Oscilloscope RTSA Function Operation Guide and Applications

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Introduction

This guide explains the usage and applications of the real time spectrum analysis functions of the RFA option (SDS7000A-RFA) available on the SDS7000A series Oscilloscopes.

The primary functions include:

- Real-time spectrum analysis with up to 1 GHz of real-time bandwidth. This includes monitoring up to 8 GHz signals (with an 8 GHz oscilloscope model). Real time settings can be configured within the oscilloscope and include windowing, trace, and view options.
- Embedded SigVSA signal analysis software demodulates complex RF signals with onboard capture and analysis of wireless communications protocols.

This guide includes:

RTSA Configuration

The RTSA provides a dynamic frequency-based view of RF signals on the oscilloscope's display. Enabling this feature requires a SDS7000A series oscilloscope with FW version higher than V1.1.9.1R1 with the RFA option (SDS7000A-RFA) enabled.

Open the Spectrum Analysis toolkit by accessing the utility menu as shown:

Access: Utility-----Spectrum Analysis

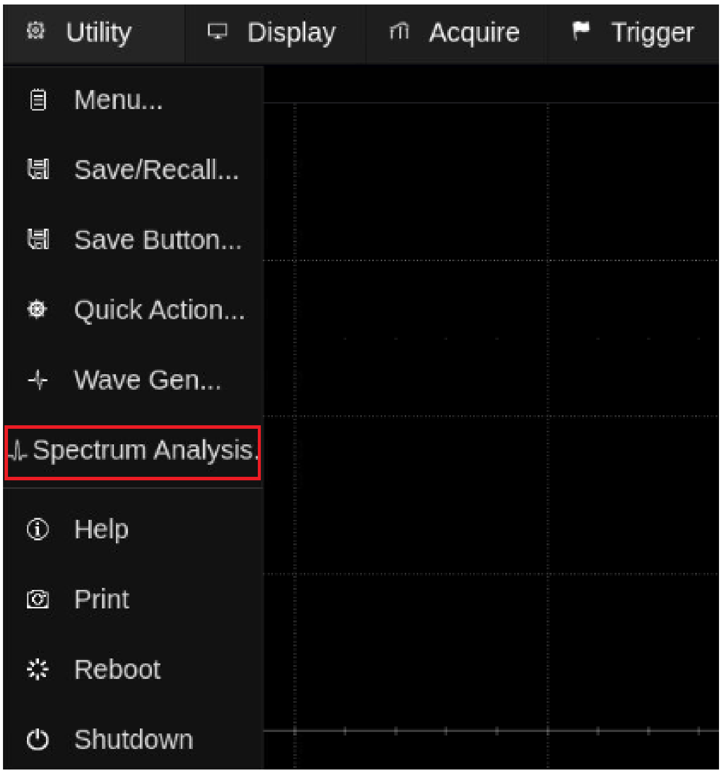

Figure 1 RTSA Function Access

Configuration of the Real-Time Spectrum Analyzer is done with menus like a spectrum analyzer including frequency, amplitude, configuration, and markers. Utilize the right-hand menus to configure your setup and display the real time spectrum. Use the lower channel popup window to set basic channel configuration.

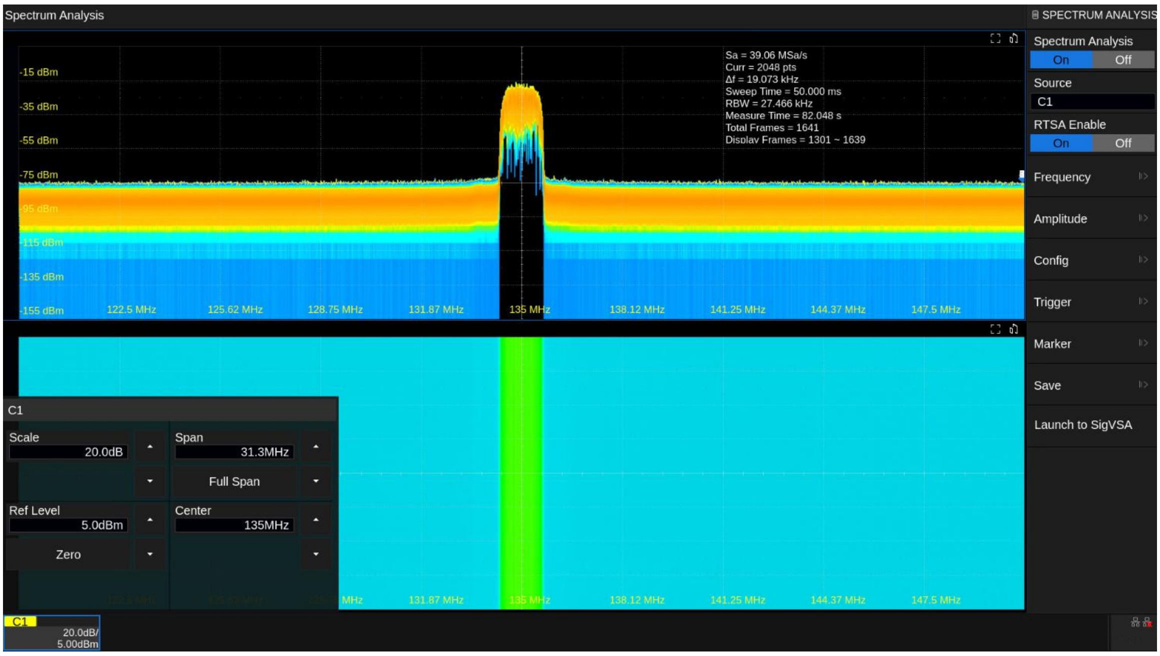

Figure 2 RTSA Interface

The channel selection tab in the lower left corner is consistent with that in the oscilloscope, where you can adjust the scale and reference level. You can also use the knobs on the keypad to adjust the parameters. The right-side menu contains the parameter setting options. In the source menu, you can switch between the channels (C1/C2/C3/C4). In the RTSA interface, the input impedance of each channel is fixed at 50Ω.

Display of Parameter Information: Parameter information is displayed on real-time spectrum analysis in a block which can be dragged to any convenient position. The list shows the current use of the FFT sampling rate (Sa), the FFT max points (Curr), the FFT sequence including the frequency interval between two neighboring points (Δf, i.e., Sa/Curr), the Sweep Time, and the resolution bandwidth (RBW). After turning on the Spectrogram view of the RTSA, three additional parameters will appear: measure time, total frames, and display frames. There is an upper limit for the number of display frames; the most recent 340 frames of the Spectrogram are displayed in a FIFO (first in, first out) manner.

Frequency: Select the start frequency and end frequency of the signal as well as the size of the span in the frequency menu. The selectable analysis bandwidths are 125MHz. 250MHz, 500MHz and 1GHz with each step doubling the span.

Amplitude: In the Amplitude interface, the reference level, unit and scale are displayed. The reference level corresponds to the value indicated by the top scale line in the spectrum analysis interface, with a minimum resolution of 0.1dBm.

The default unit is dBm, and the scale is changed in steps of 1-2-5-10.

