An Introduction to FFT EMI Receivers

Introduction

An evolution in EMI receiver design is underway to take advantage of today's digital signal processing (DSP) technologies, using fast Fourier transform (FFT) techniques to simultaneously measure emissions over a wide frequency range, of greater 100 MHz, with greater dynamic range then traditional receivers. Advantages are numerous, allowing new and creative ways to streamline EMC testing. This drive for greater efficiencies is spurred by the desire to increase competitive advantages through reducing product test effort, thereby improving time to market. Due to the versatility of the EMI receiver in the areas of site qualification, pre-test, mitigation, and formal test, efficiency gains related to the EMI receiver have potentially the greatest impact on EMC test processes. These benefits are achieved by measuring emissions over a frequency range in only a few seconds, versus hours compared with more traditional methods using older receiver technologies. To take advantage of the full benefit of this technology, a complete redesign is required, rather than bolting FFT DSP circuitry into existing architectures. This paper provides basic information about FFT and the benefits of the DSP-based EMI receiver using FFT measurement methods.

Design Considerations for FFT EMI Receivers

There are several issues to consider when spectral analysis is performed on (sampled) analog waveforms that are observed over a finite interval in time.

Windowing

Although the use of FFT to interpret data is very good for those cases where data is periodic and repeating, any discontinuities can result in a poor representation.   In some cases phantom signals may result from improper translation of the original data, such as in the case of impulsive signals. By applying a known function discontinuities may be addressed, thereby reducing inaccurate translation of data. The use of a known function is referred to as Windowing[i]. For EMI FFT receivers a Gaussian function is a good choice, which tends to match an EMI receiver's IF filters[ii].

Figure 1 shows examples of FFT without and with Windowing. As shown, windowing significantly improves side lobe sensitivity.

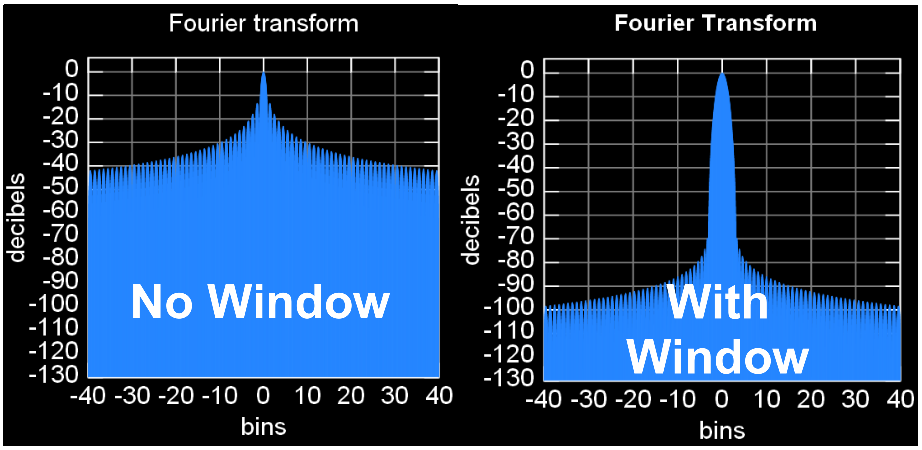

Figure 1: Effect of windowing

Overlapping Windows

Additionally, overlapping windows is necessary when observing and measuring over a spectrum that is larger than the individual window bandwidth. Of upmost importance is the degree of window overlap. To ensure measurement tolerance is met in accordance with regulatory requirements window overlap must be considered a design goal. Figures 1 and 2 show examples of overlapping windows, the relationship of error to the percent overlap, and the increase in dynamic range associated with greater overlap.

