still cannot reveal the relationship between two signals, further signal processing techniques aimed at correlation analysis will be employed.

In the following sections, the setup for synchronized measurement is introduced, then the correlation analysis example of a television product is provided. The signal processing techniques, e.g., STFFT, envelope correlation, coherence factor and cross-correlation, are explained in detail in this example.

II. MEASUREMENT SETUP FOR SYNCHRONIZED NEAR-FIELD AND FAR-FIELD

While evaluating the EMI status of a product, the emission signal, whose level is close or exceed the regulation limits, will be of prime concern. This signal is usually in a limited frequency band. High speed oscilloscope can capture all of its details, if the sampling rate and recording length are correctly selected. A scope can simultaneously acquire one or several near-field signals along with the far-field signal from the antenna. Using this method, the time delays and the waveforms of these signals can be compared. Some radiated signals have distinct pulses in their waveforms that can be easily correlated to the near-field signal, e.g., the EMI noise caused by switched mode power supplies [3]. The synchronized measurement is a particularly fast method of locating the source of this type of signal. If neither the near-field signal nor the far-field signal has any clear feature in its waveform that enable identification, post processing methods will be used to determine their relationship.

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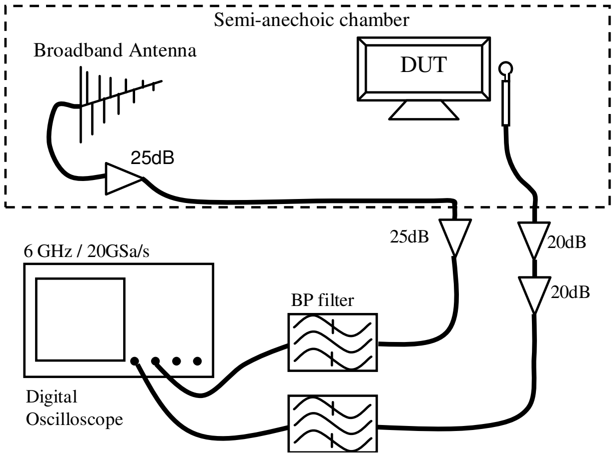

Figure 1. Illustration of measurement setup

A possible setup of the synchronized measurement is shown in Fig. 1. This setup is similar to that of the normal far-field measurement, but one additional signal path from the near-field probe is set up and band-pass filters are inserted in both near-field and far-field signal paths. In the chamber the DUT is rotated to the direction from which it provides its maximum radiation to the antenna in the concerned frequency band. And the antenna is also polarized to receive the maximum radiated field. The near-field probe is carefully placed on the DUT in an effort to cause as little interference to the radiation as possible. The band-pass filters are selected according to the frequency of the critical signals. Their bandwidths are narrow, e.g., 30 MHz. They not only exclude the unwanted signals, but also limit the bandwidth of the input signals to the oscilloscope. The limited bandwidth allows a low sampling rate (The lowest sampling rate is two times the bandwidth according to Nyquist rule). It should be noticed that the band-limited signal will be down converted by the sampling, if the sampling rate is below the signal's frequency. The memory size is usually limited by the hardware. The lower the sampling rate, the longer the time recording length will be. Long data records are always advisable for this analysis. The far-field signal is usually set as the trigger signal.

The cables and amplifiers have a linear phase. However, the log-periodic antenna usually does not have a linear phase. It is a structure of coupled resonant dipoles, and its impulse response shows strong ringing [4]. However, the measurement system has a limited bandwidth of about 30 MHz. Over a narrow bandwidth the log-periodic antenna excites only a few elements. The ringing of the antenna and the filters will limit the ability to distinguish signals in time. Only a few nanoseconds of ringing were observed while most timing analyzed has at least tens of nanoseconds. Thus, no problems were observed caused by using a log-periodic antenna.

