MIL-STD-461 Testing Advantages Using Time Domain Scan EMI Receivers

Application Note

Products:

- R&S®ESW EMI Test Receiver
- R&S®ESR EMI Test Receiver

ROHDE&SCHWARZ

Application Note

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1 Introduction

Even when using various time-saving procedures, Electromagnetic Interference (EMI) measurement times are still very long – typically several hours for radiated emissions measurements. The introduction of spectrum measurements based on fast Fourier transform (FFT) – also known as a time domain scan – allows a significant reduction in measurement times and improves the probability of intercept (POI) without affecting accuracy. EMI FFT based receivers can significantly reduce test times, in some cases by a factor of up to almost 2000, using time-domain methods to identify the disturbance spectrum.

While many test engineers are following MIL-STD-461, some may not be familiar with the specifics of time domain scan in version MIL-STD-461G (**Figure 1**). In this version, Section 4.3.10.3 Emissions testing Table II provides the specifications for Bandwidth and Measurement times for all types of measuring receivers, including the FFT-based receiver.

TABLE II. Bandwidth and measurement time.

Frequency Range	6 dB Resolution Bandwidth	Minimum Dwell Time		Minimum Measurement Time Analog-Tuned Measurement Receiver [1/]
		Stepped-Tuned Receiver [1/] (Seconds)	FFT Receiver [2/] (Seconds/ Measurement Bandwidth)	
30 Hz - 1 kHz	10 Hz	0.15	1	0.015 sec/Hz
1 kHz - 10 kHz	100 Hz	0.015	1	0.15 sec/kHz
10 kHz - 150 kHz	1 kHz	0.015	1	0.015 sec/kHz
150 kHz - 10 MHz	10 kHz	0.015	1	1.5 sec/MHz
10 MHz - 30 MHz	10 kHz	0.015	0.15	1.5 sec/MHz
30 MHz - 1 GHz	100 kHz	0.015	0.15	0.15 sec/MHz
Above 1 GHz	1 MHz	0.015	0.015	15 sec/GHz

1/ **Alternative scanning technique**. Multiple faster sweeps with the use of a maximum hold function may be used if the total scanning time is equal to or greater than the Minimum Measurement Time defined above.

2/ **FFT Receivers.** FFT measurement techniques may be used provided that FFT operation is in accordance with ANSI C63.2. The user interface of the measurement receiver must allow for the direct input of the parameters in Table II for both FFT Time Domain and Frequency Stepped modes of measurement in the same manner, without the necessity or opportunity to control FFT functions directly.

Figure 1. Mil-STD-461G Table II adds the measurement parameters enabling the use of FFT based EMC receivers.

Taking the R&S EMI test receiver as an example, this paper compares the measurement speed and level measurement accuracy of a conventional swept frequency spectrum analyzer against the speed and accuracy of advanced time domain scanning. It also contains guidance on making optimum use of time domain scans, plus their advantages in capturing intermittent signals with an improved POI. For those unfamiliar with FFT based receivers, we will start with an overview of the technology that makes them work.

Before we get started, it is good to discuss the relationship of MIL-STD-461G, ANSI C63.2, and CISPR 16-1-1. For years, MIL-STD-461G has deferred the requirements of the measuring receiver to the ANSI C63.2 Specification. ANSI C63.2, in turn, defers to the body of work in CISPR 16-1-1 to define the requirements of receivers. CISPR (International Special Committee on Radio Interference) first embraced FFT technology with its publication in June 2010 of Amendment 1 to the third edition of CISPR 16-1-1, which permitted the use of FFT-based test instruments in standard compliant measurements. So, MIL-STD-461G receiver performance is referenced to CISPR in terms of defining the requirements for time domain overlap and frequency to create reproducible results independent of the type of receiver used for testing.

2 Comparing Architectures

2.1 Sweeping Spectrum Analyzers

Spectrum analyzers have long been used for EMI measurements. Their broad frequency range, relatively fast frequency sweeps, and multi-use capabilities have made them widely available. **Figure 2** shows a typical block diagram. The local oscillator (LO) is swept across a frequency range to control the measurement frequency. It should be noted that a spectrum analyzer designed for compliant EMI measurements has a substantial amount of hardware and signal filtering that is different from a normal spectrum analyzer. As mentioned previously, the performance requirements of an EMI compliant spectrum analyzer are defined in CISPR 16-1-1.

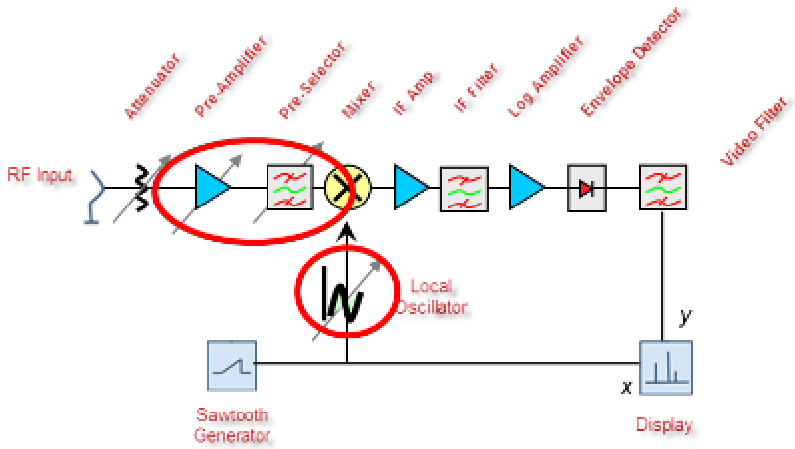

Figure 2. Typical spectrum analyzer block diagram.

The spectrum analyzer converts its input signal through a number of intermediate frequencies. At the final intermediate frequency (IF), IF filters limit the signal to the desired measurement bandwidth – 10 kHz, for example. The IF is rectified to produce a video voltage representing the signal level versus time. This video voltage is sent to the detector circuits. The detectors deliver standard-compliant, weighted measurement results at their outputs: the peak value, average value, quasi-peak value, etc.

As the spectrum analyzer continuously sweeps across the frequency range, one must determine what the measurement time is at each frequency per the standard by adjusting the slew rate of the sweep from Table II (**Figure 1**). The sweep speed and number of steps needs to be adjusted per the MIL-STD-461 standard to ensure that both enough time is spent at each frequency to detect the pulsed emissions and the number of point of resolution are adequate to represent the frequency bin resolution required by the standard. In this example shown in **Figure 3**, the required frequency bin resolution is ½ RBW in the measurement range (200 MHz to 1 GHz), the analyzer must be segmented into 16 separate sweep ranges to provide enough horizontal frequency resolution for the analyzer display.