Figure 2: Large degree of window overlap

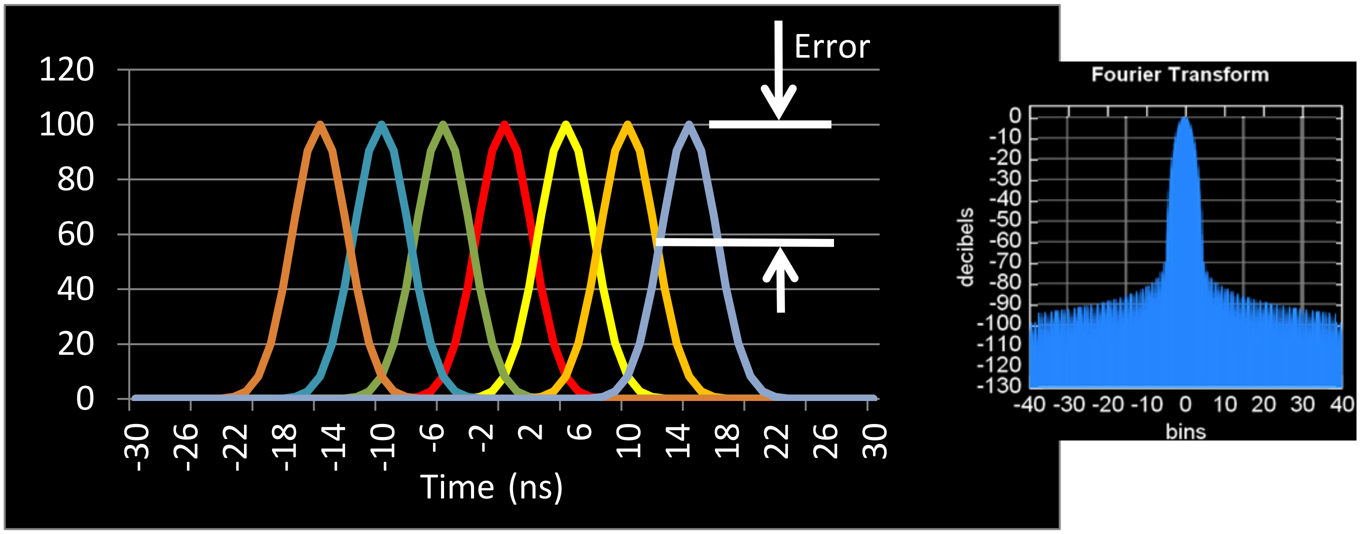

Figure 3: Minimal degree of window overlap

Sampling Rate

Another consideration when applying FFT is the sampling rate, designated as Fs. Inadequate sampling can create aliasing effects, whereby the original signals are indistinguishable, resulting in errors of the modeled signal. The Nyquist rate is the minimum sampling rate, of the highest frequency, required to avoid aliasing. The minimum sampling rate required for proper representation of the original signal is ½ FS, which equals twice the highest frequency contained within the signal.

Figure 4: Sampling - time domain perspective

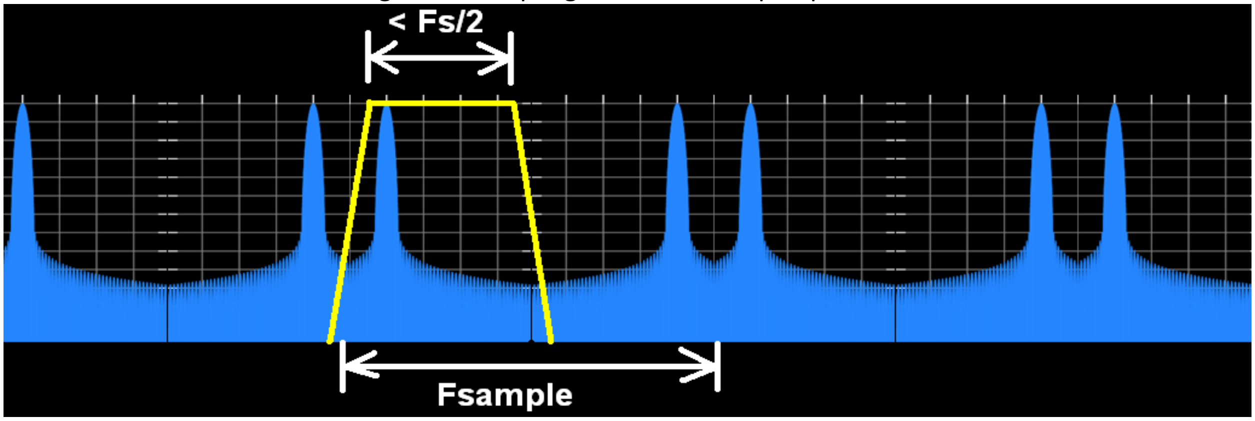

Figure 5: Nyquist sampling - frequency domain perspective shows sampling relative to the frequency and time domain sampling, respectively.

