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EMI-Debugging of Complex Systems using different time, modulation, STFFT and Frequency Domain Signal Analysis Techniques

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***Abstract*— One faces a difficult situation in EMI debugging if multiple sources radiate at the same frequency, especially, if little details on the EUT are provided. In this paper, we apply and compare a set of signal analysis techniques for identifying radiated emission sources. First, theoretical background of Joint Time-Frequency Analysis (JTFA) is given and an algorithm using Short-Term Fast Fourier Transform (STFFT) approach is applied for the data analysis. STFFT analysis provides an exclusive insight into time-dependent emission processes. Also, narrow span and zero span spectrum analysis are discussed. Special emphasis is given on signals sideband characteristics.**

Keywords-JTFA; Fast Fourier Transform (FFT); STFFT; Zero Span; Sidebands; Dithered Clock

I. INTRODUCTION

Every experienced EMC engineer knows a multitude of EMC analysis techniques. The art of solving a complex EMC problem lies in the application of the right method at the right time. The scope of techniques covers probing methods, shielding, signal analysis etc. Illustrating all is obviously beyond this paper. This paper concentrates on signal analysis techniques that span from the time domain via the intermediate modulation and STFFT domain into the frequency domain. The paper is organized along results mainly obtained from one EUT.

The EUT exhibited the spectral signature show in Fig. 1:

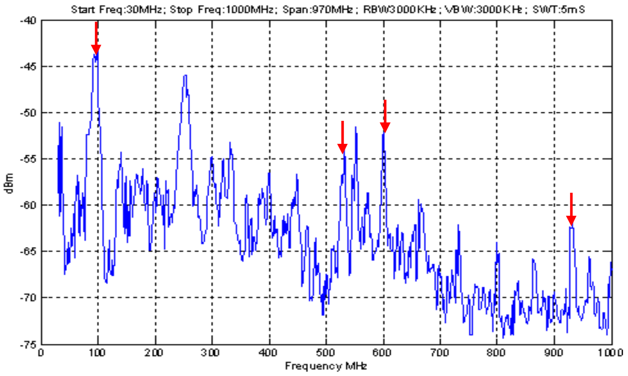

Fig. 1: *Spectral signature of an EUT. The arrows indicate frequencies that are analyzed further to illustrate the signal analysis techniques*.

II. BETWEEN TIME AND FREQUENCY DOMAIN: JOINT TIME FREQUENCY ANALYSIS (JTFA)

Engineers are naturally acquainted to use either time or frequency domain. For example, a sine wave codes to a Dirac pulse if its Fourier analysis is performed. The reason is that the Fourier analysis determines the correlation between the signal and a large set of sine waves. If the frequencies match, the "correlation" is one. With conventional spectral analysis we are having difficulties to identify the time history of a signal (although sidebands occur as an effect time variation of a signal).

However, there are infinite number of signal analysis techniques that lay between time and frequency domain. They all have in common that they analyze how the spectral content of a signal evolves with time. To stay within the example of the sine wave above, one could find the correlation of an input signal with a short burst of sine waves (maybe a few periods long). The "correlation" would be one, if the input signal is at the same frequency and occurs at the same moment in time as our burst of sine. Following along this thought, we see that optimal analysis of a signal is performed if we search for the "correlation" with a signal that equals the input signal.

In numerical implementations, the Fourier analysis is implemented as FFT. The method above, which correlates with a short burst of sine wave is implemented numerically as the Short Term FFT. Other choices of Joint Time Frequency Analysis (JTFA) techniques are Wigner-Vill distribution, Gabor expansion, Wavelets and Short-Term Fast Fourier Transformation and etc [1]. We skip a detailed discussion of advantages of the different techniques and limit our self to the STFFT, mainly because of its easy implementation and fast calculation.

The data that needs to be processed must be a long time domain record. In our examples we typically use 2 megasamples of data taken between 1-20 GS/sec. For example, if 1 GS/sec is used, a time history of 2 ms is recorded. This is typically sufficient for switched power supplies as they have switching frequencies from kHz to several MHz. However, other processes might have a longer cycle time, such that either many records need to be taken or an oscilloscope having a deeper memory needs to be used.

