Application Note

Understanding SDRs and their RF Test Requirements

Signature™ MS2781B High Performance Signal Analyzer

Evaluating the analog front-end radio portion of an SDR requires test equipment that is as flexible, programmable, and wideband as the radio.

Evaluating tactical software-defined radios (SDRs) poses no small challenges for test engineers. Even in just considering the analog hardware attributes of these radios, a test engineer is faced with enough bandwidth for multiple communications standards, the capability of transmitting and receiving signals at high data rates, and the capability for simultaneous operation of multiple radio channels. Even ignoring spread-spectrum operation, such as frequency-hopped signals, the analog portion of these radios resembles multiple radios and requires special test needs.

An SDR is not unlike a personal computer, wherein the function of the computer is defined by its software. In the same way, the functionality of the radio is defined by software loaded into the radio. The hardware must be relatively generic but extremely broadband, with the software controlling frequency, modulation, channel bandwidth, security functions, and waveform requirements. Although the concept of an SDR was developed by the military to meet the requirements for reliable and secure communications across different branches of the armed forces, there is increasing interest in the technology for commercial applications. FlexRadio Systems (www.flex-radio.com), for example, currently manufactures the SDR-1000, a commercial SDR for use by amateur radio operators. It incorporates a direct-digital synthesizer (DDS) for frequency agility and waveform flexibility from 12 kHz to 60 MHz.

For the purpose of this application note, however, the focus will be on tactical SDRs for military use. The United States Department of Defense (DoD) is driving the development of SDR technology through its $1 billion Joint Tactical Radio System (JTRS) program. The goal of the program is to replace traditional hardware radios with units covering 2 MHz to 2 GHz and beyond that can emulate any radio by changing software. Software upgrades sent via wireless networks will keep fielded JTRS devices current and compatible. In addition to the US DoD, most European defense agencies have SDR development programs similar to the JTRS program. Most development programs specify SDRs in a wide range of footprints, from compact, manportable units to vehicle-mounted and shipboard platforms.

According to the SDR Forum (www.sdrforum.org), an industry group organized to foster and standardize SDR technology, SDRs are "radios that provide software control of a variety of modulation techniques, wide-band or narrow-band operation, communications security functions such as hopping, and waveform requirements of current and evolving standards over a broad frequency range."

In the military, SDR applications are emerging rapidly as the technology advances to enable their effective use. SDR solves the existing incompatibilities between the command and control radio systems of the various branches of the armed services as well as with the communications systems of allied and coalition forces, enabling all units to work together as a single team. Future SDRs will seamlessly operate with the latest single-channel ground and airborne radio system (SINCGARS) units, for example.

The SDR Forum requires an SDR to provide software control of a variety of modulation techniques, wideband or narrowband operation, communications security functions (such as frequency hopping and encryption), and waveform requirements for current and evolving standards. The SDR should be able to store a large number of waveforms and add new ones via software download.

Current Radios

Current multiband tactical radios operate from 2 to 512 MHz. SDRs will cover that range and more, with current SDR designs extending from 2 MHz to 2 GHz and beyond to handle high-data-rate waveforms. The tactical radios that SDRs emulate, of course, differ widely in design and operating characteristics. The high-frequency (HF) spectrum from 1.6 to 30.0 MHz is still one of the most widely used communications bands, with HF radios developed for tactical (short-range) and strategic (long-range) communications in World War II. But large power amplifiers, antennas, and robust antenna matching circuitry are needed for long-range communications, and such components are not well suited to extended battery life. As a compromise, HF tactical radios often provide medium-range communications when operating from a battery pack and longer-range communications when connected to a vehicular power supply (Figure. 1).

Figure 1. HF tactical radios provide long-range communications capabilities using frequencies from 1.6 to 30 MHz. (Photo courtesy of Harris Corp.)

