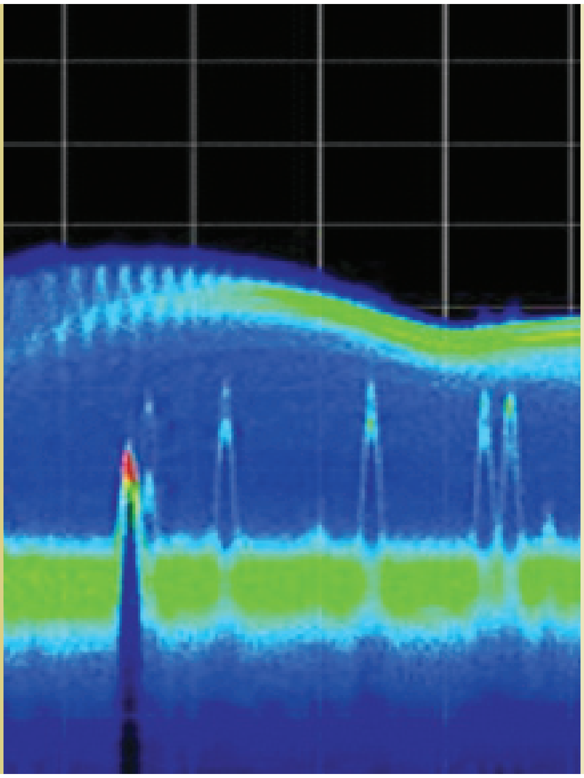
Application Note



Testing Modern Radios

Solutions for designing Software Defined Radios that employ legacy and modern modulation schemes with frequency hopping techniques

Designers have long sought to improve the performance and resiliency of radio communications. With the radio frequency (RF) spectrum becoming more crowded and interference more prevalent in recent years, these efforts have become increasingly critical. This is especially true for those developing military and civil defense radio applications. Military applications must perform in mission critical environments, where malicious signal jamming is common and robust, adaptive communications are required.

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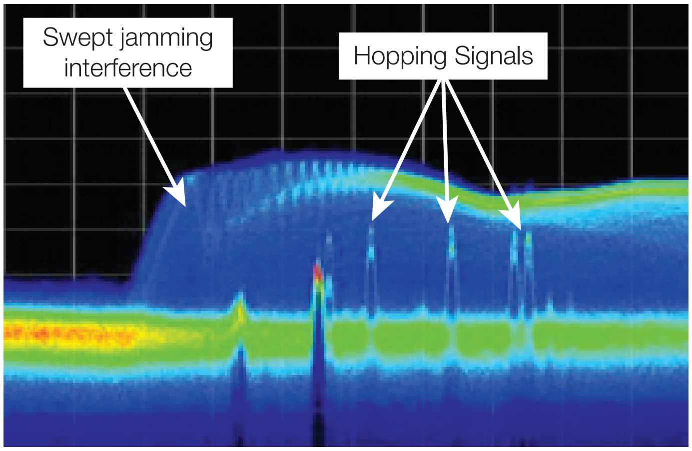


Figure 1. Frequency hopping signals jammed by large interference. Signal captured off-the-air by a Tektronix Real-Time Spectrum Analyzer (RTSA) using Digital Phosphor Technology (DPX).

Several techniques are now being employed to ensure efficient communications across the chaotic radio spectrum. Chief among them is Software Defined Radio (SDR), which uses software to dynamically control communications parameters such as the frequency band used, modulation type, data rates and frequency hopping schemes. The United States Department of Defense is driving the development of SDR technology through its multi-billion dollar Joint Tactical Radio System (JTRS) program. Most defense agencies around the globe have SDR development projects similar to the JTRS initiative. These efforts employ SDRs for a broad array of applications in a wide range of footprints, from compact, portable units to vehicle-mounted and shipboard platforms. A number of commercial applications have also surfaced that utilize many of the SDR technologies used by the defense electronics industry. Despite the wide variety of SDR applications and footprints, one trait is common among them: frequency hopping. Employed in analog as well as SDR systems, frequency hopping is used to:

- Avoid detection
- Mitigate jamming and interference
- Improve performance in an environment with multi-path and fading

Frequency hopping is utilized in conjunction with coding to spread the information over a wide spectrum of frequencies, making systems more robust. If a particular frequency is jammed, the system may lose only the information being transmitted at that frequency, rather than an entire data stream. In these circumstances, interleaving and forward error correction (FEC) can be used to recover data lost during the jammed hop. While frequency hopping is a proven method for improving radio communications, its use continues to evolve. The faster a signal hops, the less likely it is to face detection, interference or jamming. So although frequency hopping is not a new technique, military and civil defense entities as well as the consumer market, which invariably follows are continually striving to increase the speed of frequency hopping in modern radios to further improve and reinforce performance. These efforts have led to notable design and test challenges. Frequency hopped signals and interference sources operate in extremely complex, time varying spectrums. The erratic behavior of these signals can make them difficult to acquire, verify and measure. Effectively designing and testing modern radios that employ increasingly fast frequency hopping techniques requires new tools and methodologies.

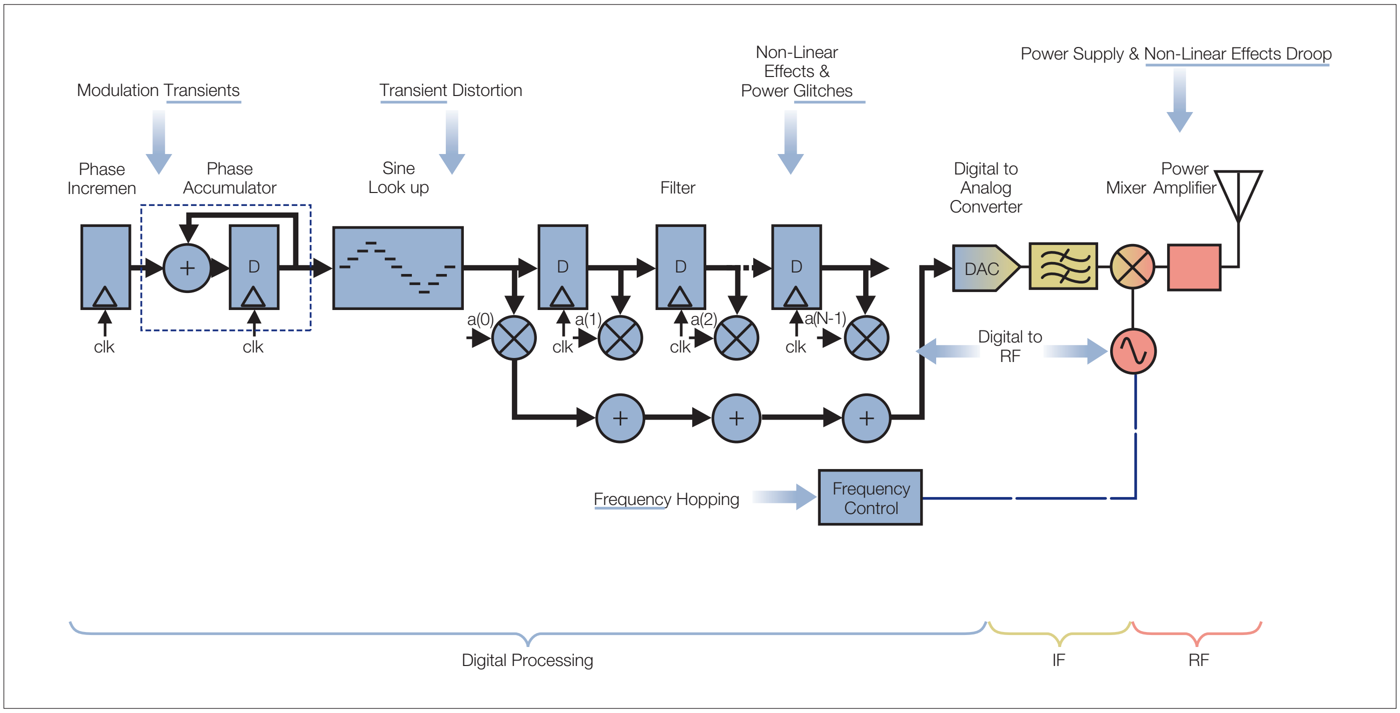


Figure 2. Possible error sources in a simplified SDR block diagram.

