Complex UWB Signal Generation using Advanced Waveform Editing Tools

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Abstract

New RF transmission systems, like UBW-WiMedia, are proliferating. This is causing engineers to look for better ways to simulate intricate RF signal behaviors and interactions. At the same time, a push for higher data rates makes margin testing even more important. This article will discuss the challenges of generating UWB, and other digitally modulated signals, with Arbitrary Signal Generators (AWGs) and explore the various options design engineers have.

Introduction

As RF signals become more and more complex, it is necessary to utilize tools that enable RF engineers to synthesize these signals for development and conformance test use. However, as bandwidths widen and the physical layer (PHY) and Media Access Control (MAC) structure become more complex, synthesis becomes more difficult. Perhaps the most technically challenging signals today are the Ultra-Wide Bandwidth (UWB) signals. Let's look at both the UWB signal and the hardware/software tool set that can synthesize signals like this.

What is UWB?

Regulators, in the U. S., Canada and worldwide are approving unlicensed use of short range, low power, Ultra-Wide Band (UWB) RF devices in the 3.1GHz to 10.6GHz spectrum. The regulatory bodies have chosen to define UWB by its bandwidth-to-carrier frequency ratio rather than any specific modulation type. For instance, the U. S. standard states that a signal is UWB if it has a bandwidth greater than 20 percent of the carrier frequency, or is wider than 500 MHz.

Fractional bandwidth = $(f_H - f_L)/fc > 20\%$

Where:

f_H = the high edge of the signal
f_L = the low edge of the signal
fc = the center frequency of the signal

or where the total bandwidth is greater than 500 MHz.

Because of this ruling, there are several types of UWB applications in use today. Time-Hop UWB (TH-UWB) uses a series of very short impulses and selects a pseudo-random time position for each pulse. Direct Sequence UWB (DS-UWB) assigns positive or negative values to each bit, and pulse shapes the resultant signal for transmission. Multi-Band Orthogonal Frequency Division Multiplex (MB-OFDM) uses the massively parallel carrier structure of OFDM and further enhances that with optional frequency hopping. This is the modulation method chosen by the WiMedia group for short-range computer links such as wireless USB and the next generation Bluetooth signals.

The popularity of UWB technologies are growing because they have a number of advantages over other RF transmission methods, not the least of which are the higher data rates possible using UWB transmission methods. Other advantages include the potential for good immunity to both multi-path and single carrier interference. Although the RF spectrum is too crowded to dedicate bands to signals that have bandwidths measured in GHz, UWB can co-exist with existing users if the UWB signal has low power and limited range. These restrictions are not a hindrance for many short-range computer peripheral applications.

On the UWB transmit side, low power and limited range can make an effective UWB signal nearly invisible to existing spectrum users. In addition, some countries have a requirement for Detect and Avoid (DAA) technology, which allows UWB signals to avoid bands already in use. On the UWB receive side, the wide bandwidth tends to give immunity from single carrier interference. Developers may want to simulate multi-carrier interference scenarios. We will take a closer look at WiMedia's MB-OFDM to understand both the signal and simulation techniques.

WiMedia's® MB-OFDM

Current low cost OFDM modulators can only achieve a little over 500 MHz of modulated signal bandwidth. Using a simple frequency hop pattern over three bands, in conjunction with a conventional OFDM modulator, designers can create over 1.5 GHz of bandwidth. This allows further spreading of the conventional OFDM signal and makes it UWB for regulatory purposes.

