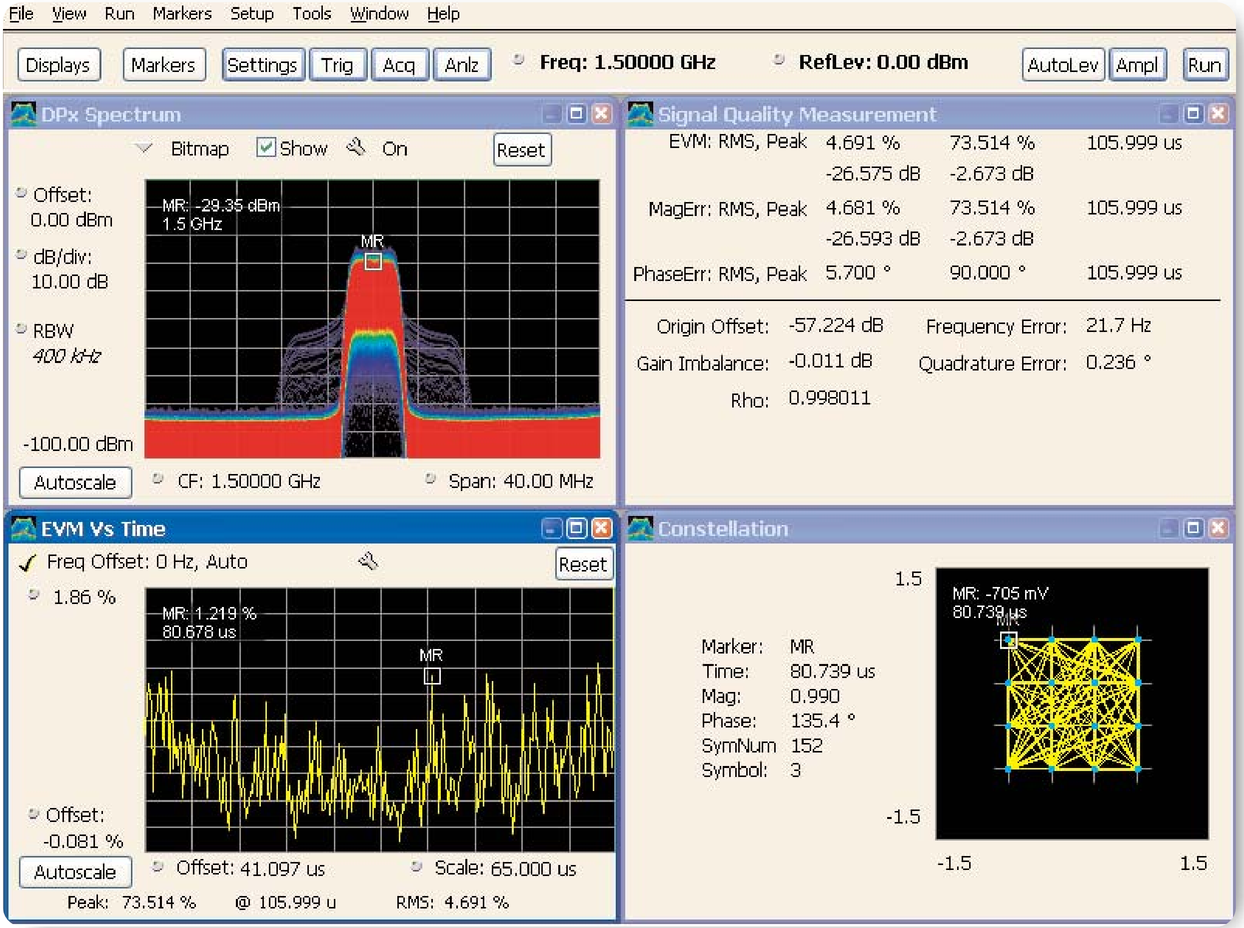
Software Defined Radio Testing Using Real-Time Signal Analysis



Freq: 1.50000 GHz
RefLev: 0.00 dBm

☑ Show

Offset: 0.00 dBm
dB/div: 10.00 dB
RBW 400 kHz
-100.00 dBm
CF: 1.50000 GHz
Span: 40.00 MHz

EVM: RMS, Peak	4.691 %	73.514 %	105.999 us
	-26.575 dB	-2.673 dB	
MagErr: RMS, Peak	4.681 %	73.514 %	105.999 us
	-26.593 dB	-2.673 dB	
PhaseErr: RMS, Peak	5.700 °	90.000 °	105.999 us

Origin Offset: -57.224 dB
Frequency Error: 21.7 Hz
Gain Imbalance: -0.011 dB
Quadrature Error: 0.236 °
Rho: 0.998011

✓ Freq Offset: 0 Hz, Auto
1.86 %
Offset: -0.081 %
Offset: 41.097 us
Scale: 65.000 us
Peak: 73.514 % @ 105.999 u RMS: 4.691 %

Marker: MR
Time: 80.739 us
Mag: 0.990
Phase: 135.4 °
SymNum 152
Symbol: 3

Introduction

Software Defined Radios (SDRs) are driving the integration of digital signal processing (DSP) and radio frequency (RF) capabilities. This integration allows software to dynamically control communications parameters such as the frequency band used, filtering, modulation type, data rates and frequency hopping schemes. SDR technology can be seen in wireless devices used for military and civil government applications to commercial network deployments.

Compared to traditional RF transceiver technologies, SDR is advantageous because it offers increased flexibility. SDR provides the ability to reconfigure key system performance and functions on the fly.

Software Radios, however, introduce a host of new problems not present in traditional wireless designs. This application note expands on the basic principles described in the Tektronix Application Note, ***Software Defined Radio: An Integrated Test Method for Designing Software Communications Architecture (SCA) Compliant Radios***. Specific examples of common transmitter design issues and how to easily identify and diagnose them using a Real-Time Spectrum Analyzer (RTSA) will be examined.

What is a SDR?

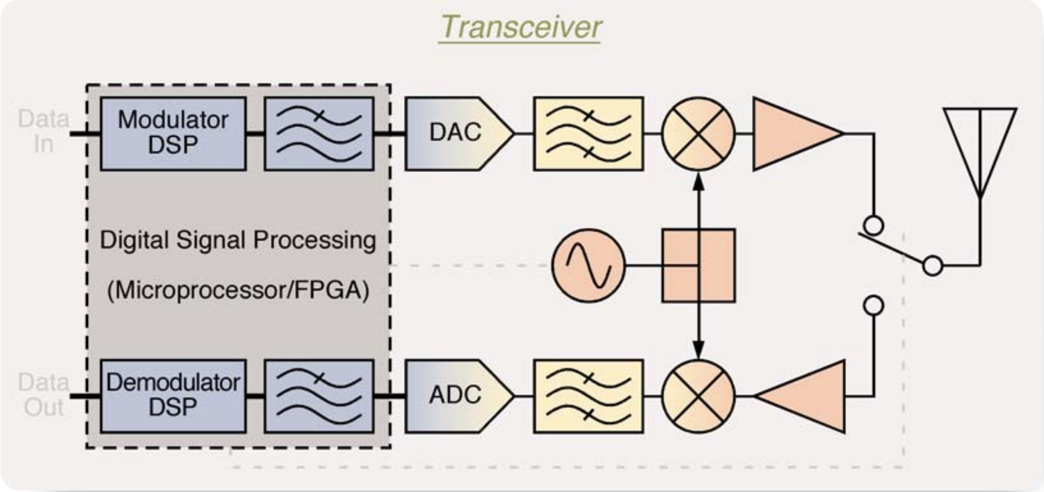
A SDR is a communication device whose operation is controlled by software. One of the most significant implications at the physical layer is that the hardware in a robust SDR design requires extensive flexibility and high performance over a wide range of operating parameters in order to answer the demands of the software.