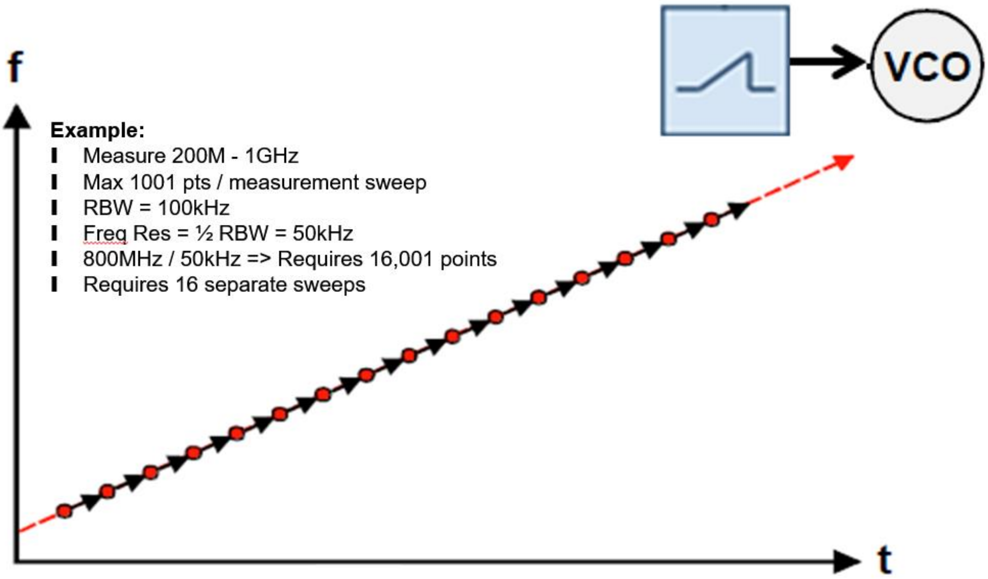

Figure 3. Sweeping Spectrum Analyzer – a typical swept analysis with 1001 pt resolution

Figure 4 shows an example of the number of sweeps required for compliance to MIL-STD-461G for the different frequency test bands with the minimum frequency bin resolution for a spectrum analyzer with 1001 points of horizontal resolution.

Frequency Banding	RBW	Freq Step 1/2 RBW	# Required Points	# Required Sweeps with max 1001 points
150kHz - 30MHz	10kHz	5kHz	5971	6
30MHz - 200MHz	100kHz	50kHz	3401	4
200MHz - 1GHz	100kHz	50kHz	16001	16
1GHz - 18Ghz	1MHz	500kHz	34001	34
18GHz - 40GHz	1MHz	500kHz	44001	44

Figure 4. – Common test bands and number of sweeps required for MIL-STD-461G

2.2 FFT-based EMI Receiver

The high-level block of an FFT-based receiver using time-domain scan is shown in **Figure 5**. There are three stages: RF; Wideband IF; and Digital Data processing. While there may be substantial architectural differences between an EMI compliant swept analyzer and FFT-based EMI receiver, the CISPR 16-1-1 measurement requirements have been defined to assure the receivers will give the same measurement results to a variety of signal conditions.

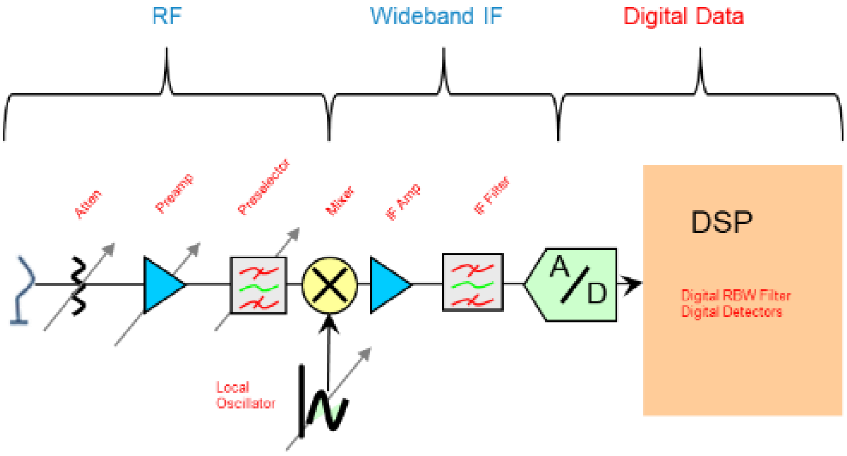

Figure 5. FFT-based time domain scan EMI receiver design

2.2.1 RF Stage

The combination of preselection and the A/D converter determine the dynamic range of the RF stage. In the RF stage, the purpose of preselection is to reduce the peak pulse voltage through band limitation and thus avoid overloading any mixers, IF amplifiers or the A/D converter. The receiver's converter and digital signal processing operate at a resolution of 16 bits and thus have so much dynamic range that the preselection filters can be much wider than in earlier generations of instruments and do not limit the overall dynamic range. This is important to allow the instrument to compute the FFT over as large a frequency range as possible.

2.2.2 Wideband IF stage

Unlike a traditional swept analyzer where the IF bandwidth maybe equivalent to the measurement Resolution Bandwidth, the FFT-based analyzer can take advantage of a wideband IF stage. In this architecture, the FFT-based test receiver digitizes the signal mixed onto the intermediate frequency before the signal is limited to the chosen IF bandwidth (**Figure 5**). The availability of A/D converters with a high sampling rate and a wide dynamic range makes this possible. The latter is not just applied together with the measured signal within the IF bandwidth, but depending on the bandwidth before the A/D converter (pre-A/D), together with the sum signal within "n" bandwidths, where "n" is the ratio of the pre-A/D converter bandwidth to the selected measurement bandwidth. The receiver uses Fast Fourier Transforms (FFT) to compute the relevant frequency bin resolution required from the time domain signal of the digitized IF. The IF contains the spectrum to be measured in the time domain –hence the term "time domain scan".

The FFT parameters and the time domain signal window are set in such a way that the resolution bandwidth and filter characteristics match the IF bandwidths stipulated in CISPR 16-1-1. In this way, the receiver implements a filter bank with effectively several thousand parallel filters. After each of these filters there are a rectifier and detectors. Instead of a single measured value representing the frequency range of each measurement bandwidth (e.g. 10 kHz), this approach delivers many parallel measured values covering the frequency range of several thousand measurement bandwidths at the same time (**Figure 6**). This reduces the measurement time by a factor that corresponds to the number of parallel measurement bandwidths within the FFT analysis bandwidth.

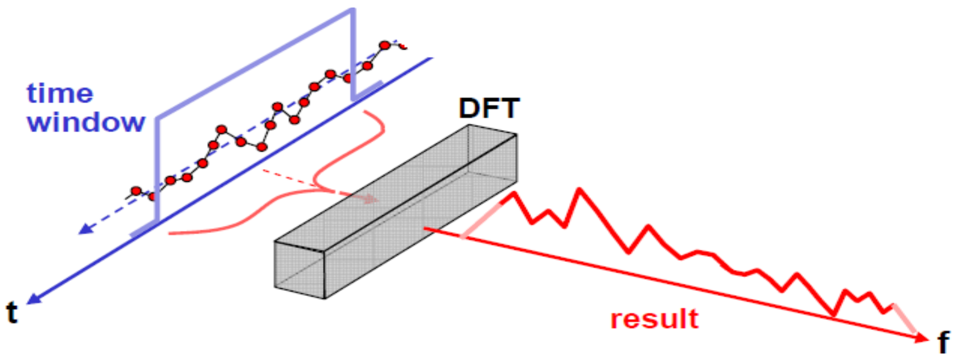

Figure 6. Time domain scan

2.2.3 Digital Data (DSP)

In the next stage, the digital downconverter reduces the data rate to match the measurement bandwidth. Then, the signal processing carries out the FFT computations and returns the frequency spectra. Depending on the instrument settings (the measurement bandwidth, for example), the FFT can be up to 16,384 frequency bins in length (16k-FFT). This FFT length and the wide preselection make it possible to capture the whole of MIL-STD-461G, from 150 kHz to 30 MHz, at the standard-compliant measurement bandwidth of 10 kHz.