Due to signal congestion in the over-crowded HF band, HF radios must often compete with interference from other transmitters. To combat interfering signals, HF radio front ends are usually designed with high intercept points and employ sharp cutoff filters to eliminate unwanted signals. Documentation such as MIL-STD-188-141B4 clearly defines the performance requirements of a tactical HF radio. Information bandwidths are limited, often only 3 kHz wide, requiring stable frequency synthesizers in the radio's front-end circuitry along with narrow intermediate-frequency (IF) filters so that transmitted signals do not spill into adjacent bands.

As frequencies increase (and wavelengths diminish), the range of tactical radios decreases but so also does the size of the antenna, the transmit amplifier, and the impedance-matching circuitry for very-high-frequency (VHF) radios in the range 30 to 225 MHz. Suitable for medium propagation distances, VHF radios have wider channels and IFs (to 25 kHz) than HF radios in order to support higher data rates. For VHF radios, frequency congestion and the co-location of interference signals are similar to the problems faced by HF radios, requiring stable front-end frequency synthesizers and tight filters. To maintain data integrity, VHF radios require extremely linear amplifiers for transmission, although the inefficiencies of Class A amplifiers result in shortened battery life.

Moving up in frequency, ultrahigh-frequency (UHF) radios span 225 to 512 MHz as part of both terrestrial line-of-sight (LOS) links and satellite-communication (satcom) systems. To use smaller antennas in tactical designs, UHF radios require relatively high-power transmit amplifiers and low-noise amplifiers (LNAs) prior to the receive electronics. Guidelines for these requirements are listed in MIL-STD-188-181B. Often, directional antennas are employed with UHF radios to increase system gain and data rates on both receive and transmit links. For high data throughput, UHF radio hardware must provide fast transmit-to-receive switching and fast frequency hop rates, requiring the use of agile frequency synthesizers such as direct-digital-synthesizer (DDS) sources. Often the choice of radio synthesizer is a tradeoff between switching speed and phase noise.

Software Solution

These three types of radio, along with coverage of higher frequencies, are encompassed in an SDR. While current hardware SDR designs vary (covering the entire 2 to 2000 MHz band continuously or splitting the band into two switched segments, for example), the software portion of the radio is clearly defined by the Software Communications Architecture (SCA).
In an SDR, the software defines radio operation from the physical layer through higher-level protocol layers. The SCA is an open-architecture framework that aims for the portability, reusability, and scalability of the software and hardware developed under its guidelines to ensure that radios and software from one vendor work with the hardware and software from another vendor.

The SCA was promoted during the development of the JTRS program, and has been adopted by the US military as the standard software radio architecture for military communications systems. The SCA will likely be the guiding force for compatibility in commercial SDR designs as well. For example, the SCA now forms the basis of the SDR Forum's Software Radio Architecture (SRA).

The current SCA specification includes two methods for communications between SDR modules: using the middleware Common Object Request Broker Architecture (CORBA) and the Hardware Abstraction Layer (HAL) for high-demand communications between embedded hardware. CORBA interfaces are defined using Interface Definition Language (IDL) code, which is programming language independent and can be compiled into programming languages such as C++.
The SCA ultimately provides an Operating Environment (OE) for the SDR system. The OE combines the set of Core Framework (CF) services, interfaces, board support packages, operating system, and middleware services to host an SCA application. A typical SDR waveform includes all radio functions from the user input to the RF output: the combination of components, interconnections, and software needed to make the SDR behave in a certain way.

An ideal SDR receiver would digitize signals from the antenna so that received information spends the majority of its time in the digital realm. But current analog-to-digital converter (ADC) technology lacks the combination of bandwidth and bit resolution needed for this "direct-to-digital" receiver architecture. As a result, the analog front ends of SDRs still resemble the superheterodyne architectures of their analog HF, VHF, and UHF counterparts, albeit with the possibility of all three bands being handled by a single set of components (Figure 2).