Configuration: The maximum number of FFT points (2k/4k/8k/16k/32k/64k/128k/256k/512k/1M/2M/4M/8M) can be set in the configuration interface, and the more FFT points you choose corresponds to a smaller resolution bandwidth resulting in a lower noise floor. At the same time, the selection of the window function type can also be changed. This table describes the characteristics of each window type (table 3).

Window	Characteristics	Main lobe width	Side lobe suppression	Maximum amplitude error
Rectangle	The best frequency resolution The worst amplitude resolution It is equivalent to the case of no window	$4\pi/N$	-13dB	3.9dB
Blackman	Poor frequency resolution Better amplitude resolution	$12\pi/N$	-58dB	1.1dB
Hanning	Better frequency resolution Poor amplitude resolution	$8\pi/N$	-32dB	1.4dB
Hamming	Better frequency resolution Poor amplitude resolution	$8\pi/N$	-43dB	1.8dB
Flattop	The worst frequency resolution The better amplitude resolution	$23\pi/N$	-93dB	$<$ 0.1dB
Blackman-Harris	Poor frequency resolution Better amplitude resolution	$14\pi/N$	-67dB	0.9dB
Gaussian	Better frequency resolution Better amplitude resolution	$7.3\pi/N$	-55dB	1.0dB

Figure 3 Window Types and Characteristics Table

Using a window minimizes discontinuities at the end of the signal interval, reducing spectral leakage and improves frequency resolution. Select the appropriate window based on the signal type and measurement purpose.

When RTSA Enable is off, you can select the number and type of traces to display in the configuration interface and enable the Math function to perform the athematic operations on the traces.

Currently, the maximum number of traces that can be set is 4, and each trace can be displayed in six ways (Clear Write, Max Hold, Min Hold, Average, View, Blank).

- Clear Write: Erases any data previously stored in the selected trace, and display the data sampled in real-time of each point on the trace.
- Max Hold: Retain the maximum level for each point of the selected trace. Update the data if a new maximum level is detected in successive sweeps and form a peak envelope.
- Min Hold: Display the minimum value from multiple sweeps for each point of the trace and update the data if a new minimum is generated in successive sweeps and form a valley envelope.
- Average: Set up to 100 averages to average the results of multiple calculations and reduce the effects of noise and other random signals.
- View: Freezes the current spectrum display, pauses FFT processing, and maintains the contents of the current display buffer.
- Blank: Disable the trace display and all measurements of this trace.

In the trace window, we can also choose to turn on the Math functions. When Math operations are enabled, it will display five options: Output trace, Input Trace X, Input Trace Y, Offset and Function. When performing math operations, we need to select a trace channel as the output channel of the calculation results. At the same time, we can select traces for Input Trace X and Input Trace Y. Offset is a settable value with a setting range of -100dB to 100dB. Three operations are available X-Y+Offset, X+Y+Offset and X+Offset. The results are displayed in the Output trace.

The math function can only be used when the RTSA enable is turned off.

When RTSA Enable is ON, you can select from Five view combinations: Density, Spectrogram, 3D, 3D+Spectrogram and Density+Spectrogram:

- **Density**: The frequency of signal occurrence is visualized using a color scale, with cool to warm colors indicating the probability that the points in a frame of the waveform would appear in the corresponding coordinate points. The density map can display multiple waveforms frames simultaneously and distinguish the probability of each Event's occurrence. This provides detailed frequency domain characteristics, helps identify rare signals, and allows observation of long term signal trends, offering more time-dimensioned acquisition information than a traditional spectrogram.

- **Spectrogram**: Record the frequency domain characteristics of each event over time, the time represented by each trace that appears in the spectrogram is the sweep time, the signal amplitude of each frequency point is represented by different colors, i.e., the X-axis corresponds to the frequency of the sampling point, the Y-axis represents the time, and the color is the third dimension representing the amplitude of the signal, which is commonly used in wireless communication debugging and signal monitoring. Spectrograms are effective at evaluating interference patterns and troubleshooting system and RF environmental changes over time.

- **3D Map**: The 3D waterfall graph displays the observation window of waveform data in real time on the axes of time, frequency and amplitude, with the colors representing the amplitude values in the three coordinates, the peaks corresponding to the red vertex, and the valleys expressed in cool blue, which enables an intuitive three-dimensional view to present the changes of the signal's frequency-domain components over time. The sweep time for RTSA can be set from 30ms to 50s, with minimum step size of 1 ms. In the 3D map view, the number of FFT points is fixed at 2k and cannot be adjusted, but the window type can be changed normally.

Detector Settings:

The detector type of the traces and the detector type of the spectrogram can be set, and there are four types of detectors available (Positive peak, Negative peak, Average, Sample).

- Positive Peak: For each trace point, Peak detector displays the maximum value of data sampled within the corresponding time interval.

- Negative Peak: For each trace point, Negative Peak detector displays the minimum value of data sampled within the corresponding time interval.

- Sample: For each trace point, Sample detector displays the level corresponding to the central time point of the corresponding time interval.

- Average: For each trace point, Average detector displays the average value of data sampled within the corresponding time interval and reduces the effect of noise.

Trigger: The trigger type can be selected in the trigger menu, and the default setting is Free Run.

When the RTSA Enable is off, it can be switched to IF Magnitude trigger, and there are two triggering modes: edge and state. In edge triggering mode, you can select the triggering edge as rising edge or falling edge, and trigger when the state value is set and the signal level is detected to exceed the set level. In state trigger mode, the trigger can be selected to be triggered in high level state or low level state and will be triggered when the signal reaches the set level value.

When the RTSA enable is on, the trigger is fixed as on free run, and a new frequency mask trigger function is available. This is similar to the oscilloscope mask test function. A custom mask spanning power and frequency can be created, loaded, and saved to the RTSA. The mask can monitor any one trace and trigger when the signal enters the masked area on the display.

Marker: We can add a cursor to the trace in the Marker tools which provide two types of cursors: peak and marker. Under the peak cursor type, the oscilloscope will automatically mark up to 10 peak points according to the set search threshold and search excursion, and the peak points are numbered according to the frequency from smallest to largest, and you can choose to turn on the display of the peak table, frequency, and delta values. When turned on, the amplitude, frequency, and delta in amplitude and frequency of each peak point compared to peak point 1 will be displayed. The criteria for selecting the peak is that the peak point should be greater than the search threshold, and if the search excursion is also set, the difference between the peak and the amplitude of the left and right minima needs to be greater than the set search excursion value in order to be judged as a peak.

The Marker tool behavior adds the ability to set the frequency manually using the Universal/A button on the keypad. Up to 8 markers can be set up with the same options as the peak tools.

