Design and Test Challenges of Frequency-Hopping Radios

The erratic behaviour of frequency-hopped signals makes them difficult to capture, verify and measure. Hence more effective tools and processes are required to design and test modern radios that employ increasingly fast 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.

Several techniques are now being utilised to ensure efficient communications across the jam-packed radio spectrum. Chief among them are 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.

Military radio applications, which must perform in mission-critical environments where malicious signal jamming is common, frequently employ SDR technologies. They can be found in a wide range of footprints, from compact, portable units to vehicle-mounted and shipboard platforms. A number of commercial applications, such as wireless local-area networks (WLANs) and 3G-based cellular communications, have also surfaced recently that employ many of the SDR technologies first used by the defence electronics industry.

Despite the wide variety of SDR applications and footprints, one trait is common among them: frequency-hopping. Employed in analogue as well as digital radios, frequency hopping is used to improve performance, avoid detection and mitigate jamming and interference, such as multipath and fading.

Frequency hopping is utilised in conjunction with coding schemes, which improve the ability to recover from interference and fading, 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, designers 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 behaviour 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.

**Faster hopping leads to new design and test challenges**

Faster frequency hopping poses a number of challenges when designing communication systems, especially the system architecture and frequency synthesisers. Modern radios are complex systems, and the controlling software, digital signal processor (DSP) and...
system components all must work in concert to ensure optimal performance. Because software actively alters SDR 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 also common.

Designing fast frequency synthesizers presents a significant challenge as well. For example, a joint tactical information distribution system (JTIDS) deployed by the US armed forces working in an L-Band TDMA network 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 26μs time; 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 centre frequency of their modulation analyser. However, conventional test equipment are not capable of demodulating today’s wide-band hopped signals. Because these signals hop over the band of operation, analyses of off-centre frequencies are required to ensure optimal 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. These include modulation transients, non-linear effects of amplifiers, and digital-to-RF crosstalk, to name a few.

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 bits to continuously variable analogue 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 analysers 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 its domain (logic analysers for digital triggers, oscilloscopes for time-domain amplitude triggers and spectrum analysers for frequency-domain triggers).

An integrated, end-to-end test system comprising real-time spectrum analyser (RTSA), arbitrary waveform generator, oscilloscope and logic analyser can be invaluable for testing SDRs. Select instruments from leading test and measurement vendors are able to work in unison—with cross-triggering and time-correlated subsystem views—to verify SDR per-
formance and perform multiple test procedures at the physical and various software layers. These test systems can also be used to understand the complex interactions between SDR subsystems in the frequency and time domains, especially in bursted or frequency-hopping 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, RT&SAs 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. The acquired signals are presented in a time-correlated fashion, helping designers see how anomalies in the digital and analogue blocks of an SDR will propagate to the RF output as impulse noise.

The unique ability of these RT&SAs 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 analyser can capture the digital baseband signal and compare it to the symbol table produced by the RTSA. Furthermore, some RT&SAs offer offline software that can be used to analyse acquired data from the logic analyser and oscilloscope, allowing hardware and software measurement correlation.

**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 analysers were able to test IQ signals directly, and fewer spectrum analysers could test the baseband IQ signals with DC offset. Engineers have been forced to use oscilloscopes with additional software for post analysis.

Select RT&SAs enable baseband IQ testing using differential inputs. Doing so delivers measurement consistency when analysing IQ, IF and RF signals. Testing IQ signals with an RTSA also reduces system complexity and simplifies testing procedures, while offering higher dynamic range and greater memory depth than general-purpose instruments.

Modern RT&SAs bring baseband, RF and post-analysis functionality together. For example, pre-eminent RT&SAs can perform DC baseband measurements with 14-bit analogue-to-digital conversion (ADC), ensuring measurement accuracy. Some also possess 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 set. In addition to EVM, these RT&SAs provide fully time-correlated measurements across multiple domains (time domain, frequency domain, modulation domain and constellation). This capability can be invaluable for troubleshooting frequency-hopping SDRs.

**Frequency settling time measurements for 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 optimal synthesiser operation and maximises 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.

Leading RT&SAs offer 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 do-
main, a few RTSAs are able to produce a live RF view of the spectrum and provide a frequency mask trigger (FMT). These unique features simplify the troubleshooting of frequency-hopping signals.

A live RF view gives engineers a tool to instantly discover problems. In allowing users to view the actual signals for the first time, the latest RTSAs provide unmatched insight into RF signal behaviour. With spectrum updates that are at least 500 times faster than swept spectrum analysers, transient changes in frequency can be seen directly on the display. In the realm of SDR, this capability 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 a live, real-time view, the 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.

The combination of a live RF spectrum view and frequency triggering provides designers with a unique ability to find and troubleshoot problems frequently encountered with SDRs and the digital RF environment.

**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 analysers (VSAs) offer vector analysis for on-centre frequencies, but only very limited analysis of signals that are off-centre (i.e., 300 kHz or less). Most vector analysers lack the carrier tracking capability to demodulate the hopped signals across the full captured bandwidth.

Some RTSAs 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-centre frequency. One can choose to demodulate any of the captured signal hops, viewing time-correlated measurements from multiple domains with detailed modulation quality analysis.

Despite their ability to improve SDR performance, frequency-hopping techniques present unprecedented design and test challenges that conventional test instruments are unable to address. These radios require a new, flexible, integrated approach to SDR subsystem and system validation.

Leading-edge RTSAs deliver time-correlated measurements in multiple domains and the ability to see a live view of the RF spectrum. In addition, they provide an FMT, baseband IQ measurements and off-centre hopped signal demodulation. These capabilities simplify the testing and analysis of frequency-hopping radios, which are common in today’s digital RF world. Working alone or in concert with other sophisticated test equipment, advanced RTSAs represent the most effective test solution for modern radio communication design, in-lab RF debug and in-field system evaluation.

The author is country marketing manager at Tektronix India