While MIL-STD-461G requires only a peak-detector, commercial test specifications (i.e. standards) require different detectors when evaluating disturbance signals – peak value and average value detectors, and more complex detectors like the quasi-peak, CISPR-average and RMS-average detectors, for example. While not required for MIL-STD testing, these detectors do provide valuable insight in the evaluation of time-varying signals (like pulsed or spread spectrum). In classic receivers, after band limitation, the video voltage is sent through the IF filter (e.g. 10 kHz or 100 kHz) into the detector circuit. A current, classic EMI test receiver can operate multiple parallel detectors and display them at the same time, but only for a single frequency. An FFT-based test receiver computes many FFTs and therefore spectra during the configured measurement time. The digital detector circuit first puts the frequency spectra in series and generates up to 16,384 video voltages on neighboring frequencies. The receiver analyzes each of these video voltages with the same number of parallel detectors and, after the dwell time, returns not just one level value but several thousand.

A field programmable gate array (FPGA) provides the requisite computing power. The entire processing chain, from the A/D converter to the detectors, is set up in such a way that all the computing operations can be performed in real time. This means that the measurement results are shown on the display after a measurement time of, say, one second, but in contrast to a classic test receiver, an FFT-based test receiver can do this for multiple frequencies at once rather than just for a single frequency. It is important to emphasis that the behavior of the FFT-based EMI receiver architecture will provide the same measured results of the EMI compliant swept analyzer; the results tend to produce substantially faster results with higher degree of reproducibility in the FFT-based receiver due to the increased probability of intercept. The swept analyzer would be required to sweep multiple times to see a time-varying signal given similar test conditions.

3 How an FFT-Based Receiver Operates

3.1 The Windowing Function

The Fourier transformation is a mathematical method that provides a simple means of breaking down into frequency components a signal that varies versus time. It uses the Fourier integral to compute the frequency spectrum from a time domain signal. Because the Fourier integral's integration boundaries extend from minus infinity to plus infinity, the observation period is, in theory, infinite. In practice, the fast Fourier transform (FFT for short) is applied. The FFT is computed with a defined number of discrete values and therefore covers a limited time. The duration of signals to be measured and the FFT length generally do not match, because the signals observed are mixed, consisting of periodic, non-periodic and noise components. The FFT extracts part of the time signal in such a way that jumps occur in the signal at the beginning and end of the FFT. This results in significant quantities of signal components that are not part of the actual spectrum. The occurrence of these sidelobes in the spectrum is referred to as leakage (**Figure 7**).

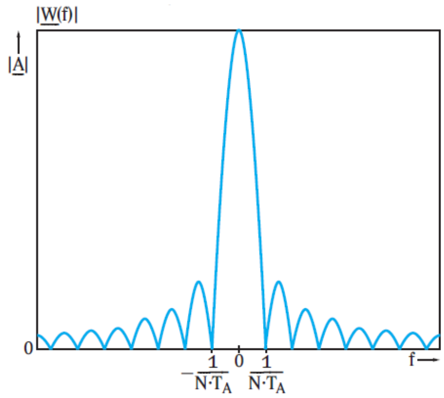

Figure 7. Spectral diagram of leakage caused by time limitation of the signal.

This is remedied by applying a window function to the samples in the time domain that shows and attenuates the signal at the beginning and end of the FFT (**Figure 8**). The signal is periodized, diminishing the sidelobes to the extent that they no longer play a role (**Figure 9**).

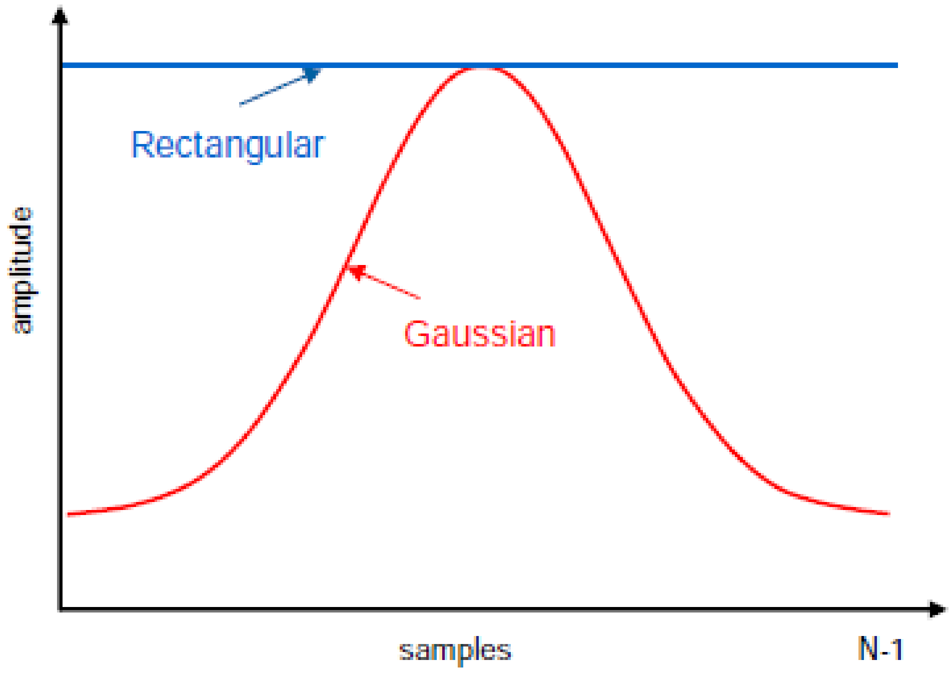

Figure 8. Rectangular and Gaussian windows.

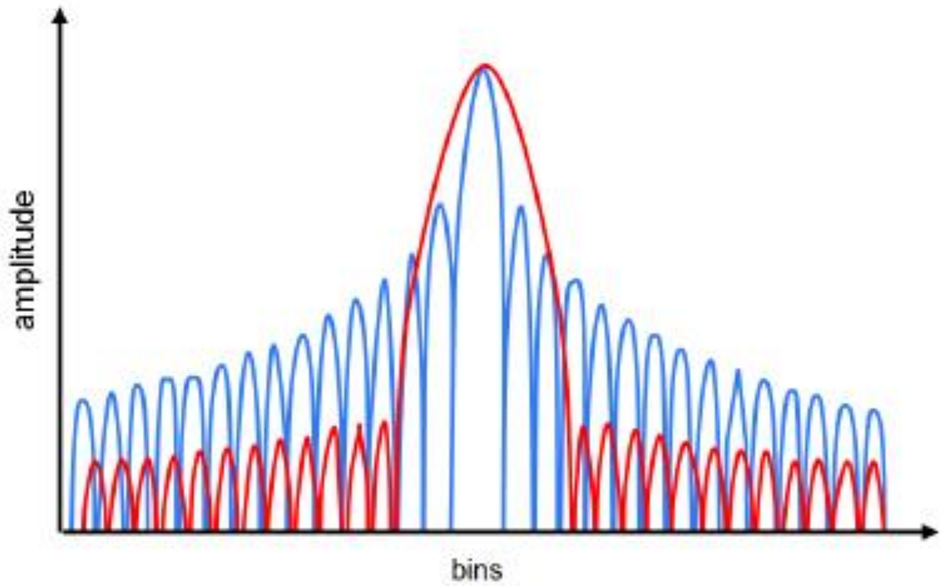

Figure 9. Blue indicates strong leakage (rectangular window) with many sidelobes, red shows leakage greatly reduced by the Gaussian window function.

The window function selected in the time domain defines the filter shape of the measurement bandwidth in the frequency range. The standard applied (CISPR 16-1-1, for example) determines the shape of filter to be used (**Figure 10**).