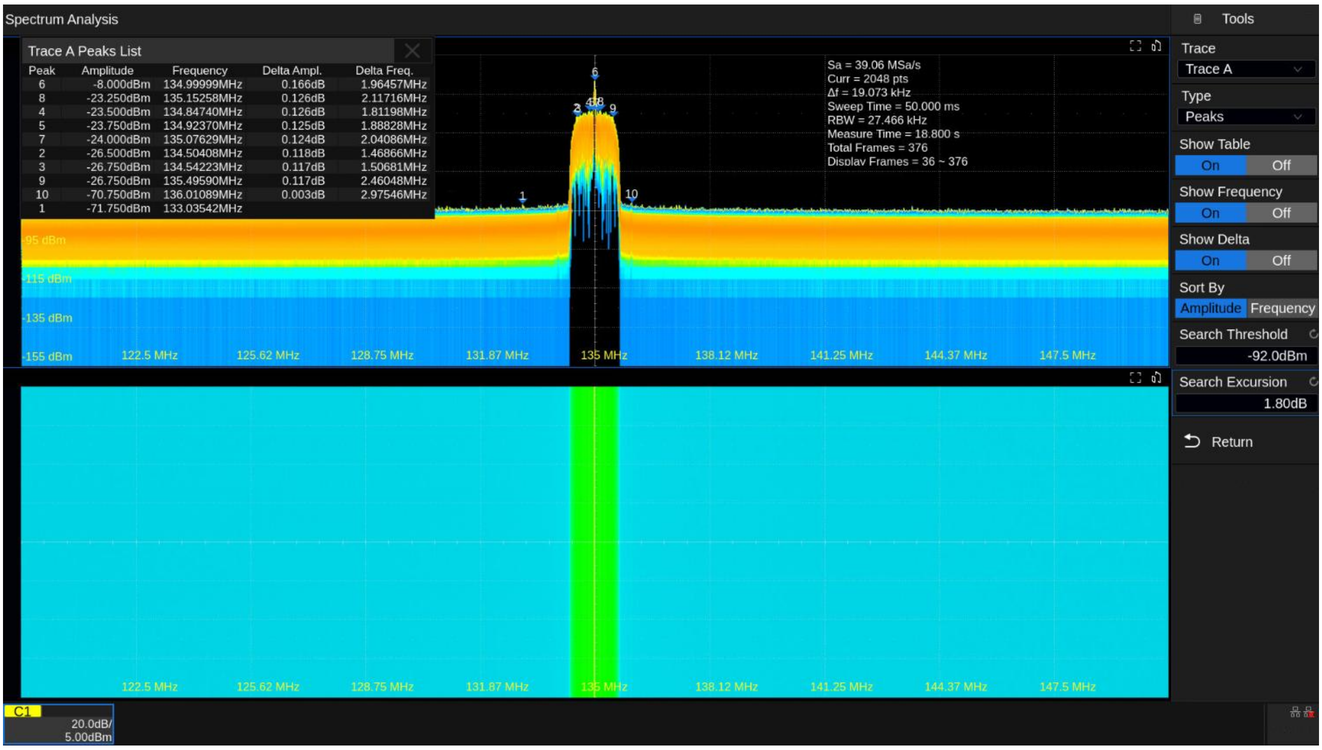

Figure 4 Peak Cursor Display

Save: The Save menu allows us to save the datastream results as IQ data in .txt file format. The saved data can be further analyzed using the SigVSA software.

SigVSA vector signal analysis software is integrated into the RTSA and available for the PC, allowing users to analyze modulated signals. The software supports analysis of general OFDM signals, cellular protocol standard signals such as 4G LTE and 5G NR, and various general modulation signals.

Utilizing the SigVSA software, we can connect with the oscilloscope to get the real-time captured waveforms directly or we can also save the waveform data file for offline analysis.

Figure 5 Instrument and PC Display of SigVSA signal analysis

Digital Signal Processor Configuration

A Digital down converter (DDC) is a digital signal processing technology that converts RF signals into baseband signals to reduce the complexity of the subsequent processing. This is achieved mainly through the mixing, filtering and sampling of high-frequency signals as well as IQ signal acquisition.

In the receiver architecture, DDS is used to generate the quadrature principal oscillator signal and mix it with the input signal to shift the spectrum to the baseband and then filter out the high-frequency components and mirror interference after mixing with a low-pass filter. This is followed by a down sampler section which reduces the data rate and sends it to a subsequent module for processing.

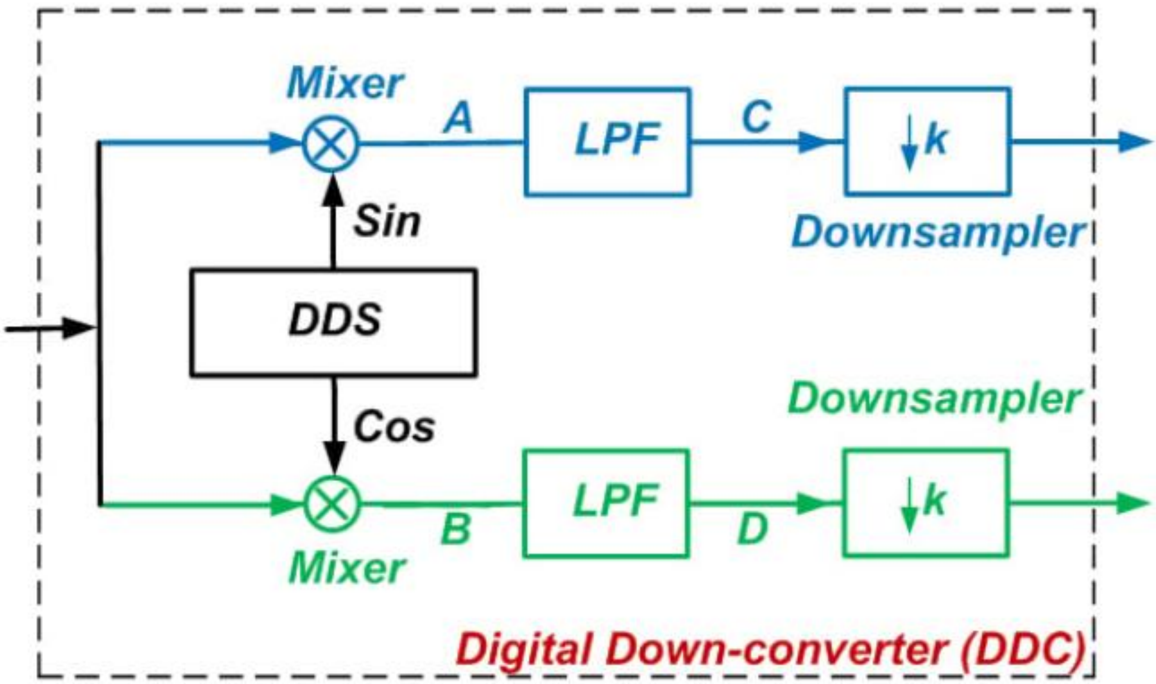

Figure 6 Receiver Digital Down-Conversion Module - Credit: Steve Arar @ All About Circuits (https://www.allaboutcircuits.com/technical-articles/dsp-basics-of-digital-down-conversion-digital-signal-processing/)

Assume the digital signal acquired by the ADC is $S(t)$,where $A(t)$ is the baseband signal amplitude , $\varphi(t)$ is the baseband signal phase , ω_c is the carrier signal frequency , ω_{lo} is the frequency of the generated local oscillator signal.