More and more RF devices are being designed for software control, which changes the design requirements and introduces the need for new testing methodologies. In addition to network control of the operating frequency, more advanced SDRs allow dynamic control of modulation scheme, frequency hopping patterns, power levels, filtering, coding schemes and data rates. This added complexity presents not only RF design challenges, but also changes the nature of RF testing. Software now defines analog/RF performance testing and continued analog/RF test must be considered for software regression testing in addition to physical layer testing performance. Traditional transmitter tests, for example, measure power, modulation, spectrum occupancy and interference as steady state quantities. RF Testing must be an integral part of SDR testing.

SDR designers must produce devices that are much more adaptable. This goal, along with the need for producing devices which are financially viable, is forcing designers to use different approaches. These circumstances are bringing about the emergence of “Digital RF,” where much of the design is implemented in software through the extensive use of DSP. In addition, digital correction techniques are being used to simplify designs. Techniques such as direct up-conversion to RF from the output of a Digital to Analog Converter (DAC) allow much more of the analog hardware to be integrated, delivering greater flexibility and adaptability.

The dynamic generation of RF waveforms through DSP and the integration of digital and RF circuits, often on the same IC, create issues not seen in traditional RF transceiver designs. Furthermore, the performance of SDR transmitters must be verified with measurements that are beyond the traditional RF transmitter conformance tests, including software regression testing. Simply passing conformance testing does not ensure a device will work properly; system behavior needs to be carefully and thoroughly observed since software is continually changing the system parameters. These software-controlled changes commonly cause glitches, intermittent interference, pulse aberrations, digital to RF couplings and software-dependent phase errors are commonly caused by these software controlled changes.

Truly addressing these myriad of new transients and problems requires SDR system designers to fully analyze and characterize their system. As system parameters change over time, performing frequency selective triggering is necessary to pinpoint the instant a transient event occurs. A transient signal event may include: misaligned filter or gain changes, race conditions in software, etc. cause spectrum anomalies. Performing multiple domain, time-correlated analysis is required to determine the specific cause of each problem. And capturing the entire event seamlessly into memory is invaluable for subsequent, in-depth analysis, as it can be difficult to recreate the conditions under which the trigger occurred. These advanced troubleshooting methods of verifying signal performance over time, combined with traditional static conformance tests, are important for efficient SDR testing.



▶ **Figure 1.** *Functional block diagram of a typical SDR transceiver implementation.*

Transceiver Testing

As previously mentioned, there are many ways to implement a SDR. To minimize the complexity of the SDR, the designer will choose the minimum number of components needed to achieve the required functionality. Using a SDR Transceiver as an example, transmit components might include:

- Power Amplifiers
- Mixers
- DACs
- Oscillators
- DSP circuitry

On the receiver side, similar trade-offs are made to minimize complexity while still achieving the required functionality. Components might include:

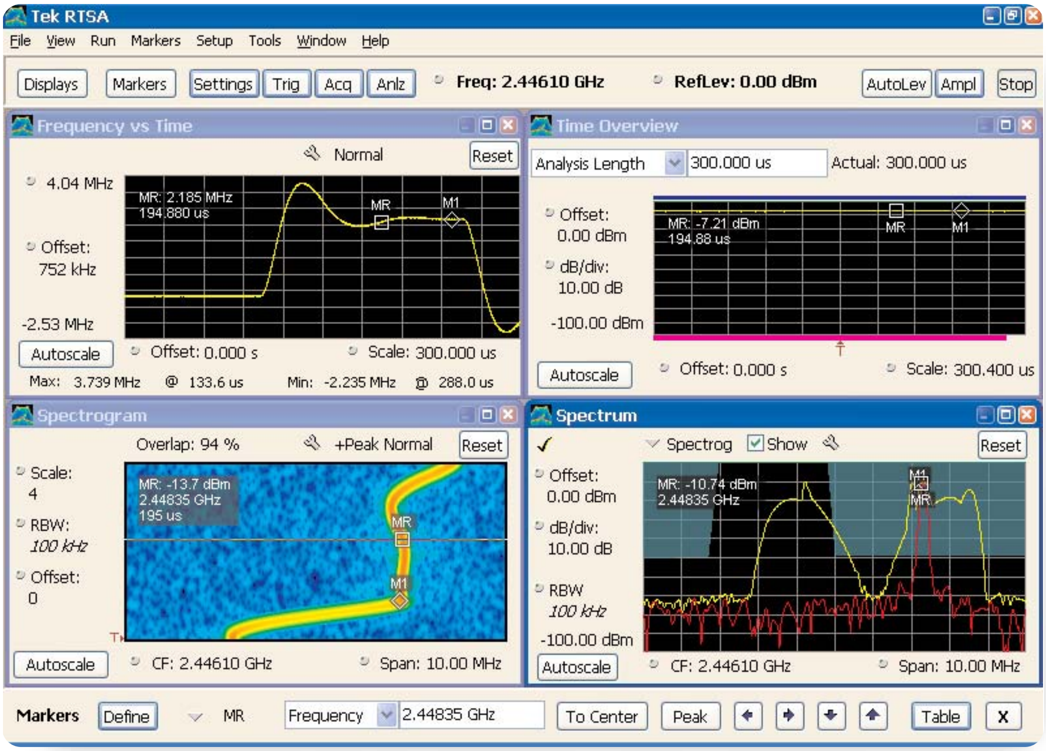
- Low Noise Amplifiers
- Mixers
- ADCs
- Oscillators
- DSP circuitry

Figure 1 shows a simplified functional block diagram of the transceiver, without Digital Intermediate Frequency (IF) or Digital RF. Note that each of the blocks in this diagram could be controlled by software or entirely implemented in software.

Verifying the performance of a typical SDR transceiver requires an integrated testing strategy that correlates measurements taken at different points along the transmit/receive chain. For example, an intermittent signal can be captured by the Frequency Mask Trigger (FMT) of a RTSA. The RTSA can use the frequency mask violation to then trigger a logic analyzer and oscilloscope, allowing the user to look at the digital and analog properties of the associated signals. Using this approach, the designer can determine if there is something happening in either the logic circuitry or analog control voltages that correlates to the frequency domain violation. In addition to bridging the digital/RF divide through advanced triggering, the RTSA can analyze and display the signal in the time, frequency and modulation domains, all of which are correlated.

Beyond Steady State Conformance Testing

SDR testing inherently includes traditional transmitter testing. Each of the different possible configurations for the radio must conform to traditional specifications such as Occupied Bandwidth, Channel Power and Adjacent Channel Power. For systems with Time Division Duplexing or Time Division Multiplexing, there are timing requirements such as Rise Time and Fall Time. Unlike a conventional transmitter, the SDR device must pass these tests under a much wider variety of operating modes, increasing the complexity of the conformance testing. Over-the-air software configurability will add a new dimension for testing.