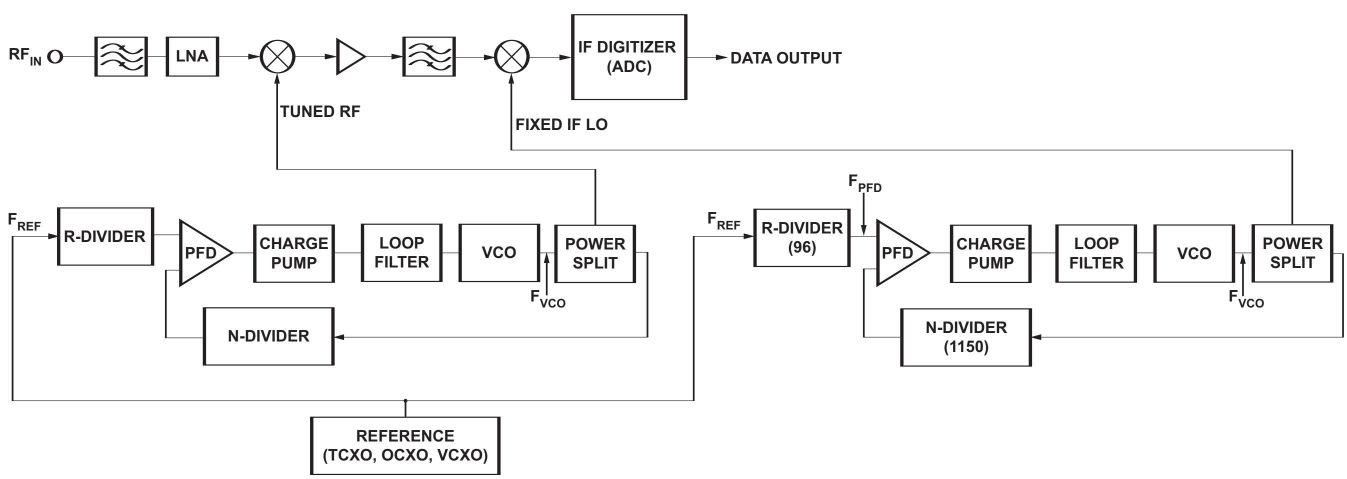

Figure 2. Although an SDR is controlled and configured by software, it relies on a traditional analog transceiver architecture to receiver and transmit analog signals.

Analog signals are downconverted in frequency in an SDR's receiver front end, then converted to a digital IF via an ADC. Switchable analog filters select a desired radio channel, but filtering and signal processing at IF and baseband are implemented by means of digital signal processing (DSP) and sharply defined digital filters to remove images and interference. In the transmitter, digital baseband/IF signals are converted to the analog realm by means of digital-to-analog converters (DACs) and subsequently translated to the desired transmit frequencies by means of analog frequency upconverters.

Sample SDRs

One of the best known of SDR suppliers to both military and civilian customers is the RF Communications Division of Harris Corporation (www.harris.com). Harris, selected by the DoD's JTRS Joint Program Office for the Step 2B validation of the JTRS platform and the SCA specification for battery-powered, manportable SDR platforms, has leveraged its FALCON II AN/PRC-117F radio to create the JTRS prototype. Having successfully demonstrated voice and data waveforms in 2001, Harris has been extensively involved in the development of SDRs and the evolution of the SCA standard. Among its SDR waveforms, Harris has developed 28 Mb/s offset quadrature phase-shift-keying (OQPSK), 60 Mb/s OQPSK, and 274-OQPSK configurations. These custom waveforms, of course, exceed the performance of standard Falcon II radios which provide bits rates to 64 kb/s in AN/PRC-117F(C) configuration.

The company's single-channel RF-300M-HH JTRS SCA-enabled hand-held radio (Figure 3) is programmable with a variety of platforms including SINCGARS, HAVEQUICK II, VHF/UHF AM and FM waveforms. A future optional software upgrade will provide APCO 25 Land Mobile Radio support for interoperability with civil authorities. The RF-300M-HH is fully compliant with JTRS and covers 30 to 512 MHz and provides an adjustable transmit power to 5 W. It can also be optionally equipped with a built-in Global Positioning System (GPS) receiver.


