Software Defined Radios Require a Thorough Trouble-shooting Strategy

The added complexity of SDR design introduces a host of new problems not present in traditional wireless design.

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More than ever, radio frequency (RF) technologies are being developed for adaptation &#151 adaptation to a crowded RF spectrum, adaptation to varying network conditions and adaptation to changing device usage. Nowhere is this more evident than with Software Defined Radios (SDRs), which enable software to dynamically control communications parameters such as the frequency band used, modulation type, data rates and frequency hopping schemes.

SDR delivers more flexibility than conventional RF technologies, and allows efficient device reconfiguration in response to changing environments. Software Radios, however, introduce a host of new problems not present in traditional wireless designs. One of the most significant challenges at the physical layer is that the hardware in a robust SDR design requires extensive agility and performance over a wide range of operation. SDRs are now being used in a number of areas including 3G wireless base stations and user equipment, military radios (like Joint Tactical Radio Service in the US military), land mobile radio (like Project 25 in the US and Project MESA in Europe), and in satellite transceivers.

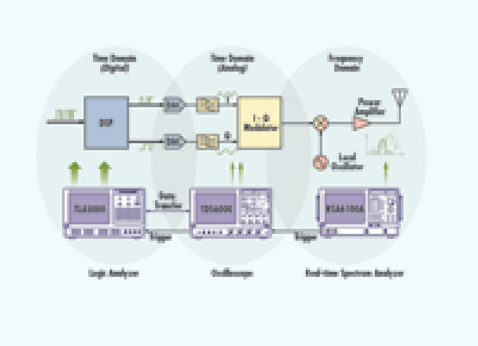

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Figure 1: Functional block diagram of a typical SDR transmitter implementation and testing setup.

This level of flexibility and the many possible radio variants complicate SDR design and mandate new testing methodologies. In addition to the ability to change frequency, more advanced SDRs allow control of modulation rates, frequency hopping sequences, power levels, coding schemes and channel filtering. The dynamic generation of RF waveforms through digital signal processing (DSP) and the integration of digital and RF circuits, often on the same IC, also create issues not seen in traditional RF transceiver designs with dedicated operation.

This added complexity also changes the nature of RF testing. The performance of SDR transmitters must be verified with measurements beyond the traditional RF transmitter conformance tests. Simply passing conformance testing does not ensure a device will work properly nor does it ensure product quality. SDR transmitters must conform to the requirements of many systems, including ones foreseen as future requirements. These transmitters can make use of cognitive intelligence and dynamically adapt to current conditions and requirements. These complex software-controlled changes commonly cause glitches, intermittent interference, pulse aberrations, digital to RF couplings and software-dependent phase errors.

Truly addressing these new transients and problems requires SDR system designers to fully analyze and characterize their system *simultaneously in both the time and frequency domains.* As system parameters change over time, anomalous signal events and non-linear device behavior can be readily discovered with Digital Phosphor Spectrum, DPX&#153, showing a life RF signal representation. Performing frequency selective triggering is necessary to pinpoint the instant a transient event occurs. 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. These advanced troubleshooting methods combined with traditional static conformance tests are important for thorough SDR testing.

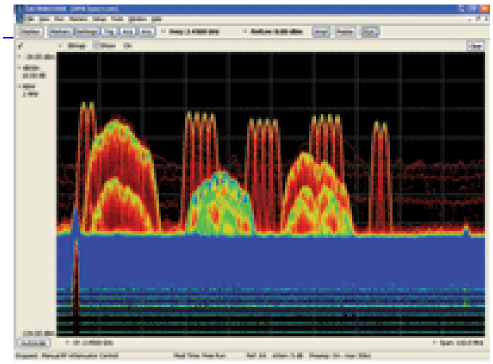

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Figure 2: Digital phosphor display of a 110 MHz span showing the 2.4 GHz ISM band. The signal here was similar to what was shown in Figure 2. Now depicted with a digital phosphor and a Max Hold trace, a live RF representation of the true signal behavior can be seen.

Transceiver Testing

Using a SDR Transceiver as an example, transmit components might include power amplifiers, filters, mixers, DACs, oscillators and 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.

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 triggered by the Frequency Mask Trigger (FMT) using a Real-Time Signal Analyzer (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, RTSAs 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. For frequency hopping systems, there can be both frequency and time domain specifications related to the hopping PLL system. Unlike a conventional transceiver, the SDR device must pass these tests under a much wider variety of operating modes.

