EMI Failure Analysis Techniques: II. Joint Time-Frequency Analysis

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1. Introduction

Time domain and frequency domain are two extremes of a large set of signal analysis techniques. Time domain gives the best time resolution, but no direct frequency information. The best frequency resolution is obtained in the frequency domain where, however, time variations of the signal are not visible. Joint time-frequency analysis allows moving continuously between time and frequency domain; time resolution can be traded off for frequency resolution or vice versa. This approach reveals how the signal spectrum evolves over time. For instance, when a specific power MOSFET is turned on, the RF signal caused by this specific switching event can be identified. There are a few joint time-frequency analysis techniques [1]. This article focuses on the short-term Fast Fourier Transform (STFFT) for its easy implementation and fast calculation [2] [3]. Using wavelet transformation will achieve better time/frequency resolution, but wavelet computation is slower. Using STFFT, 2 mega samples of time domain data can be analyzed in seconds over the complete frequency range. Wavelet analysis can be used as a second step to focus on specific switching events [4]. Good examples of this approach are available at [5].

The basic process of STFFT is illustrated in Figure 1: a long time-domain data set with a sampling rate of Sa (time step $dt = 1/Sa$) is cut into many small segments with N_S samples in each. The length of each segment is $\Delta T = N_S \cdot dt = N_S/Sa$ and the interval is Δt ($\Delta t = \Delta T$ when there is no overlap). The discrete-time Fourier Transform (DFT) of each segment is computed to generate its short-term frequency content. The amplitude of DFT v.s. frequency is plotted along y-axis and aligned in time with its segment along x-axis, to form an overall spectrogram where the color scale represents the amplitude. The time resolution of STFFT is Δt. The frequency resolution is $1/\Delta T = Sa/N_S$. A better time resolution requires a shorter segment, whereas a better frequency resolution needs more data in each segment. By fine tuning the segment length and overlapping, and selecting a proper window function for DFT, a good compromise can be achieved.

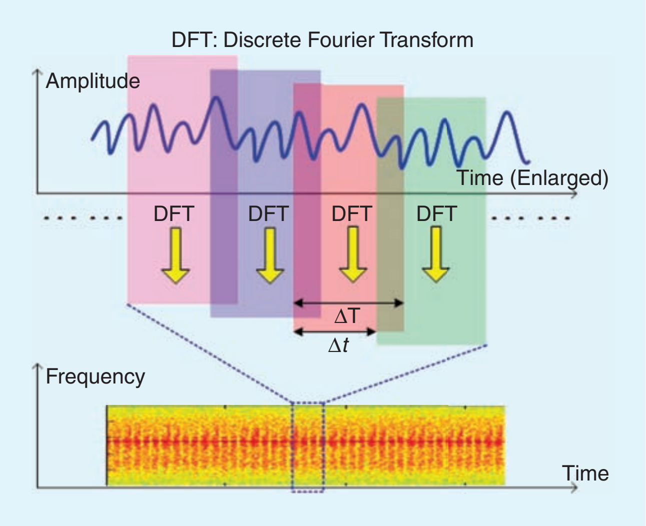

Fig. 1. Basic STFFT process.

The signal is measured in time domain by an oscilloscope. Other instruments, such as a real-time spectrum analyzer from Tektronix or equivalent instruments from Agilent or National Instruments can provide a similar analysis; however, they are usually limited to a sampling bandwidth of 200 MHz or less. A broadband oscilloscope, on the other hand, is usually available, and it offers GHz bandwidth. We often use 2 mega samples at 5 GSa/sec, which gives a 400 μs capture window. A low pass filter, with a stop frequency of 1 GHz or so, is also needed at the input to avoid aliasing. If much slower processes need to be captured, such as a video signal with a repeat rate of 16.6 ms, the recording and processing of sufficiently long data become difficult with the limited memory depth of the oscilloscope. In such cases, down-sampling or down-mixing techniques are useful; the basic idea is to move the spectrum of interest to a lower frequency, so that a lower sampling rate can be used.

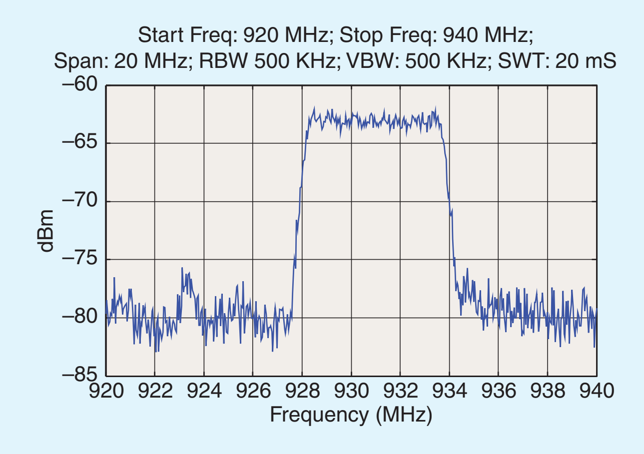

Fig. 2. Narrowband spectrum at 931 MHz of a far-field signal.

