EMI Failure Analysis Techniques:
I. Frequency Spectrum Analysis

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Introduction

Products fail electromagnetic interference (EMI) tests. This can be a disappointing experience, or it can be part of a design strategy that seeks to implement only the needed countermeasures and thus accepts, or even encourages failures on the initial EMI test. Either way, the reason for the failure must be determined. A variety of methods exist that help locate the source, coupling path, and antenna. No single method is the best option in all cases. A good electromagnetic compatibility (EMC) engineer should understand and have experience with a wide range of failure analysis methods and thus be able to select the most appropriate ones for a given problem.

This series of articles explains a set of methods for the analysis of EMI failures. Each method is categorized based on two criteria: 1) Does the method determine the source, coupling path or the antenna of an EMI problem? 2) Is the method simple, or does it require special equipment and advanced processing? We want to explain methods and guide EMC engineers in selecting the right one by evaluating the advantages and limitations of each method. Table 1 provides an overview of the major EMI analysis techniques that have been studied and practiced in our lab.

In this article, several frequency spectrum analysis strategies are suggested. Often the spectrum is just observed using typical EMI settings: 120 kHz resolution bandwidth (RBW), peak or quasi-peak. However, with very little effort more information can be obtained just using the spectrum analyzer. At first, it is worthwhile to distinguish broadband from narrowband signals. Then zero span analysis is suggested. If an oscilloscope is attached to the antenna, the time evolving spectrum can be observed and the correlations between near-field probing and far-field can be performed. Some of these analyses could quite easily be implemented in automated software, such that a critical frequency is analyzed further, to give the designer additional information.

Broadband Spectrum Measurement

As a first step in EMI evaluation, an overview is useful of the radiated emission from the EUT in the entire frequency range of interest. Such an overview locates the problematic frequencies in the spectrum and compares their amplitude with the maximum allowed by EMC regulations [1]. A typical far-field measurement setup is shown in Figure 1.

A large RBW of 100 kHz ~ 1 MHz is usually used to measure radiated emission from 30 MHz up. To obtain a quick overview, max-hold is used while rotating the turntable and gathering data in both antenna polarizations and at various heights.

A typical result is shown in Figure 2, which compares three televisions (TV) of the same model. The broadband signals around 65 and 270 MHz and narrowband signals at about 150 and 490 MHz are relatively strong in comparison with the emission limit.

Differences are apparent among the supposedly identical TVs. What can we learn from these differences? Experience tells us that mass produced electronic boards are very similar, but their mechanical assemblies are more likely to vary. For example, contact between metal parts and routing of cables tend to vary more than the signals on a PCB. Thus, at frequencies where electronic products of the same model show considerable difference, a focus on these mechanical assembly factors can help identify EMI coupling paths.

Narrowband Spectrum Measurement

Analysis of narrowband signals requires looking at the spectrum near the carrier frequency. The objective is to find the EMI source by correlating local signals to the far-field. This correlation is trivial if there is only one semiconductor operating at that frequency; this situation would be nice but it is rare. In most systems, many integrated circuits (IC), or even modules,

TABLE 1. OVERVIEW OF THE EMI ANALYSIS TECHNIQUES.