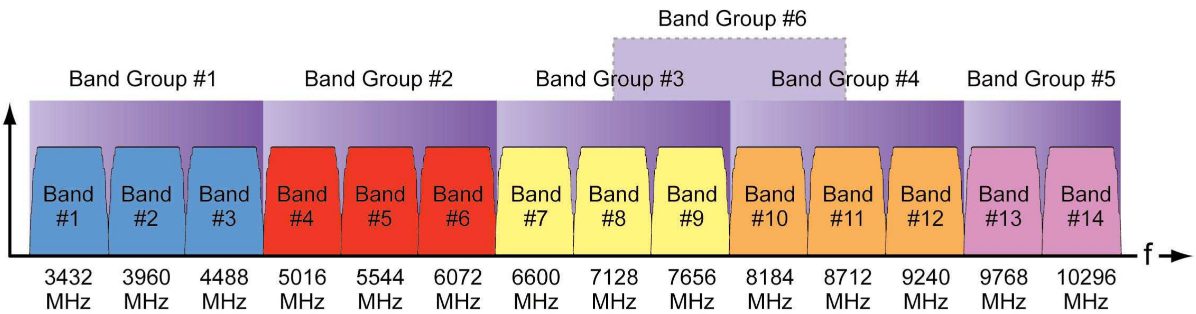

Figure 1. WiMedia® Band Groups.

The WiMedia specification divides the UWB frequency spectrum into band groups with included sub-bands. Each of the bands has a bandwidth of 528MHz. The physical layer uses 122 OFDM sub-carriers in each of the 528MHz bands.

Hardware for Synthesis of MB-OFDM Signals

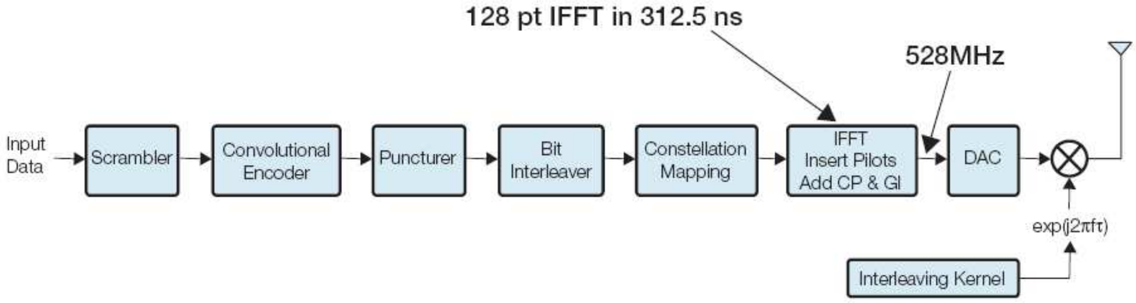

Figure 2. UWB-WiMedia® Tx Chain.

UWB signals, as the name implies, are very wide band. This makes signal generation a challenge, particularly when the signal generator needs to be flexible. Most common laboratory signal generators are capable of generating only a few tens or hundreds of megahertz (MHz) of bandwidth, which is far short of the bandwidth necessary for most UWB signals.

Different UWB modulation types require different signal synthesis techniques. Designers often create signals like TH-UWB and DS-UWB at baseband. Other signals like MB-OFDM are more typically upconverted to the appropriate RF band. Upconversion methods require less baseband bandwidth from the signal generator, but add the complexity of an external up-converter or modulator.

A simple solution is to use the UWB's own system software to generate test signals, but this approach is can have issues. The primary problem is that, early in the development cycle, the design may not be working properly, leading to potentially serious test issues. In addition, the radio system under development usually lacks the ability to add impairments and can be cumbersome to manipulate for test purposes.

A preferred approach is to use a known good Arbitrary Waveform Generator (AWG) with a software package that can reliably synthesize both general purpose and standards based signals, with or without impairments. This eliminates uncertainty with the test signal and provides an easy-to-use human interface, accelerating the design and debug process.