$$S(t) = A(t) \cdot \cos\left(\omega_c t + \varphi_{(t)}\right)$$

The generated orthogonal local oscillator signals are combined to achieve spectral shift and obtain the I and Q signals:

$$\mathrm{I}(t) = S(t) \cdot \cos(\omega_{lo} t) = \frac{A(t)}{2}\left[\cos\left((\omega_c - \omega_{lo})t + \varphi(t)\right) + \cos\left((\omega_c + \omega_{lo})t + \varphi(t)\right)\right]$$

$$\mathrm{Q}(t) = S(t) \cdot (-\sin(\omega_{lo} t)) = \frac{A(t)}{2}\left[\sin\left((\omega_c - \omega_{lo})t + \varphi(t)\right) - \sin\left((\omega_c + \omega_{lo})t + \varphi(t)\right)\right]$$

These signals are then filtered to preserve the critical data elements in the baseband:

$$\mathrm{I}_{filter}(t) = \frac{A(t)}{2}\cos\varphi(t)$$

$$\mathrm{Q}_{filter}(t) = \frac{A(t)}{2}\sin\varphi(t)$$

After DDC, the amplitude and phase of the original signal are preserved. The two generated signals are resampled to reduce the data volume and improve processing efficiency.

The basic implementation of digital down conversion is setup using an FPGA with a Numerically Controlled Oscillator (NCO) to generate a quadrature principal oscillator signal which is mixed with the input signal.

After mixing, the high-speed data stream is initially decelerated by a cascaded integrator comb filter (CIC) that extracts an arbitrary factor from the data stream, followed by a half-band filter (HB) to further decelerate the data rate while maintaining the linear phase, followed by a FIR filter for the down conversion:

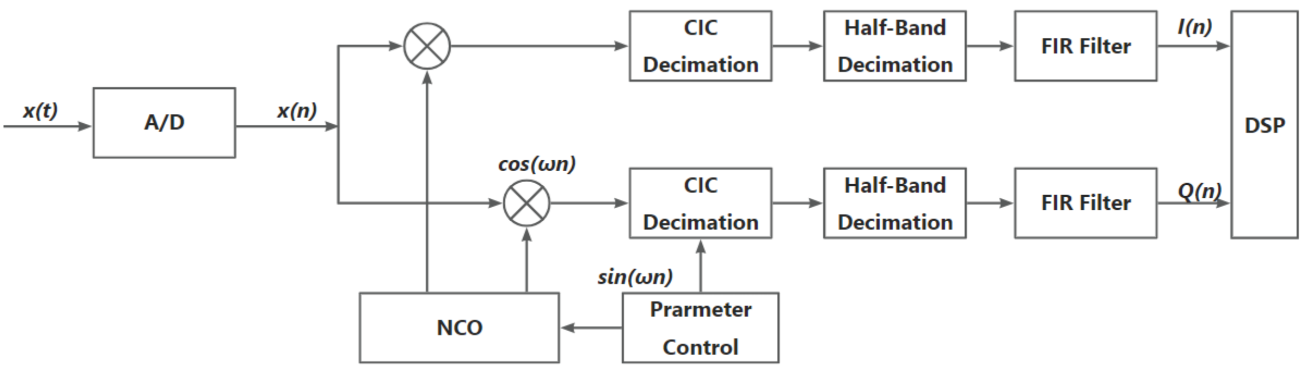

Figure 7 FPGA Digital Down-Conversion Architecture

Implementing the DDC function in oscilloscopes using FPGAs or ASICs reduces computational load while preserving essential signal parameters.

RTSA Features

In the FFT function that comes standard with most oscilloscopes, the oscilloscope directly performs FFT operations on the time-domain signals acquired by the ADC to process the data in the full frequency band. While the time domain and the frequency domain share the same data stream and the time base needs to be adjusted to increase the sampling length when obtaining smaller resolution bandwidths, which decreases the oscilloscope's processing speed. Processing data in this way requires a sufficiently high sampling rate to achieve the analysis of high-frequency signals. Since the oscilloscope’s storage space is limited, the duration for analyzing signals at high sampling rates is correspondingly reduced.

In the acquisition and processing module of the SDS7000A, a DDC structure is implemented. The signal is down-converted to baseband and only data within a specified Bandwidth at a set center frequency is displayed. The data can then be re-sampled at a lower sampling rate. Additionally, the time domain and the frequency domain data are captured independently, enabling longer signal acquisition and analysis periods.

Using this structure, with the same storage space, the processing speed can be maintained at a lower RBW, significantly improving the RTSA functionality. In this way, the spectrum parameters can be set directly during parameter adjustment without impacting the time-domain parameters. The signal processing resides within a dedicated FPGA allowing the oscilloscope to process data in real time without impacting other analysis functions.

The speed of the processing enables the real time analysis of each time data set to be completed while the next capture is in progress. This creates overlapping FFTs that improve the accuracy of RF events that occur near the edge of a capture. Additionally, there are windowing options to further diminish errors. With the standard configuration of FFTs overlapping at 50%, the FFTs can be interleaved so that signal continuity and accuracy is maintained.

In the RTSA function, you can also isolate the signal to be acquired using the frequency mask trigger. In the template editing interface, you can add the number of mask points and set the frequency and amplitude of these points and then apply them after completing the settings in the RTSA function. When the trigger is switched to the stop state a capture will be triggered and stopped when the signal in the frequency domain meets the mask setting conditions displaying the correct spectrum view:

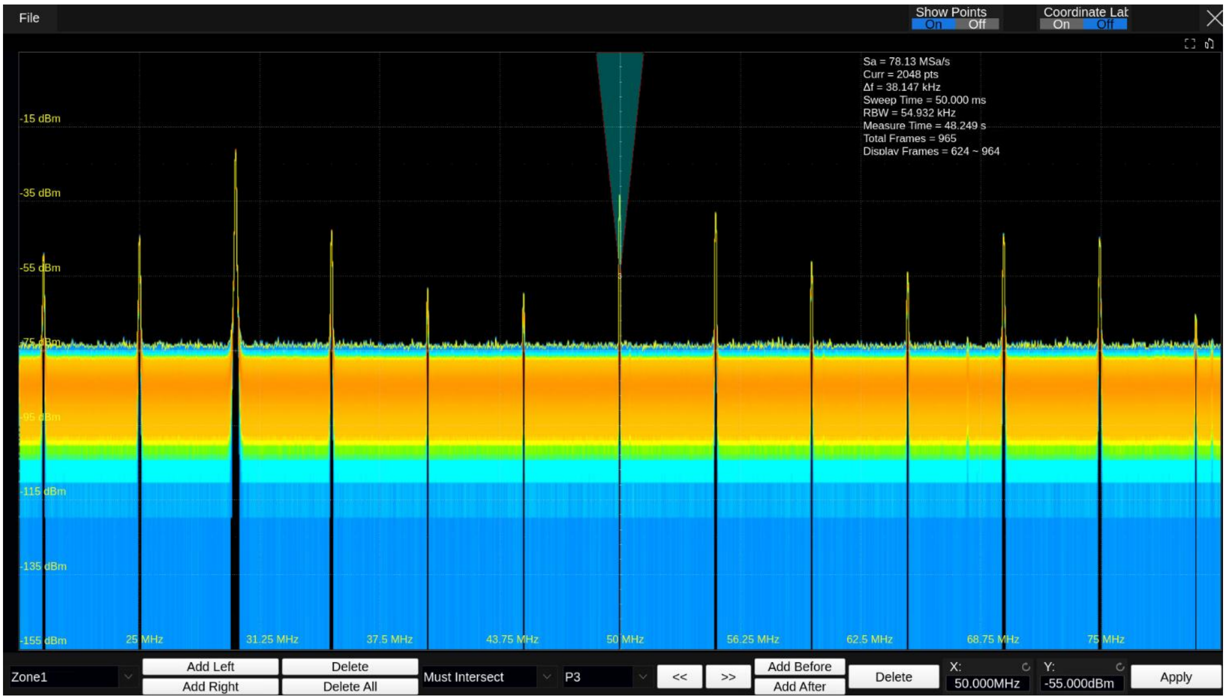

Figure 8 Mask Trigger Example

100% POI Minimum Signal Duration of RTSA

Understanding probability of intercept

Real-time spectrum analysis functionality is commonly used in spectrum monitoring and transient signal capture. It is important to note that the concept of "real-time" is relative, meaning that the FFT processing speed must keep pace with the data acquisition rate to enable gap-free analysis of the data. Real-time spectrum analysis cannot capture every signal that appears, and the analysis capabilities vary among different real-time spectrum analyzers. Therefore, specific parameters are required to evaluate their performance.

The Probability of Intercept (POI) is a key parameter often used to assess the performance of real-time spectrum analyzers. Generally, the minimum signal duration for 100% POI is used to characterize the analyzer's ability to accurately capture and report dynamic signals. Signals faster than the 100% POI time may still get captured but would typically be attenuated. During FFT processing, window functions must be applied to the acquired data points. However, this causes a reduction in the amplitude of data at the edges of each data frame due to the windowing effect. To address this, overlap processing is typically employed, with a 50% overlap scheme being commonly adopted. For example, with a 50% overlap, data points at the edge of one data frame will be positioned near the center of the adjacent data frame. This overlap strategy compensates for the loss of information at the frame edges caused by the window function while also reducing amplitude errors. As illustrated in Figure 7 under the 50% overlap condition, the signal duration must cover at least one full acquisition window to ensure accurate amplitude measurement.

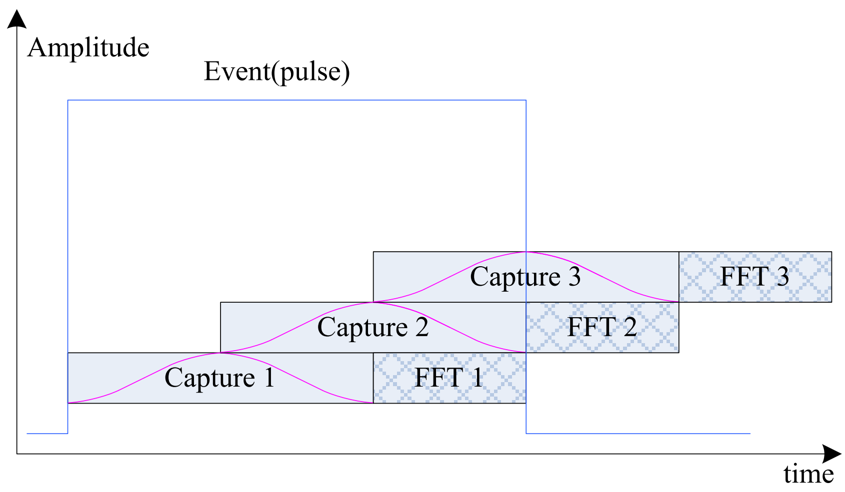

Figure 9 100% POI Minimum Signal Duration

In the RTSA function of the SDS7000A, when calculating the theoretical value for 100% POI with a span of 500 MHz, the FFT length is fixed at 2048 points, and the window width is adjustable. Using a window width of 2048 points, the signal must cover one complete FFT window. Without overlap, the required signal length is:

$$2048 + 2048 - 1 = 4095\text{pts}$$

After applying overlap processing with a 976 points overlap under a 500 MHz span and a sampling rate of 625 MHz, the 100% POI under these conditions is:

$$\frac{4095 - 976}{625} = 4990.4\text{ns}$$

4.99 microseconds is the shortest duration RF signal that is guaranteed to be accurately measured on the SDS7000A in RFA mode with a span of 500 MHz.

Result Verification

After obtaining the theoretical 100% POI duration, we proceed to practical testing under the RTSA function to verify whether the corresponding signal can be captured and whether the amplitude measurement is accurate. We first use an RF signal generator to produce a pulse-modulated signal, controlling the signal duration by adjusting the pulse width. In the oscilloscope's RTSA mode, we set the span to 500 MHz and the sweep time to 50ms. The RF source is configured with a carrier frequency of 2 GHz, an output amplitude of −20dBm, and modulated with a single pulse. The pulse period is set to match the RTSA sweep time of 50ms, and the pulse width is adjusted to 30µs. If the signal is consistently captured across multiple attempts without any deviation in frequency and amplitude from the transmitted signal, it confirms that the set pulse width is at least as wide as the actual 100% POI time. In practical testing environments, factors such as the RF source's output characteristics and cable losses can affect the power level.