Freq: 2.44610 GHz
RefLev: 0.00 dBm

Frequency vs Time:
4.04 MHz
Offset: 752 kHz
-2.53 MHz
MR: 2.185 MHz 194.880 us
Offset: 0.000 s
Scale: 300.000 us
Max: 3.739 MHz @ 133.6 us
Min: -2.235 MHz @ 288.0 us

Time Overview:
Analysis Length 300.000 us
Actual: 300.000 us
Offset: 0.00 dBm
dB/div: 10.00 dB
-100.00 dBm
MR: -7.21 dBm 194.88 us
Offset: 0.000 s
Scale: 300.400 us

Spectrogram:
Overlap: 94 %
Scale: 4
RBW: 100 kHz
Offset: 0
MR: -13.7 dBm 2.44835 GHz 195 us
CF: 2.44610 GHz
Span: 10.00 MHz

Spectrum:
Offset: 0.00 dBm
dB/div: 10.00 dB
RBW 100 kHz
-100.00 dBm
MR: -10.74 dBm 2.44835 GHz
CF: 2.44610 GHz
Span: 10.00 MHz

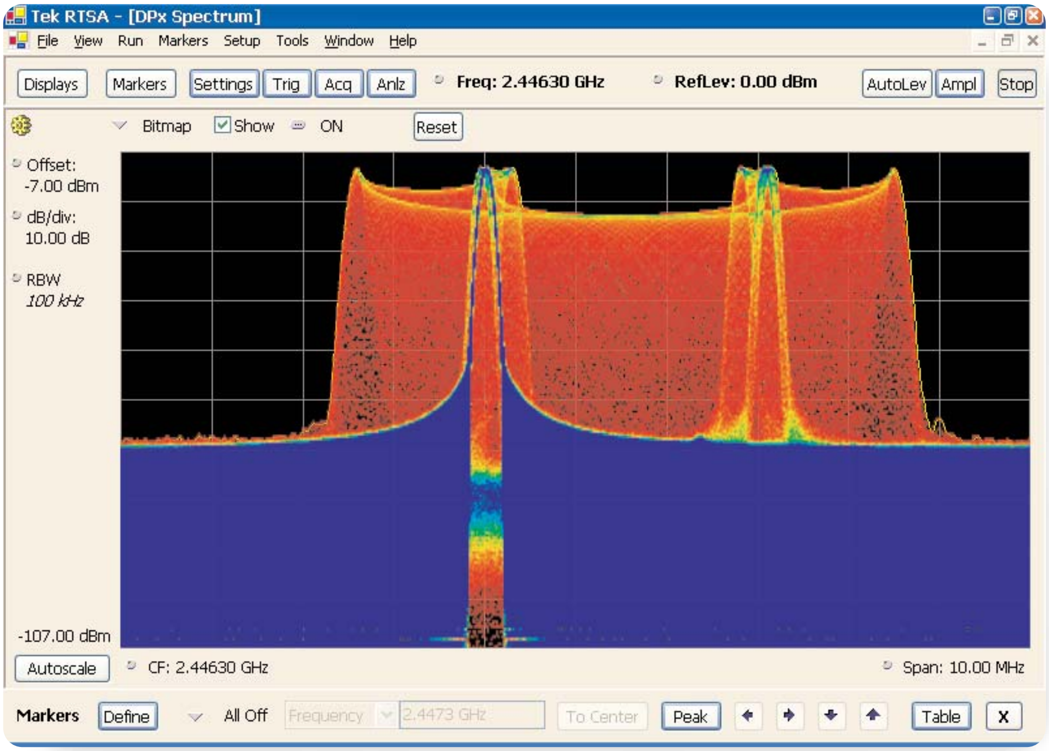
Markers: MR Frequency 2.44835 GHz

▶ **Figure 2.** *The frequency settling time of a PLL using a Tektronix RSA6100A series RTSA. With the markers turned on, all of the measurements automatically correlate in all domains.*

Modulation quality measurements are also a significant part of conformance testing. For digitally modulated signals, these usually include Error Vector Magnitude (EVM) or correlated power (RHO) measurements. Moreover, SDR designs that support analog modes must pass conformance tests. Modulation quality is both a conformance measurement as well as a system performance issue. Poor EVM reduces data rate, clarity of voice transmissions and transmit range. The EVM measurement also provides insight into potential transmitter problems. For these reasons, EVM is one of the first things to examine when troubleshooting a SDR.

Unfortunately, conformance testing alone is not sufficient for ensuring a SDR works properly. In order to achieve network flexibility, each SDR device will have to change significant operating parameters over time to keep up with the network demands. Of course, all of these changes are implemented by software controlling transceiver hardware. Therefore, a tool to help capture possible RF glitches, transients and other anomalies is essential. Determining which component has caused the problem can be a significant task as well, and a thorough troubleshooting strategy is required. To make the devices and network function correctly, it is necessary to consider new testing methods that help characterize and analyze how the SDR RF links change over time.

The RTSA offers powerful capabilities for SDR troubleshooting. First, it is important to discover the existence of a problem in the physical layer. These transient events can occur very quickly and designers need the ability to observe them in the frequency domain as they change over time. An example is shown in Figure 2,



Freq: 2.44630 GHz
RefLev: 0.00 dBm
Offset: -7.00 dBm
dB/div: 10.00 dB
RBW 100 kHz
-107.00 dBm
CF: 2.44630 GHz
Span: 10.00 MHz

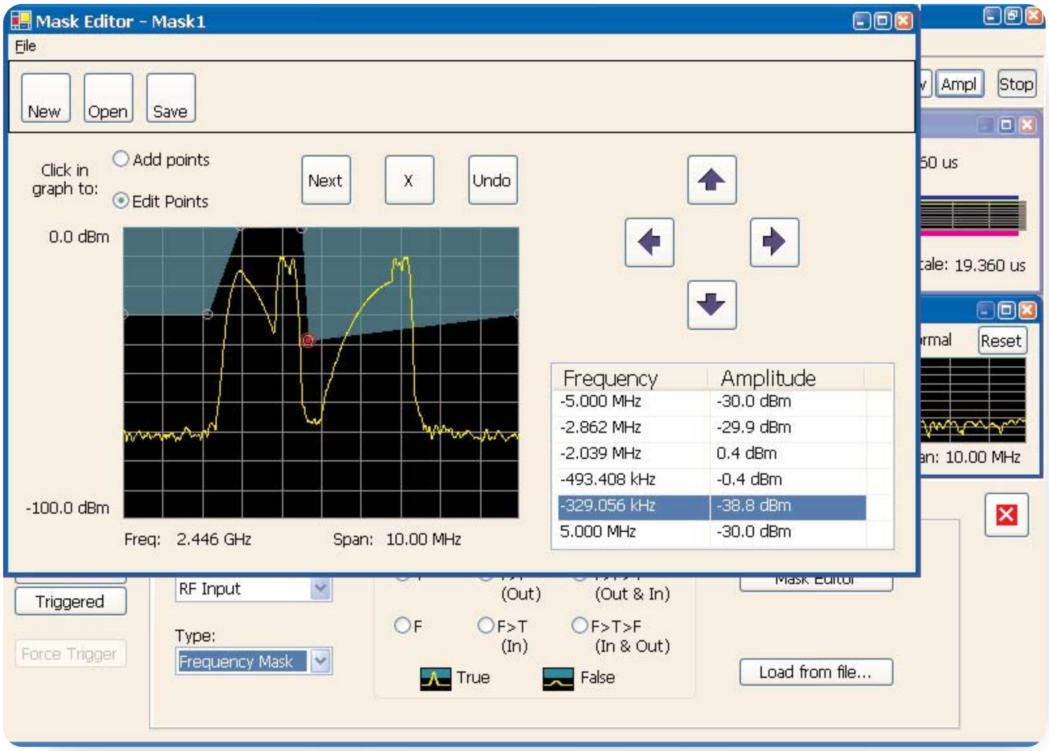
▶ **Figure 3.** *DPX display showing the same PLL settling time measurement on the RSA6100A. Because DPX displays statistical information, the specific time-varying nature of the signal can be viewed. Unlike any other spectrum analyzer, the RSA6100A shows this interaction with stunning clarity through DPX.*

where the Phase Locked Loop's (PLL's) settling time can be directly observed using the RTSA's Frequency vs. Time measurement. After a problem has been discovered, the RTSA allows users trigger, capture and analyze the associated signals in multiple, time-correlated domains. This ability to extend beyond pure conformance testing is necessary for dynamic signal characterization and troubleshooting.