Evolving Design and Test Challenges

Faster frequency hopping poses a number of challenges when designing communication systems, especially the system architecture and frequency synthesizers. Modern radios are complex systems, and the controlling software, digital signal processor (DSP) and system components all must work in concert to ensure optimum performance. Because software actively alters a radio's operating parameters, there are countless hardware/software combinations that can cause errors. Modulation and filtering transients, distortion, non-linear power effects, pulse aberrations, frequency tuning and settling, power supply coupling, digital to RF couplings and software-dependent phase errors are common. Designing fast frequency synthesizers presents a significant challenge as well. A Joint Tactical Information Distribution System (JTIDS) working in L-Band, for example, operates at 38,461.5 hops per second. This means the frequency synthesizer has to hop from one frequency to the next, settle and communicate in less than 26 microseconds; system transient responses must be settled in just a few hundred nanoseconds to enable error-free communication. Impaired modulation quality due to frequency settling of hopped carriers is one of the primary sources for poor transmitter quality and low system data rates. In the past, designers were able to use conventional test equipment to demodulate stationary carriers located at the center frequency of their modulation analyzer. Unfortunately, conventional test equipment is not capable of demodulating today's wideband hopped signals. Because these signals hop over the band of operation, analyses of off-center frequencies are required to ensure optimum modulation quality. The dynamic generation of RF waveforms through DSP and the integration of digital and RF circuits often on the same integrated circuit (IC) also create issues not seen in traditional RF transceiver designs. Figure 2 shows some of the error sources found in SDRs: Modulation transients, Non-linear effects of amplifiers, and Digital to RF crosstalk to name a few. The performance of SDR transmitters must be verified with measurements that are beyond the traditional RF transmitter conformance tests. Simply passing these tests does not ensure a device will work properly, and system behavior must be carefully and thoroughly observed since software is continually changing system parameters.

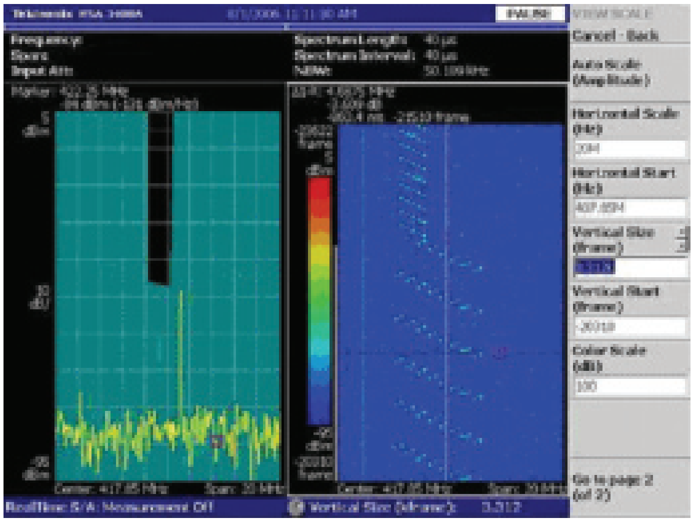


Figure 3. A fast hopped signal captured by a Tektronix Real-Time Spectrum Analyzer (RTSA). The left side displays the user-defined Frequency Mask Trigger (FMT), while the right side spectrogram displays the captured hopping signal.

Test Solutions

Truly addressing these challenges requires SDR designers to fully analyze and characterize their systems. Discovery of true system behavior is important to identify potential RF spectrum anomalies. As system parameters change over time, performing frequency selective triggering is necessary to pinpoint the instant a transient event occurs. Performing time-correlated analysis in multiple domains is required to determine the specific cause of each problem. Capturing the entire event seamlessly into memory is valuable for subsequent analysis, as it can be difficult to recreate the conditions under which the transient occurred. These advanced troubleshooting methods of verifying signal performance over time, combined with traditional conformance tests performed under steady-state conditions, are necessary for comprehensive SDR testing.

Verifying overall system performance and troubleshooting at the system level

Having a verified system architecture design is vital to the success of a modern communication system. The more access points that are tested and verified, the less likely it is that issues will manifest during the last system integration phase. Some of the major contributors to system failures are DSP, RF circuitry and the controlling software. A verification debug tool will greatly aid system designers in effectively discovering problems. Once an error has been identified, it must be isolated and understood. To isolate a problem and determine its root cause, it is important to time-correlate the error back through the signal path. Since the signal information changes form in an SDR design from digital words to continuously variable analog voltages several pieces of test equipment may be needed to diagnose the exact source of problems. Because the problem may occur at any point in the signal path, and memory capacity in oscilloscopes and logic analyzers is limited, the ability to simultaneously trigger multiple test instruments and capture the exact moment in time that the event occurs is important. This requires that each instrument be able to trigger in their domain (logic analyzers for digital triggers, oscilloscopes for time domain amplitude triggers and spectrum analyzers for frequency domain triggers) and that trigger latency between each instrument is determinstic.

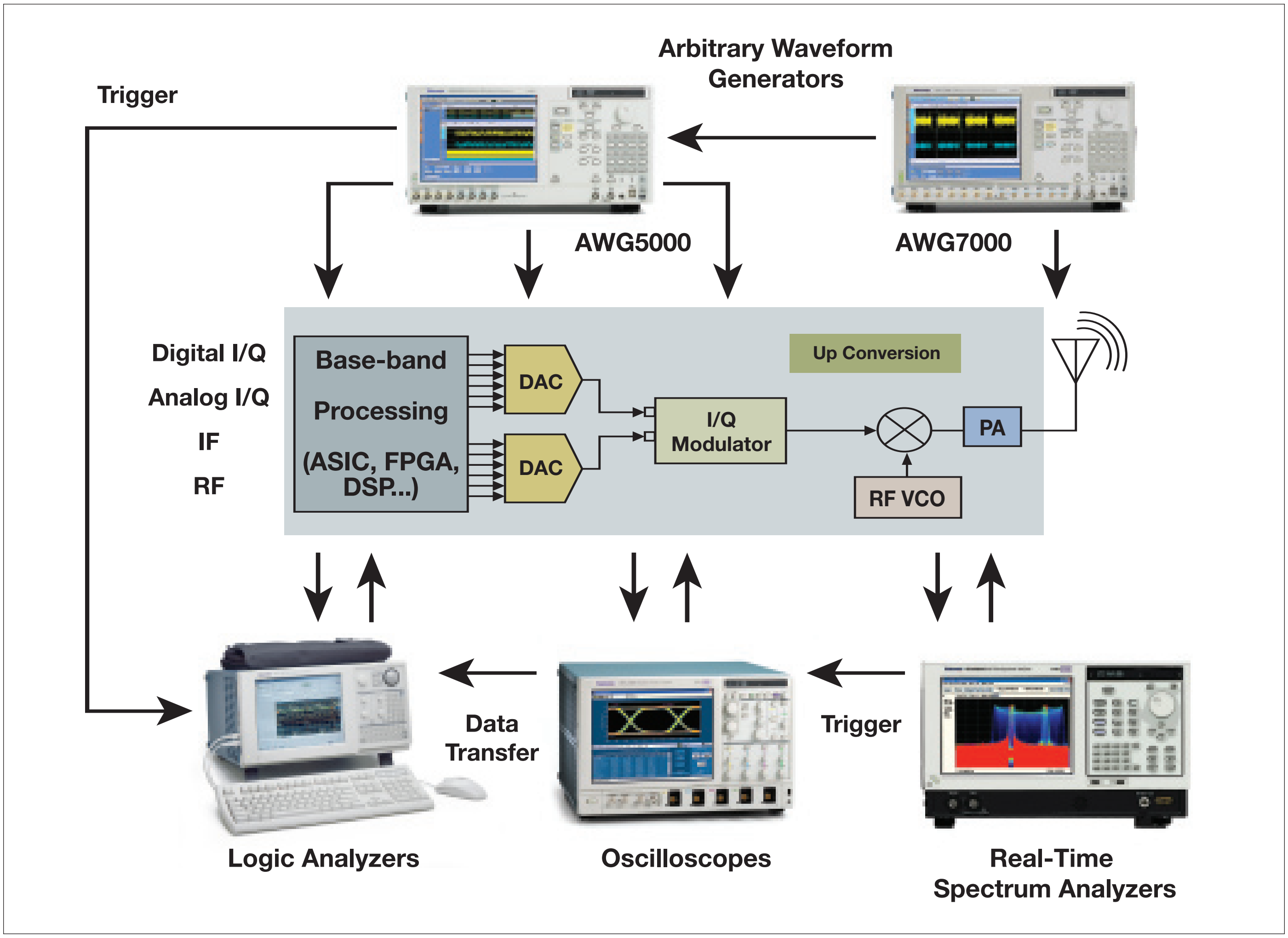


Figure 4. An integrated, end-to-end test system for verifying and troubleshooting SDRs, featuring Tektronix Real-Time Spectrum Analyzer (RTSA), Arbitrary Waveform Generator (AWG), Oscilloscope and Logic Analyzer.