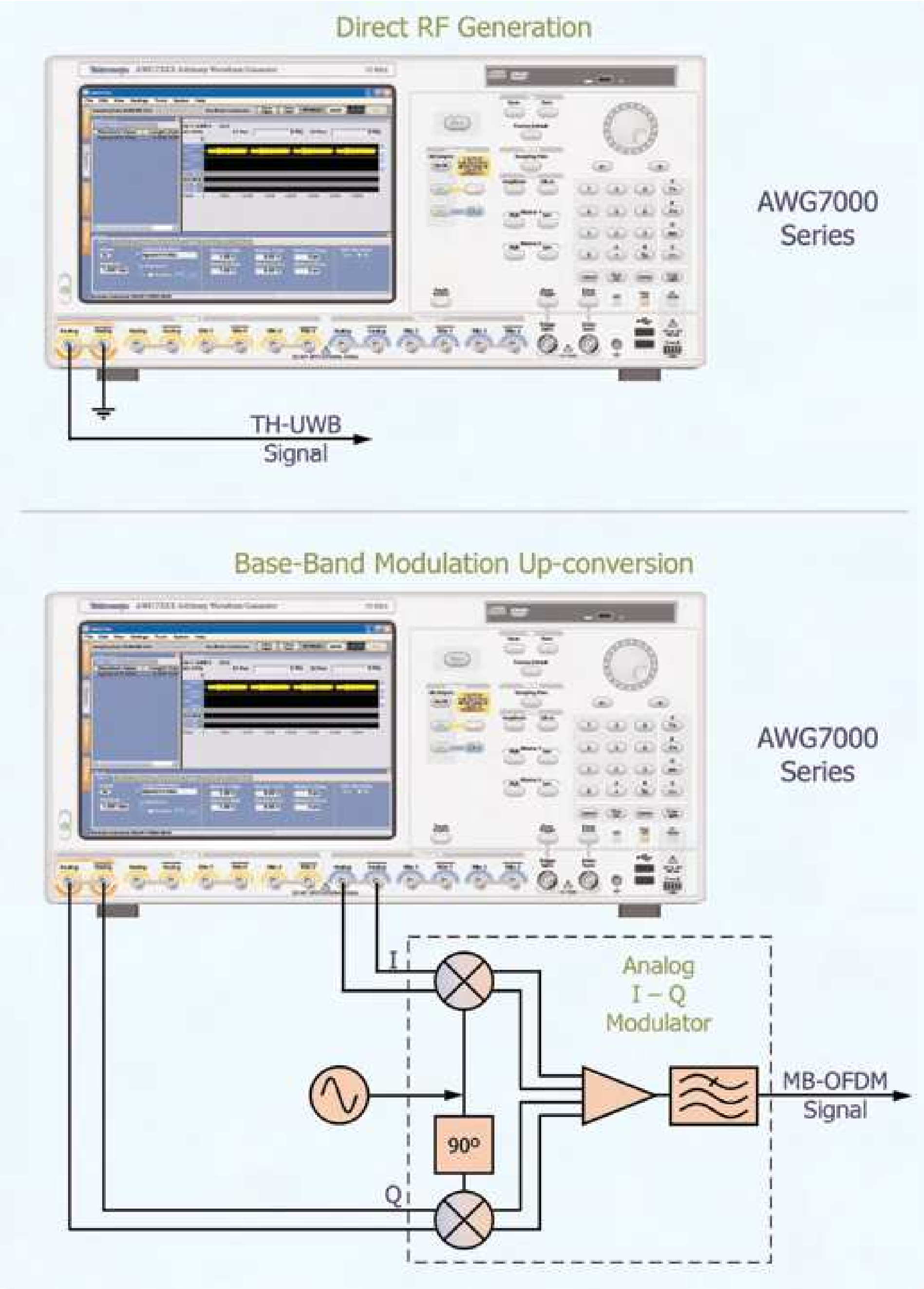

Figure 3. A modern AWG supports direct base-band and external I–Q modulator/upconverter UWB signal generation approaches.

A modern AWG can directly generate RF for BG1 and BG2 of the WiMedia MB-OFDM signals. Band Group #1 requires a minimum sampling rate of 10GS/s and analog bandwidth of 5GHz. Band Group #2 requires 15GS/s sampling speed and 7.5 GHz analog bandwidth. The speed and the analog bandwidth requirements for the AWG depend mainly on the specific band groups to be covered and not on the hopping nature of the final signal. The advantages of direct synthesis include no need for external devices and simpler calibration needs. It also provides direct base-band outputs, and even I-Q outputs for up-conversion needs as illustrated in figure 3. These outputs are available in differential form to allow a direct interface with popular balanced amplifier and mixer components and so offer the improved noise immunity of common mode rejection.