Discover

DPX™ digital phosphor display technology, traditionally used in advanced oscilloscopes, has been applied to the RF domain and is now employed by the Tektronix RSA6100A Series RTSAs. In allowing users for the first time to view "live RF" signals, DPX provides unmatched insight into RF signal behavior.

In Figure 3, a RTSA with DPX shows a frequency hop that occurs once every 1.28 seconds. This signal has roughly 200 µsec dwell time at the new frequency. After the hop, the signal returns to the original frequency. The frequency hopping, overshoot and ringing are plainly visible in the DPX display. This level of signal insight is nearly impossible with conventional spectrum analyzers because there is no way to reliably capture this portion of the signal for analysis. The change in signal power level, which can be seen directly on the DPX display, is too small to reliably trigger on using conventional spectrum analyzers. In the realm of SDR, DPX provides a completely new way to quickly assess the "RF health" of a signal, helping ensure high-quality designs and reliable device operation.



Click in graph to: ○ Add points ● Edit Points

Freq: 2.446 GHz

Span: 10.00 MHz

Frequency	Amplitude
-5.000 MHz	-30.0 dBm
-2.862 MHz	-29.9 dBm
-2.039 MHz	0.4 dBm
-493.408 kHz	-0.4 dBm
-329.056 kHz	-38.8 dBm
5.000 MHz	-30.0 dBm

Triggered

RF Input

Type: Frequency Mask

▶ **Figure 4.** *The FMT can be drawn arbitrarily to capture infrequently occurring events. In this example, an infrequently occurring frequency hop can be triggered on consistently. This unique capability greatly assists in troubleshooting intermittent faults.*

Trigger

Once a glitch or transient has been identified using DPX, the RTSA's FMT can reliably capture the signal for in-depth analysis. As shown in Figure 4, the frequency mask is user-defined and can be drawn to best capture the signal. In the example of the infrequently occurring frequency hop, the user is able to define the mask to trigger on the frequency excursion, rather than attempting to trigger on a change in power, there was no change in power during this glitch. The DPX display demonstrated that the signal hops to roughly 3 MHz above the signal of interest. The frequency mask is defined as an envelope around this signal, and the instrument triggers once the signal enters the frequency mask area.

Capture

In the previous example, the length of the captured data record for analysis was 900 µs. For the RTSA's maximum real-time bandwidth of 110 MHz, the maximum capture time is approximately 1.7 seconds. This provides sufficient time to capture most signal glitches and transients encountered in a SDR. Captured files can be re-used many times, allowing analysis by multiple users and with varying measurement settings, without having to re-acquire the data.

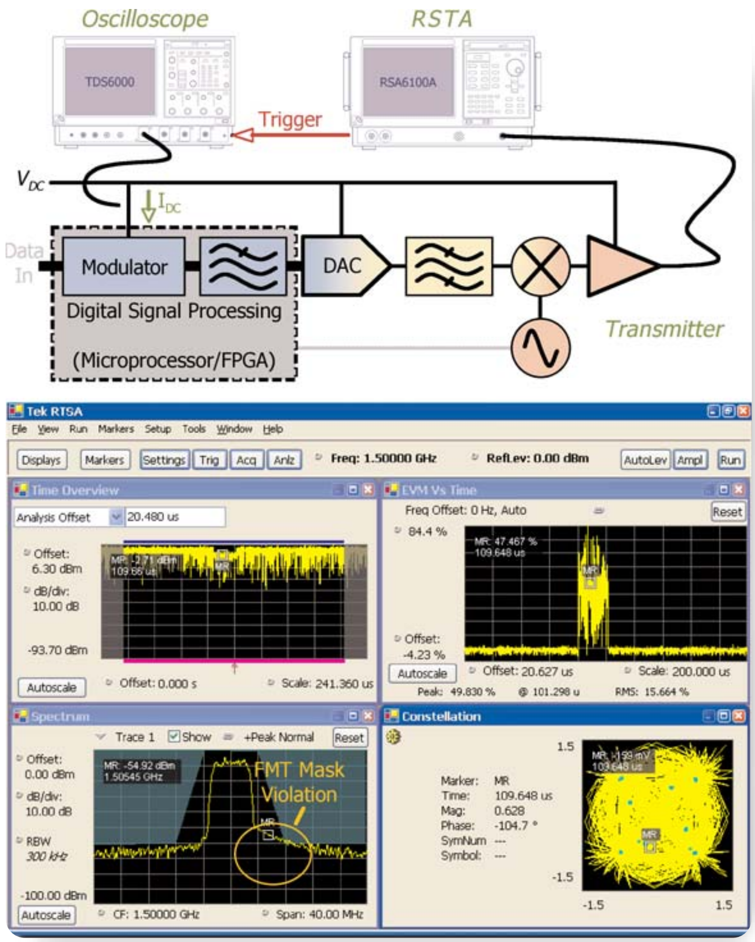
Analyze

An instrument is of limited use if it merely reports a measurement failure. In-depth analysis of signal data at a particular moment in time is essential for determining what else was occurring at that time. The ability to pinpoint where an anomaly has occurred in time is a significant benefit of multi-domain correlated analysis. The RTSA provides this ability because it captures a long time record covering a wide frequency bandwidth. For example, if a high EVM value is observed for a digitally modulated signal, the user can also peer into the frequency domain to determine if there was an unexpected excursion, perhaps from a long PLL settling time. Because SDR devices have so many possible mode changes controlled by software alone, the RF hardware must be designed with sufficient robustness to ensure proper operation in all conditions. With multi-domain analysis, the RTSA provides a means to measure the hardware robustness by allowing the developer to pinpoint signal problems at specific moments in time and correlate the results.

Application Examples

Power Supply Droop Affecting RF Output

Power supply droop from DSP activity can affect the RF output. SDR designs often include a Central Processing Unit (CPU) and a FPGA. The amount of current consumed by the digital components is a function of the code being executed. As a result, some sections of code can place a heavy demand on the CPU causing momentary power supply fluctuations. In addition, transceivers capable of simultaneous transmit (Tx) and receive (Rx) often execute complex DSP operations that depend on the contents of a received signal. This can affect the bias voltages of the analog RF transmitter chain, particularly in battery powered devices, resulting in an asynchronous momentary loss of signal quality. Thus, it is desirable to see how the transmitter output changes over time while monitoring the various power supply voltages and correlate the results.



Freq: 1.50000 GHz
Ref.Lev: 0.00 dBm

Analysis Offset 20.480 us
Offset: 6.30 dBm
dB/div: 10.00 dB
-93.70 dBm
MR: -2.71 dBm 109.66 us
Offset: 0.000 s
Scale: 241.360 us

Freq Offset: 0 Hz, Auto
84.4 %
MR: 47.467 % 109.648 us
Offset: -4.23 %
Offset: 20.627 us
Scale: 200.000 us
Peak: 49.830 % @ 101.298 u
RMS: 15.664 %

Trace 1 ☑ Show +Peak Normal
Offset: 0.00 dBm
dB/div: 10.00 dB
RBW 300 kHz
-100.00 dBm
MR: -54.92 dBm 1.50545 GHz
CF: 1.50000 GHz
Span: 40.00 MHz

Marker: MR
Time: 109.648 us
Mag: 0.628
Phase: -104.7 °
SymNum ---
Symbol: ---

▶ **Figure 5.** *(Upper) Text set up showing RTSA FMT output for capturing a signal on an oscilloscope. (Lower) Multi-domain view of a capture record, showing how (clockwise from the upper left display) Power vs. Time, EVM vs. Time, Constellation Diagram interrelate and Spectrum shown with FMT. In this example, it can be seen that as the power supply dips momentarily, the EVM increases.*

One approach is to trigger on the current fluctuations with an oscilloscope, and use the trigger output to initiate RTSA or VSA signal captures to observe the transmitter output. The disadvantage with this approach is current fluctuations may or may not actually cause RF problems, leading to many false triggers. The RTSA offers another potentially more useful approach with its FMT. Setting a frequency mask trigger near the transmit spectrum can capture momentary spectral re-growth jumps, triggering RTSA and oscilloscope captures. Since spectral re-growth is adversely affected by power supply droop, only those events that alter the transmit spectrum are captured for analysis, eliminating false triggers. Time correlated RTSA functions such as EVM vs. Time, Frequency vs. Time, Phase vs. Time, Power Level vs. Time, CCDF, ACLR or Spectrogram can be viewed to determine how changes in the RF output relate to DSP supply power requirements and signal quality. In this screen capture we see that EVM increases noticeably from power supply droop. The unique FMT feature and time correlated multiple domain analysis make finding asynchronous DSP caused events easy.