An integrated, end-to-end test system comprising Tektronix Real-Time Spectrum Analyzer (RTSA), Arbitrary Waveform Generator (AWG), Oscilloscope and Logic Analyzer can be invaluable for testing SDRs. These instruments are able to work in unison with cross-triggering and time-correlated subsystem views to verify SDR performance and perform multiple test procedures at the physical and various software layers. The test system can also be used to understand the complex interactions between SDR subsystems in the frequency and time domains, especially in bursted or frequency hopped signals. When filtered and amplified, software anomalies can create temporal RF impulse bursts of energy at the RF output. To isolate software and hardware performance, the RTSA can be used to trigger on transients in the frequency domain, capture the events into memory and drive the other test instruments to probe possible error sources (as illustrated in Figure 2). The key to capturing the transients in the frequency domain is Tektronix' Frequency Mask Trigger (FMT). Once acquired, the signals are then presented in a time-correlated fashion, helping designers see how anomalies in the digital and analog blocks of an SDR will propagate to the RF output as impulse noise.

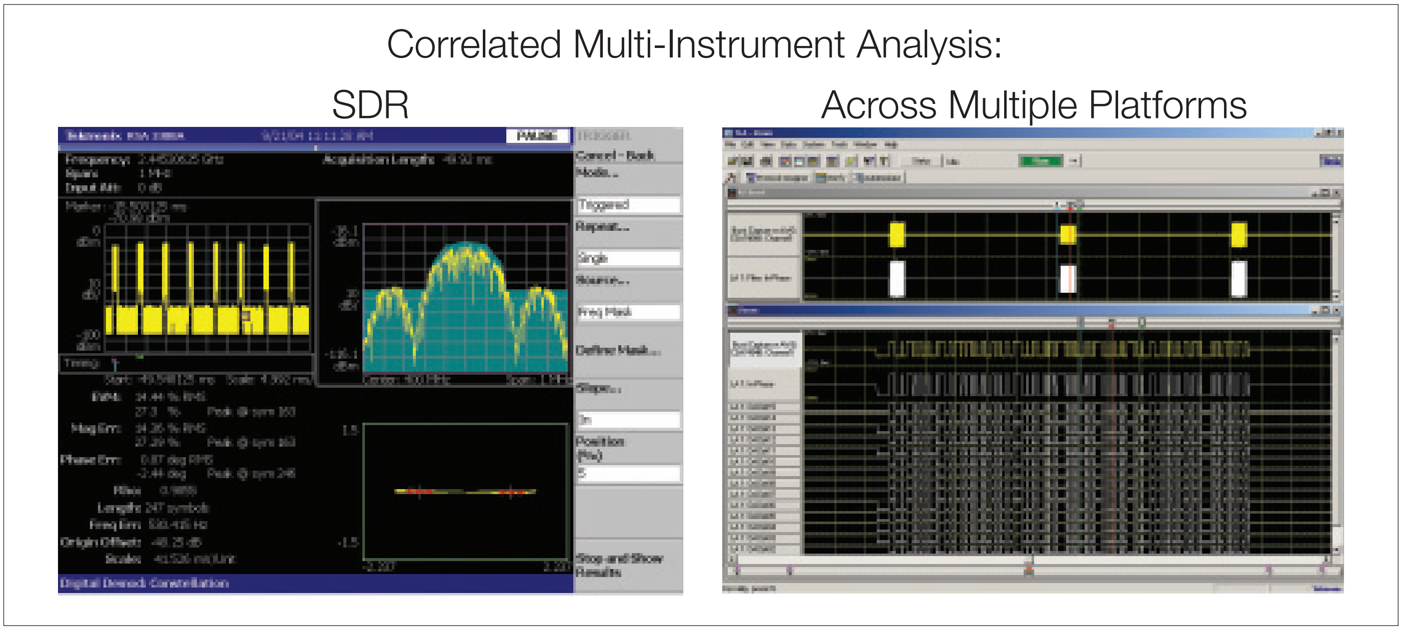


Figure 5. Time-correlated, multi-domain analysis of a BPSK signal that has violated a spectrum mask. The left side shows the RF waveform as captured by a Real-Time Spectrum Analyzer (RTSA). The right side shows the corresponding analog and digital channel views captured with an oscilloscope and logic analyzer.

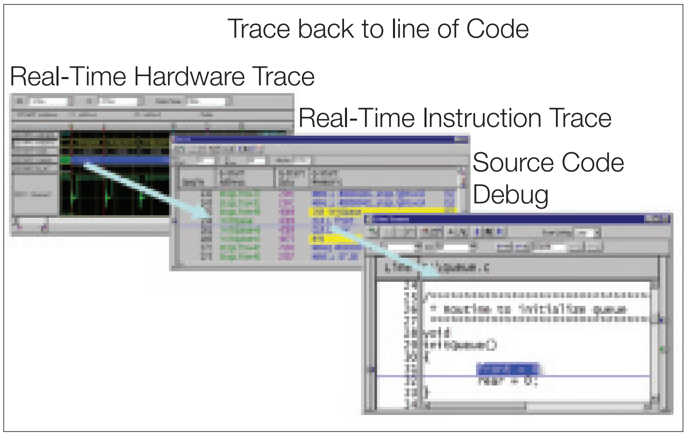


Figure 6. Logic analyzer data of the event triggered by the RTSA can be traced back to its software origins (hardware trace, instruction branch and line of source code).

The unique ability of the RTSA to find problems from spectral transients can be used to trigger the other instruments and obtain time-correlated views of vastly different hardware and software functional implementations. For example, 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. Furthermore, the RTSAs off-line software (RSAVu) can be used to analyze acquired data from the logic analyzer and oscilloscope, allowing hardware and software measurement correlation.