Software for Signal Synthesis

In the case of WiMedia MB-OFDM development and conformance testing, it is necessary to synthesize both the PHY layer and the MAC layer of the signal. This places unique demands on the signal-synthesizing tool. PC software is available for AWGs that make quick work of creating both general-purpose digitally modulated signals and the specific MB-OFDM signals needed for WiMedia development and conformance testing. Let's take a look at the requirements to better understand the demands on the signal syntheses tool.

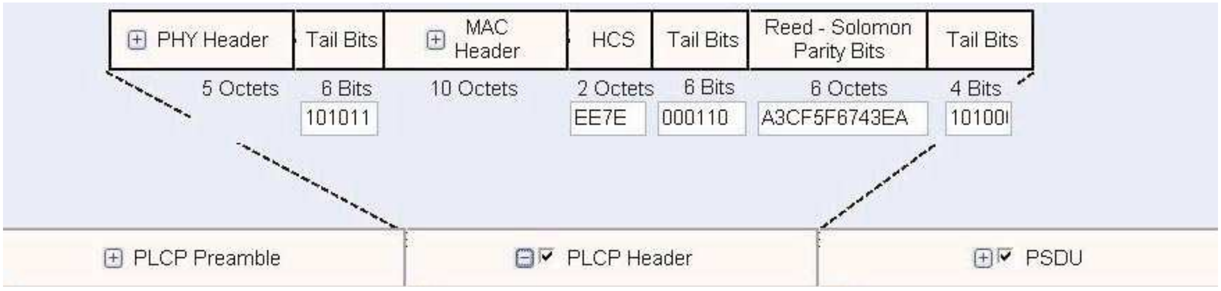

Figure 4. PPDU structure.

Figure 4 shows the format of the Physical Layer Convergence Protocol (PLCP) and the PLCP Protocol Data Unit (PPDU), which is composed of three major components:

- PLCP Preamble
- PLCP Header
- PSDU – PHY Service Data Unit

PLCP Preamble

The PLCP preamble is the first component of the PPDU and has a packet/frame synchronization sequence and a channel estimation sequence. The purpose of the PLCP preamble is to aid the receiver in timing synchronization, carrier-offset recovery and channel estimation.

There are two types of preamble: a standard PLCP preamble and a burst PLCP preamble. The burst preamble is only used in the streaming mode when a burst of packets is transmitted, separated by a Minimum Inter-Frame Separation (pMIFS) time.

PLCP Header

The PLCP header is the second major component of the PPDU. The goal of this component is to convey necessary information about both the PHY and the MAC to aid in decoding the PSDU at the receiver. The PLCP header is composed of a PHY header, MAC header, and Header Check Sequence (HCS), tail bits and Reed-Solomon parity bits, as well as tail bits at the end of the PLCP header to return the convolutional encoder to the zero state. The Reed-Solomon parity bits improve the robustness of the PLCP header.

PSDU

The PSDU is the last major component of PPDU. This component combines the frame payload with the frame check sequence (FCS), tail bits and the pad bits, which align the data stream on the boundary of the symbol interleaver.

Signal Synthesis and Margin Testing

Modern signal synthesis software allows for not only generating signals in the WiMedia conformance mode, but for developers, to customize the frame generation both in content and timing for all parts of the frame. This enables the characterization of the receiver beyond the boundary conditions set by the WiMedia protocol.