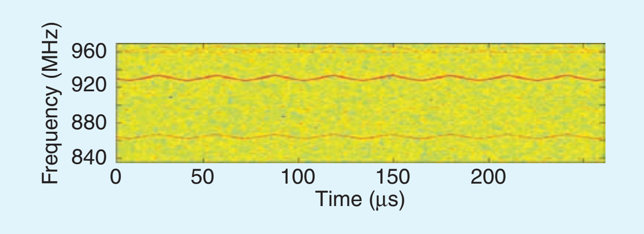

Fig. 3. STFFT result zoomed in to 840~960 MHz, showing the dithered clock. Other dithered signals are visible at 860 MHz and 960 MHz.

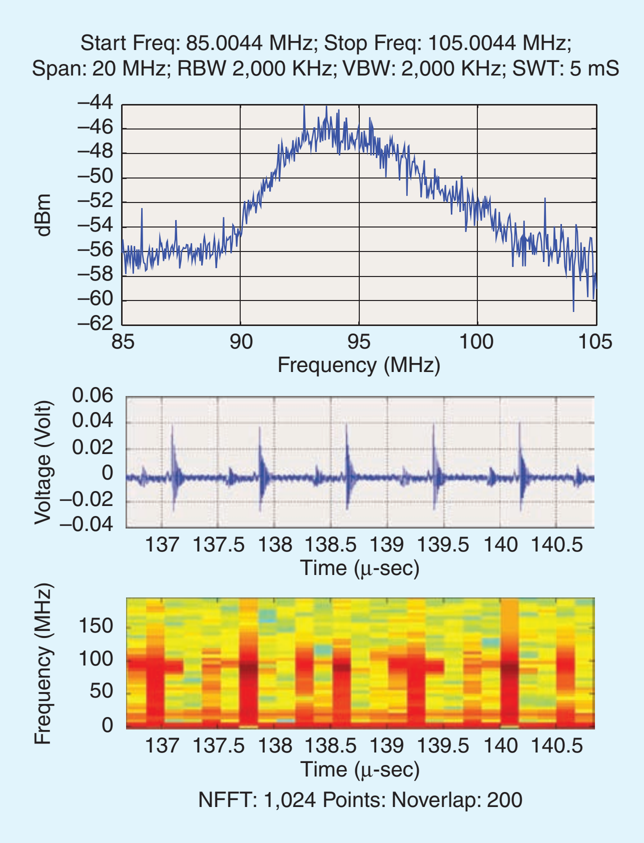

Fig. 4. EMI of a switched power supply. Top: spectrum analyzer peak detection of the far-field signal. Middle: time domain waveform. Bottom: STFFT of the time domain signal.

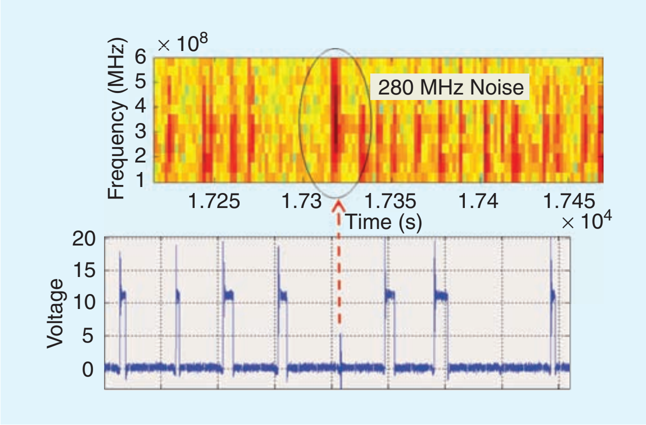

Fig. 5. Strong 280 MHz centered broadband emissions shown in the STFFT domain (top) and output voltage at the switch in the buck converter (bottom).

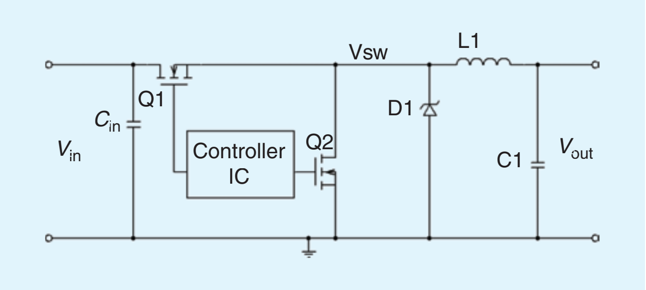

Fig. 6. Typical circuit diagram of a synchronous DC-DC buck converter.