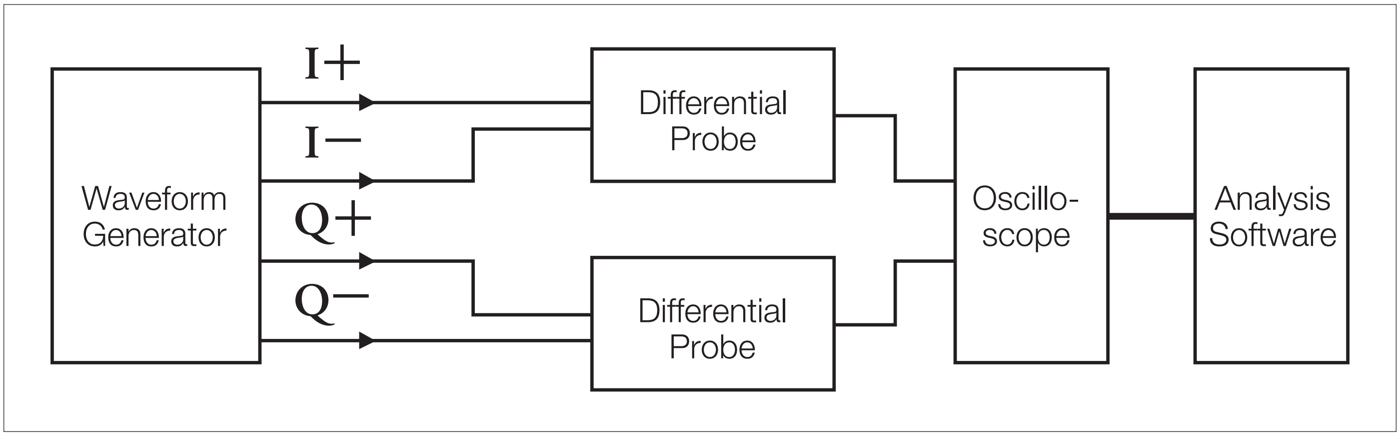
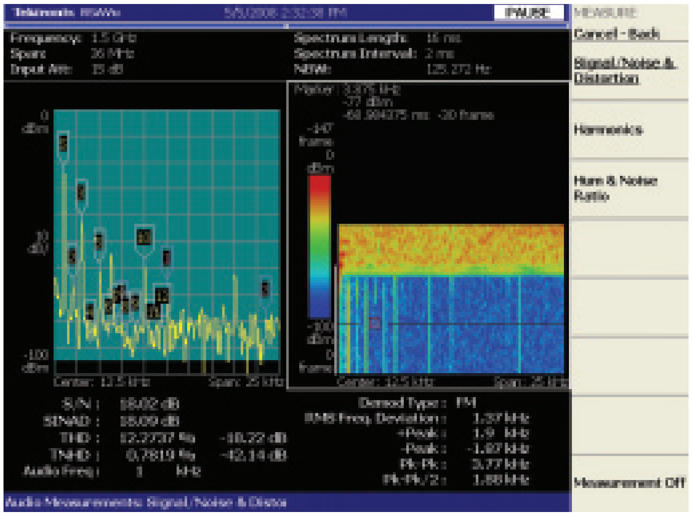


Figure 7. The conventional way of testing baseband IQ signals using an oscilloscope.

Correlated Multi-Instrument Analysis: SDR Across Multiple Platforms

Verifying baseband IQ waveform quality

Verifying baseband IQ waveform quality is important to both system engineers and Field Programmable Gate Array (FPGA) designers. It helps engineers test the baseband to ensure it is properly functional at an early stage of development because many of the problems involved in digital circuits are in the FPGA design. The baseband signals in the actual designs and applications are differential (I+, I-, Q+ and Q-) and may possess a DC offset. In the past, very few spectrum analyzers were able to test IQ signals directly, and fewer spectrum analyzers could test the baseband IQ signals with DC offset. Engineers have been forced to use oscilloscopes with additional software for post analysis. Some RTSAs enable baseband IQ testing using differential inputs. There are a number of benefits of using an RTSA when testing IQ signals: consistency of IQ, IF and RF measurement tool and analysis, reduced system complexity and simplified testing RTSAs have higher dynamic range, and greater memory depth than general purpose oscilloscopes. Tektronix RTSAs bring baseband, RF and post analysis functionality together. The RSA3000 series, for example, can perform DC baseband measurements with 14 bit analog-to-digital conversion (ADC), ensuring measurement accuracy. They also posses the differential IQ input function, which enables engineers to connect the RTSA directly to baseband IQ signals for error vector magnitude (EVM) analysis without any additional differential probe sets. In addition to EVM, RTSAs provide fully time-correlated measurements across multiple domains (i.e., time domain, frequency domain, modulation domain and constellation).



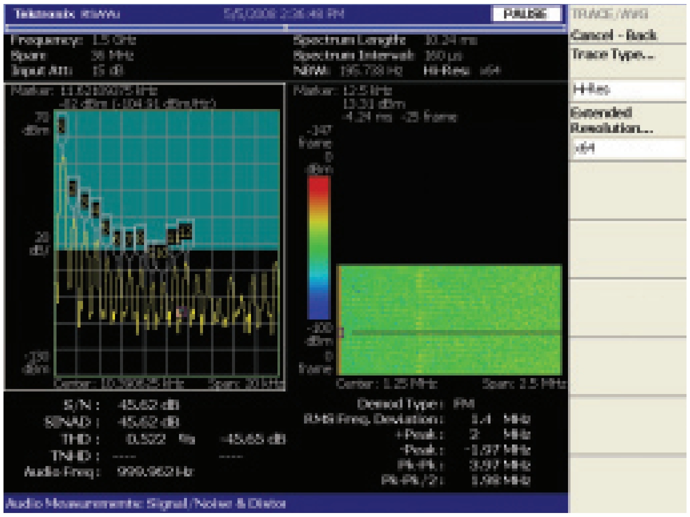
Frequency: 1.5 GHz
Span: 36 MHz
Input Att: 15 dB
Spectrum Length: 16 ms
Spectrum Interval: 2 ms
NBW: 125.272 Hz

Marker: 3.875 kHz
-77 dBm
-68.984375 ms -20 frame

S/N : 18.02 dB
SINAD : 18.09 dB
THD : 12.2737 % -18.22 dB
TNHD : 0.7819 % -42.14 dB
Audio Freq : 1 kHz

Demod Type : FM
RMS Freq. Deviation : 1.37 kHz
+Peak : 1.9 kHz
-Peak : -1.87 kHz
Pk-Pk : 3.77 kHz
Pk-Pk/2 : 1.88 kHz

Figure 8. The Audio Spectrum and Spectrogram displays allow designers to understand the nature of distortion by viewing harmonics and non-harmonic components over time. Distortion parameters are calculated for each FFT frame in the Spectrogram display.



Frequency: 1.5 GHz
Span: 38 MHz
Input Att: 15 dB
Spectrum Length: 10.24 ms
Spectrum Interval: 160 µs
NBW: 195.739 Hz Hi-Res: x64

Marker: 11.52109375 kHz
-82 dBm (-104.91 dBm/Hz)

Marker: 12.5 kHz
13.31 dBm
-4.24 ms -25 frame

S/N : 45.62 dB
SINAD : 45.62 dB
THD : 0.522 % -45.65 dB
TNHD : ---- ----
Audio Freq : 999.962 Hz

Demod Type : FM
RMS Freq. Deviation : 1.4 MHz
+Peak : 2 MHz
-Peak : -1.97 MHz
Pk-Pk : 3.97 MHz
Pk-Pk/2 : 1.98 MHz

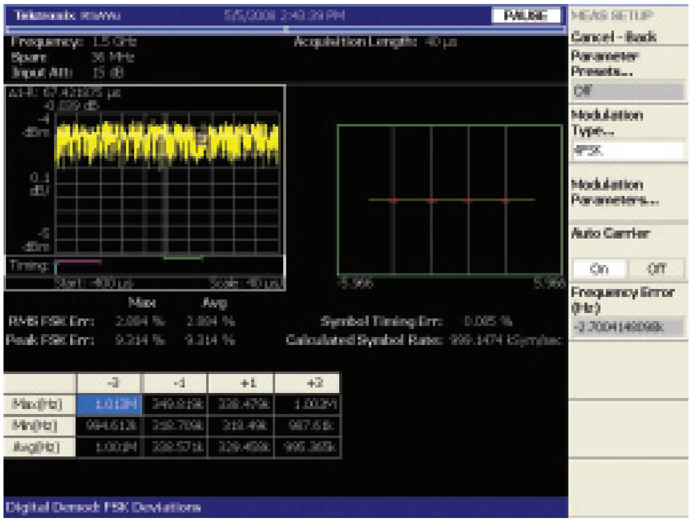
Figure 9. RTSAs are an effective tool for evaluating signals with high modulation indices. Above is an example of a wideband FM signal where the modulating tone is 1 kHz and the peak deviation is 2 MHz (MI = 2000). The demodulated audio spectrum on the left clearly shows the modulating fundamental and its associated harmonics. SINAD, THD and the measured 1 kHz modulating signal are clearly visible in the readout display at the bottom of the diagram.