Method		Application	For identifying	Complexity
Frequency spectrum analysis [2][3]	Broadband measurement	Obtain an overview of the radiated emission. Distinguish between narrowband and broadband signals.	General	Easy
	Narrowband measurement	Analyze at very narrow span to identify fine spectra details, e.g., sidebands, for distinguishing between possible sources.	Source	Easy
	Zero span measurement	For narrowband signal: differentiate AM or FM modulation. For broadband signal: determine switching frequencies.	Source	Easy
Short term FFT analysis [4]		Reveal how a signal spectrum evolves with time. Identify EMI sources from multiple broadband sources in a complex system.	Source	Complex
Correlation analysis [5][6]		Analyze mathematical correlation between near-field sources and far-field, or among multiple near-field observations.	Source	Complex
Resonance analysis [7]	Swept frequency measurement	Investigate the resonance behavior by substituting a swept frequency clock for the source.	Coupling path/antenna	Moderate
	Resonance identification	Use manual probing or near-field scanning to locate the resonance on a printed circuit board (PCB) or metal structure.		Moderate
	Resonance scanning	S21 scanning for each point on a PCB using a cross probe to find local resonance and coupling path.		Complex
Port voltage and port impedance measurement		Measure between two metal parts on a PCB or enclosure to find suspected antenna structure and noise voltage.	Coupling path/antenna	Easy
Transfer impedance measurement		Quantify coupling path (coupling strength from the source to other structures). Substitute an external signal for a possible EMI source.	Coupling path	Complex
Near-field scanning [8] [9][10]		Use scanning system to obtain the E or H field distribution across the user-defined area on the equipment under test (EUT).	Source/ coupling path	Complex
Current clamp and E/H field probe measurement		Measure common mode current on cables, then estimate far-field. Measure or inject E/H field on EUT.	Source/ coupling path	Moderate
TEM cell measurement [11] [12]		Determine the main EMI excitation mechanism: E or H field coupling. The board has 10 cm × 10 cm standard size.	Coupling path	Complex
Small techniques	Obtain radiation pattern using spectrum analyzer	A quick view of the radiation pattern of the EUT.	Antenna	Easy
	Use strong magnet to remove effect of a ferrite	A fast method to remove the effect of ferrite without physically changing the circuit/board structure.	Coupling path	Easy
	Press and observe amplitude change to distinguish contact and proximity effect	Loose contact of metal connectors or proximity of noisy cables to metals may cause bad repeatability of EMI tests. By observing the magnitude in zero span measurement, abrupt changes indicate contact effect, while smooth changes indicate proximity effect.	Coupling path	Easy

operate at the same frequency or with the same harmonics. The underlying idea is to identify subtle differences in the near spectrum among signals having the same frequency and then correlate those differences to the far-field spectral signature.

For example, in a phase locked loop (PLL), the reference signal from a crystal oscillator has very low phase noise and no sidebands. But the PLL might add phase noise and side bands. It is sometimes possible to add a signal of e.g., 100 kHz to a clock to cause some phase modulation (i.e., periodic jitter, sidebands) in certain branches of a clock tree. If the 100 kHz sidebands show up in the radiated emissions, it can be concluded that the emissions are caused by the clock tree branches that contain the intended phase modulation, which is easy to detect, and in many cases will not affect the functionality of the system.

Figure 3 shows a narrowband measurement (100 Hz RBW and 6 kHz span) of the far-field radiation at 125 MHz from a mother board. There are two signals very close in frequency: one is from the on-board clock, the other is PLL recovered from LAN signal. In a broadband measurement, the two signals will show up as one. To identify the signals, one method is to heat up the crystal oscillator in the LAN switch that provides the LAN signal to the PLL. The clock recovered from the incoming LAN will follow the drift of the crystal oscillator frequency.

A data signal and clock signal provide another example. Data signal is more likely to be amplitude modulated whereas clocks are often phase modulated. Power supply variations may modulate the PLL phase at the data frequency, thus data and clock have similar sideband structures, but one is phase modulated and the other is amplitude modulated. Zero-span analysis or I/Q demodulation can differentiate between amplitude and phase modulation, even if the sideband magnitude is the same.

Figure 4 shows the far-field signal from an EUT. The EUT has many clocks, but they are all phase locked to an 18 MHz reference. The insert in Figure 4 shows the near spectrum and sidebands of the harmonic centered at 144 MHz. Those sidebands are usually visible at kHz or lower span setting. For each harmonic, the measurement software captures not only its amplitude in 120 kHz RBW, but also its sidebands in a span set by the user, providing data for correlation between near-field and far-field.

If it is not clear which IC is contributing to the far-field emission, the source can sometimes be identified by correlating the sideband structure of the far-field to the different possible ICs (more advanced correlation techniques for broadband signals will be addressed in a later article). Instead of the far-field, a current clamp is often used to measure cable current that determines the far-field; another option is the voltage across a slot, if this slot is the radiating antenna. The reason for substituting the far-field by a relevant near-field measurement is to avoid field changes caused by person standing around the EUT while probing to find the best correlation.