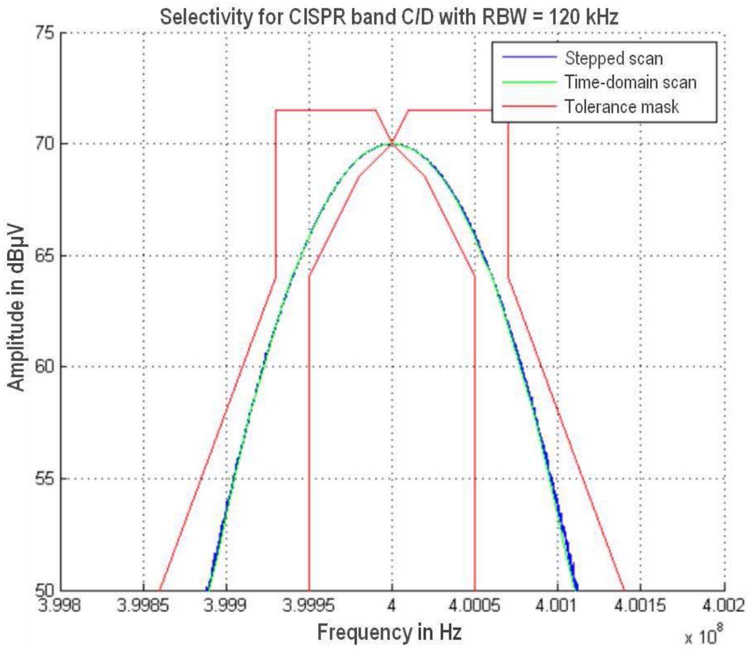

Figure 10. Tolerance mask as per CISPR for a measurement bandwidth of 120 kHz, and the EMI test receiver's filter shapes.

The EMI receiver multiplies the samples in the time domain with a Gaussian window. This has two advantages: The leakage is suppressed, and the FFT computation produces Gaussian measurement bandwidths that exactly fit the tolerance masks defined in the standard.

3.2 Overlapping in the Time Domain

The window function is multiplied with the samples in the time domain. Brief events (i.e. pulses) are only mapped correctly by a single FFT if they lie in the middle of the window. The window function weakens the signal at the edges (**Figure 11**).

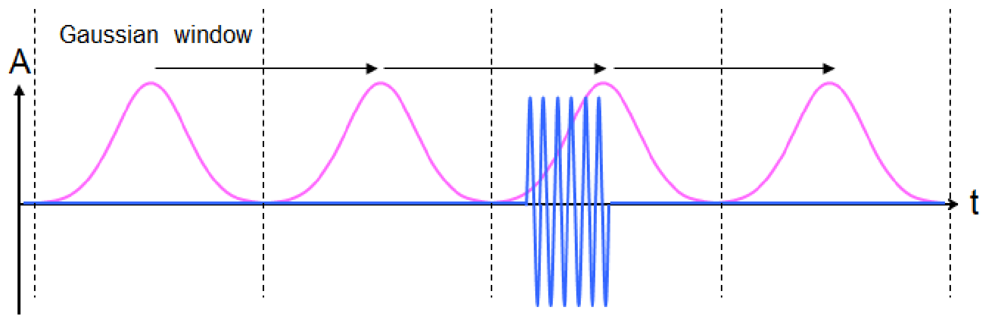

Figure 11. The window function weakens the pulse at the edge.

The solution is to compute many FFTs while shifting the window by a small percentage of its length between one FFT and the next (**Figure 12**).

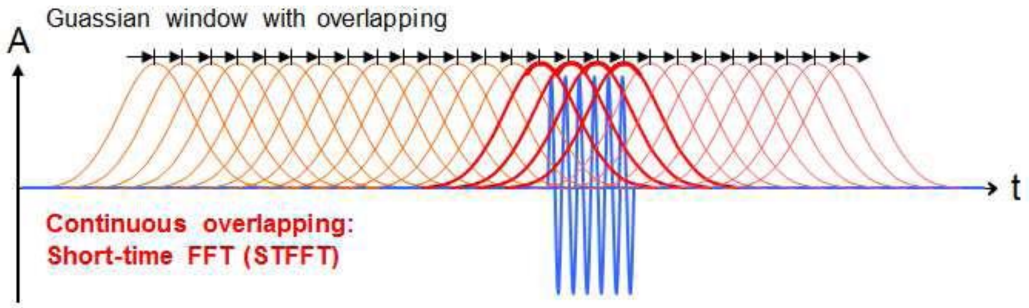

Figure 12. The short-time FFT consists of highly overlapping FFTs. The level is indicated correctly by the combined FFTs shown in red.

CISPR 16-1-1 requires a minimum overlap of 75 % between the FFTs to ensure that the level measurement uncertainty for the pulse amplitude remains less than ±1.5 dB. In the R&S receivers, the FFTs overlap by at least 93 %. The detectors after the FFT evaluate all the computed spectra and therefore record the correct level for even the shortest of pulses. The residual level errors resulting from the curvature of the window are so small as to be negligible.

The advantage of the FFT process now becomes clearer with respect to a swept analyzer. It would take a near infinite number of sweeps with a swept tuned analyzer to capture the peak signal caught by an FFT analyzer in a single dwell.

3.3 Overlapping in the Frequency Domain

In the time domain, the Gaussian window function is transformed by the FFT into a Gaussian measurement bandwidth. This produces discrete, overlapping measurement bandwidths in the frequency range. If a sinewave carrier is located exactly between two of these measurement bandwidths referred to as frequency bins, the result is a level error. In the frequency domain, too, the level error depends on the overlap.

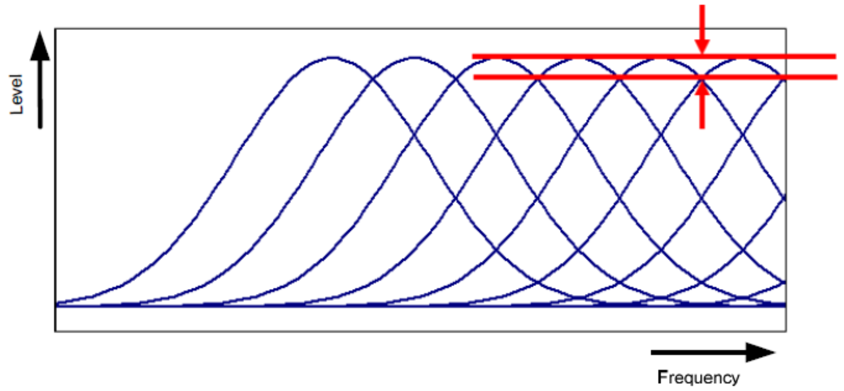

Figure 13. The picket fence effect.

While the frequency bin resolution of MIL-STD-461G is a minimum of half of the measurement RBW, FFT-based EMI receivers have a spacing between adjacent frequency bins of a quarter of the 6 dB measurement bandwidth – that is, 2.5 kHz at a measurement bandwidth of 10 kHz. The narrower spacing between bins reduces the level error. In a classic test receiver using stepped frequency scans, the picket fence effect (**Figure 13**) occurs in the same way because this receiver type conducts measurements with discrete frequency spacings. The FFT-based method has an advantage because, despite the spacing of a quarter of the measurement bandwidth (which is prescribed to ensure a smaller measurement error), the measurement time remains short. The frequency swept spectrum analyzer can increase the step size to half or even the whole of a measurement bandwidth and reduce the number of individual measurements and the overall measurement time too. However, this can only be accomplished at the expense of a much greater measurement error with narrowband disturbance signals. This issue does generally not affect broadband disturbance signals because the signal power is distributed so evenly across the spectrum that the highest level is found.