The STFFT implementation [2] splits the signal into overlapping segments, windows each and performs a zero-padded, length NFFT discrete Fourier transforms. The main parameters that allow moving between pure time and pure frequency domain is the length of each segment. If, e.g., the segment length would be set to be equal to the total record length, then a pure FFT would be performed. For our analysis between 100 and 2000 segments are typically used. A shorter segment improves the time resolution on expense of frequency resolution.

Example 1: Signal at 930 MHz

As seen in Fig. 1 there is an emission at around 930 MHz. Using a span setting of 2 MHz/div the signal appears as shown in Fig. 2

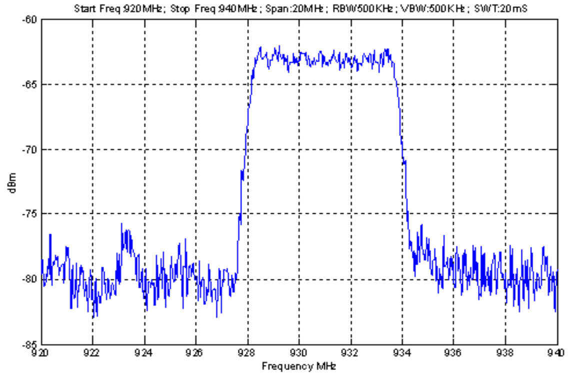

Fig. 2: *Signal around 930 MHz using 2 MHz/div and peak detection.*

Without further information one would have difficulties to understand the type of signal. However, the STFFT reveals the nature of the signal:

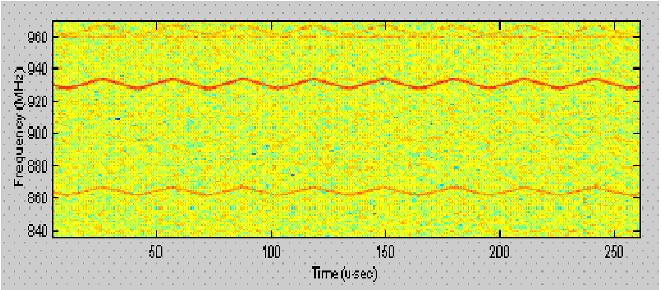

Fig. 3: *STFFT of the time domain record recorded at the log-per antenna output, zoomed into frequencies around 930 MHz.*

The STFFT shows that the signal is a frequency modulated carrier. The carrier base frequency is around 931 MHz modulated by a 33kHz triangular wave. It is a dithered clock. Besides the main dithered clock mixing products are also visible at 860 and 960 MHz.

Example 2: Signal at 600 MHz

Another signal can be seen at 600 MHz. Its spectrum (spectrum analyzer) is shown in Fig. 4. Again, without further information, one would have difficulties to understand the single peak at 600MHz. The STFFT reveals details:

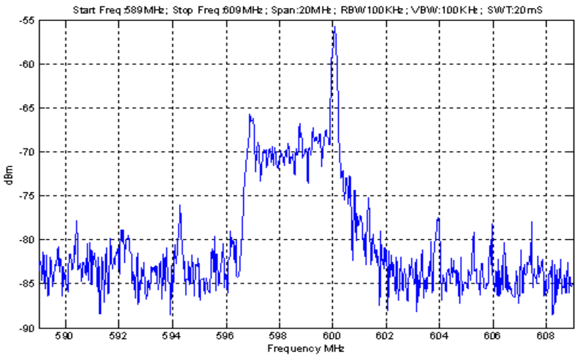

Fig. 4: *Spectrum around 600 MHz using 100kHz RBW and peak detection.*

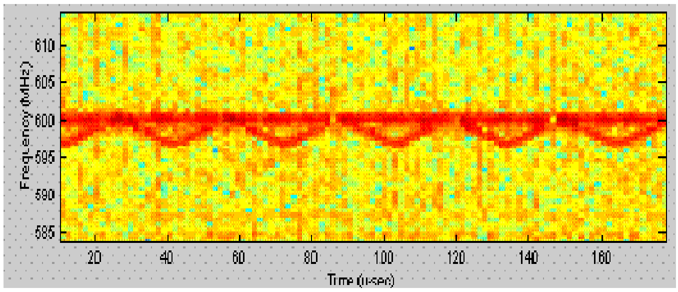

Fig. 5: *STFFT of the time domain records zoomed into the frequency range around 600 MHz.*

The STFFT (Fig. 5) indicates that the spectrum is caused by two signals: One at 600MHz, the other being a harmonic of the dithered clock.