A really difficult EMI debugging situation occurs when a problematic radiation is caused by more than one antenna and coupling path. In such situations counter-intuitive phenomena can be confusing. For example, shielding a product may create stronger

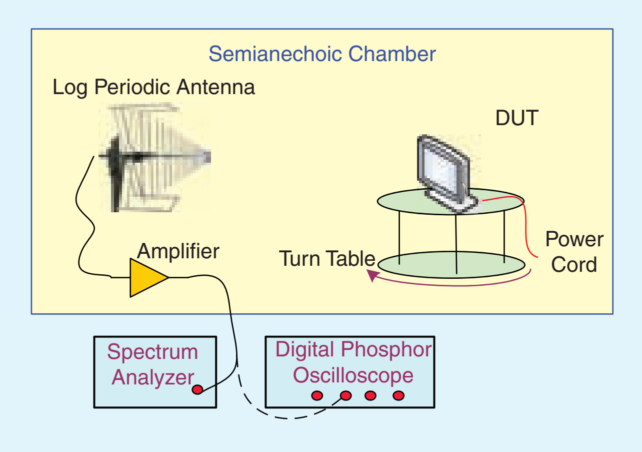

Fig. 1. Typical far-field broadband measurement setup.

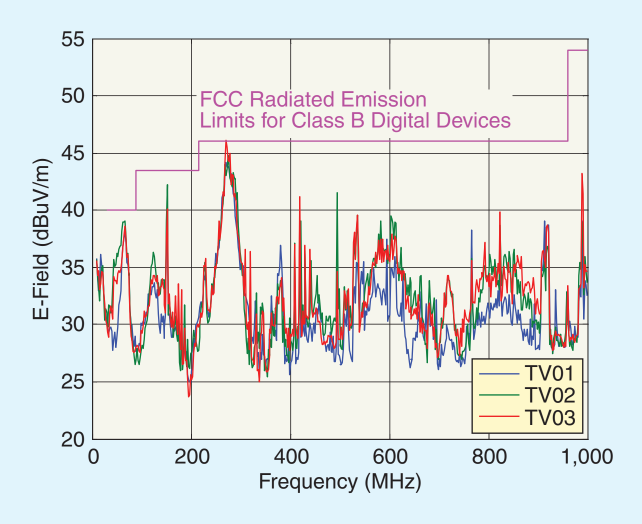

Fig. 2. Far-field radiation measurement on three TVs.

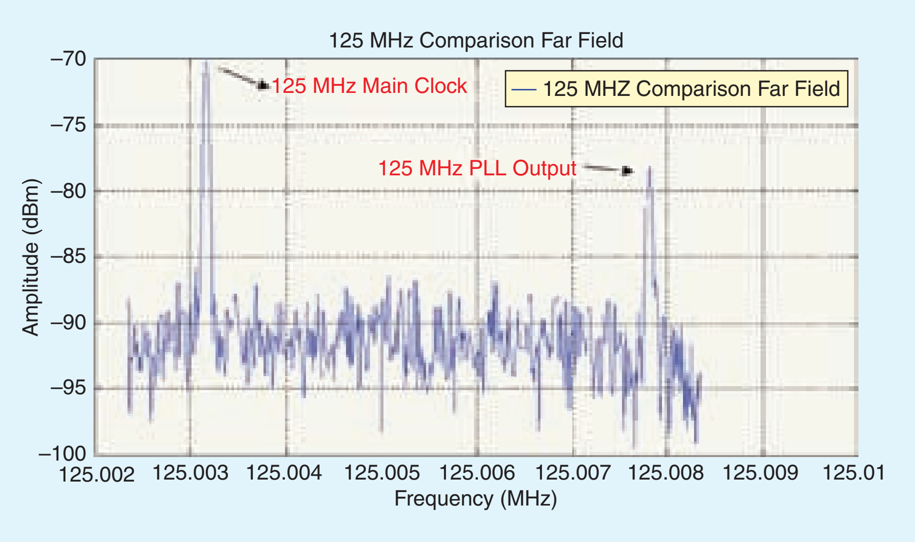

Fig. 3. Narrowband measurement of the far-field radiation at 125 MHz from a mother board.