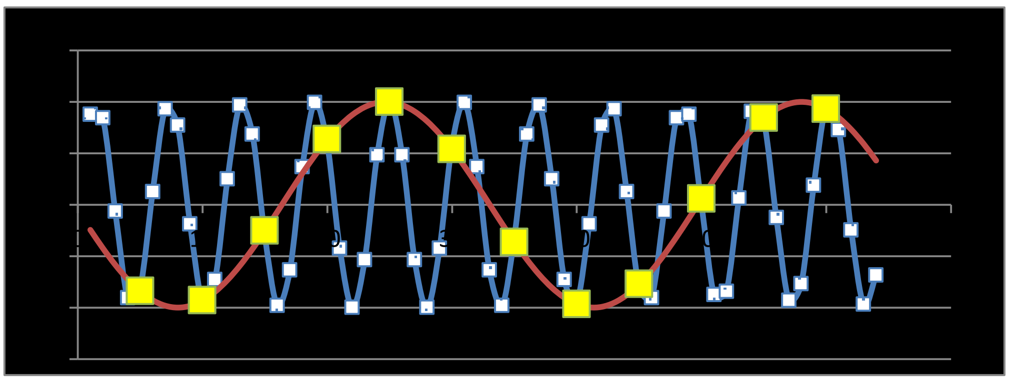

Figure 4: Sampling - time domain perspective

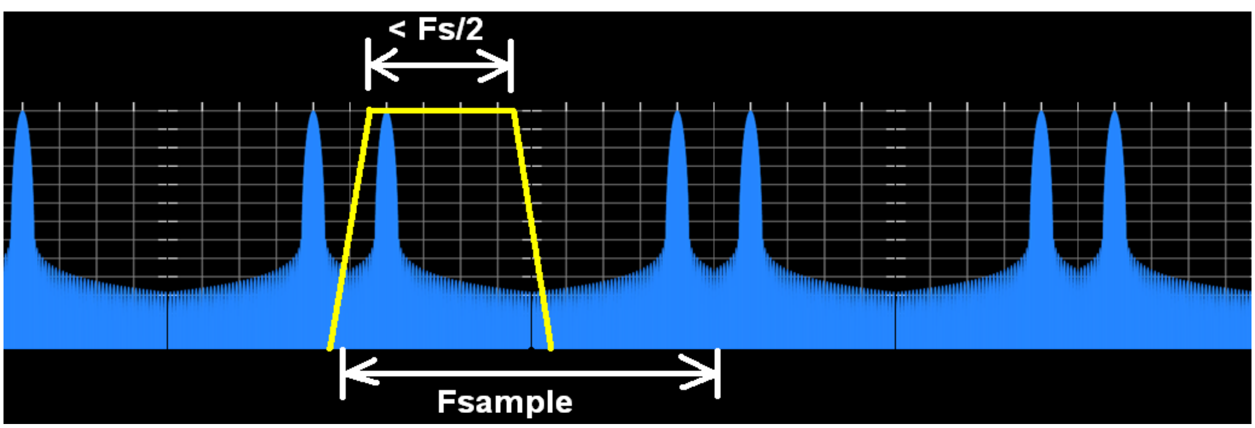

Figure 5: Nyquist sampling - frequency domain perspective

EMI Receiver Requirements

A conventional receiver or spectrum analyzer utilized in the measurement of radiated or conducted emissions must comply with either national or global EMI standards as a minimum, such as CISPR 16-1-1. These standards specify characteristics of peak, quasi-peak, CISPR-average (or average), and RMS-average detectors, in areas such as: input impedance, bandwidth, overload factors, sine-wave voltage accuracy, responses to pulses, sensitivity, limitations of intermodulation effects, limitations of receiver noise, and internally generated spurious signals. The intention of such standards is to limit potential interference by first developing a set of uniform test limits and equipment requirements. These standards encourage test repeatability and drive consistency of measurement from receiver to receiver, regardless of the manufacturer. Each detector has its own purpose, such as the quasi-peak detector, which measures the perceived annoyance factor, generally in the frequency range of 150 kHz to 1 GHz. Average detectors use a time constant to derive the emission amplitude, while the peak detector measures the emissions of raw amplitude, without any manipulation of the received signal. Each detector uses resolution bandwidths specified at -6 dB roll off versus non-EMI qualified receivers, which may use resolution bandwidth specified at -3 dB roll off. An important element to the quasi-peak and average detectors is the required filter settling time. For CISPR-compliant quasi-peak and average detectors, settling time is on the order of one to two seconds. FFT EMI receivers have proven to meet these requirements and comply with standards such as CISPR 16-1-1.

An area of concern with any EMI receiver is accurate measurement of an emission with extreme dynamic range. Due to the wide variety of test conditions and product types, EMI receivers must be able to handle — without performance degradations — high amplitude signals over wide frequency ranges, while also measuring low levels signals. Without pre-selection filters, high amplitude signals may cause overloading