III. FAR-FIELD AND NEAR-FIELD CORRELATION ANALYSIS

The setup in the previous section was used to identify an EMI source in a television product. The problematic signal was a complex narrowband signal centered at 667.6 MHz that has multiple sources and multiple modulations. Its spectrum is shown in Fig. 2. The sidebands of the radiated signal are not symmetrical. This unsymmetrical shape was caused by the superstition of several radiated signals in the same frequency band. Since the sidebands did not have a clear structure, it is difficult to correlate the radiated signal to a source by its spectrum. Zero span signals with different sweep times are shown in Fig. 3. AM modulation is clearly visible. There were at least two modulation signals: one had a periodicity of 16.7 ms (60 Hz) with downward pulses, as shown in the top plot of Fig. 3; the other had a periodicity of about 15 µs, as shown in the bottom plot of Fig. 3. The complexity of this signal made it difficult to identify the sources using only SA measurements.

To search for the source, a near-field probe was moved around the TV. Several spots with high signal level at 667.6 MHz were found. However, it was difficult to determine which one was the root source or a point in the coupling path. The relationship between the radiated signal and near-field probe signal can be revealed by applying different post processing techniques to the time synchronized measurement data. These signal processing techniques can be explained by analyzing a set of data in which the near-field signal was obtained from a current clamp around an LVDS cable. The common mode current in the cable was a suspected noise source. In this measurement, the sampling rate was set as 2 GSa/s, and 8 ms of data were recorded. This setup is typically sufficient for analyzing signals in the kHz to MHz frequency range.