Example 3: Switched Power supply

Switched power supplies are most often the cause of broadband noise. In systems having multiple supplies it is often difficult to distinguish between EMI caused by individual supplies. Further, the turn-on or the turn-off of MOSFETs can lead to different signatures and, depending on which switching edge is leading to the EMI, different countermeasures are needed [3]. Fig. 6 the STFFT of a time record is shown. The time record has been recorded using a near field probe close to one of the switched power supplies. The lower part of the figure shows the time domain record, the upper the STFFT.

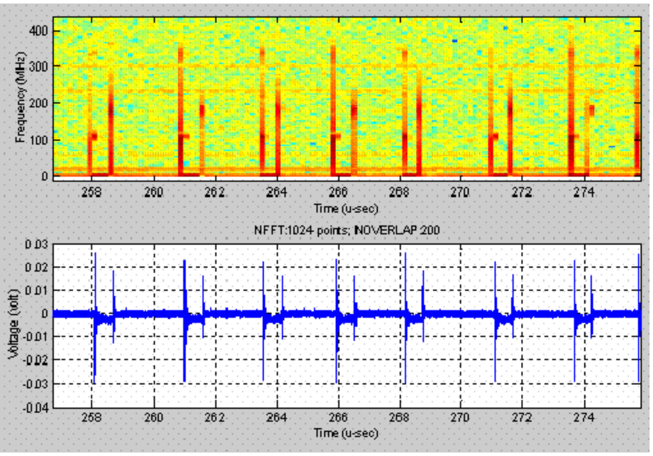

Fig. 6 *Time domain record (lower half) and STFFT (upper half) detected using a small loop close to a switched power supply.*

The STFFT reveals:

- A switching frequency of about 2 us. Note: The switching frequency is not constant, i.e; this system uses both Pulse Width Modulation and frequency adjustment for regulating the voltage.
- The turn-on of the MOSFET (e.g., at 266 us) rings around 100 MHz.
- The turn-off (e.g., 264 us) rings around 180 MHz.

This power supply did not couple strongly to the outside of the system as the time signature captured at the log-per antenna did not show the same periodicity. However, another supply caused significant emissions.

Example 4: Second Switched Power supply

A second switched power supply lead to emissions around 100 MHz. The emissions, as seen in a spectrum analyzer using peak detection and 2 MHz RWB is shown in Fig. 7:

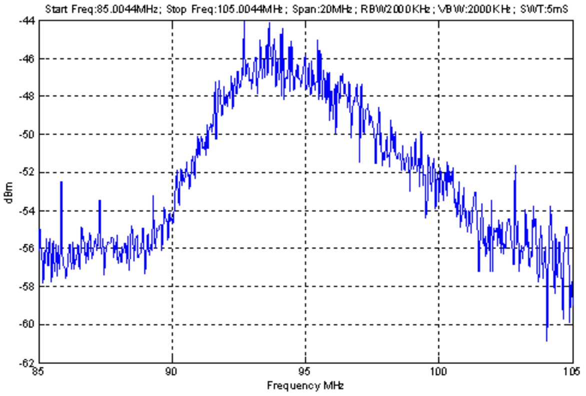

Fig. 7: *Spectrum caused by a switched power supply as seen at the lop-per antenna output.*

The STFFT (Fig. 8) reveals details about the cause of the emissions: It is a switched power supply that switches at about 1 MHz. The turn-off of the MOSFET leads to ringing at around 100 MHz.

III. SIDEBAND BEHAVIOR

Often, there is information within the small span sidebands of a signal that reveals its origin. For example, the harmonics of a clock will have very little phase noise, if the clock is based on a crystal. However, if the clock has been "processed" via a PLL, then phase noise and possible sidebands are introduced.

An example of two signals that emit on exactly the same frequency is shown below (Fig. 9). However, one of the signals has strong sidebands, the other not. Without analyzing the signal in narrow span, one would have difficulties to identify which of the possible two sources is received at the log-per antenna.