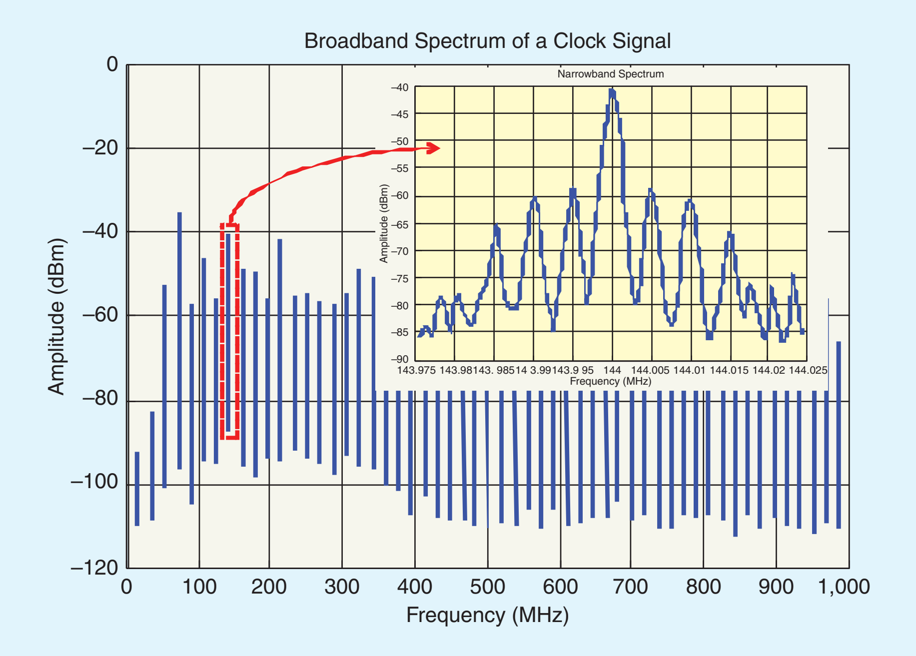

Fig. 4. Super narrowband scan of the far-field signal from an EUT.

emission! As an example, the EMI antenna receives the vector sum of the signals. If two sources of similar magnitude reach the antenna, they can constructively or destructively interfere. If they interfere destructively and one signal is shielded, the total signal will increase.

When multiple sources transmit at the same frequency but differ in spectral details, the source can still be identified by carefully analyzing the narrowband spectrum of the far-field and comparing it with that of locally measured signals. The case illustrated in Figure 4 shows how two potential EMI sources can be differentiated from sideband spectra. If the far-field is dominated by a signal with sidebands, a modification will change both the carrier and the sidebands. This is the case at 72 MHz (Figure 5).

But at 252 MHz the situation is quite different. The signal received by the log-periodic antenna is a superposition of both sources, and the modification affects only the signal without sidebands. We will observe the spectrum shown in Figure 6.

If these two signals radiate from different antennas, the two antennas likely have different radiation patterns (Figure 7). In such a case, the sideband-to-carrier ratio will be a function of the antenna rotation. In Figure 8, the carrier signal is reduced by about 5 dB if the turntable is rotated from 86° to 191° but the sidebands remain at about -70 dB. Two sources, one with sidebands and one without, are emitted from different antenna structures.

Zero Span Measurement

Two signals may have similar sideband magnitudes, but different modulations. Amplitude modulation (AM) cannot be distinguished directly from small-angle frequency

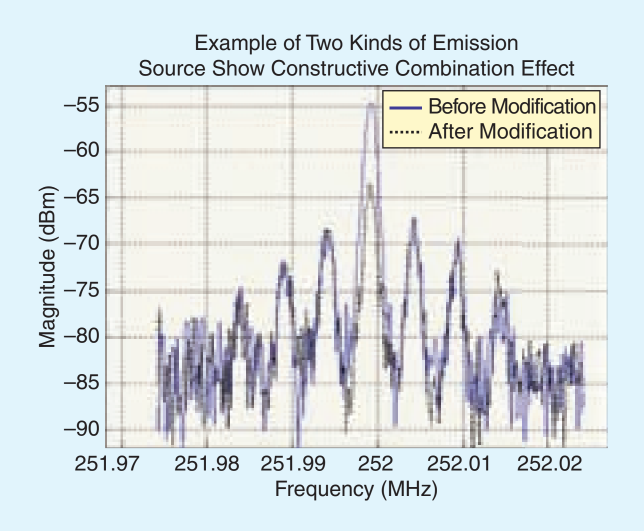

Fig. 6. Far-field before and after a modification at 252 MHz. Only the signal having no sidebands is reduced by the modification.