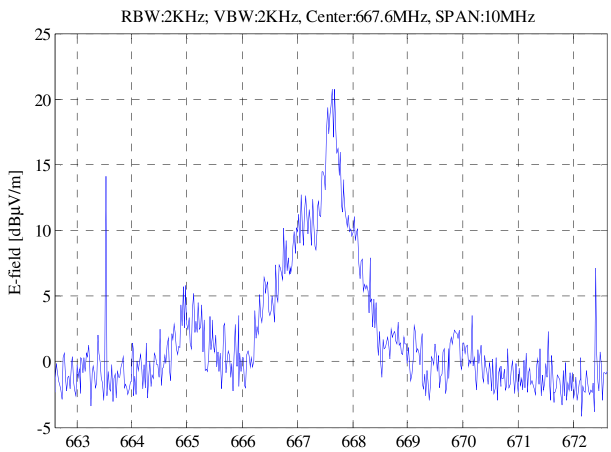

Figure 2. Spectrum of the 667.6 MHz radiated signal

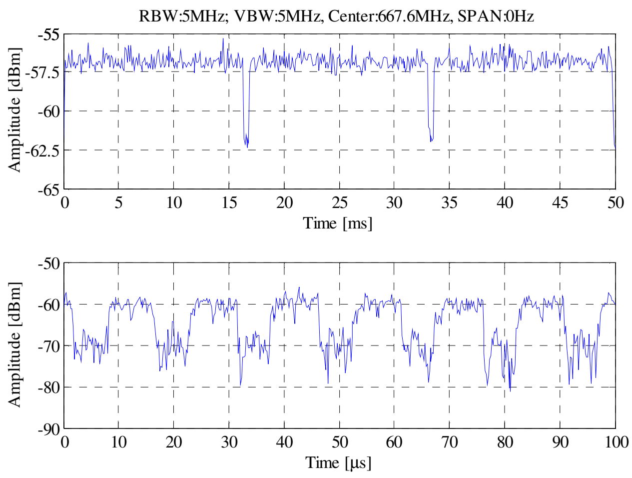

Figure 3. Zero-span signals at 667.6 MHz with 50ms and 100 µs sweep time

A. *STFFT Analysis*

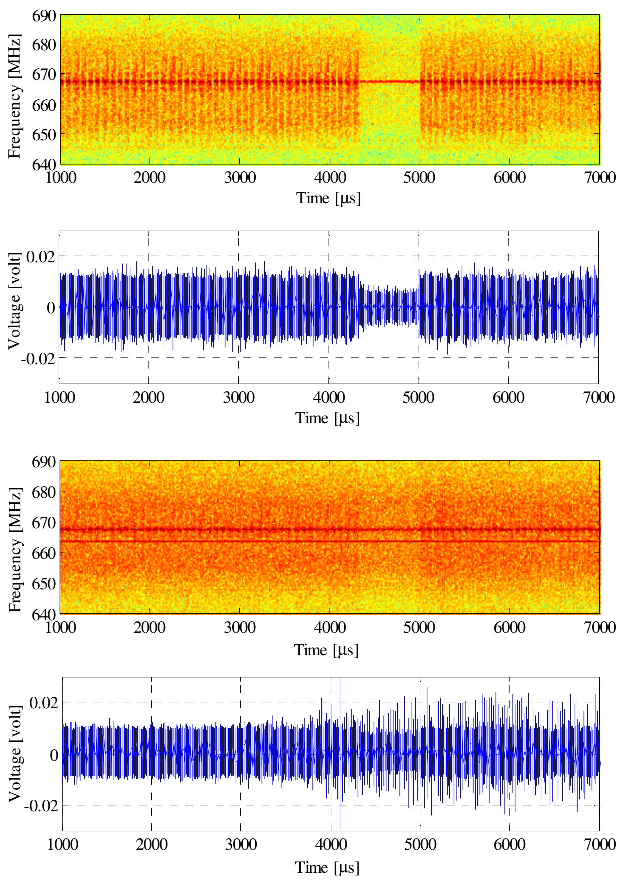

Figure 4. STFFT spectrograms (1st and 3rd plots) and time domain waveforms (2nd and 4th plots) of near-field and far-field signals

The STFFT analyzes the time evolution of the spectral components enabling identification of both FM and AM signals. It splits a long time record into smaller segments and performs an FFT on each of them. The length of each segment controls the resolution of the results. In this case, the time resolution was set to 4 µs, and the frequency resolution was set to 250 kHz. See [5]-[8] for further information on joint-time frequency domain techniques in EMI analysis.

The STFFT analysis results shown in Fig. 4 were calculated in Matlab using the SPECTROGRAM function [9]. The first and the third plot are the time-frequency spectrograms of the near-field signal and the far-field signal, respectively. The second and the fourth plots are the time domain waveforms of the near-field signal and the far-field signal, respectively. The first and second plots show that the near-field signal is an AM signal modulated by pulses of different width, and that its spectrum is symmetrical. The far-field signal in the third and fourth plots looks very noisy. It can be regarded as a combination of three signals: an AM modulation signal similar to the near field signal, a clock signal at 663.5 MHz, and a signal resembling the noise whose spectrum is broader and more uniform. As viewed from the time domain, there is a noticeable drop in signal around 4800 µs in the near-field signal. However, the corresponding drop off can only barely be seen in the far-field signal. Other signals overwhelm this feature. The STFFT analysis indicates a weak correlation between the near-field signal from that location and the far-field signal. Other analysis techniques have been used to identify the relationship of this highly complex radiated signal.

B. Envelope Correlation

The envelope of AM modulated signals signal can be used to show correlation. The envelope data can be obtained by extracting the amplitude data from the STFFT spectrogram at the carrier frequency, i.e. plotting one row of data in the STFFT spectrogram. This envelope is similar to the zero span signal in SA measurement.

In order to compare the shape of two signals, the cross-correlation function is applied. The cross-correlation function for two sequences is given by:

$$R_{xy}(m) = E\left\{x_{n+m} y_n^*\right\} = E\left\{x_n y_{n-m}^*\right\}, \quad (1)$$

where x_n and y_n are jointly stationary random processes and $E\{\}$ is the expected value operator. If the processes x_n and y_n are uncorrelated, the cross-correlation function will be zero. If the two processes are correlated, it will reach its maximal value when m corresponds to the time lag between the two processes. In practice, only a finite segment of one realization of the infinite-length random process is available. The raw value of cross correlation function is calculated by

$$\hat{R}_{xy}(m) = \begin{cases} \sum_{n=0}^{N-m-1} x_{n+m} y_n^* & m \geq 0 \\ \hat{R}_{yx}^*(-m) & m < 0 \end{cases} . \quad (2)$$

The Matlab function XCORR [9] can be used to implement the cross-correlation calculation.