Having two signals at the same frequency poses significant problems in implementing countermeasures. It may lead to counterintuitive results. One example is:

<u>After reducing one signal, the received signal increases!</u>

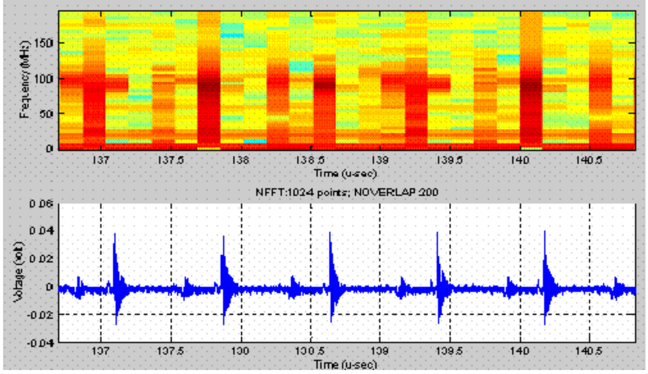

Figure 8: *STFFT and time domain record of a switched power supply having a switching frequency of about 1 MHz.*

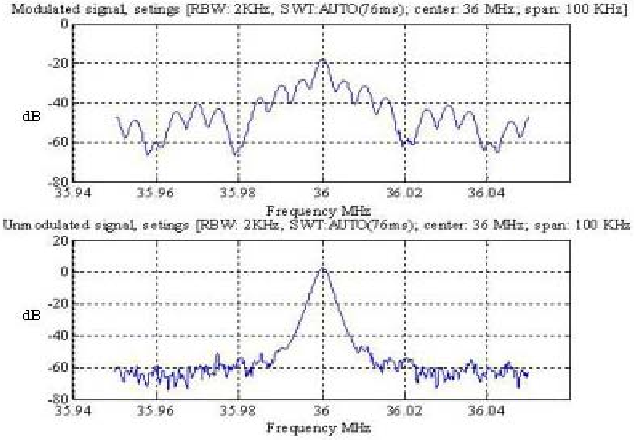

Fig. 9: *Narrow span of two signals that occupy the same frequency. The top signal has sidebands, the lower has no sidebands.*

This will occur if the received signal strength was reduced due to destructive interference before the modification was introduced. The modification reduces one of the signals, i.e., the total signal increases as the destructive interference is less efficient thereafter. This effect may be directional (i.e., it only occurs in one direction) or it may occur in all directions. The difference is rooted in the number of antennas involved. If both signals are radiated via the same antenna (e.g., the same cable), then both signals will create similar radiation pattern. However, if both signals are radiated by different antennas, then we might observe some directions in which destructive interference takes place while in other directions additive interference occurs.

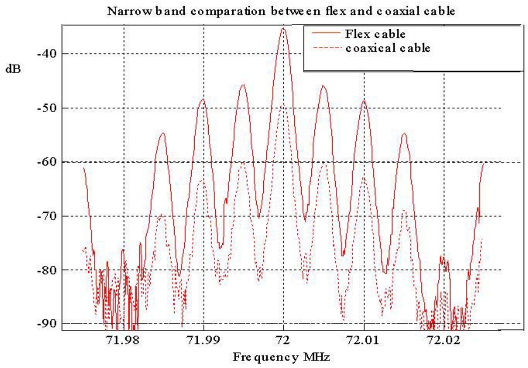

Fig. 10: *Normal behavior of sidebands and a carrier: A modification changes the sidebands and the carrier by the same amount. This indicates that one signal, having sidebands, is dominating the emissions.*

An effect observed is shown in Fig 11.

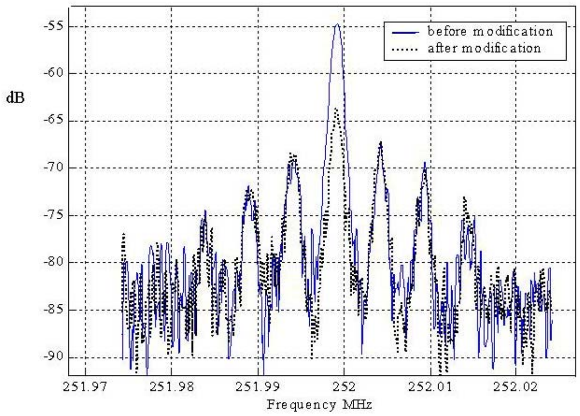

Fig. 11: *A strong sign of having two sources that radiated at the same frequency. The modification reduces the carrier signal, but the sidebands remain the same. This indicates that two signals, one with sidebands, one without superimpose.*

If two signals radiate at the same frequency that can be distinguished by, e.g., their sideband or phase noise structure, then it is possibly to identify the fact that two signals are both contributing significantly to the radiation. However, if both signals cannot be distinguished, then the counterintuitive results may lead to delays in the implementation of countermeasures. If one is confronted with a very difficult EMI problem, showing confusing results, one needs to be aware of the possibility superposition in complex, but phase locked systems, analyzing signals in narrow span can help in identifying such situations.