Figure 3. The single-channel RF-300M-HH JTRS SCA-enabled hand-held radio operates from 30 to 512 MHz and supports a variety of existing radio platforms including SINCGARS and HAVEQUICK II radios. (Photo courtesy of Harris Corp.)

Spectrum Signal Processing (www.spectrumsignal.com) offers a leading SDR development platform, the SDR-3000 Military Communications Rapid Prototyping Development Platform (MRDP). The platform consists of three main elements: an RF transceiver subsystem, a signal-processing section, and an SCA software environment. The RF transceiver consists of CompactPCI cards from Digital Receiver Technology (www.drti.com) that receive signals from 0.5 MHz to 3 GHz and convert these to digital IF bandwidths as wide as 30 MHz, and also generate analog transmit signals from 40 MHz to 2.9 GHz based on digital IFs as wide as 16 MHz. The transceiver platform also uses GPS as an absolute time reference, and performs slow and fast frequency hopping at rates to 5000 hops/s when triggered with external sources.

Test Challenges

The modular architecture of the SDR-3000 offers insight into test needs for the analog front-end circuitry. Although future SDR designs may cover even greater frequency ranges, this platform's receiver spans almost 3 GHz with modulation bandwidths as wide as 30 MHz. Within that spectrum, the possible combinations are endless. An ideal test solution would perform measurements on every possible SDR hardware/software combination or waveform. In reality, such a solution would require the test equipment manufacturer to program instrumentation for as many as 30 or more SDR waveforms (hardware/software combinations), in some cases based on modulation formats not yet created. Test equipment suppliers would need a crystal ball to properly prepare for SDR front-end testing. In addition, it is usually not sufficient to simply test a simple waveform, such as FM, as this almost never will exercise the radio hardware over its full capabilities. For example, the peak-to-average of an FM signal is very low, so it will not show clipping problems in power amplifiers.

A more practical solution to SDR front-end testing is to focus on the radio's analog/RF characteristics, which effectively end at the ADCs and digital IFs. As seen from the SDR-3000 example, even this amount of testing is not trivial, since the SDR platform's receiver and transmitter encompass such wide instantaneous bandwidths over extremely wide frequency spans.

Testing an SDR platform such as the SDR-3000 requires both a test signal source and a wideband signal analyzer. Both instruments must provide enough frequency range (0.5 MHz to 3 GHz) to cover the radio's range, with adequate instantaneous bandwidth to handle the different SDR modulation formats.

The test signal source will be used to "exercise" an SDR's analog radio section. To do so, it must essentially emulate an SDR's transmitter, covering the full frequency range and controlling complex modulation formats, such as OQPSK. The test signal source should be able to switch signal formats quickly, under software control, in the manner of an SDR, and provide stable, low-phase-noise signals, good amplitude control, and relatively fast switching speed. It should provide programmable signal bandwidths, narrow enough to emulate the 3 kHz or less of HF radio channel bandwidth and wide enough to accommodate emerging high-data-rate, wide-channel radios operating in both terrestrial and satellite links.

The signal analyzer must provide the capability to evaluate an SDR's transmitted signals. As such, it should emulate an SDR's receiver, covering the frequency range and bandwidth of current radios but including extended range to include analysis of harmonic signals and future extensions. Unlike a spectrum analyzer that tunes across the spectrum with a relatively narrow analysis bandwidth (determined by the resolution-bandwidth filter), a signal analyzer appropriate for testing an SDR's transmitter must provide a wide instantaneous bandwidth in order to capture the full bandwidth of the transmitted channel and, ideally, any frequency-hopped signals when the SDR is operating in agile-frequency mode. For measurement flexibility, the analyzer should offer a variety of triggers, spectral masks, and cursor functions to isolate and identify desired and interference signals.