Envelope analysis results are shown in Fig. 5. The top two plots show the envelopes of the near-field and the far-field signals. They are both periodical signals. The correlation function in the third plot indicates that the two envelope signals have the same periodicity. The separation between peaks clearly shows that the periodicity of the envelope signal is about 15 µs, which confirms that the near-field and far-field signals contain the same AM modulation component.

C. Coherence Factor

The most direct way to detect the relationship of two signals is to employ the coherence factor. The coherence factor is defined as

$$C_{xy}(f) = \frac{\left|P_{xy}(f)\right|}{\sqrt{P_{xx}(f)P_{yy}(f)}}, \tag{3}$$

where P_{xy} is the cross power spectral density of sequences "x" and "y", and P_{xx} is the power spectral density of sequence "x", and P_{yy} is the power spectral density of sequence "y". Coherence factor is a function of frequency, the value of which is between 0 and 1. If two signals are linearly related, the coherence factor will be "1" for all frequencies. A coherence factor of "0" indicates that two signals are not related.

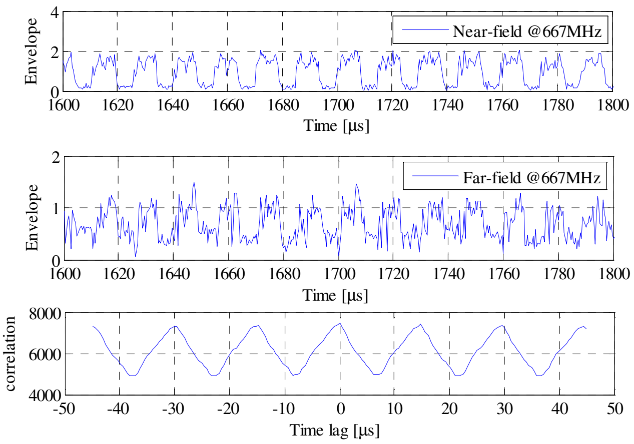

Figure 5. Envelope correlation analysis result of the near-field signal and far-field signal (The first two plots are envelope waveforms, and the third is cross-correlation function.)

The coherence factor can be calculated by the MSCOHERE [9] function in Matlab. The results of coherence factor analysis are shown in Fig. 6. The unit of the Y axis is dB. Because band-pass filters were used in these measurements, the peaks outside the frequency band around 667.6 MHz are caused by random noise. A fairly high correlation can be observed in the narrow frequency band around 667.6 MHz. This method did not reveal the relationship very well in this case, but this method is thought to be worth mentioning. When several sets of experimental data from different near-field probe positions are available, the coherence factor can be employed to determine which near-field signal best correlates to the far-field signal.

D. Cross-correlation Function

Finally, direct calculation of the cross-correlation function was applied to the near-field and far-field signals. This function can provide the exact time lag of two correlated signals, because the position of the maximal value in the cross-correlation function corresponds to the time lag between the two signals. In addition, the periodicity in the cross-correlation function indicates the periodicity of the original two signals.