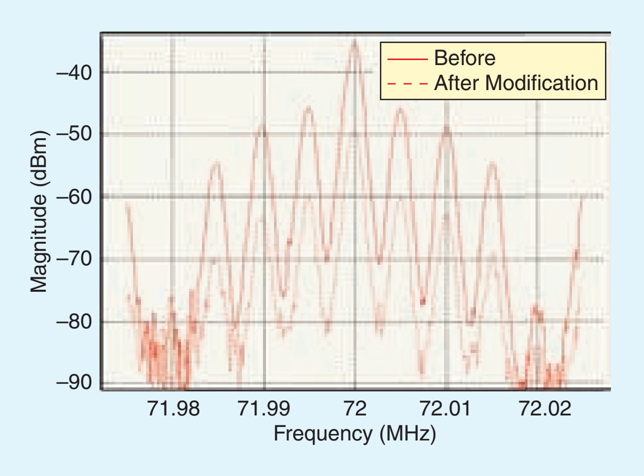

Fig. 5. Far-field before and after modification at 72 MHz. Main signal and sidebands change by the same amount. The far-field is dominated by the signal with sidebands.

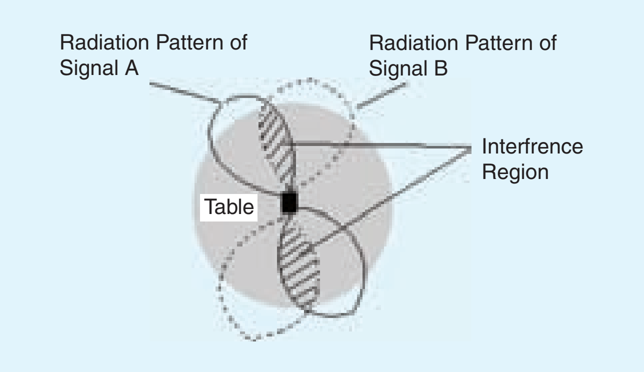

Fig. 7. Two sources distinguished by the sidebands pattern have different antenna structures, thus different radiation patterns.

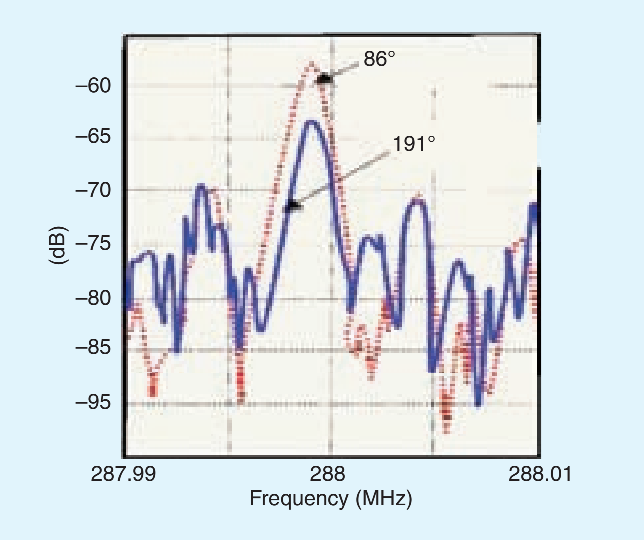

Fig. 8. Far-field spectrum around 288 MHz for two turn-table positions.

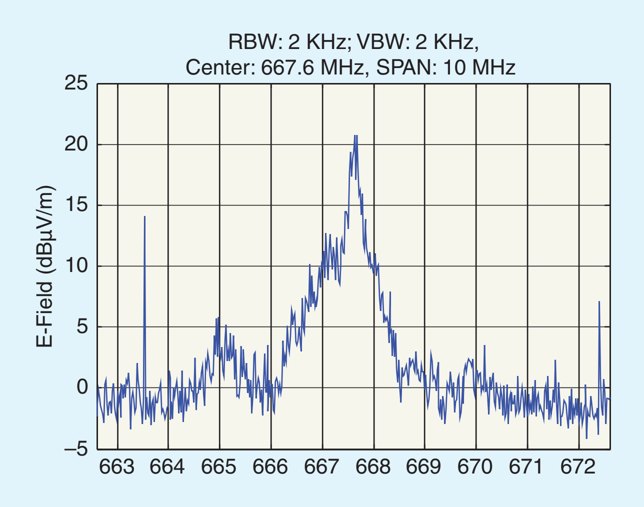

Fig. 9. Spectrum of the 667.6 MHz radiated signal has very complex sidebands, together with some clock signals.