Hardware Test Solutions

An example of a solution for testing SDR front-end performance is the MG3700A Vector Signal Generator and the Signature High Performance Signal Analyzer from Anritsu Company (www.us.anritsu.com). The MG3700A Vector Signal Generator (Figure 4) is very much like the software-programmable transmitter portion of an SDR. The signal generator spans 250 kHz to 3 GHz (to 6 GHz as an option) with 0.01 Hz frequency resolution. It can generate channel bandwidths as wide as 120 MHz with its internal in-phase/quadrature (I/Q) modulator and as wide as 150 MHz using external I and Q modulation sources. Its internal modulation source is a 160-MSamples/s arbitrary waveform generator. Output levels can be set from –140 to +13 dBm with absolute level accuracy of ±0.5 dB. The frequency switching time ranges from 10 to 40 ms from a GPIB command to within ±0.1 PPM of a new frequency. In addition to its functions as a signal source, the MG3700A has a built-in bit-error-rate tester (BERT) with 20 Mb/s capability (an option extends this to 120 Mb/s) that can measure bit-error rates (BERs) from 0 to 1 percent.

Figure 4. The MG3700A Vector Signal Generator provides a wide modulation bandwidth from 250 kHz to 3 GHz (to 6 GHz as an option) with an internal arbitrary waveform generator to emulate the waveform flexibility of an SDR.

It is the MG3700A's waveform programmability that makes it suitable for SDR front-end testing. Since it can be programmed for existing and emerging waveforms, the generator can be programmed to emulate any form of waveform or pair of waveforms, given its dual waveform memory locations. Standard MG3700A generators are programmed more for commercial wireless communications testing than for tactical radio testing, and include waveforms for cellular wideband code division multiple access (WCDMA) signals, wireless local area network (WLAN) signals, multicarrier cable-television (CATV) signals, and options for TD-SCDMA and Public Radio System waveforms such as RCR STD-39 and ARIB STD-T61/T79/T86 waveforms. The signal generator is shipped with a useful Windows-based software program called IQproducer™ with an intuitive graphic user interface (GUI) to simplify the creation of the complex waveforms such as those found in tactical radios. In addition, operators can build even more-complex waveforms using software tools, such as MATLAB®, load the programs onto the MG3700A's hard disk, and import the code into the generator's waveform memory.

The MG3700A includes a 40-GB hard disk for mass storage and smaller amounts of waveform memory to directly "feed" the internal arbitrary waveform generator. The standard waveform memory can store 128 MSamples/channel across the two (I and Q) channels and is the largest size available in Vector Signal Generators today. As an option, this can be expanded to 256 MSamples/channel. In addition, the MG3700A provides two separate (A and B) waveform memory locations, so the total amount of waveform memory is actually 256 MSamples (standard) or 512 MSamples (option) when combining the channels and memory locations. The two memory locations can be used to generate simultaneous waveforms or complex signal formats containing desired signals with jamming or interference sources. The level, frequency, and timing of the two signals can also be easily offset to allow the creation of in channel or out-of-channel interfering signals. A sequence mode allows operators to create complex sequences of changing signals and waveforms and store the sequence in memory for future use.

Of course, such flexible signal generation would be meaningless without a means of evaluating an SDR's own generated waveforms. For that purpose, the Anritsu Signature™ MS2781A High Performance Signal Analyzer (Figure 5) can substitute as the receiver in an SDR. It covers a frequency range of 100 Hz to 8 GHz with low phase noise (–116 dBc/Hz offset 10 kHz from a 1 GHz signal) and high amplitude accuracy (0.65 dB over the full frequency range). Signature's dynamic range is well matched to the needs of SDR testing, with a third-order intercept of +22 dBm and displayed average noise level (DANL) of –167 dBm (0.1 Hz RBW) by virtue of its 14-bit ADCs. The analyzer features an instantaneous demodulation bandwidth of 8 MHz (30 MHz as an option) to scrutinize the widest transmitted SDR channels.