2. Applications of STFFT

The insight provided by this transformation is illustrated below with three examples. Figure 2 shows the far-field signal at around 931 MHz from a desktop PC. The signal spreads over a bandwidth of 6 MHz; and its nature remains unclear until the STFFT is applied—shown in Figure 3 a dithered clock, i.e., a clock frequency modulated by a sine wave.

The second example shows three views (Figure 4) of the far-field caused by a switched power supply. The spectrum analyzer reveals only a broadband signal at around 95 MHz; it does not tell which switching edge is causing the emission, nor does it permit a distinction between various power supplies if all emit in the same frequency range. The time domain signal, however, reveals two switching events, i.e., the turning on and off of a MOSFET. The switching rate is about 0.8 μs. In the STFFT we see the spectral energy of both switching events; one covering a broader bandwidth and the other with its energy concentrated around 95 MHz.

One further example of a switched power supply causing EMI problem is shown in Figure 5. Strong 280 MHz centered broadband emissions were observed in the STFFT. The circuit was a synchronous DC-DC buck converter, with a typical circuit topology [6] shown in Figure 6. The voltage on the switch output in the buck converter, Vsw, is displayed at the bottom of Figure 5. The moment of the strong broadband noise was aligned to a false switching event. The broadband pulse was caused by a control error in design, which allowed both FETs to turn on simultaneously. This error led to a current spark as the

TABLE 1. SUGGESTED MEASUREMENT SEQUENCE FOR EMI SOURCE IDENTIFICATION.

Measurement			Objective
1	Far-field measurement (frequency domain, peak hold)		Obtain an overview. Distinguish between narrow band and broad band signals.
1.1	Narrowband signals	Check for sidebands using kHz span	Identify possible modulations that will help to correlate far-field to many possible near-field sources.
		Zero span to check on signals having sidebands	Determine if sidebands are from AM or FM modulation.
1.2	Broadband signals: zero span		Determine switching frequencies.
2	Time domain measurement using oscilloscope attached to the far-field antenna		In depth analysis of broadband signals and modulation of narrowband signals.
2.1	Apply STFFT to time domain data		Reveal how spectra change with time, e.g., identifying switching events in switched power supplies.
2.2	Attach near-field probe to second channel, and probe the EUT while observing the far-field in time domain		Observe the timing between the far-field and the near-field to identify which switching event is causing the far-field signals.
2.3	Correlation analysis with synchronized measurement (to be covered in next article)		When multiple near-field sources potentially cause the emission at the same frequency and the near-field spectra cannot be visually correlated to far-field sideband signature, a mathematical correlation analysis can be performed.

input 12 V was shorted to reference rail via a small loop with a few nH of equivalent inductance.

For complex broadband signals, such as data bus problems or systems having many switched power supplies, the STFFT technique is especially useful to identify the sources of emissions and to correlate individual switching events to far-field emissions. For narrowband signals, however, a heterodyne receiver based spectrum analyzer is superior; it can provide not only a much greater dynamic range, but also a kHz, even Hz resolution of the signals close to the carrier. An FFT would require a very long data record. For example, if we capture 400 μs of data, the basic FFT resolution would be 2.5 kHz ($=1/400\mu s$) at best.

Summary

The STFFT method is often used to identify the source of emissions in complex systems where multiple broadband sources exist, such as switched power supplies with DC-DC converters. The identification is made by comparing the STFFT result of each local source with that of the far-field signal.

During EMI failure analysis, a variety of techniques can be used for source identification. Table 1 explains a suggested measurement sequence for source identification in complex systems. Part one, frequency domain measurement techniques, has already been covered in the first article. 2.1 and 2.3 in part two, time domain measurement techniques, is covered in this and the next article.

Conclusion

This article, the second in a series on EMI failure analysis, presented the joint time-frequency analysis techniques. STFFT analysis was introduced as a very useful method among a variety of source identification techniques. It intuitively displays the spectrum evolvement over time, offering a new perspective that cannot be achieved by separate time or frequency domain analysis.

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Biography

Weifeng Pan *is currently an EMC design engineer at Google Inc., in Mountain View, California. He received the PhD degree in 2009 from the Electromagnetic Compatibility Lab at the Missouri University of Science and Technology. In 2008, he was an intern at IBM, Research Triangle Park, North Carolina. He worked as an RF design engineer at UTStarcom (China) from 2002 to 2005. He received the BSEE degree in 1999 and the MSEE degree in 2002 from Tsinghua University, in Beijing, China. His interests include electromagnetics, EMC and signal integrity.*

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