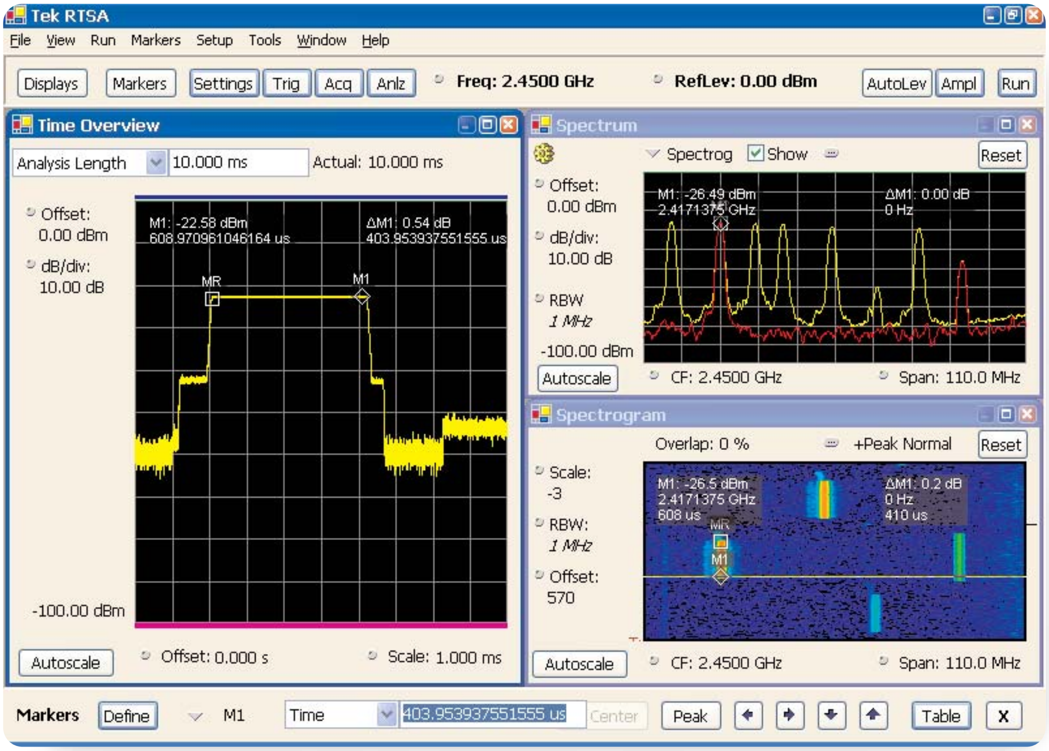
Frequency Hopping and Transmitter Testing

Frequency hopping is used in many systems, including those that are software defined. There are three main reasons for using frequency hopping:

–To avoid detection

–To avoid jamming and interference

–To improve performance in an environment with multi-path and fading



Tek RTSA

Freq: 2.4500 GHz

RefLev: 0.00 dBm

Time Overview

Analysis Length 10.000 ms Actual: 10.000 ms

Offset: 0.00 dBm

dB/div: 10.00 dB

-100.00 dBm

M1: -22.58 dBm 608.970961046164 us

ΔM1: 0.54 dB 403.953937551555 us

Offset: 0.000 s

Scale: 1.000 ms

Spectrum

Offset: 0.00 dBm

dB/div: 10.00 dB

RBW 1 MHz

-100.00 dBm

M1: -26.49 dBm 2.4171375 GHz

ΔM1: 0.00 dB 0 Hz

CF: 2.4500 GHz

Span: 110.0 MHz

Spectrogram

Overlap: 0 %

+Peak Normal

Scale: -3

RBW: 1 MHz

Offset: 570

M1: -26.5 dBm 2.4171375 GHz 608 us

ΔM1: 0.2 dB 0 Hz 410 us

CF: 2.4500 GHz

Span: 110.0 MHz

Markers M1 Time 403.953937551555 us

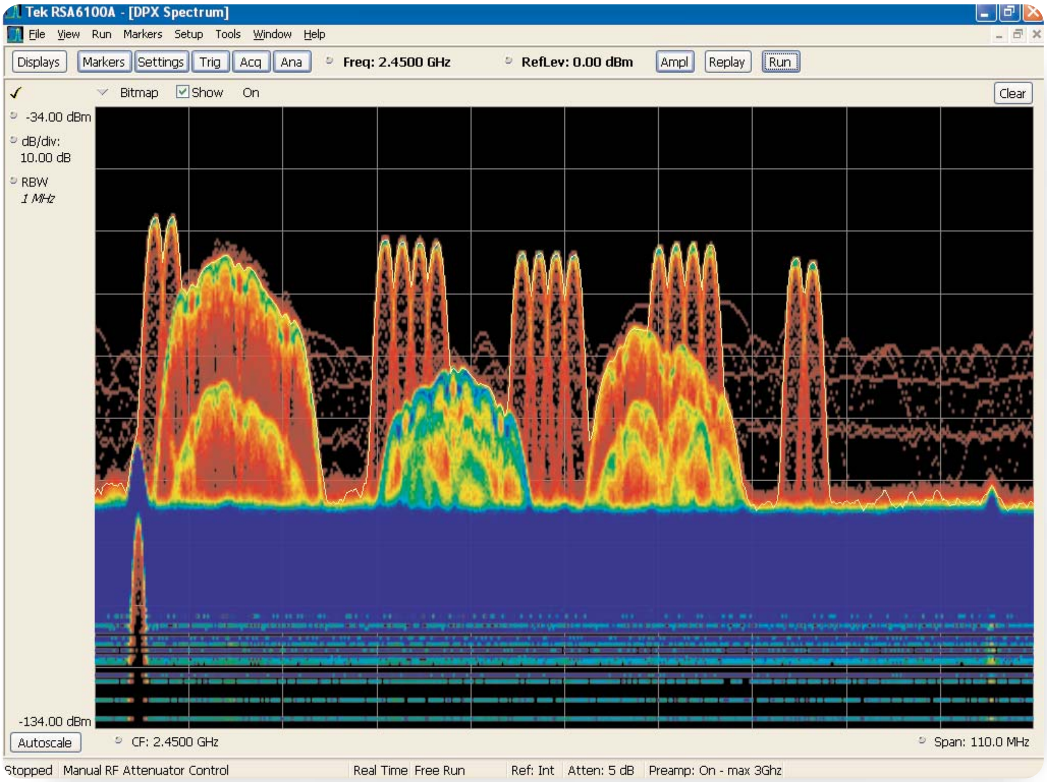
▶ **Figure 6.** *Bluetooth® hopping sequence with (clockwise from the left), Time Overview, Spectrum trace of a specific moment in the spectrogram and Spectrogram displays. This allows specific measurements over time of a hopping sequence, as well as providing the user a way to quickly identify problems with DPX using markers in multiple domains that are automatically correlated in time and/or frequency .*

Frequency hopping is used in conjunction with coding to spread the information over a wide range of frequencies. This makes systems more robust because data is redundantly transmitted over several frequencies. If a particular frequency is jammed, the system may only lose the information being transmitted at that frequency, rather than an entire data stream. Error correction decoding is used to recover data lost during the jammed hop.