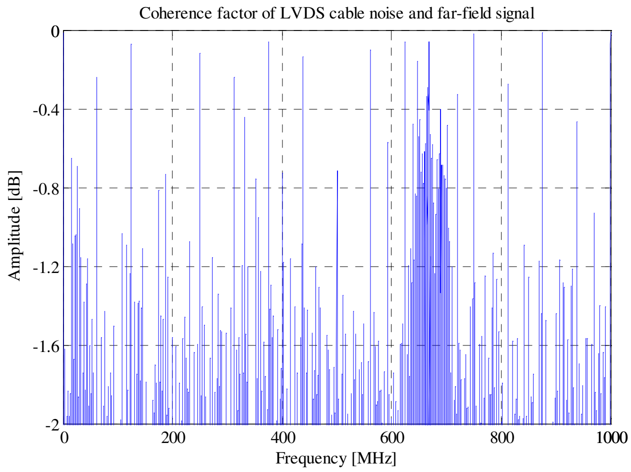

Figure 6. Coherence factor of near-field and far-field signals

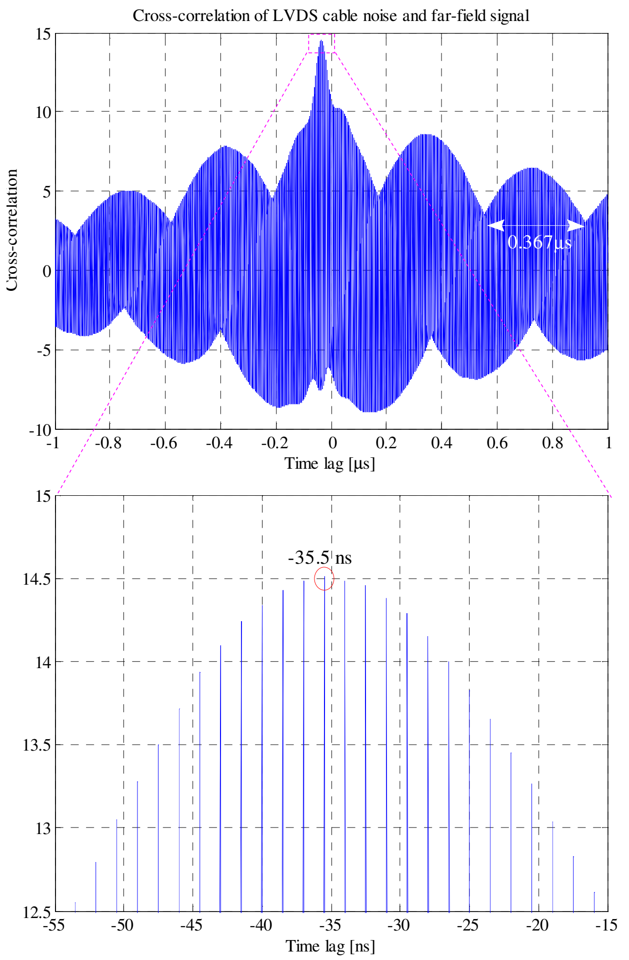

Figure 7. Cross-correlation function of near-field and far-field signals

Fig. 7 shows the direct correlation function of the near-field and the far-field signals. The largest peak indicates that the near-field signal is 35.5 ns earlier than the far-field signal. This delay is determined by the distance between the antenna and DUT, the differences in cable lengths, and the differences of amplifier delays. When several sets of experimental data from different near-field probe positions are available, the relative delay time values can help to determine the root source.

The separation between the peaks in the bottom plot of Fig. 7 is about 15 ns, which corresponds to a 667.6 MHz component in two signals. The envelope of the cross-correlation function also has a period of 0.367 us, which corresponds to a 2.7 MHz AM modulation signal in both the near-field and far-field signals. This modulation signal will cause the sidebands shown at 665 MHz and 670.3 MHz in Fig. 2. Furthermore, the highest peak in the cross-correlation function is much steeper than the other peaks, which indicates random noise matching between the near-field and far-field signals. To summary, the cross-correlation function effectively reveals the delay and periodicity information of two correlated signals.

IV. CONCLUSION

In this paper, the near-field and far-field synchronized measurement method using a high speed oscilloscope and related post processing techniques are introduced. The proposed approach can help determine the relationship between near-field signals and very complex far-field signals, which is useful in identifying the EMI source and coupling paths. STFFT analysis provides in-depth information about the signal's composition. The coherence factor can be used to evaluate the similarity between two signals in the frequency domain, while the cross-correlation function provides insight into this similarity in the time domain and the exact delay time between the two recorded signals. Various post-processing techniques can be applied to the recorded waveforms to determine to what extent the near-field probe signal is correlated with the far-field signal.

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