Transmitter Measurements

Legacy modulation schemes

SDR designs which include compatibility with legacy modulation formats present a number of unique test challenges. First, a complete set of traditional modulation and distortion measurements are required to characterize compliance to the replacement transmitter. Such measurements include FM deviation or depth of AM modulation, as well as, S/N, SINAD, THD and Total Non-Harmonic Distortion (TNHD). These latter measurements require the spectrum analyzer to include specific audio filters and de-emphasis settings to produce valid results. For some transmitters, measurements such as Hum and Noise may also be required to understand the amount of un-intended modulation present in the transmission from sources other than the originating test signal.

While compliance measurements ultimately boil down to meeting numeric test values, failure to meet specification requires designers to understand the nature of the distortion in order to isolate the problem. This is where an RTSA, such as the RSA3000, can significantly improve time-to-insight in resolving critical design issues. Besides offering all these traditional distortion measurements in a single instrument, real-time analyzers offer the ability to view the audio spectrum to understand which harmonic and non-harmonic components contribute most to the distortion metric. In addition, viewing the spectrogram of the demodulated audio can give the designer insight into which distortion products are at the source of non-compliant behavior. By viewing the time-varying nature of the audio signal, such as during transmitter turn-on, the audio spectrogram shows when and where distortion products first appear and, how they behave over time. Tools such as time-correlated markers allow the user to scroll though the spectrogram display to see how both the spectrum and audio distortion parameters change over time allowing the designer to isolate the problem faster compared to traditional distortion analyzers.



Frequency: 1.5 GHz
Span: 36 MHz
Input Att: 15 dB
Acquisition Length: 40 µs

	Max	Avg
RMS FSK Err:	2.004 %	2.004 %
Peak FSK Err:	9.214 %	9.214 %

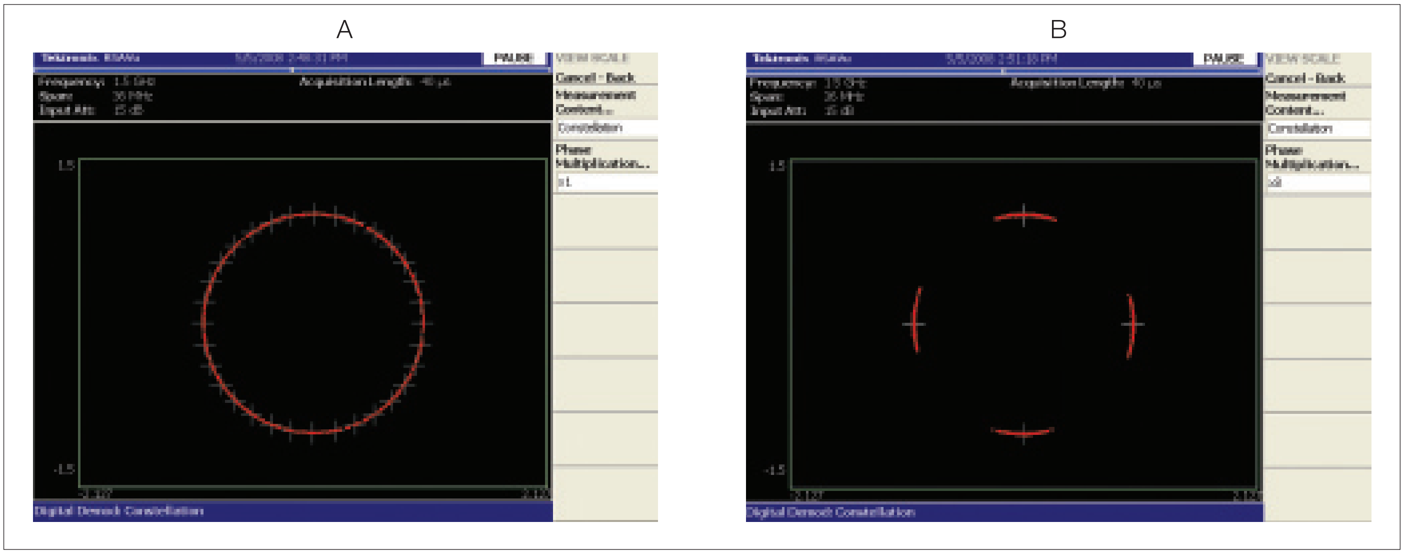
Symbol Timing Err: 0.005 %
Calculated Symbol Rate: 999.1474 kSym/sec

	-3	-1	+1	+3
Max(Hz)	1.013M	349.919k	328.479k	1.002M
Min(Hz)	994.613k	318.709k	318.49k	987.61k
Avg(Hz)	1.003M	328.571k	329.459k	995.365k

Figure 10. RTSAs display numerous FSK and symbol timing errors to speed RF debug. Note how all relevant FSK parameters are displayed on one screen, including symbol timing error.

A second test challenge involves characterizing radios utilizing high modulation indices (peak deviation / modulating signal). Modems for data and telemetry systems in which wideband FM modulation (>1 MHz deviation) is employed routinely have modulation indices exceeding 1000, requiring the spectrum analyzer to not only possess enough demodulation bandwidth, but also to have enough resolving power in the demodulated audio signal to compute SINAD and THD. Real-time analyzers offer high resolution modes through the use of variable-length FFTs allowing users to see how the modulating signal changes with increases in modulation rate.

A final challenge exists for designers of multi-level FSK radios. FSK is a legacy modulation format used in SINCGARS (Single Channel Ground and Airborne Radio System) and other VHF radios for secure tactical military communications. While validation of modulation compliance to a standard may be a straight-forward task of measuring rms and peak FSK errors, designers need additional tools that allow them to investigate the cause of non-compliance. Such tools allow the engineer to investigate frequency deviations for each symbol point, as well as symbol timing errors over any portion of the transmission. The RSA3000 consolidates a number of FSK measurements on one display to speed the task of RF debug and design compliance.



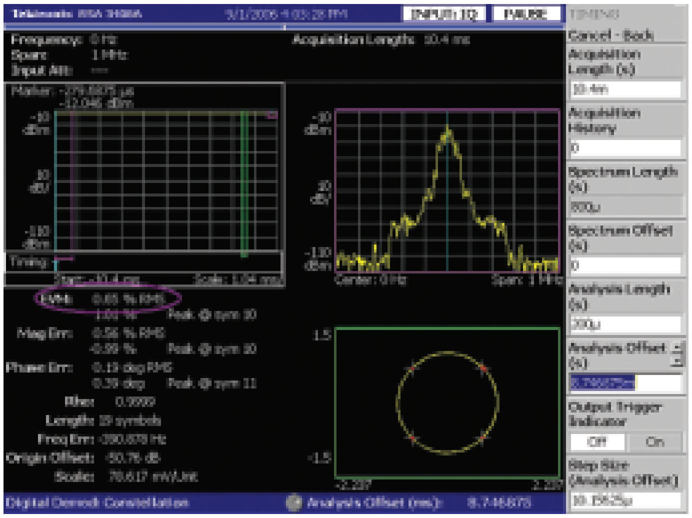
Frequency: 1.5 GHz
Span: 36 MHz
Input Att: 15 dB
Acquisition Length: 40 µs

Figure 11. RTSAs offer unique displays to show the nature of EVM errors. This example in (a) shows how phase errors mask the individual symbol points on the constellation diagram, however, multiplying the phase states in this multi-h CPM signal (b) reduces the number of phase states so the nature of the constellation errors can be understood.

Modern modulation schemes

MIL-STD-188-181C defines several telecommunication formats for tactical and long-haul communications. Continuous Phase Modulation (CPM) and Shaped Offset QPSK (SOQPSK) are two such constant envelope formats being used by the US Department of Defense and NATO allies for telemetry and voice communications. Analysis tools for these modulation schemes need to be easy to use to help the designer quickly understand signal quality, yet flexible enough to accommodate variants to the standard. A good example of a tool possessing both capabilities is the RSA3000 which supports multiple modulation index CPM, or multi-h CPM. Multi-h CPM is a quaternary format which changes the modulation index each symbol to provide waveform coding gain. Signal quality can be measured by first viewing the symbol table to select the portion of the burst to be evaluated (e.g. preamble or payload). Once selected, the real-time analyzer can easily display the constellation diagram of the transmission; however, phase errors in this 32 point constellation make qualitative analysis difficult as the decision points must be within 6 degrees of the ideal decision points. The result is a blurring or masking of any qualitative information on the traditional constellation diagram even though the measured EVM is correct. A unique feature of the real-time analyzer is its ability to multiply the measured phases by a constant thereby reducing the total number of occupied phase positions. This tool provides the designer with insight into the type of error present in the signal (e.g. AM/AM or AM/PM). Reducing the total number of phase positions changes only the location of the symbols and not the magnitude of the errors such that the total EVM visible on the constellation diagram is unaffected.