In addition to the common measurements of hop timing, frequency settling time and amplitude settling time, there are several other measurements that can be used to troubleshoot hopping radios. Hopping involves the interaction of frequency, time and modulation domains.

The ability to show all three domains in a correlated fashion can be an invaluable tool in troubleshooting SDR devices.

In Figure 6, a Bluetooth® signal is displayed. The RTSA's spectrogram (lower right) shows the frequency behavior over time. It can be seen that there is high spectral energy around these hops. In this case, when the frequency hopping occurs, it could be possible that the transmitter may be interfering with neighboring devices. It is important that the instrument used to capture the frequency hopping have a wide enough real-time bandwidth to capture a large partition of the hopping sequence bandwidth, as well as the frequency splatter that occurs around it.



Freq: 2.4500 GHz

RefLev: 0.00 dBm

Bitmap ☑ Show On

-34.00 dBm

dB/div: 10.00 dB

RBW 1 MHz

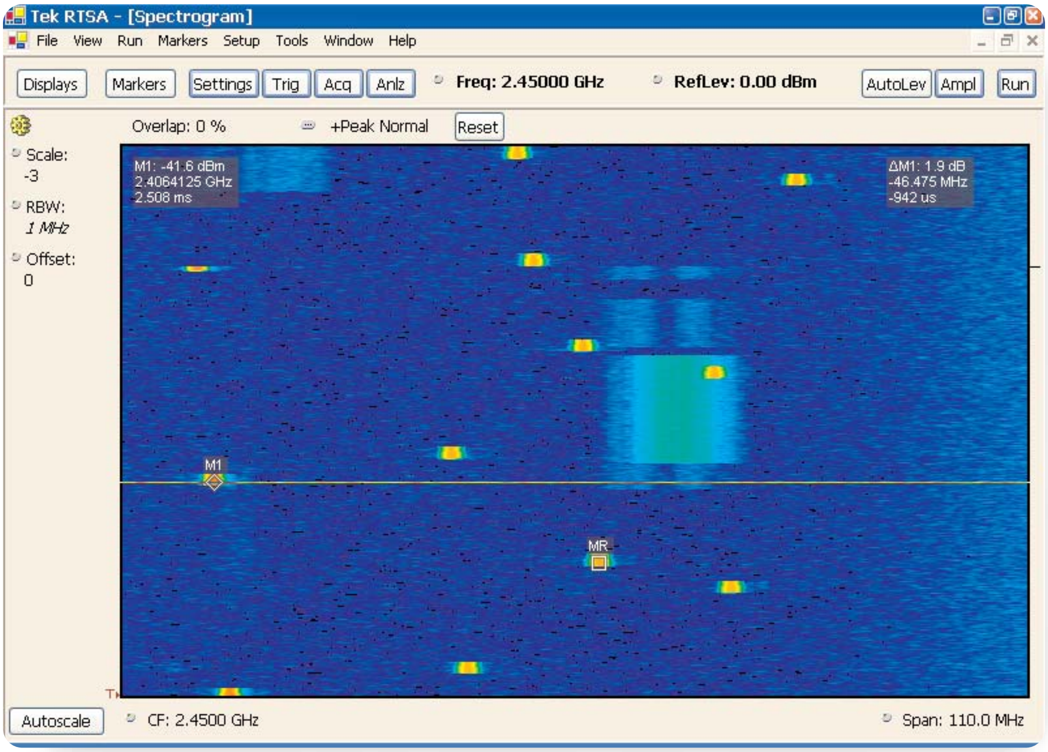
-134.00 dBm

CF: 2.4500 GHz

Span: 110.0 MHz

Stopped Manual RF Attenuator Control Real Time Free Run Ref: Int Atten: 5 dB Preamp: On - max 3Ghz

▶ **Figure 7.** *DPX™ of a 110 MHz span showing the 2.4 GHz ISM band. The signal here was similar to what was shown in Figure 7. Now depicted with a DPX™, a live RF representation of the true signal behavior can be seen.*



Freq: 2.45000 GHz

RefLev: 0.00 dBm

Overlap: 0 %

+Peak Normal

Scale: -3

RBW: 1 MHz

Offset: 0

M1: -41.6 dBm
2.4064125 GHz
2.508 ms

ΔM1: 1.9 dB
-46.475 MHz
-942 us

CF: 2.4500 GHz

Span: 110.0 MHz

▶ **Figure 8.** *Spectrogram of a 110 MHz span showing the 2.4 GHz ISM band. In this example, a Bluetooth device can be seen frequency hopping, with the marker set up to measure the time interval between hops. Also, in the middle of the display, a 20 MHz WLAN signal is present. It is interesting to note that a Bluetooth® frequency hop occurs during the WLAN signal; the interference with the WLAN signal could have made it not recognizable.*

While Bluetooth® is not necessarily implemented using a software radio, it provides a good example of the challenges that arise when trying to implement a frequency hopping system. For most frequency hopping systems, it is important to be able to measure each of the hopping frequencies. For example, the Bluetooth specification requires each of the 79 hopping frequencies (with 1 MHz channel spacing) to be within 75 KHz of the specific value. This ensures proper interoperation between different manufacturers' devices. For this measurement, the instrument being used to measure the hopping sequence must cover the entire hopping range. In the case of the 2.4 GHz ISM band, the RSA6100A's 110 MHz real-time bandwidth is sufficient to cover the entire 83 MHz band and also check for out of band interference. Figure 7 shows a DPX™ display of a Bluetooth device hopping in the presence of 20 MHz WLAN signals. Figure 8 shows a Spectrogram display of a Bluetooth device hopping. Figure 9 shows a Bluetooth® signal's hopping sequence over a time interval, now with multi domain views to measure specific signal interactions. The spectrogram in Figure 9 shows the timing information of the Bluetooth and WLAN signal interactions.

Because of the RSA6100A's high-performance bandwidth, it is possible to analyze the hopping sequence and perform a frequency settling time measurement on each of the frequency hops (with 6 nsec timing resolution at 110 MHz real-time bandwidth) for settling times as low as 60 nsec. When making frequency settling time measurements, there is a trade-off between an instrument's time resolution and frequency resolution. For very wide frequency spans, there will be improved timing resolution but reduced frequency resolution of the Frequency vs. Time display.