Modulation quality measurements are also a significant element 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 analog modulation conformance tests. 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.

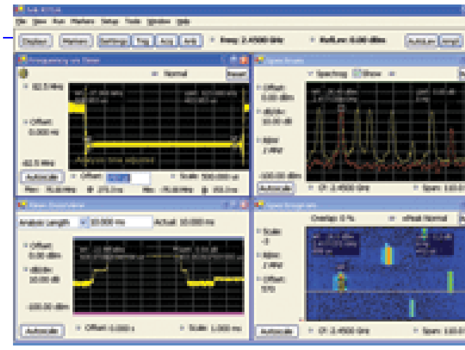

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Figure 3: Bluetooth hopping sequence, including (clockwise from the upper left) Frequency vs. Time, Spectrum with red Spectrogram Trace of a specific moment in time, Power vs. Time overview and Spectrogram of the 110 MHz hopping sequence.

Beyond conformance testing, a tool to help capture possible RF glitches, transients and other anomalies and device behavior changing over time is essential. Determining which component has caused the problem can be a significant task, and a thorough troubleshooting strategy is required. It is necessary to consider new testing methods that help characterize and analyze how the SDR RF links change over time.

Leading RTSAs offer powerful 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 today’s RTSAs give designers the ability to observe them in the frequency domain as they change over time. Using the RTSA to discover anomalous signal behavior, the user can trigger, capture and analyze the associated signals in multiple, time-correlated domains, allowing dynamic signal characterization and troubleshooting.

Frequency Hopping and Transmitter Testing

Frequency hopping is used in many systems, including those that are software defined, to avoid detection, jamming and interference and to improve performance in an environment with multi-path and fading. Frequency hopping spreads the information over a wide range of frequencies. This makes systems more robust because frequency dependent errors such as interference or fading result in loss of only a fraction of the data. With the addition of techniques such as forward error correction coding, interleaving, and retransmission with Hybrid ARQ, data lost during the jammed hop can then be efficiently recovered.

Figure 2 shows a digital phosphor display of a Bluetooth device hopping. Digital phosphor display technology, traditionally used in advanced oscilloscopes, has been applied to the RF domain and is now employed by select RTSAs. In allowing users for the first time to view “live RF” signals, digital phosphor technology provides excellent insight into RF signal behavior.

In Figure 3, a Bluetooth&reg signal is displayed. The RTSA’s spectrogram (lower right) shows the frequency behavior over time and the 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.

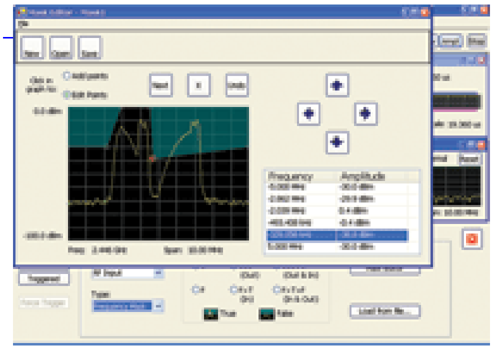

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Figure 4: The FMT can be drawn arbitrarily to capture frequency hopping events. In this example, a Bluetooth frequency hop can be triggered on consistently. This unique capability greatly assists in troubleshooting intermittent faults.

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 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. In the case of the 2.4 GHz ISM band, RTSAs that feature 110 MHz real-time bandwidth are sufficient.

In another example, shown in Figure 4, the RTSA is used to troubleshoot an infrequently occurring, difficult to detect signal. This could be the result of a frequency switching transient, which can also result in an even larger phase transient. This could be caused by improper control of a PLL circuit to change to a particular frequency. Once a glitch or transient has been identified using digital phosphor technology, the FMT of RTSAs 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 a Bluetooth frequency hop, the user is able to define the mask to trigger on a specific frequency hop, rather than the change in power level. The digital phosphor display demonstrates that the signal hops to roughly 3 MHz above the signal of interest. The frequency mask is arbitrarily defined as an envelope around this signal, and the instrument triggers once the signal enters the frequency mask area. Using a RTSA with 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 µsec spectrum timing resolution at 110 MHz real-time bandwidth using select RTSAs) for settling times as fast as 60 &#181sec.

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 digital phosphor 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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