The narrow spacing of the measurement bandwidths naturally means more measured values, so the receiver needs to have sufficient memory capacity to record the results. Rohde & Schwarz EMI receivers can store 4 million level values for each detector measured. With a measurement bandwidth of 10 kHz and a resulting offset of 2.5 kHz, this is sufficient for a frequency range of 10 GHz.

3.4 Detectors

A frequency bin represents the measurement bandwidth of an FFT frequency. The frequency bin is observed versus time, across many FFTs issuing from the FFT block. The level versus time corresponds to the video voltage present in the classic test receiver after the IF filter and rectifier. The big advantage of the FFT-based method is that it delivers a very large number of video voltages at the same time by lining up the FFT-computed spectra. The measurement bandwidth of each frequency bin in the FFT corresponds to the IF bandwidth in the classic receiver. The FFT works like multiple IF filters arranged next to one another in the frequency range. The classic receiver feeds the video voltage to the detector circuit directly. Similarly, the FFT-based receiver feeds multiple video voltages at once to a large number of digital detector circuits.

The way the EMI test receiver's peak detector is set up is simple: It stores the highest value of the video voltage during the measurement time. All this requires is a controller and a memory location for the level value of each frequency. The weighting detectors as set out in the CISPR 16-1-1 standard for commercial applications – quasi-peak, CISPR-average and RMS average– are significantly more complex and compute-intensive. The charge and discharge time constants and the meter time constant are implemented by means of multistage filter functions; they call for a large amount of memory. One of the design goals with R&S receivers is not just to perform measurements on many frequencies in parallel, but to have the capacity to measurement numerous detectors simultaneously. To accomplish this, they have parallel filter functions and detectors (**Figure 14**).

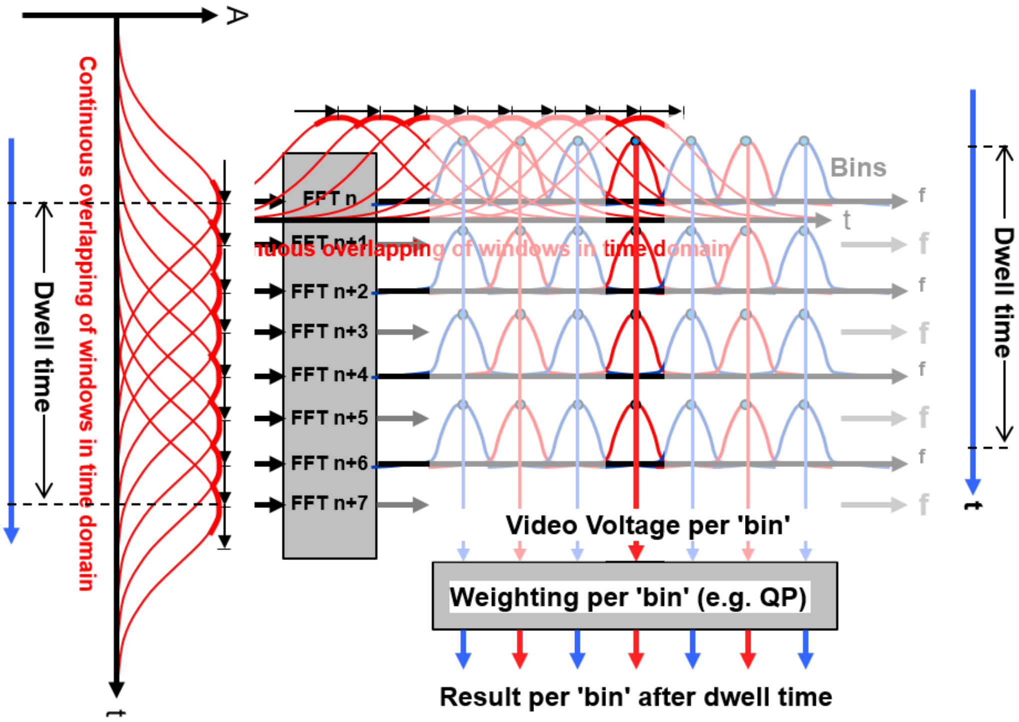

Figure 14. FFT process overlaid in Time

4 Choosing the Right Measurement Time

When measuring an unknown disturbance signal in a frequency spectrum, the EMI test receiver must analyze a specific frequency range – ideally in as short a time as possible. In practice, settling time is relevant in connection with narrow measurement bandwidths. The EMI test receiver takes this into account automatically. However, users must always consider how the disturbance signal behaves versus time. Continuous and clocked narrowband disturbance signals and continuous, intermittent broadband disturbance signals can occur. To correctly measure intermittent disturbance signals, it is essential to configure a sufficiently long measurement time that will allow the highest level to be recorded reliably.

MIL-STD-461G defines minimum measurement times for analog test receivers and minimum observation times for synthesizer-based test receivers (both stepped tuned and FFT receivers) (**Figure 15**). For instruments that only generate disturbances at intervals, the measurement time must be extended so that it is sufficiently long to record every disturbance that occurs. As we will see later, the FFT is superior at capturing intermittent signals. If FFT measurement time has to be increased then analog sweep time will increase as well, thus FFT is still much faster.

TABLE II. Bandwidth and measurement time.

Frequency Range	6 dB Resolution Bandwidth	Minimum Dwell Time		Minimum Measurement Time Analog-Tuned Measurement Receiver 1/
		Stepped-Tuned Receiver 1/ (Seconds)	FFT Receiver 2/ (Seconds/ Measurement Bandwidth)	
30 Hz - 1 kHz	10 Hz	0.15	1	0.015 sec/Hz
1 kHz - 10 kHz	100 Hz	0.015	1	0.15 sec/kHz
10 kHz - 150 kHz	1 kHz	0.015	1	0.015 sec/kHz
150 kHz - 10 MHz	10 kHz	0.015	1	1.5 sec/MHz
10 MHz - 30 MHz	10 kHz	0.015	0.15	1.5 sec/MHz
30 MHz - 1 GHz	100 kHz	0.015	0.15	0.15 sec/MHz
Above 1 GHz	1 MHz	0.015	0.015	15 sec/GHz

1/ **Alternative scanning technique**. Multiple faster sweeps with the use of a maximum hold function may be used if the total scanning time is equal to or greater than the Minimum Measurement Time defined above.

2/ **FFT Receivers.** FFT measurement techniques may be used provided that FFT operation is in accordance with ANSI C63.2. The user interface of the measurement receiver must allow for the direct input of the parameters in Table II for both FFT Time Domain and Frequency Stepped modes of measurement in the same manner, without the necessity or opportunity to control FFT functions directly.

Figure 15. MIL-STD-461G bandwidth and measurement times now include a footnote for FFT receivers.

Footnote 2 in the table states that the FFT measurement techniques may be used provided that FFT operation is in accordance with ANSI C63.2. After our example of determining measurement time, we will show how the R&S user interface allows for the direct input of the parameters for both FFT Time Domain and Frequency Stepped modes of measurement in the same manner, without the necessity or opportunity to control FFT functions directly so the integrity of compliant measurements is held intact.

First, let us consider an example that compares the properties of a stepped frequency scan with those of a time domain scan. A signal generator supplies a carrier at 100 MHz that is pulse-modulated with a period of 12 ms. The test receiver conducts measurements with an observation time of 10 ms per frequency step (**Figure 16**).