Freq: 2.4500 GHz
RefLev: 0.00 dBm

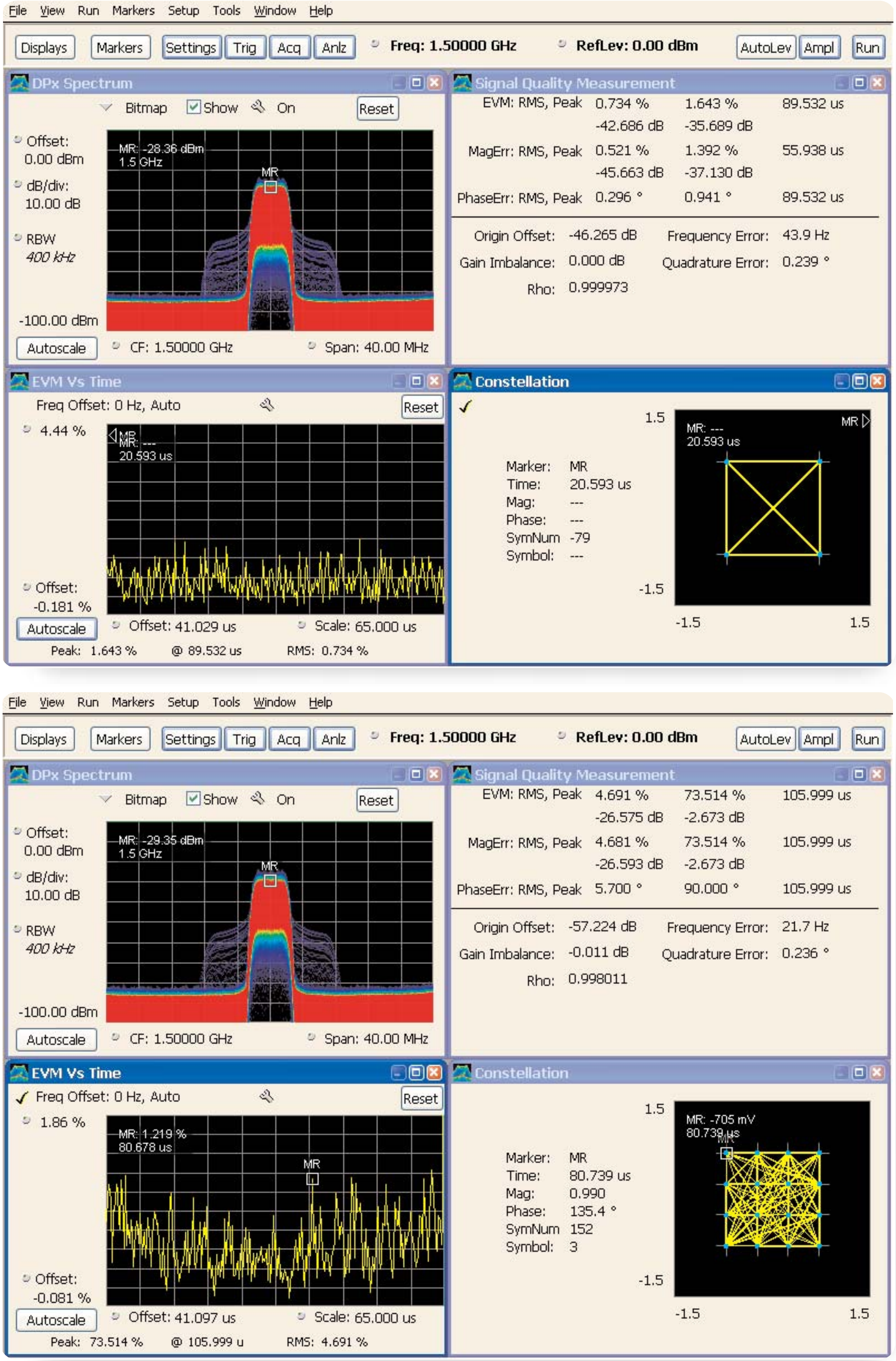
Frequency vs Time:
Offset: 0.000 Hz
Offset: 150 us
Scale: 500.000 us
Max: 75.00 MHz @ 273.3 ns
Min: -75.00 MHz @ 153.3 ns

Spectrum:
Offset: 0.00 dBm
dB/div: 10.00 dB
RBW *1 MHz*
CF: 2.4500 GHz
Span: 110.0 MHz

Time Overview:
Analysis Length 10.000 ms
Actual: 10.000 ms
Offset: 0.00 dBm
dB/div: 10.00 dB
Offset: 0.000 s
Scale: 1.000 ms

Spectrogram:
Overlap: 0 %
Scale: -3
RBW: *1 MHz*
Offset: 570
CF: 2.4500 GHz
Span: 110.0 MHz

▶ **Figure 9.** *Bluetooth hopping sequence, including (clockwise from the upper left) Frequency vs. Time, Spectrum with red Spectrogram Trace of a specific moment in time, Power vs. Time overview and Spectrogram of the 110 MHz hopping sequence.*



Freq: 1.50000 GHz
RefLev: 0.00 dBm

DPx Spectrum: Bitmap ☑ Show On
Offset: 0.00 dBm
dB/div: 10.00 dB
RBW 400 kHz
-100.00 dBm
MR: -28.36 dBm
1.5 GHz
CF: 1.50000 GHz
Span: 40.00 MHz

Signal Quality Measurement
EVM: RMS, Peak 0.734 % 1.643 % 89.532 us
-42.686 dB -35.689 dB
MagErr: RMS, Peak 0.521 % 1.392 % 55.938 us
-45.663 dB -37.130 dB
PhaseErr: RMS, Peak 0.296 ° 0.941 ° 89.532 us
Origin Offset: -46.265 dB
Frequency Error: 43.9 Hz
Gain Imbalance: 0.000 dB
Quadrature Error: 0.239 °
Rho: 0.999973

EVM Vs Time
Freq Offset: 0 Hz, Auto
4.44 %
MR: ---
20.593 us
Offset: -0.181 %
Offset: 41.029 us
Scale: 65.000 us
Peak: 1.643 % @ 89.532 us RMS: 0.734 %

Constellation
Marker: MR
Time: 20.593 us
Mag: ---
Phase: ---
SymNum -79
Symbol: ---
MR: ---
20.593 us

Freq: 1.50000 GHz
RefLev: 0.00 dBm

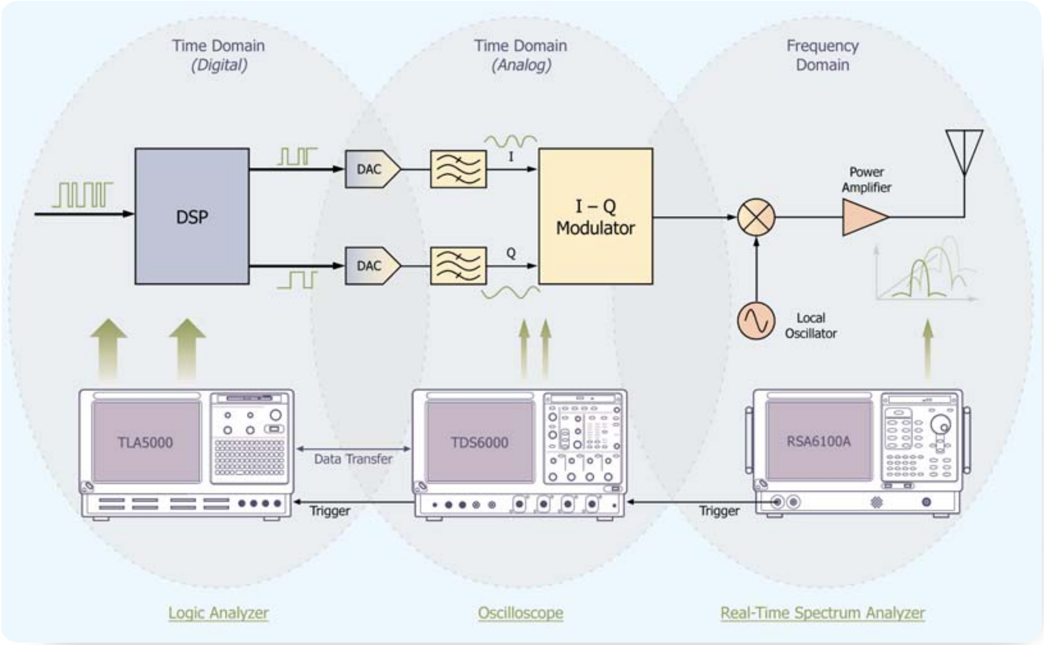
DPx Spectrum: Bitmap ☑ Show On
Offset: 0.00 dBm
dB/div: 10.00 dB
RBW 400 kHz
-100.00 dBm
MR: -29.35 dBm
1.5 GHz
CF: 1.50000 GHz
Span: 40.00 MHz