of the receiver front end, resulting in artifact signals. These artifact signals will appear as if generated by the DUT, providing incorrect DUT test measurement results. Preselectors, which reside in the RF section, prevent this overload condition from occurring. The benefits of preselection filters are most often seen during conducted emissions testing. Although preselection filters prevent, to some degree, overload conditions, they do not necessary protect RF circuitry from damage of very high transient events. In many cases, a transient limiter is recommended to provide protection of the RF front end during conducted emission testing. Again, FFT EMI receivers that are CISPR 16-1-1 compliant tend to contain pre-selection filters, so they can handle impulsive signal while having greater dynamic range.

Also, a traditional EMI receiver may use as a default frequency step sizes of 50 kHz in the 30 – 1000 MHz frequency range, with a 100 kHz resolution bandwidth (see Table 1: MIL-STD-461F Dwell Times below). This approach has led to relatively longer test times over a FFT-type EMI receiver, by a factor of 8000 in some cases. Furthermore, as dwell times increase, so does test efficiency when employing a FFT EMI receiver. Although the dwell time is specified in many standards, DUT performance must be fully understood in the event process, and cycle time must exceed the time specified in the applicable standard. If process or cycle times do exceed the dwell specified in the standard, test dwell times must be increased to ensure emissions are not missed.

FREQUENCY RANGE	6DB BANDWIDTH	DWELL TIME	MINIMUM MEASUREMENT TIMEANALOG MEASUREMENT RECEIVER
30 Hz - 1 kHz	10 Hz	0.15 sec	0.015 sec/Hz
1 kHz - 10 kHz	100 Hz	0.015 sec	0.15 sec/kHz
10 kHz - 150 kHz	1 kHz	0.015 sec	0.015 sec/kHz
150 kHz - 30 MHz	10 kHz	0.015 sec	1.5 sec/MHz
30 MHz - 1 GHz	100 kHz	0.015 sec	0.15 sec/MHz
Above 1 GHz	1 MHz	0.015 sec	15 sec/GHz

Table 1: MIL-STD-461F Dwell Times

Advantages of Unique Functions

Process speed improvement, the availability of large memory for data storage, and capacity of handling large amounts of data gives developers an opportunity for infinite feature creation. As a result, unique features are growing rapidly as designers continue to respond to requests. Some features include:

1. Four detector measurement time: 150 kHz to 30 MHz → 2 sec., and 30 MHz to 1 GHz → 7 sec. In this case peak, quasi-peak, average, and RMS average detectors simultaneously perform emission measurements. The specific measurement time is accomplished through an instantaneous bandwidth of 140 MHz.
2. Processes peak, auasi-peak, average, and RMS average detections simultaneously at 8,192 frequency points, which reduces test time, is possible.
3. Scan 4 GHz every second with the peak detector, i.e. covering 1 to 18 GHz in 4.25 seconds.
4. Sweeping 9 kHz to 30 MHz (CISPR bands A and B) in 2 seconds with all CISPR detectors is possible.
5. Processing 30 to 1000 MHz (CISPR bands C and D) in 7 seconds with all CISPR detectors is possible.
6. 3D spectrogram offers engineers the ability to better understand emission characteristics. In some cases, the ability to discriminate emissions of concern may not be possible using a conventional receiver. As an example: An incorrect measurement may occur in a case of impulsive emissions measurements. Measurement of the peak of the envelope may actually have lower overall quasi-peak measurements than that of the continuous emissions, which lies within the same frequency span.
7. The FFT-based EMI receiver has enormous benefit in speed of overall test time and, more importantly, test quality. Using the instantaneous bandwidth, maximum hold feature, the receiver will measure emissions during the product cycle. This feature is most beneficial during long dwell time operations. By setting the receiver to its instantaneous bandwidth (e.g. 140 MHz), any number of signals may be measured during that dwell time, not just one, as with conventional receivers.
8. The ability to use large displays offers the end user the ability to manage process flows more easily, without the nesting typical of traditional receivers.
9. As with all CISPR 16-1-1 qualified receivers, it important for FFT receivers to have preselection circuitry to properly measure impulsive signals.

10. The potential for greater usefulness during product life over conventional receivers is achievable. This stems from greater use of digital circuitry, resulting in a reduced need for calibration and repair.
11. The always on “fast scan” mode is unique. Unlike traditional receivers, architecture can allow full-time engagement of preselect filters without sacrificing performance or speed.
12. Calibration checks are possible by utilizing an internal wideband noise source to reduce verification time, compared to the tracking generator method used by others.
13. Selectable resolution bandwidth provides flexibility in making signal measurement in the presence of ambient signals and during mitigation efforts.
14. Auto and user-controlled attenuation features prevent harm to the receiver. The auto attenuation function overrides the user control to protect the receiver from the overload conditions.
15. Receivers may be equipped with large internal and or external hard drives (e.g. 5OO GB) and multiple types of I/O ports (USB, SATA, Ethernet [10/100/1000Mbps], and IEEE 1394a)

Advantages in Test Environment

All of the advantages of a FFT measurement approach may not be apparent at first. Further review reveals time savings in numerous test scenarios, as well as a potential to increase quality of test results. Advantages can be seen in areas of: radiated emission, disturbance power, conducted emission testing, pretest verification, test site attenuation measurements, and periodic system maintenance checks.

Radiated Emission Measurement

Efficiency gains relative to radiated emissions testing may be achieved in a wide range of test environments, such as: open area test sites (OATS), gigahertz transverse electromagnetic (GTEM) cells, anechoic chambers, and shield enclosures. In some situations, such as with prescan emission searches where turntables and masts are used, measurement of emissions may be made by syncing turntable and antenna mast speeds with the instantaneous bandwidth of the receiver. Emissions scans within a GTEM can also be reduced with adjustments to control software to increased speed of emissions gathering for each orientation of the DUT, again instantaneously gathering a wide bandwidth of emissions data. In other cases where system or test standard dwell time dictate measurement time, as in the case of CISPR quasi-peak or average requirements, the ability to simultaneous measure emissions ranges greater than 100 MHz frequency spans may save hours of test time. For scans performed with the antenna and table in a stationary position, there is no need for prescanning. The 30 MHz to 1 GHz frequency range, as an example, may be evaluated in as little at 7 seconds for peak, quasi-peak, average, and RMS-average measurements.

Absorbing Clamp Emission Measurements

Improvements may also be seen with emission measurements using the absorb clamp approach, where a maximum hold and instantaneous bandwidth features can combine to measure a cable in under 5 minutes, as compared to each signal measurement taking 3 to 5 minutes using traditional approaches. As an example, if 20 emissions are measured, the time benefit is 20:1. The ability to measure cables in this manner also avoids measure errors associated with incorrect manual peaking approaches, where highest peaks are determined by sliding the absorbing clamp back and forth along the cable, which may not actually represent the high quasi-peak emission if the peak repetition rate is slow (see Figure 6: Peak and quasi-peak emissions).