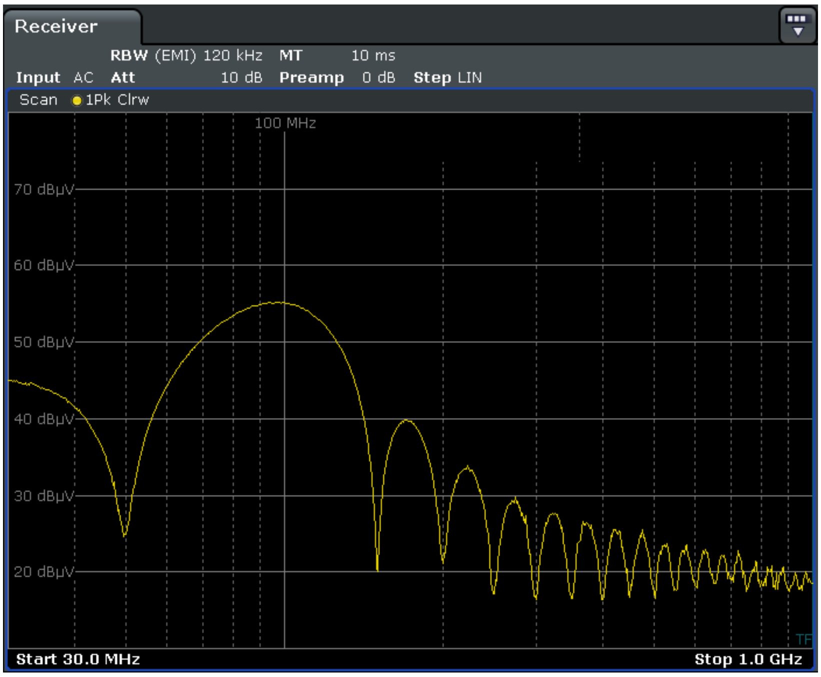

Figure 16. Stepped scan with a measurement time of 10 ms.

Close examination of the measured values using the zoom function reveals that a pulse was not always captured at every single step. This behavior can be expected with an observation time of 10 ms and a pulse spacing of 12 ms.

In **Figure 16**, however, the trace is closed. The receiver combines all the measured values that fall on a single display pixel and shows only the highest-level value. Here, 691 pixels represent 24,250 measured values. The individual values are only visible if the frequency range is stretched to the point that each pixel represents a single measured value. In **Figure 17**, it is possible to see that there is not always a pulse in each measurement interval, otherwise the trace would be closed and the signal dropouts would not be visible.

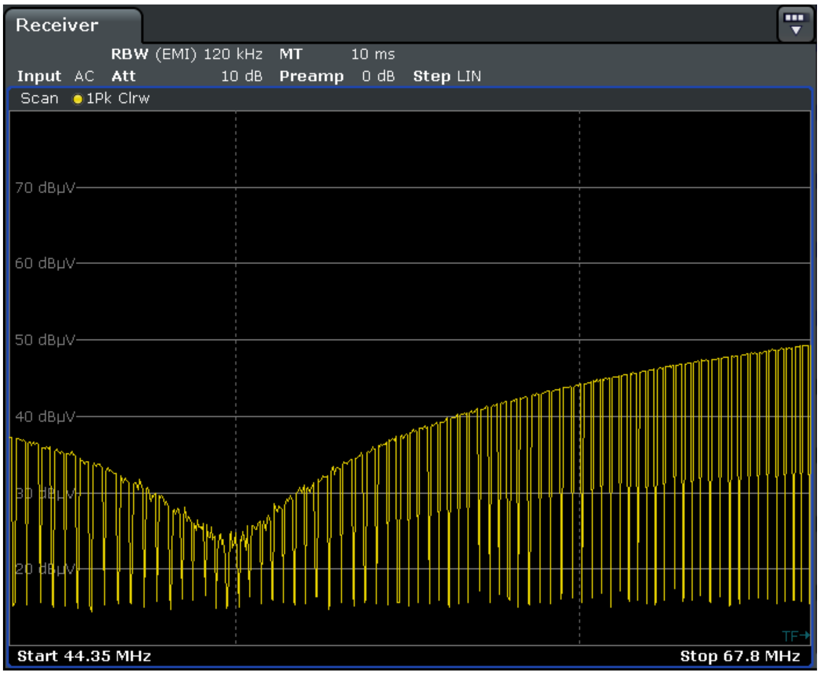

Figure 17. Stepped scan with a measurement time of 10 ms and the frequency axis stretched.

The time domain scan observes entire frequency ranges during the measurement time. If the measurement time is at least as long as the signal period, the scan captures the signal completely, without gaps (**Figure 18**).

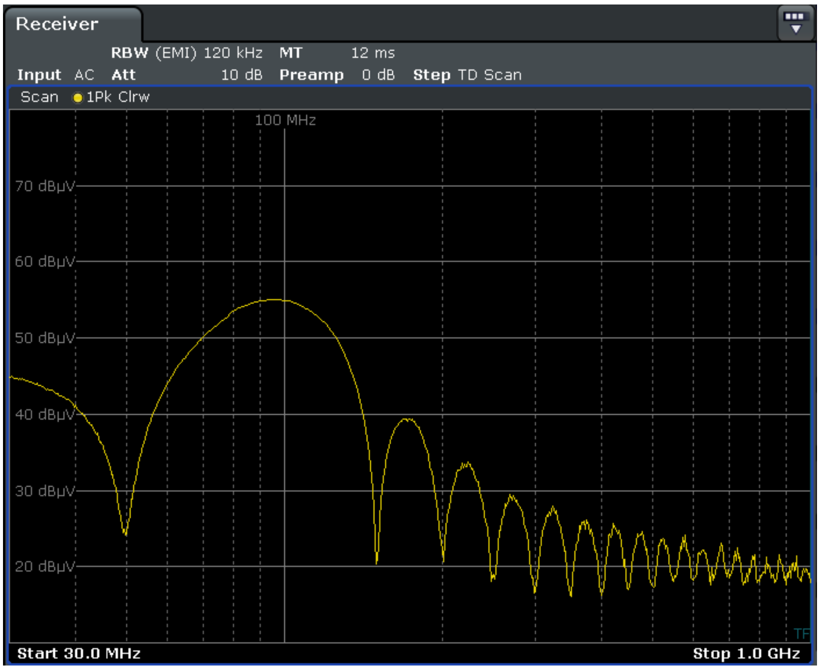

Figure 18. Time domain scan with a measurement time of 12 ms, signal with a pulse period of 12 ms.

If the measurement time drops below the pulse period, there are points at which no pulse occurs during the measurement time and thus the FFT computes zero amplitude for all the frequency bins within the FFT analysis BW. The signal is not visible in parts of the spectrum that correspond to the length of an FFT block, and not just in individual frequency steps (**Figure 19**).

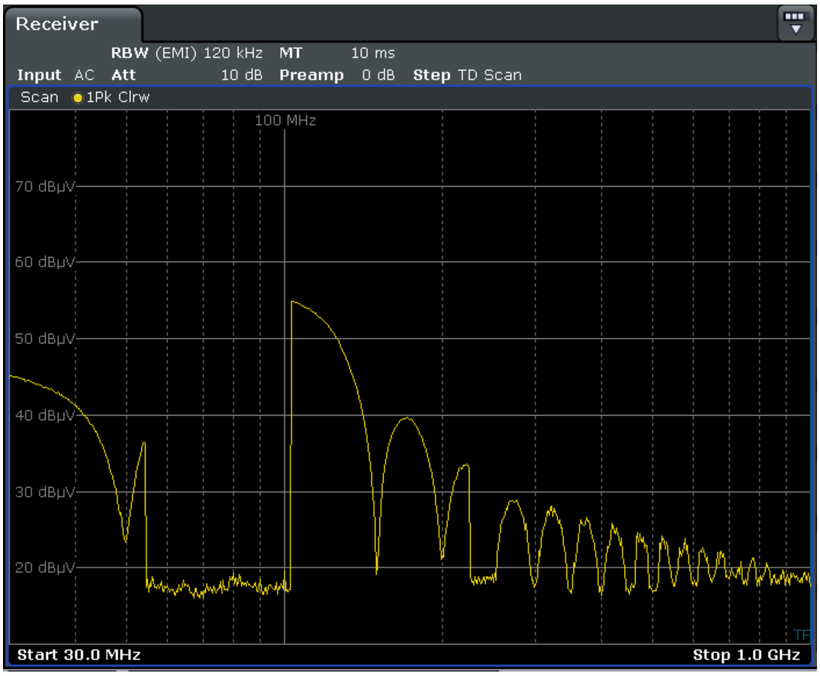

Figure 19. Time domain scan when the measurement time is shorter than the signal's pulse period.