Signal Quality Measurement
EVM: RMS, Peak 4.691 % 73.514 % 105.999 us
-26.575 dB -2.673 dB
MagErr: RMS, Peak 4.681 % 73.514 % 105.999 us
-26.593 dB -2.673 dB
PhaseErr: RMS, Peak 5.700 ° 90.000 ° 105.999 us
Origin Offset: -57.224 dB
Frequency Error: 21.7 Hz
Gain Imbalance: -0.011 dB
Quadrature Error: 0.236 °
Rho: 0.998011

EVM Vs Time
✓ Freq Offset: 0 Hz, Auto
1.86 %
MR: 1.219 %
80.678 us
Offset: -0.081 %
Offset: 41.097 us
Scale: 65.000 us
Peak: 73.514 % @ 105.999 u RMS: 4.691 %

Constellation
Marker: MR
Time: 80.739 us
Mag: 0.990
Phase: 135.4 °
SymNum 152
Symbol: 3
MR: -705 mV
80.739 us

▶ **Figure 10.** *Two modulation schemes within the same signal. For each display, the EVM vs. Time and Signal quality can be seen. With a single capture, the RSA6100A can analyze each of the modulation schemes employed. DPX is available as a good indication of the transients present. A higher adjacent channel noise floor would be seen when there is a glitch or transient event like a modulation change.*



▶ **Figure 11.** *Typical setup for cross triggering multiple instruments and end-to-end analysis, from the digital bit level through RF component level. Triggering between instruments is possible to show the affects of changing signal parameters in each of these distinct domains.*

Transient Caused by Modulation Changes

Adaptive modulation and coding schemes are used in many modern communications systems. In 3GPP HSDPA, for example, the system's protocol determines whether to use 16-QAM or QPSK, based on the fading environment and network loading. These modulation schemes can change on a frame-by-frame basis. In Figure 10, the effects of the signal changing from QPSK to 16-QAM are shown. In this example, DPX display in the upper left continuously monitors the signal, the signal is changing back and forth between QPSK and 16-QAM. The blue shoulders on the DPX display indicate where the adjacent channel performance is degraded significantly. During these times, it is likely that there was a violation of the adjacent channel power specifications. Here, DPX™ is showing a glitch that is present as a result of changing the modulation format and manifesting as variations in the EVM.

Cross-talk from Other Devices on a Board

RF designs are migrating to silicon implementations for increased integration. This is leading to lower costs and shrinking RF transceiver footprints. In some cases, most of the RF design is implemented in the digital domain, with a direct conversion to IF at the end to minimize the need for expensive analog RF hardware. This forces the high-speed digital components into close proximity with the RF components. In computers, CPU and bus operating frequencies and harmonics are approaching the RF transmitting and receiving frequencies. For example, many CPUs are operating at or near the 2.4 GHz frequency used in many consumer electronics deployed in the ISM band, including the computer's own integrated Wireless Local Area Network and Bluetooth® devices. With improper isolation, it is possible to have cross-talk or bleed over between these various systems.

In order to isolate these problems, it is important to trace the signal through the RF receive and transmit path of interest in order to identify where interference is occurring. The RTSA can capture the signal in the RF and IF portions of the signal paths, and a Logic Analyzer can capture the digital baseband signal and compare it to the Symbol Table produced by the RTSA. Figure 11 shows a typical testing setup for this type of analysis, representing an integrated, end-to-end test solution for a typical SDR transceiver chain.

Transient Distortion Effects

The goals of improving power consumption and lowering cost are at the heart of most SDR efforts. Many designers are turning to digitally enhanced RF power amplifiers (PAs) in order to achieve efficiency and cost reductions. Unlike the linear PAs commonly used in the past, many PAs intended for SDRs are highly non-linear and depend on DSP to meet performance requirements. There are several techniques in use, either alone or in combination:

- Crest factor reduction – The digital IQ stream destined for up-conversion is analyzed prior to the D/A converter. The peaks are identified and the signal is purposely distorted in order to reduce the peak-to-average ratio. A large reduction in crest factor can be achieved with a small increase in transmitted EVM.
- Digital pre-distortion – The non-linear characteristics of a PA are learned as part of a factory calibration. These characteristics are then used to pre-distort the digital IQ stream prior to D/A conversion in such a way that the PA gives the correct output.
- Digital feedback linearization – Containing the output spectrum from a digitally linearized PA is one of the most difficult problems facing RF designers. A successful technique is to measure the spectrum of a transmitter and to use DSP to change the non-linear pre-distortion coefficients in a feedback manner. This technique typically involves down-converting the signal to an IF or baseband and using a high quality A/D converter to feed a high-speed DSP processor. The DSP processor performs successive measurements of the output spectrum, compares it with the spectrum of the input IQ stream and adjusts the non-linear corrector to minimize the differences.

Transient distortion effects show up as momentary spectrum mask violations in response to changes in the level of the transmitted RF. They occur because the non-linear behavior of amplifiers is highly temperature dependent. A change in the input signal changes the power and the temperature of the semiconductor devices used in the PA. These transient distortion effects typically settle much more slowly than the data being transmitted and much too fast for digital feedback linearization. These transient effects are highly dependent on environmental conditions and are hard to predict from a factory calibration. Pre-distortion coefficients that are correct for steady state operation temperatures may be quite incorrect during a thermal transient. Transient distortion effects typically settle in tens of microseconds to milliseconds, depending on the particular devices and power levels in use.

These transient distortion effects can be diagnosed using the RSA6100A Series. The events can be “discovered” using DPX this allows never seen before insight into signal behavior changing over time showing a 'live RF' signal display. The transient itself will cause a trigger event to capture the signal instability by using the user-defined FMT. The entire event can be captured into a deep memory. Because of the RSA's architecture, information before and after the signal instability can be captured. Complete analysis of the frequency, time, and modulation domains can be performed without recapturing the event.

Non-linear Effects and Glitches During Power Ramping

Both conventional transceivers and SDR devices can have output power levels that change over time. These power levels can increase to the point where an amplifier in the signal chain is occasionally driven to saturation. Clearly, there will be gross distortions when an amplifier is driven into saturation, but there can also be undesirable effects when an amplifier is operated near saturation. These effects are more subtle and include an increase in the amplifier's Peak-to-Average Ratio (PAR). As a result, the amplifier may be driven into compression more frequently than desired, potentially causing momentarily higher Adjacent Channel Leakage Ratios (ACLRs). This can lead to interference with adjacent signals, but not necessarily a higher EVM.

The effects of this type of distortion can be observed with the RSA6100A Series by using the DPX feature, which displays a live RF signal picture of events as they occur. The analyzer is also able to trigger on these events using the FMT for selective frequency domain triggering, capturing the entire non-linear event and displaying the correlated Complementary Cumulative Distribution Function (CCDF) and ACLR measurements with the Spectrogram. It is important in this case to be able to look at the signal behavior over time and correlate different measurements that describe how the signal is affected when the power is ramping up or down.

For a more detailed discussion, please see the Tektronix application note, Wide Band Distortion Characterization and Troubleshooting Using a Real-Time Spectrum Analyzer.

Conclusion

SDR is an emerging implementation for RF transceivers and places additional requirements on RF hardware. In order to deal with the complexity presented in the research and development of software radios, RTSAs are used extensively to test the time-varying requirements of the multiple modes of operation. These unique instruments, with DPX display, frequency mask triggering and time-correlated, multi-domain analysis capabilities, are excellent troubleshooting tools when designing and characterizing SDR devices.

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