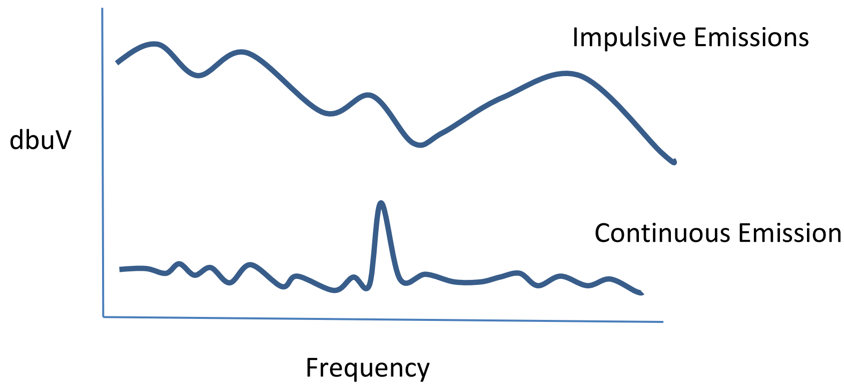

Figure 6: Peak and quasi-peak emissions

Conducted Emission Measurements

As with radiated emissions, the benefits of performing CISPR or FCC-conducted emission testing are significant. Scans with Quasi-peak and average detectors from 9 kHz to 30 MHz may be performed in as little as 2 seconds.

Pre-test Verification

Increasing confidence without increasing the effort of test setup verification is possible when using the FFT-based EMI receiver. Rather than reviewing one or even a small set of emissions from a known noise source, as is the case most often used with a conventional EMI receiver, complete spectrums maybe reviewed in less than the time it takes conventional EMI receivers. This applies to conducted emissions (power line or telecom), radiated emission, and system maintenance checks, and cable insertion loss measurements.

Normalized Site Attenuation Measurement Efficiency Gains

Qualification efforts associated with the requirements of ANSI C63.4 (Methods of Measurement of Radio-Noise Emissions from Low-Voltage Electrical and Electronic Equipment in the Range of 9 kHz to 40 GHz) normalized site attenuation measurement can be reduced through FFT measurement technics. For instance, test time is reduced when performing V_{Direct}, and site attenuation measurements when a calibrated noise source is used in conjunction with the FFT EMI receiver. Although not a significant improvement in time over current approaches used by conventional receivers, there is still an efficiency gain with the FFT EMI receiver.

Non-compliant Emissions

In the event it is necessary reduce emission levels, the measurement portion of the task is greatly reduced with FFT EMI receivers having as an example +100 MHz instantaneous bandwidth, allowing engineers the flexibility to determine better solutions that more closely meet design and production expectations. In addition, new tools such as 3D spectrograms may be used to identify with greater certainty the origins of emissions, giving engineers greater opportunity to develop more appropriate solutions.

Conclusion

As shown, properly designed FFT EMI receivers will not only meet standards such as CISPR 16-1-1, but will also improve quality of test measurements and streamline testing, saving test cost and aiding in efforts to reduce time to market. In addition to greater speed, greater sensitivity, implementation of 3D spectrograms, and traditional features (e.g. wide range of bandwidth selection, adjustable scan rate, dwell time options, multi-function marker controls, transducer correction factors, limit line selection, auto/manual attenuation, and frequency and time domain views) are common place. Some receivers offer software applications that allow easy access to controls through keyboard, mouse, and large monitors to reduce nested option scenarios, streamlining operation of the tool.

References

[i] *Reference Data for Engineers: Radio, Electronics, Computer, and Communications (Seventh Edition)*, Edward C. Jordan, Sams Publishing (Indianapolis), pg. 28-22, July 1985.

[ii] “A Novel Ultra-fast High Resolution Time-domain EMI Measurement System based on Field Programmable Gate Arrays”, Stephan Braun, Reinhard Schneider and Peter Russer, International Symposium on Electromagnetic Compatibility (Barcelona, Spain), Vol. 1, pg. 701-705, September 2006.