With measurements conducted using a time domain scan, it is especially important to configure the measurement time to suit the signal measured. Gaps in the spectrum are an indication that the measurement time is too short. Given that the overall measurement time is generally much shorter in time domain scans, users can increase the measurement time (i.e. the observation time per FFT area). Even so, the overall measurement time remains short in comparison with a stepped frequency receiver while increasing the Probability of Intercept.

As per MIL-STD-461G Table II Footnote 2, the R&S user interface allows for the direct input of the FFT time domain parameters without the necessity or opportunity to control FFT functions directly (**Figure 20**). This allows the user to configure the measurement based on the standard or a longer observation period based on the behavior of the DUT without the opportunity for errors caused by making changes to the windowing or time overlap FFT functions.

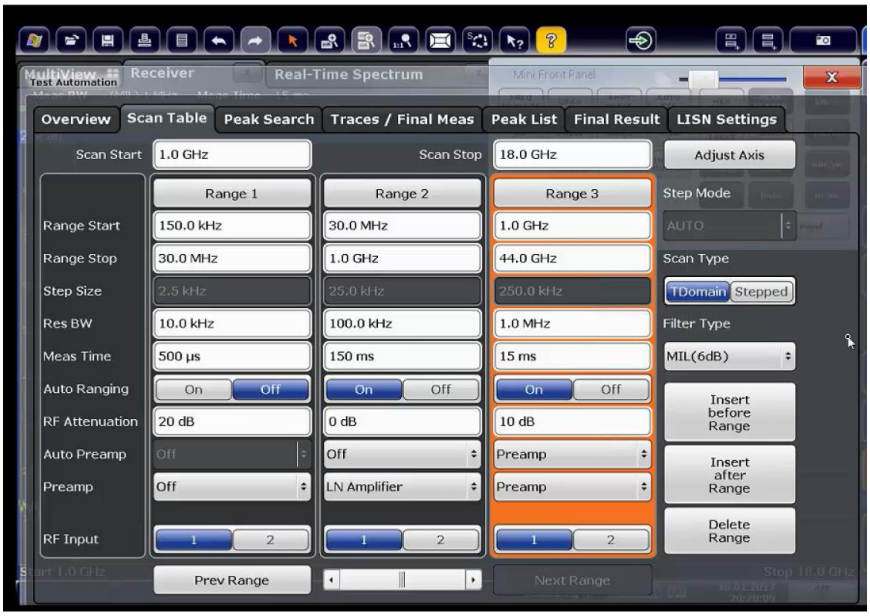

Figure 20. R&S FFT receiver user interface allows for the direct input of the measurement parameters without the necessity or opportunity to control the FFT functions directly.

5 Advantages for MIL-STD-461 and Other A&D Measurements

5.1 Speed

There are several advantages of an FFT-based receiver over a swept frequency spectrum analyzer. First, let's consider setting up an example sweep from 30 MHz to 200 MHz. To verify that the spectrum analyzer is set up to meet the minimum measurement time we need to do a couple calculations.

What does the spectrum analyzer sweep time need to be?

Sweep time = bandwidth x minimum measurement time

= (200 MHz - 30 MHz) x 0.15 sec/MHz

= 25.5 seconds, if we want to match the frequency stepped measurement Appendix A recommends doubling this to 51 seconds.

How many points are needed to meet the frequency resolution?

# of points = (bandwidth/RBW) x 2 + 1

= (170 MHz / 100 kHz) x 2 + 1

= 3,401 points

When setting up a measurement it is very important to first determine that you are meeting the minimum requirements for a compliant measurement. Sometimes errors may occur when the desire to reduce test time leads to a non-compliant measurement on a spectrum analyzer. Most EMC engineers have had to retake data because of a miscalculation at one point or another.

For the FFT based analyzer nothing needs to be calculated, the user just enters the frequency range. The resolution bandwidth (RBW) and minimum measurement time are pre-defined per the MIL-STD-461 frequency ranges on the setup menu (**Figure 21**). Sweeping 170 MHz, with a 150 millisecond dwell time, takes approximately 1 second. This reduces the error that might occur when configuring the sweep time and resolution on a traditional spectrum analyzer setup.

Figure 21. The FFT-based user interface is pre-configured for the MIL-STD requirements, with the user only needing to input the frequency range.

Another speed advantage with the FFT-based receiver is that the 150 kHz to 10 MHz and 10 MHz to 30 MHz frequency ranges can be combined into a single measurement since they have the same RBW and fit within the bandwidth of the Rohde & Schwarz EMI receivers (**Figure 22**).

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Above 1 GHz	1 MHz	0.015	0.015	15 sec/GHz

Combine Ranges with TDS

Figure 22. Combining the two frequency ranges with a common RBW allows for faster measurement times.

The R&S FFT-based receivers offer an industry advantage by using 16-bit analog to digital converters, which translates to a wider FFT bandwidth and therefore a faster time domain scan. Note that you can't calculate the exact time domain scan speed as you can for the spectrum analyzer, because the FFT bandwidth is implementation specific.

Table 1 highlights the significant speed advantages of the FFT Time Domain Scan versus the traditional analog sweep rate for each of the frequency ranges of MIL-STD-461. R&S receivers have the ability to collect measurements using either of the test modes. The speed advantage of the FFT-based configuration is from 22 to 45 times faster!

Table 1. Comparing Swept Frequency and FFT Time Domain Scan Measurement Times

Frequency Banding	RBW	Analog Sweep Rate	Analog Time	FFT Mode Dwell Time	ESW FFT Time	Speed Factor Improvement
150kHz - 30MHz	10kHz	1.5 sec/MHz	45sec	1 sec	~1 sec	~45x
30MHz - 200MHz	100kHz	0.15 sec/MHz	25.5sec	150ms	~1 sec	~25.5x
200MHz - 1GHz	100kHz	0.15 sec/MHz	120sec 2min	150ms	~4 sec	~30x
1GHz - 18Ghz	1MHz	15 sec/GHz	255 4min15sec	15ms	9.5 sec	~27x
18GHz - 40GHz	1MHz	15 sec/GHz	330 5min30sec	15ms	15 sec	~22x

5.1.1 Low Noise, 10 Hz RBW Case Study

There are some aerospace and defense applications where the resolution bandwidth needs to be significantly less than those required by MIL-STD-461. One customer application required a scan from 30 MHz to 35 MHz with a 10 Hz RBW. With the FFT-based time domain scan, the speed savings you get at this lower resolution bandwidth is even more beneficial than the standard MIL-STD-461G RBWs. With a spectrum analyzer, the minimum sweep time required in this case for a 10 Hz RBW is approximately 50,000 seconds, which is over 1000 times more time than what is required by the FFT-based measurement. When your frequency range falls within the same FFT bandwidth, the speed factor increases as more points are added.