SOQPSK is similar to traditional QPSK except the Q channel data is shifted by one-half of a symbol period and the I and Q baseband signals are shaped with a half-sine filter. This shifting and half-sine shaping makes the signal constant envelope, simplifying power amplifier design and extending battery life; critical requirements for portable radios. The RTSA is a flexible tool allowing users to customize traditional OQPSK demodulation analysis for use in tactical radio design. The inclusion of the half-sine filter shaping makes demodulating this signal type a straight-forward task on the RTSA, real-time analyzers also provide the user the ability to import custom reference and measurement filters using Matlab or other filter design tools. Filter coefficients for both real-valued and complex-valued filters can be imported into the analyzer as text files for use in design verification. The complex-valued filters are especially valuable when the designer needs to compensate or equalize the impact of other components in the system.



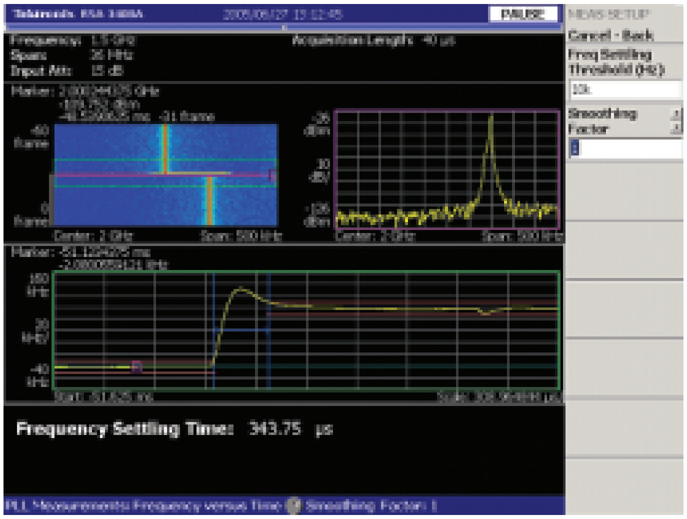
Frequency: 0 Hz
Span: 1 MHz
Acquisition Length: 10.4 ms

EVM: 0.65 % RMS
Peak @ sym 10
Mag Err: 0.56 % RMS
-0.99 % Peak @ sym 10
Phase Err: 0.19 deg RMS
0.39 deg Peak @ sym 11
Rho: 0.9999
Length: 19 symbols
Origin Offset: -50.76 dB
Scale: 78.617 mV/Unit

Acquisition Length (s): 10.4m
Acquisition History: 0
Spectrum Length (s): 800u
Spectrum Offset (s): 0
Analysis Length (s): 200u
Output Trigger Indicator: Off On

Digital Demod: Constellation
Analysis Offset (ms): 8.746875

Figure 12. Measuring a 200 µs baseband IQ signal quality with direct RTSA connection. Center frequency set as 0 Hz with span of 1 MHz.



Input Att: 15 dB
Acquisition Length: 40 µs

Freq Settling Threshold (Hz): 10k
Smoothing Factor: 1

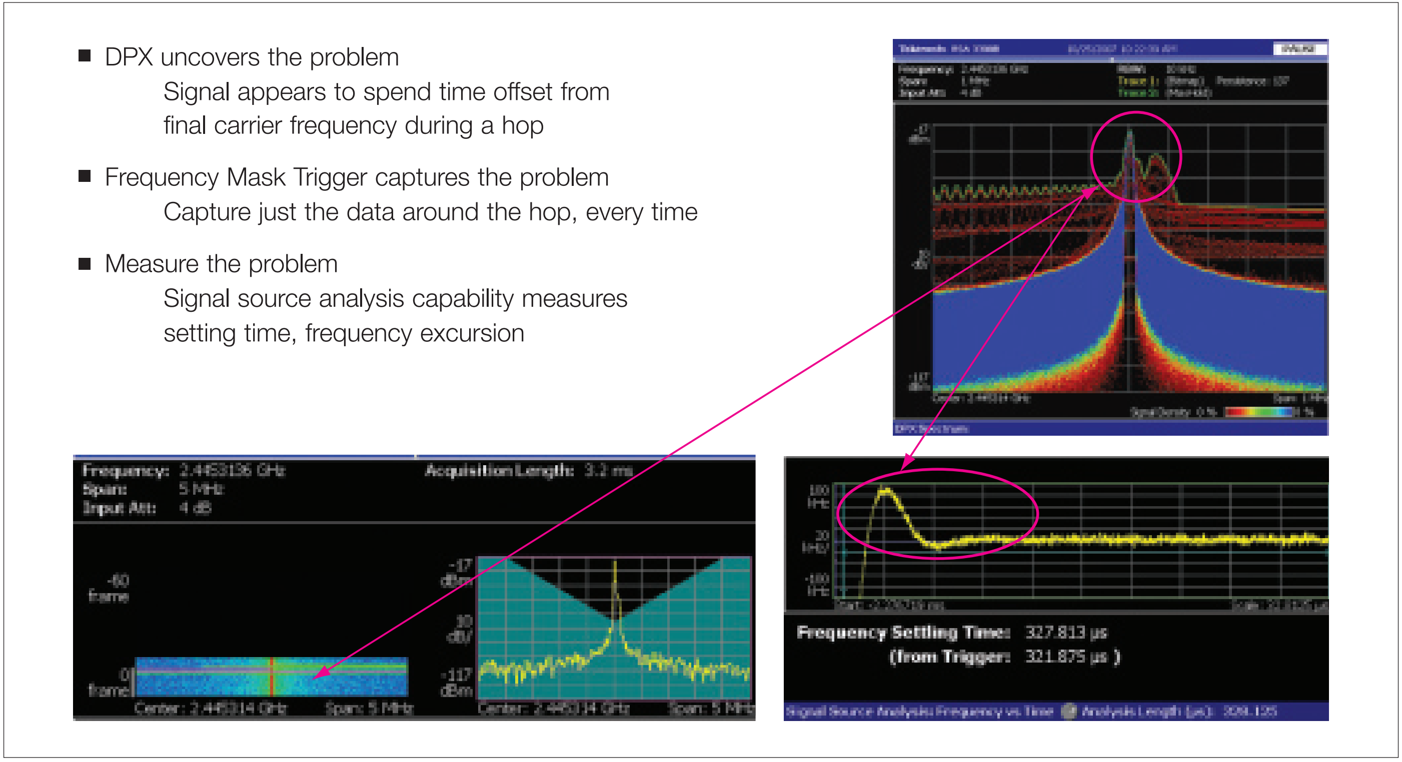
Frequency Settling Time: 343.75 µs

PLL Measurements: Frequency versus Time
Smoothing Factor: 1

Figure 13. An RTSA measuring a fast hopped signal with 343.75 µs frequency settling time. Engineers can also see spectrogram and frequency versus amplitude displays to verify system performance.