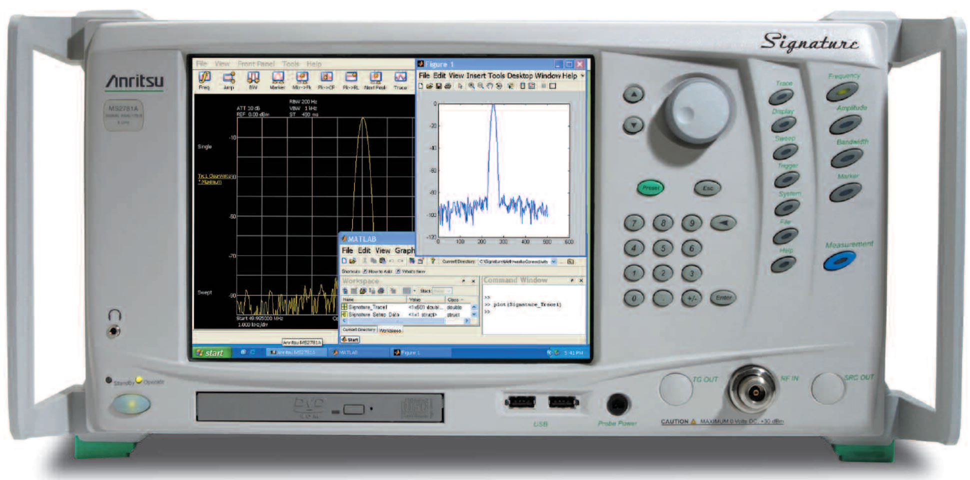

Figure 5. The Signature High Performance Signal Analyzer provides an optional instantaneous analysis bandwidth of 30 MHz from 100 Hz to 8 GHz and has the programmability to double as the receiver in an SDR.

As with the MG3700A, the Anritsu Signature High Performance Signal Analyzer is a blend of hardware and software that combine to achieve a set of measurement functions that emulate the performance of an SDR's receiver. Signature has a rich set of built-in RF measurements such as channel power, adjacent-channel power ratio (ACPR), and occupied bandwidth (OBW), as well as (optionally) modulation quality measurements for the QAM and PSK signals often found in tactical radios. Signature contains a full-featured personal computer (PC) with Windows XP Professional operating system. The embedded PC allows operators to install additional waveform analysis tools, such as MATLAB, for additional analysis power. Running MATLAB with Signature simplifies the analysis of many performance characteristics, such as frequency versus time, spectrograms (Figure 6), and unusual modulation types that can not be analyzed with traditional test equipment.

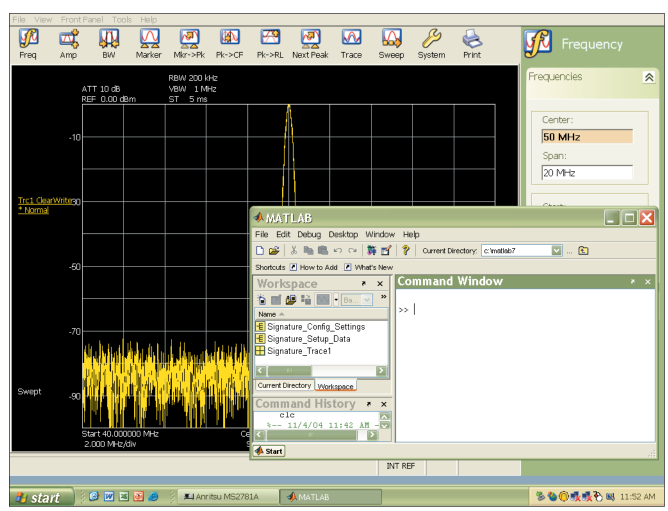

Figure 6. The Signature High Performance Signal Analyzer can be loaded with MATLAB analysis software for capturing and analyzing complex SDR transmitter characteristics.

In conclusion, test tools for SDR RF measurements should effectively emulate the behavior of the radio's receiver and transmitter sections with adequate frequency range, wide modulation and demodulation bandwidths, wide dynamic range, and excellent level accuracy to handle existing and emerging SDR designs. Although the most immediate needs for SDR testing lie in the tactical radio area, commercial SDRs are also being considered for next-generation wireless (3G and 4G) cellular standards. Given the need for interoperability in both military and civilian environments, SDRs offer practical and flexible radio solutions.

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