FFT-Based Time Domain Scan

- Frequency range of 30 MHz to 35 MHz
- 10 Hz resolution bandwidth
- Keeping the MIL-STD-461 150 millisecond dwell time
- Scan time: ~ 43 seconds
- Measured ~6 dB noise figure for the R&S ESW

5.2 Capturing Intermittent Signals

Let us look at an example that demonstrates the superiority of a FFT-based time domain scan relative to traditional spectrum analyzers to properly capture intermittent signals and to characterize a time variance spectrum. In this example, both modes of operation are set to a frequency range of 30 MHz to 200 MHz, with a 100 kHz RBW per MIL-STD-461. We will start with the spectrum analyzer mode. We can see some constant frequency components, but there is also some glitching (**Figure 23a**). Next one would turn on the max hold, which starts to fill in the spectrum (**Figure 23b**). However, with this viewpoint, we have no ability to diagnose what is going on with the time varying spectrum. Good spectrum analyzer users know how to troubleshoot this with zero span mode and some other techniques, but in this case, we are seeing a slow filling in of the spectrum. The sweep time specified in Mil-STD for this frequency range is 25.5 seconds. If we maintain this viewpoint for 25.5 seconds, we still may not capture everything. When spectrum analyzers do not display the same results as an

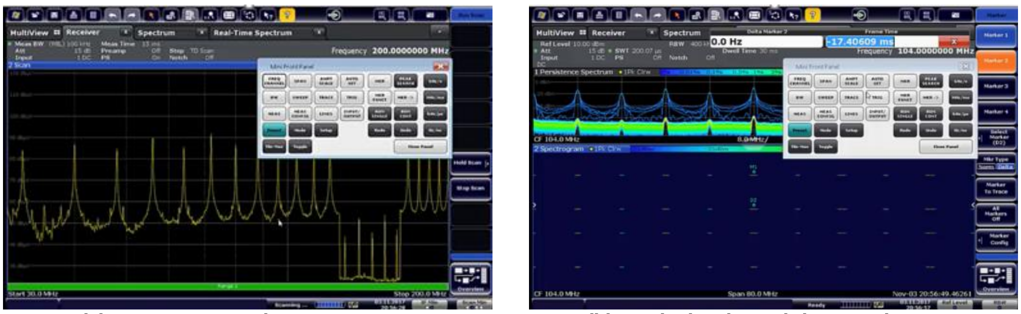
FFT measurement, is it most often because the FFT captures more intermittent signals within its analysis bandwidth. With a spectrum analyzer, an end user would need to increase the sweep time to yield a spectrum that matches the FFT capture, but this takes a long time and most users are not willing to wait.

(a) Time varying signal **(b) Using max hold**

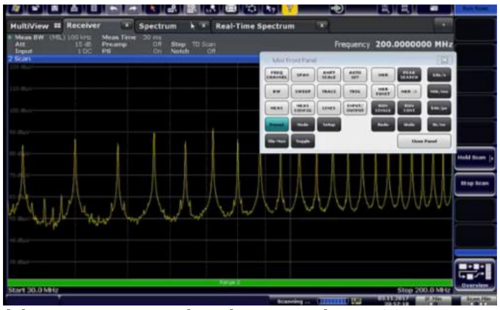
Figure 23. Capturing intermittent signals with a spectrum analyzer.

Now, let's try the same signal with the FFT-based receiver. When we run the receiver in continuous mode, there are visible dropouts that occur with each scan (**Figure 24a**). This quickly tells us that there's some time varying nature to the spectrum. By Switching to real time spectrum mode we can immediately see that there's a pulsed signal in the persistence display (**Figure 24b**).

In the real-time spectrogram display, it allows us to actually measure the repetition rate. If we put the markers on, we see it's repeating about every 17.5 milliseconds. So, our measurement time wasn't set long enough. Now we can go back to receiver mode and increase the dwell time to 17 milliseconds or longer for increased measurement confidence. Now we get the correct spectrum every single time, and it's immediate in terms of speed (**Figure 24c**).



(a) Measurement time = 15 msec **(b) Analyzing in real time mode**



(c) Measurement time increased to = 30 msec

Figure 24. Capturing intermittent signals with an FFT-based receiver.

6 Rohde & Schwarz Solutions

Rohde & Schwarz offers an exceptional range of EMC and field strength test equipment, from standalone instruments to customized turnkey systems. The EMC test solutions support all relevant commercial, automotive, military and aerospace standards as well as ETSI and FCC standards for radiated spurious emissions and audio breakthrough measurements.

R&S®ESW EMI Test Receiver

The R&S®ESW is an EMI test receiver for the frequency range from 2 Hz up to 44 GHz with outstanding RF characteristics, including high dynamic range and measurement accuracy. An external mixer option provides ability to measure in the 100s of GHz. It meets the most stringent requirements for certification measurements in line with CISPR, EN, MIL-STD-461, DO-160 and FCC. With its FFT-based time domain scan, the R&S®ESW captures and weights disturbance spectra in virtually no time. The instrument’s real-time spectrum analysis capability with spectrogram function permits a detailed analysis of disturbance signals and their history. MultiView mode delivers a straightforward display of results, even for multiple operating modes.

The R&S®ESW comes with FFT-based time domain scan as standard. Measurements that previously took minutes or hours are completed in just seconds. Even measurements that use two CISPR detectors (quasipeak, CISPR-average, RMS-average) are possible, cutting overall measurement time in half. The R&S®ESW combines the functions of an EMI test receiver with those of a full-featured spectrum analyzer in a single instrument.

Real-time spectrum analysis (R&S®ESW-K55 option) with a bandwidth of 80 MHz allows users to detect hidden or superimposed disturbances and analyze their causes using persistence mode and a frequency mask trigger. The spectrogram function provides seamless spectrum display in the time domain, making even rapidly changing disturbance signals visible. This saves considerable time and cost during product development and certification.

R&S®ESR EMI Test Receiver

The R&S®ESR is an EMI test receiver for the frequency range from 10 Hz to 26.5 GHz and complies with the CISPR 16-1-1 standard. It measures electromagnetic disturbances with the conventional stepped frequency scan or – at an extremely high speed – with an FFT-based time domain scan. At the same time, the R&S®ESR functions as a full-featured, powerful signal and spectrum analyzer for lab applications. Featuring real-time spectrum analysis capability with a wide range of diagnostic tools, the test receiver also enables detailed analysis of disturbance signals and their history. The R&S®ESR comes with clearly structured menus and an intuitive touchscreen, making it very easy to operate in any mode.

The R&S®ESR measures up to 6000 times faster than conventional EMI test receivers. Disturbance measurements that took hours in the past can now be completed in just seconds. This also applies to measurements across wide frequency ranges or with small step sizes as well as to disturbance voltage measurements using quasi-peak and average weighting. This saves considerable time and cost during product development and certification.

7 Conclusion

The introduction of time domain scan within MIL-STD-461G provides a great deal of incentive to upgrade receivers. The preconfigured MIL-STD-461 menus within the user interface of the R&S FFT-based receivers offers reduced opportunity for user configuration errors that may happen when using a traditional spectrum analyzer. The investment for a new EMI receiver may be quickly recovered with the dramatic speed advantages and increased throughput in your EMC test facilities. Finally, the ability of the Time Domain Scan to capture intermittent signals, reduces the probability of missing signals.

For more information on R&S FFT-based EMI receivers www.rohde-schwarz.com and search for **EMC & Field Strength Test Solutions.**

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