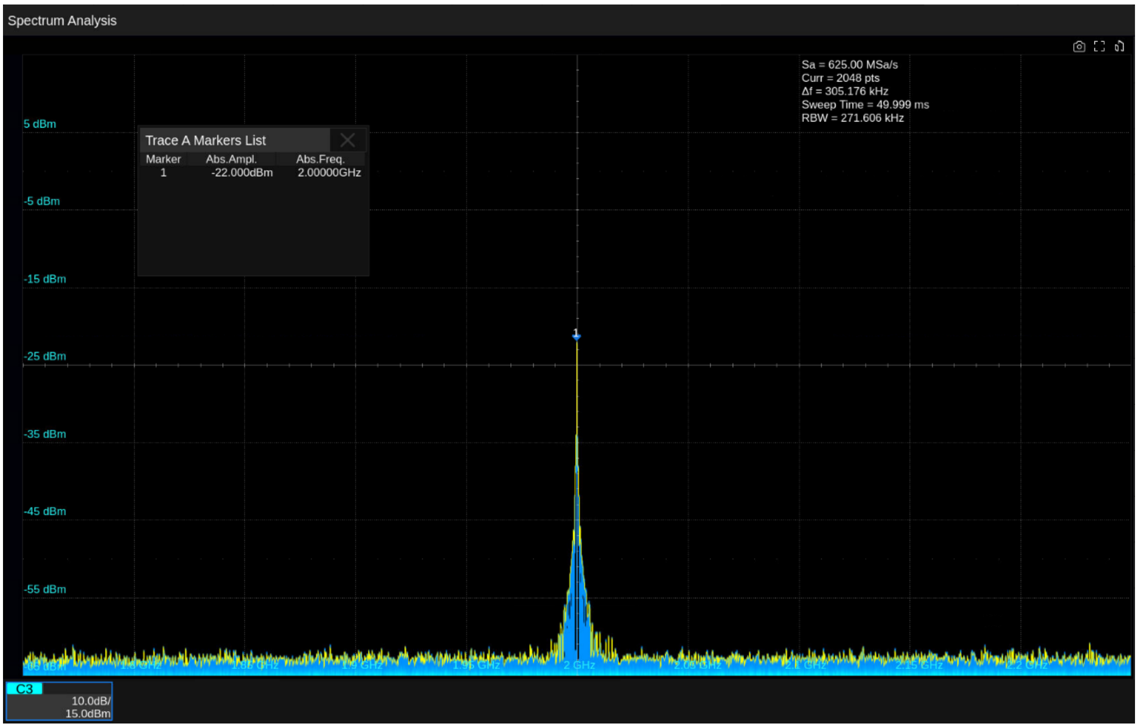

Figure 10 Amplitude of the Stable Signal

During the process of gradually reducing the pulse width for testing, when the signal pulse width reached 4µs and below, a noticeable decrease in signal amplitude was observed from the RTSA interface. This indicates that the minimum duration for 100% POI has been passed.

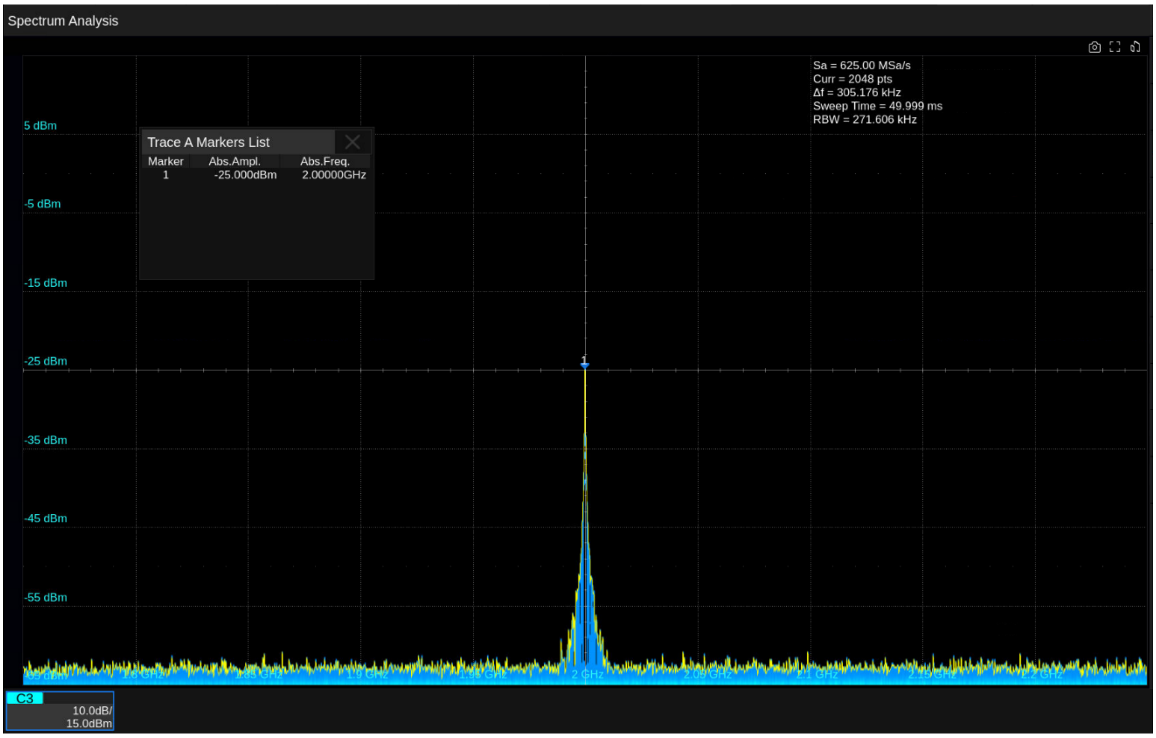

Figure 11 Amplitude of 4µs Pulse Width Signal

At this point, the frequency mask trigger function can be utilized to set a corresponding mask for the signal under test to trigger the system. For demonstration purposes, this mask is set with a relatively wide frequency range primarily to verify amplitude accuracy. By enabling both the frequency mask trigger and setting the trigger action to Stop, multiple runs are executed to check whether the signal can be stably triggered each time. When the pulse width is reduced to 4.99µs, the system continues to trigger reliably on each signal occurrence, with the amplitude and frequency remaining consistent with the stable readings observed at higher pulse widths. This experimentally confirms the system architecture and the 100% POI time duration. These screen shots confirm the settings and results:

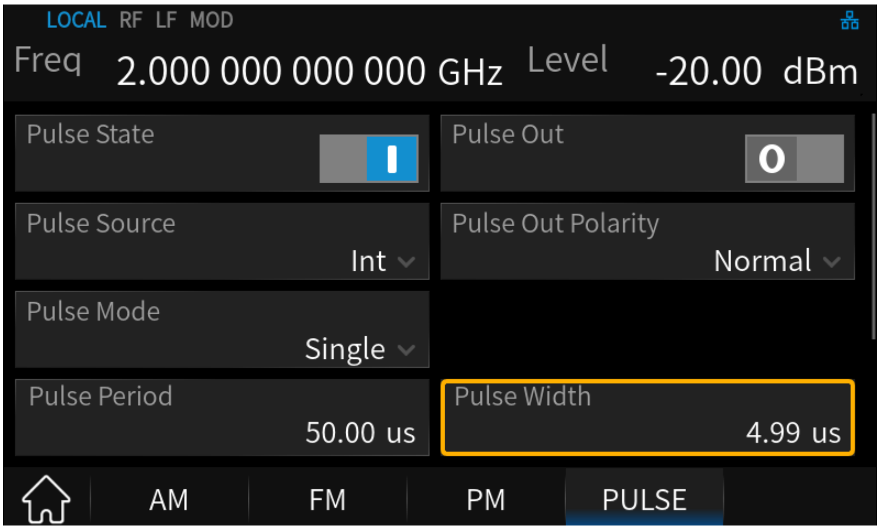

Figure 12 Pulse Configuration

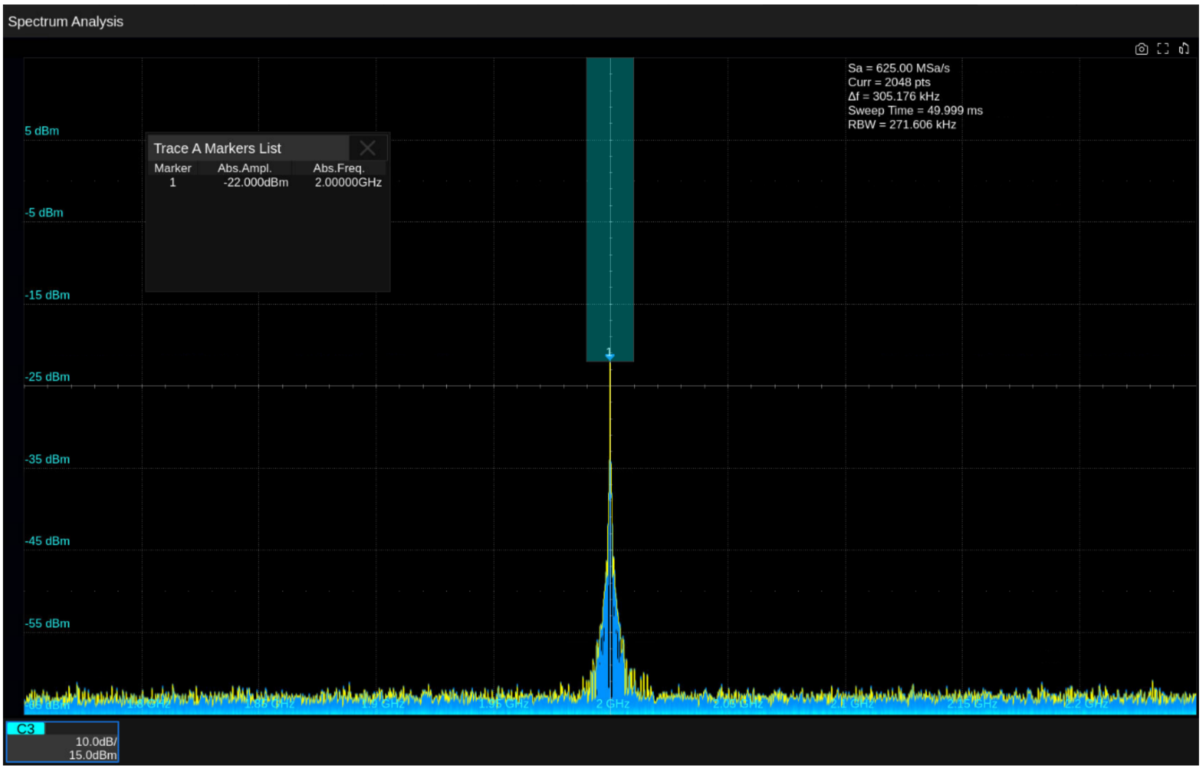

Figure 13 4.99μs Pulse Width Stable Trigger Mask

Additional Applications Overview

Signal Analysis

With real-time spectrum analysis and digital down-conversion functions, the SDS7000A is not only capable of time-domain measurements, but also of high-precision measurements in the frequency domain. With higher bandwidths and higher-speed ADCs than traditional super heterodyne architecture spectrum analyzers, the SDS7000A can capture transient burr signals and act as a signal analyzer with the built-in SigVSA software. It can analyze the acquired signals with a maximum bandwidth of 2 GHz, and has a wide range of measurement functions, from general-purpose OFDM signals to cellular protocol standard signals such as 4G LTE, 5G NR, and WLAN standard signals including IEEE802.11b/a/g/n/ac/ax/be.

Figure 14 SigVSA Analysis of a 5G NR signal

Multi-channel Synchronous Acquisition

Oscilloscopes are designed with the characteristics of multi-channel synchronous acquisition. The delay between channels can be controlled at the level of picoseconds which provides analysis bandwidth that is not possible with traditional spectrum analyzers. MIMO transmitter testing requires multiple channels to be tested at once, while maintaining accurate time synchronization between them. When testing with a signal analyzer, one analyzer is used for each channel of the system under test, and each analyzer is time synchronized. Oscilloscopes are equipped with multiple channels with low inter-channel jitter, and have a more advanced triggering system than spectrum and signal analyzers, which can accurately detect impulse signals while also displaying signal content in the frequency domain.

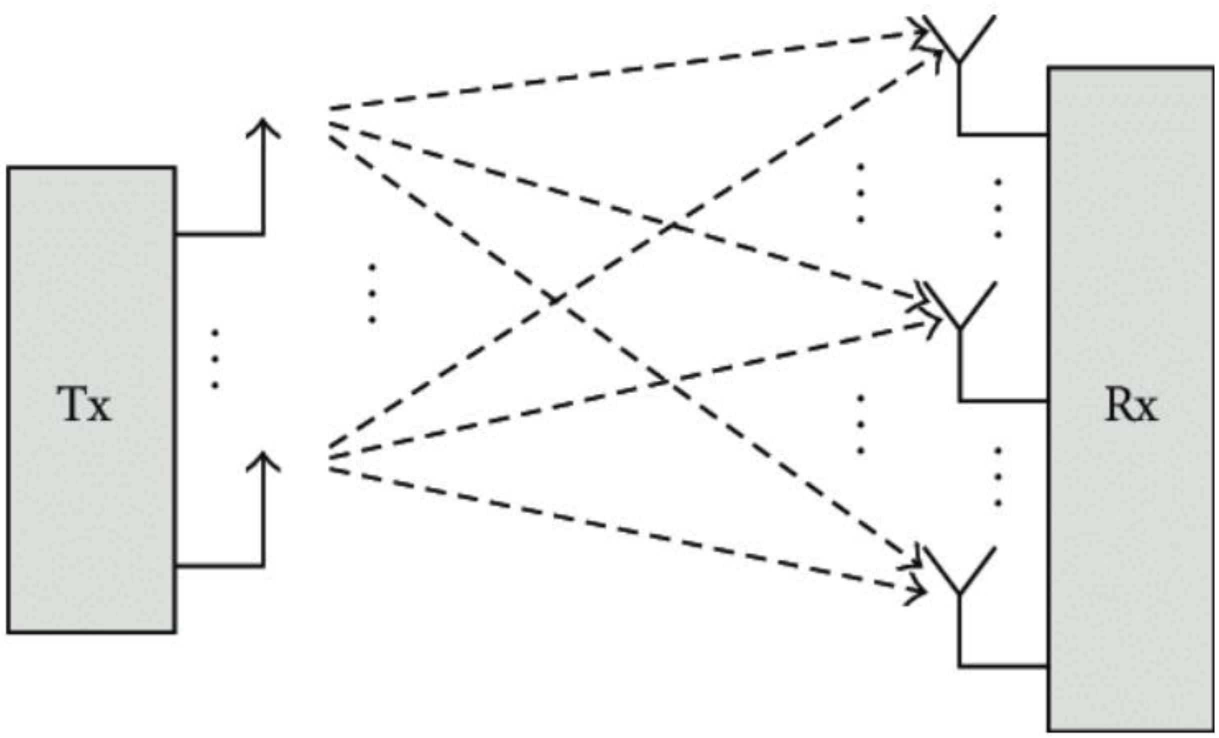

Figure 15 MIMO Test System

Utilizing a wideband oscilloscope covering the frequency of interest can be an effective alternative to multi-analyzer setups when combined with real-time analysis and demodulation.