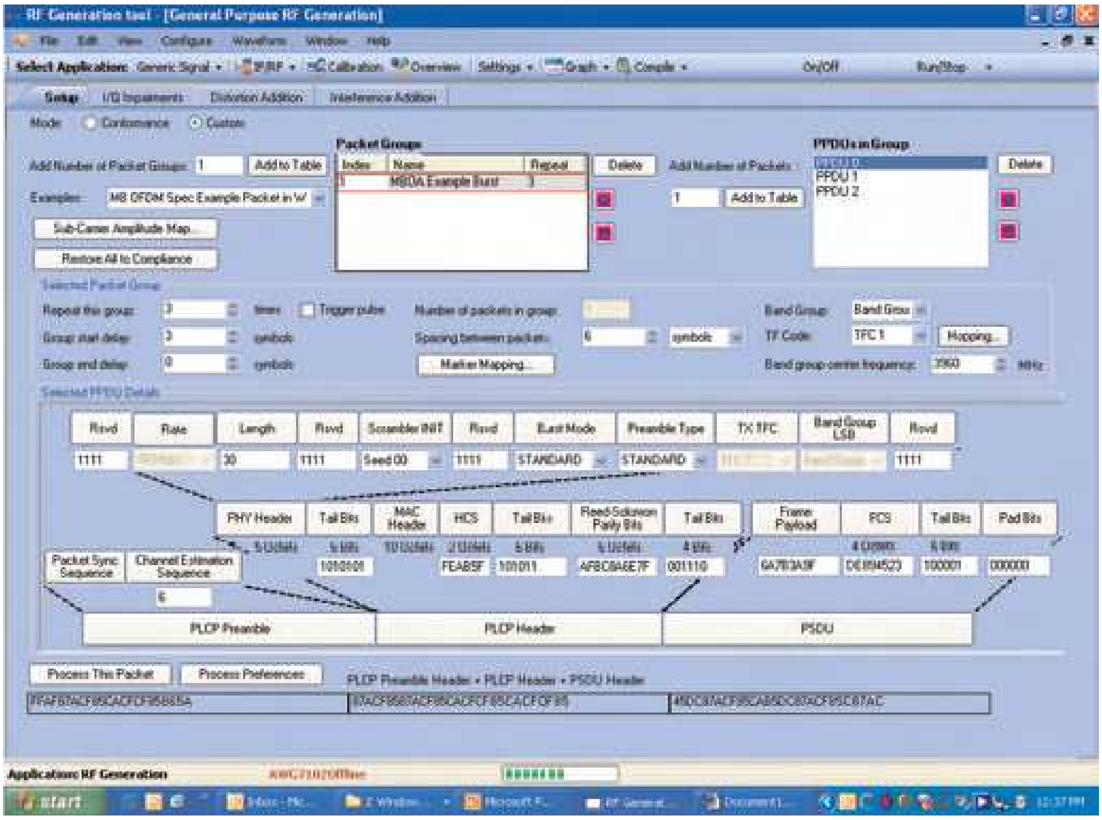

Figure 5. The RFXpress software package can synthesize WiMedia packet waveforms from the packet group level. It also provides general-purpose multi-channel modulation synthesis for UBW waveforms.

In the case of WiMedia MB-OFDM, signal synthesis software allows frame creation on a bit-by-bit basis. The software allows developers to choose the type of frame, data rates, length, modes, and even build custom Time Frequency Code (TFC) patterns. In addition, the timing of various parts of the frame is adjustable. This is essential for WiMedia conformance testing and helpful during development.