modulation (FM). IQ demodulation or a time domain view helps. IQ demodulation is not implemented in many spectrum analyzers, but zero span can reveal the amplitude demodulated signal, provided that the modulation frequency is less than half of the largest RBW of the spectrum analyzer.

The center frequency of the spectrum analyzer is set to the frequency of interest using 0 Hz span, so that the horizontal axis shows time instead of frequency. The RBW must be larger than the spectrum occupied by the modulation, and the sweep time needs to be adjusted to see the AM modulation.

Typically, switched power supplies have switching frequencies between 30 kHz and 3 MHz. Data stream AM modulation can have a much broader range, whereas periodic jitter of PLLs has no amplitude modulation.

Zero span measurement reveals how the amplitude changes with time for any modulated RF signal within a specified bandwidth. Zero span measurement is quite useful to understand which switched power supply is causing a broadband noise. In the following case, an electronic device has a narrowband radiated signal centered at 667.6 MHz (Figure 9). The sidebands of the signal are complex and unsymmetrical due to multiple sources and modulations. An ordinary spectrum measurement or time domain measurement cannot unravel the mixed signals. But zero span measurement reveals several switching activities of the complex signal under different sweep time settings. Figure 10 shows two amplitude modulation signals: one with a periodicity of 16.7 ms (from 60 Hz AC power supply) with down-going pulses, the other with a periodicity of about 15 μs (from the 66.7 kHz switching frequency of one synchronous buck converter). The next step would be using near field probing to locate the buck converter that switches at 66.7 kHz, and compare or correlate the near field signal to the far field for determining the EMI source signal.

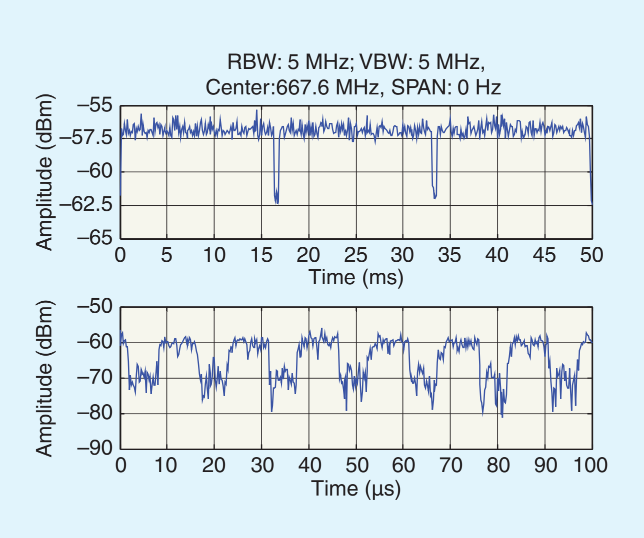

Fig. 10. Zero span measurement data at 667.6 MHz with 50 ms and 100 μs sweep time.

Conclusion

This is the first article of a series covering different techniques for EMI failure analysis. It presented an overview of the EMI analysis techniques, and started with the basic measurements that can be done with a spectrum analyzer to obtain more information relative to the standard settings. The next article will cover time domain methods and the time varying spectral content of signals.

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Biographies

Dr. David Pommerenke *received the Ph.D. from the Technical University Berlin, Germany in 1996. After working at Hewlett Packard for five years, he joined the Electromagnetic Compatibility Laboratory at the University of Missouri Rolla in 2001 where he is currently a tenured professor. He has published more than 100 papers and is an inventor on nine patents. In addition to other professional activities, he is the US representative of the ESD standard setting group within the IEC TC77b. He is a past Distinguished Lecturer for the IEEE EMC Society (2006–2007). His research interests include system level ESD, numerical simulations, EMC measurement methods, and instrumentations.*

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