Frequency settling time of hopped signals

Frequency settling time defines the length of time between two hopped frequencies. It is one of the primary contributors to a frequency hopping system's efficiency. The shorter the frequency settling time, the faster a system can hop. Measuring the frequency settling time ensures optimum synthesizer operation and maximizes overall system performance. The traditional way of measuring frequency settling time was limited by the instrumentation and was very time consuming. Engineers were forced to rely on oscilloscopes and frequency discriminators for the test, showing only the signal envelope and hinting at the stability of the signals. While oscilloscopes have excellent timing resolution, using them to measure small frequency changes can be challenging depending on the frequency resolution required for the measurement. Oscilloscopes cannot automatically measure hopped frequencies, and frequency settling time can only be estimated. The latest generation of Tektronix RTSAs offers automated frequency settling time measurements. By setting parameters such as frequency settling threshold and smoothing factor, engineers can measure the frequency settling time for hopped signals quickly and accurately. Engineers can also see the spectrum changes during the hops. In addition to time-correlated measurements across multiple domains, Tektronix RTSAs feature Digital Phosphor Technology (DPX) and Frequency Mask Trigger (FMT). These unique features simplify the troubleshooting of frequency hopping signals more effective and easier than ever before.



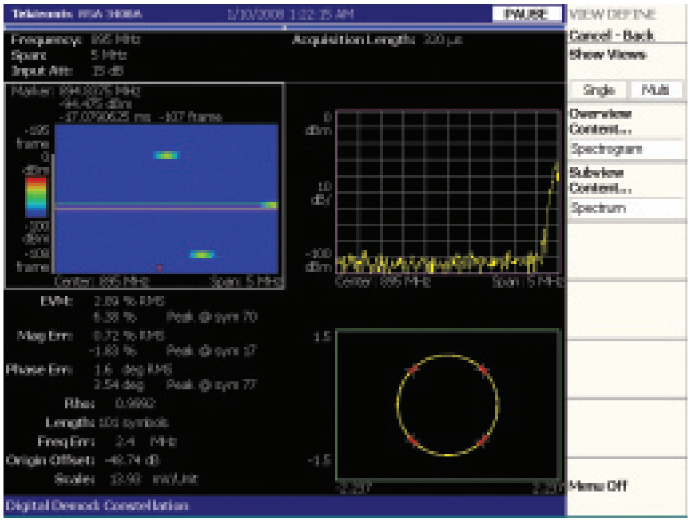
- DPX uncovers the problem
  - Signal appears to spend time offset from final carrier frequency during a hop
- Frequency Mask Trigger captures the problem
  - Capture just the data around the hop, every time
- Measure the problem
  - Signal source analysis capability measures setting time, frequency excursion

Frequency: 2.4453136 GHz
Span: 5 MHz
Input Att: 4 dB
Acquisition Length: 3.2 ms

Frequency Settling Time: 327.813 µs
(from Trigger: 321.875 µs)

Figure 14. The RTSAs unique Digital Phosphor (DPX) display and Frequency Mask Trigger (FMT) help quickly identify, capture and troubleshoot frequency hopping signals.

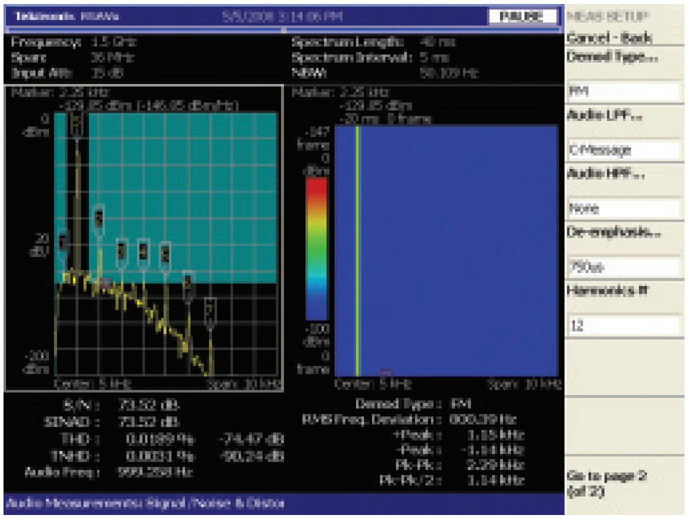
DPX technology gives engineers a tool to instantly discover problems. In allowing users to view Live RF signals for the first time, DPX provides unmatched insight into RF signal behavior. With spectrum updates that are 500 times faster than swept spectrum analyzers, transient changes in frequency can be seen directly on the DPX display. In the realm of SDR, DPX provides a completely new way to quickly assess the RF health of a signal and rapidly identify potential problems. Once a glitch or transient has been identified and defined as a frequency domain event using DPX, the RTSAs FMT can reliably capture the signal into memory for in-depth post processing analysis. The frequency mask is user-defined and can be drawn to best capture the signal. With an infrequently occurring frequency hop, for example, the user is able to define the mask to trigger on the frequency excursion, rather than the change in power level. The frequency mask is defined as an envelope around this signal, and the instrument triggers once the signal enters the frequency mask area.



Frequency: 895 MHz
Span: 5 MHz
Input Att: 15 dB

EVM: 2.89 % RMS
6.38 % Peak @ sym 70
Mag Err: 0.72 % RMS
-1.83 % Peak @ sym 17
Phase Err: 1.6 deg RMS
3.54 deg Peak @ sym 77
Rho: 0.9992
Length: 101 symbols
Freq Err: 2.4 MHz
Origin Offset: -48.74 dB

Figure 15. Demodulating a captured off-the-center hopped signal with view of the spectrogram (upper left), frequency versus amplitude (upper right), signal modulation quality (lower left) and constellation (lower right).



Frequency: 1.5 GHz
Span: 36 MHz
Input Att: 15 dB
Spectrum Length: 40 ms
Spectrum Interval: 5 ms
NBW: 58.109 Hz

Demod Type: FM
Audio LPF: C-Message
Audio HPF: None
De-emphasis: 750us
Harmonics #: 12

S/N : 73.52 dB
SINAD : 73.52 dB
THD : 0.0189 % -74.47 dB
TNHD : 0.0031 % -90.24 dB
Audio Freq : 999.258 Hz
Demod Type : FM
RMS Freq. Deviation : 800.39 Hz
+Peak : 1.15 kHz
-Peak : -1.14 kHz
Pk-Pk : 2.29 kHz
Pk-Pk/2 : 1.14 kHz

Figure 16. Designers can tailor the way SINAD is made by choosing the total number and threshold of distortion products to include in the measurement.

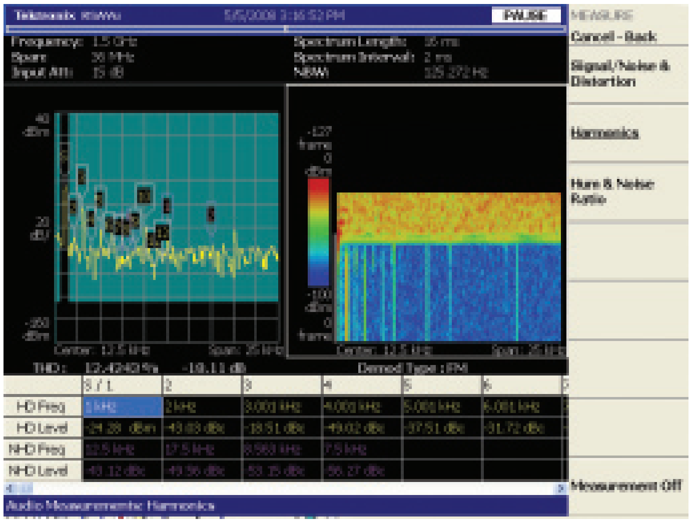
Modulation analysis of hopped signals

Modulation analysis of hopped signals across the full bandwidth requires an instrument that can not only trigger on and capture dynamic RF signals, but also has the capacity for carrier tracking vector analysis. Conventional vector signal analyzers (VSA) offer vector analysis for on-center frequencies, but only very limited analysis of signals that are off-center (i.e., 300 kHz or less). Most vector analyzers lack the carrier tracking capability to demodulate the hopped signals across the full captured bandwidth. Select RTSAs, such as the Tektronix RSA3000 series, are capable of demodulating hopped signals across the entire capture bandwidth. Engineers are able to verify and debug their designs without having to assume the modulation quality at any off-center frequencies. One can choose to demodulate any of the captured signal hops, viewing time-correlated measurements from multiple domains with detailed modulation quality analysis.