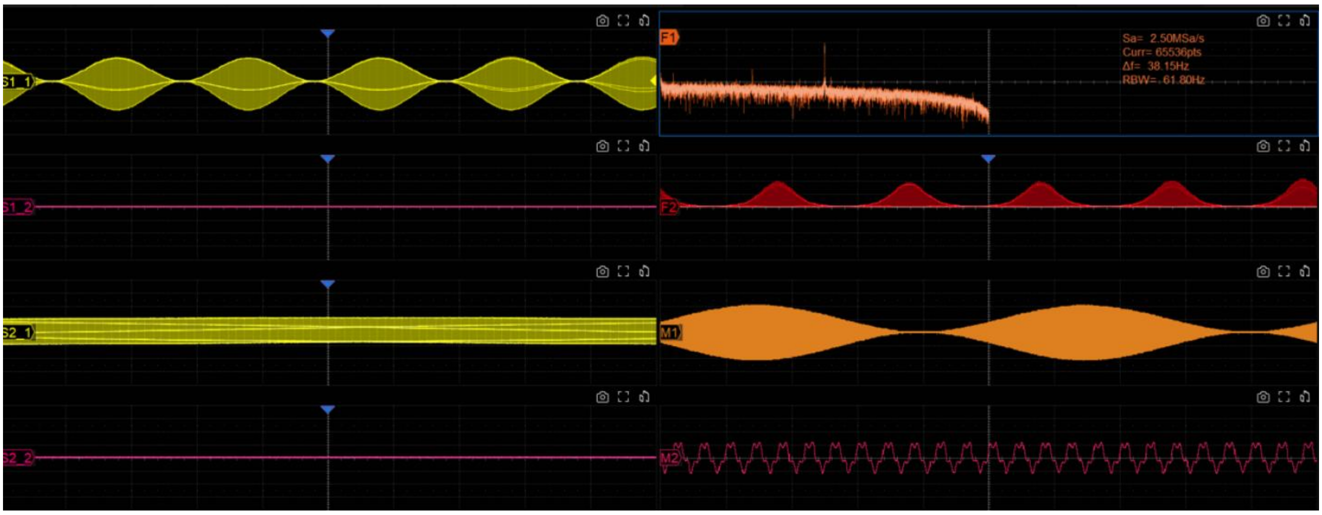

Figure 16 Multi-Channel Measurement Software

EMI Pre-Compliance Testing

Electronic products are required to be tested for how they create and interact with radiated and conducted emissions. This process is called EMI or EMC testing. Typically, final testing is done at a certified laboratory and can be time consuming and expensive. EMC Pre-Compliance testing is often done in house as part of design, development, and debug in order to be prepared to pass final testing on the first try.

Traditionally, the domain of spectrum analyzers, EMI Pre-Compliance testing can now be done efficiently with a high resolution, high bandwidth oscilloscope. Compared with the traditional FFT function, the real-time spectrum analysis function can quickly set the frequency domain measurement parameters and use the frequency mask and power trigger modes to locate the source of radiation and can be combined with the waveform of the time-domain signal to better analyze and optimize the circuit design. This combination of time and frequency information helps to debug emissions issues.

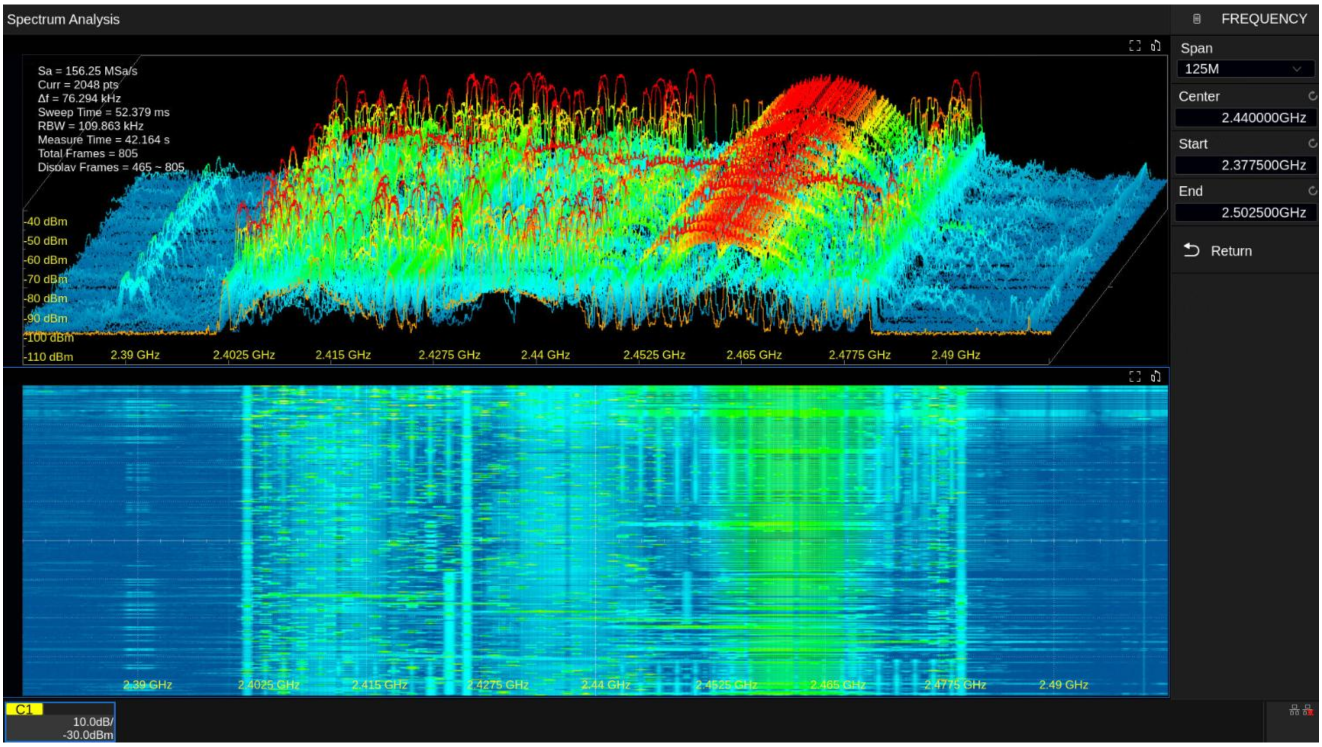

Figure 17 Real-time Monitoring of Radiation Signals

Summary

High resolution, high bandwidth, real-time oscilloscopes equipped with frequency domain analysis tools provide unique advantages in signal and spectrum analysis versus traditional spectrum analyzers. Design and development engineers can use these oscilloscopes to extend testing into critical time and frequency domain applications including complex signal analysis. While spectrum analyzers excel at analyzing low power signals with tight resolution bandwidth, high resolution oscilloscopes are a powerful measurement tool for debugging and analysis of RF signals in dynamic environments.

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About SIGLENT

SIGLENT is an international high-tech company, concentrating on R&D, sales, production and services of electronic test & measurement instruments.

SIGLENT first began developing digital oscilloscopes independently in 2002. After more than a decade of continuous development, SIGLENT has extended its product line to include digital oscilloscopes, isolated handheld oscilloscopes, function/arbitrary waveform generators, RF/MW signal generators, spectrum analyzers, vector network analyzers, digital multimeters, DC power supplies, electronic loads and other general purpose test instrumentation. Since its first oscilloscope was launched in 2005, SIGLENT has become the fastest growing manufacturer of digital oscilloscopes. We firmly believe that today SIGLENT is the best value in electronic test & measurement.

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