Moving the turntable changes the sideband composition

Following the example above, i.e., having two signals on the same frequency, but having different sidebands the sideband structure may change upon turning the turntable. This can be observed if both sources are radiated by different antennas. Each antenna has a different radiation pattern. The principle is illustrated in Fig. 12.

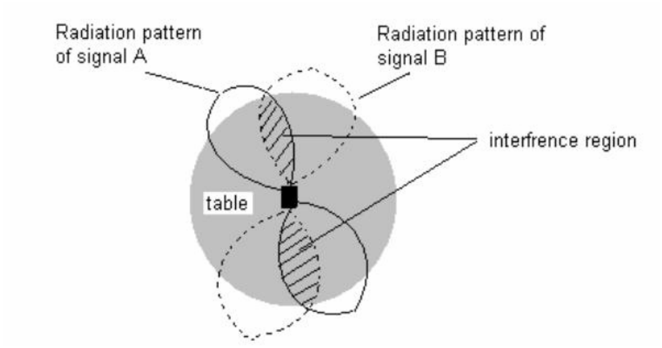

Fig. 12: *Radiation pattern of two antennas.*

Depending on the turntable position one or the other source will dominate. Luckily, for this EUT, this will be visible in the sideband structure. In analyzing Fig. 13, one can see that the main signal is reduced by turning the turntable from 86 deg to 191 deg, but the sidebands remain about the same.

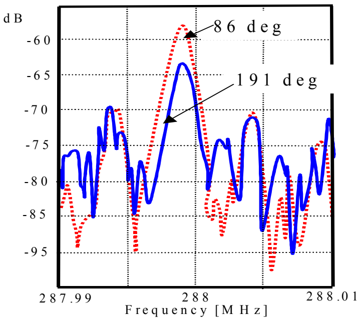

Fig. 13: *Effect on the carrier and on the sidebands for two different turntable positions.*

IV. SPECTRUM ANALYZER IN ZERO SPAN

In Fig. 14, there is a signal at 535.8 MHz. One could think this is a clock signal. Even using narrow span of a few kHz/div does not reveal strong side bands. However, if zero span is used (the spectrum analyzer then displays the envelop of the AM-modulation of a signal), one can see AM modulation at a frequency of about 67Hz. The resulting sidebands are too close to the carrier to be resolved easily. As the signal shows a strong AM-modulation it is unlikely that it is a clock signal. Most likely the AM modulation is caused by a cycle time that relates to the software on the system.

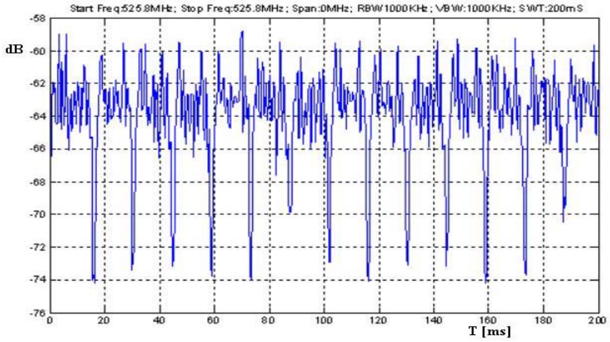

Fig. 14: *Zero span of the signal at 535.8MHz*

V. CONCLUSION

Different signal analysis techniques can be applied in EMI debugging. Each of them has its own strength:

- The Joint Time Frequency Analysis is optimal for time dependent signals. Typical examples are switched power supplies and bus signals
- Using a spectrum analyzer in narrow span will allow to investigate the sideband and phase noise structure. Often, this allows to distinguish signals that are on the same nominal frequency.
- Using zero-span the spectrum analyzer is showing AM modulation within the RBW setting. This allows to distinguish AM modulation form PM modulation. Phase modulation sidebands can be the result of PLLs. But in contrast to BUS-signals there will be no amplitude modulation on PLL signals.

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[2] Matlab help file in specgram(), www.mathworks.com

[3] Z. Li, D. Pommerenke, “EMI specifics of DC-DC buck converters,” Proceeing of International Microelctronics and Packaging Society, Oct. 2004