Receiver Sensitivity Measurements

SINAD

SINAD is perhaps the most popular sensitivity metric in receiver testing. SINAD can be described in general terms as the ratio of total signal energy to the energy contained in the noise and distortion components of the signal. Reference sensitivities of 10 or 12 dB SINAD are popular metrics with tactical radio manufacturers. These tests describe the level of sensitivity that results in good intelligibility of the transmitted signal. Besides reference sensitivity, SINAD is used as the basis for many other receiver measurements such as signal displacement bandwidth, adjacent channel rejection, offset channel selectivity and various rejection measurements. For each of these tests, SINAD is the fundamental metric for verifying design compliance. Though the RSA3000 performs SINAD automatically, the designer can tailor the way the measurement is performed by setting the total number of harmonics and the threshold levels to include in the measurement. Such flexibility allows the designer to match the requirements of the test specification, as well as, consider “what if” scenarios in the design process.



Frequency: 1.5 GHz
Span: 36 MHz
Input Att: 15 dB
Spectrum Length: 36 ms
Spectrum Interval: 2 ms
NBW: 125.272 Hz

THD: 12.4240 % -18.11 dB
Demod Type : FM

	S / 1	2	3	4	5	6
HD Freq	1 kHz	2 kHz	3.001 kHz	4.001 kHz	5.001 kHz	6.001 kHz
HD Level	-24.28 dBm	-43.03 dBc	-18.51 dBc	-49.02 dBc	-37.51 dBc	-31.72 dBc
NHD Freq	12.5 kHz	17.5 kHz	8.583 kHz	7.5 kHz		
NHD Level	-40.12 dBc	-49.56 dBc	-53.35 dBc	-56.27 dBc		

Figure 17. Harmonic and non-harmonic components are automatically tabulated for every frame in the acquisition.

Direct audio analysis

The RSA3000 real-time analyzer with its frequency coverage down to DC makes it suitable for direct audio analysis. Understanding SINAD and THD at baseband frequencies are simple one-button operations that help the user understand audio amplifier performance in man-pack and base station radios that use discrete audio components prior to the speaker. Perhaps more insightful for the receiver designer is understanding which distortion components contribute most to the sensitivity metrics and how these components vary over time. Similar to transmitter measurements mentioned previously, the real-time analyzer's spectrum and spectrogram displays show the time-varying nature of the audio and the undesired components in one display. Correlated markers can be scrolled through the acquisition to understand how distortion changes over time.

In addition, signal harmonics and non-harmonics are automatically tabulated to show the user how distortion components compare numerically to the fundamental over time. A measurement table shows the frequencies and levels for each order of the harmonics and for the non-harmonics in descending order of amplitude, corresponding to the tag number indicated on the spectrum trace. The level is indicated by absolute amplitude (dBm) only for the fundamental signal (S) and by relative amplitude to the fundamental wave (dBc) for the others. Users can scroll through the spectrogram and observe how distortion relates to the fundamental. Automatic tabulation can be helpful to further speed the task of compliance or for additional post processing as the table can be exported.

Because audio tests are made in non-50 ohm environments, the spectrum analyzer needs to accommodate high-impedance probes to prevent loading the measurement. Equally important is that the probe accommodates the voltage swing present in the measurement. Simple passive probes can often suffice as they provide an input impedance of 1k ohm or more to prevent loading the measurement while accommodating ten's of volts at the probe input. FET probes tend to have limited value since their maximum voltage rating is often too low for the required measurement and their bandwidth too high to be of any practical value. Using a FET probe with 2 or 3 GHz of bandwidth often results in the user measuring the sensitivity of the probe and not the receiver under test.

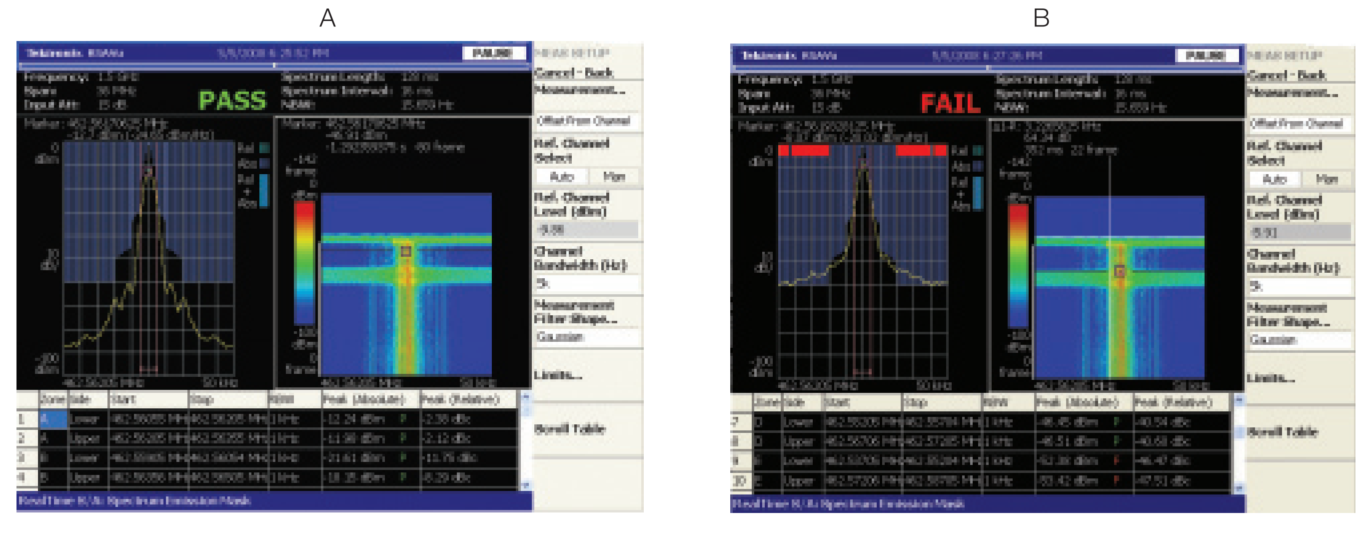


Figure 18. Real-time spectrum emission mask testing allows the designer to understand radio compliance during all radio modes, including transmitter turn-on. This transmitter passes the mask test in steady state operation (a) but non-compliance can be seen at transmitter turn-on and 352 ms after turn-on (b).

Spectrum Emission Mask Testing

Tactical radios, whether civilian or military, are required to meet spectral emission masks prior to deployment per each region's regulatory agency. Spectrum masks are typically defined to measure in-channel and out-of-channel emissions. Critical for these tests are the ability to define the measurement bandwidth for each segment, as well as, pass-fail evaluation for each defined segment in the mask. The TektronixRSA3000 offers spectrum emission masks to help the designer understand problem areas in their designs prior to formal regulatory testing. While the RTSA can perform spectrum emission mask tests similar to a traditional spectrum analyzer, it is perhaps more insightful for the designer to use real-time mask testing to show the time-varying nature of the spectral emissions from a seamless acquisition. Where traditional mask tests are useful to understand a radio's steady-state performance, the RTSA can help the designer evaluate spectral emissions during transmitter turn-on or mode changes in the SDR. Users can scroll through the time record in the spectrogram display to identify non-compliant behavior. Mask testing that requires measurements relative to an unmodulated carrier can also be made with the RTSA.

Summary

Software defined radios which integrate legacy and modern modulation schemes present unprecedented test challenges that conventional test instruments are unable to perform. Those that employ frequency hopping techniques complicate the design and validation tasks even further. These radios require a new, flexible, integrated approach to SDR subsystem and system validation. Tektronix Real-Time Spectrum Analyzers (RTSAs) deliver an all-in-one solution to improve the designer's time-to-insight and lower the manufacturers cost of test. Tools such as Digital Phosphor Technology (DPX), time-correlated measurements in multiple domains, Frequency Mask Trigger (FMT), audio distortion measurements, inclusion of modern modulation formats for tactical radios, baseband IQ measurements and off-center hopped signal demodulation are just some of the capabilities integrated in the modern RTSA. Working alone or in concert with other Tektronix test equipment, Tektronix RTSAs represent the most effective test solution for modern civil and military radio communication design, in-lab RF debug and in-field system evaluation.

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