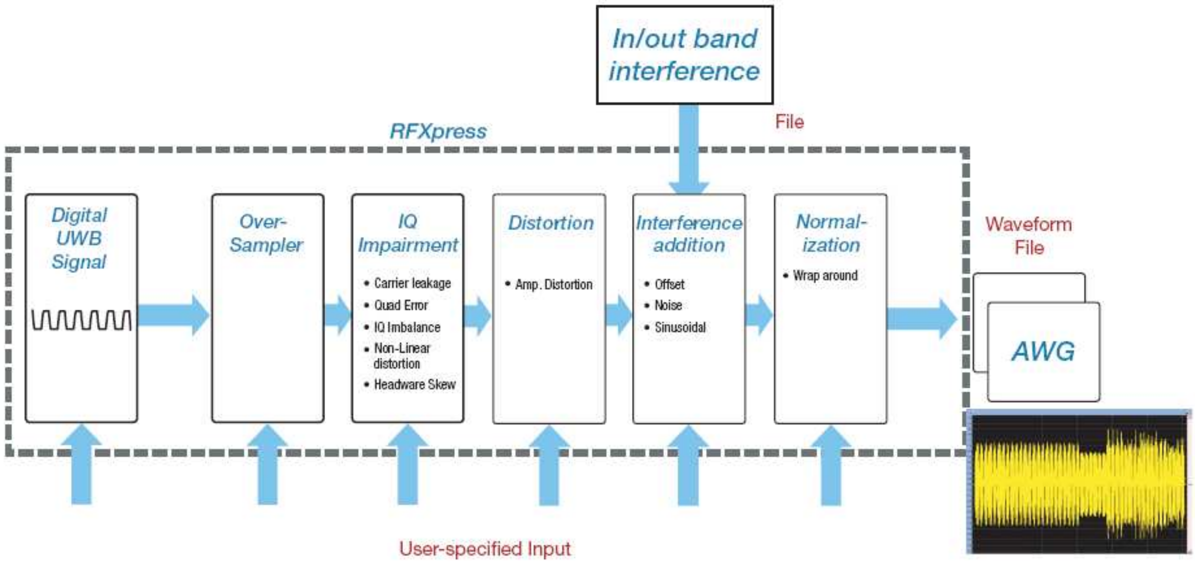

Figure 6. Signal synthesis software provides many different options for signal customization.

For both WiMedia and general-purpose digital modulations, it is important to be able to adjust the quality of the modulation. IQ impairments that can be easily generated with an AWG and signal synthesis software include carrier leakage, quadrature error, non-linear impairments (AM, FM, PM), IQ Imbalance, and IQ skew.

Often, only parts of the packet degrade during transmission. Signal synthesis software has the ability to add noise, at desired amplitudes, to a particular portion of the PPDU structure. For example, noise can be added to just the PLCP header and Payload.

Thorough receiver characterization is essential for robust designs. Custom frames, IQ impairments, and added noise are useful tools for receiver testing during development, allowing thorough margin testing. Full control of the contents of the frame may be essential during conformance testing. These adjustments allow designers to stress the receiver design thoroughly.

Interference

Experts have cited UWB interference susceptibility as a significant challenge, so let's take a closer look at this issue. The large bandwidth of a UWB signal naturally invites a wide range of potential narrow band interference sources. Both in-band and nearby out-of-band interference sources can cause problems.

UWB designs often lack the selectivity of sharp IF filters, necessitating even wider test bandwidths. Optimizing interference performance can be a particularly challenging issue as UWB links rarely have interference issues with just a single narrow-band interferer and require complex spectral test environments.

Simulating harsh interference-filled spectral environments that encompass large bandwidths can be expensive. The conventional approach of summing multiple signal sources together in order to generate a realistic interference environment typically requires a significant investment in signal sources.

A better approach to creating interference test signals is to use an AWG, with ultra wide bandwidth, and a signal-synthesizing program, to create an entire spectral environment with a single source.

There are two ways to make this happen. The first is to generate an array of narrowband spectral interferers, sum this array with a desired UWB signal, and play it all back with an AWG. Another way is to capture real environment signals with an oscilloscope for later replay with the AWG. Simply recalling the AWG setup files will produce the real environment signals. Either method allows reproducing interference signals at any site, at any time, with accuracy and precision. This makes it easy for designers to overcome interference challenges during the design cycle.

A single ultra-wideband AWG, the right software, and a high-speed oscilloscope can replace many expensive independent signal generators and is a much more cost effective and flexible solution to evaluate UWB interference susceptibility.

Tone Nulling

For UWB-WiMedia, there is a mechanism to avoid interference when UWB signals coexist with other transmitters, such as radios and radars. Detect And Avoid, or DAA, operation allows nulling of specific OFDM tones during transmission so they do not interfere with other users of the RF spectrum. It is desirable to see the impact tone nulling has on a receiver.

The most common tone-nulling example is removal of tones that overlap the radio astronomy band. The advantage of this technique is that the transmitter remains relatively simple. For example, to obtain a notch with a depth of 23 dB for the radio astronomy band, 29 tones need zeroing out. This corresponds to a total loss of 120MHz of bandwidth, something that UWB signals can accept.

Signal synthesis software tools not only allow the nulling of tones, but also allow the ability to create partially nulled tones. This enables the simulation of a real world scenario with the tone amplitudes at various levels for testing receivers.

Conformance Testing

Conformance testing is often rigorous and extensive. The WiMedia conformance test, for instance, has over 28 sections for checking proper assembly of frames. This requires a signal synthesis tool that allows easy modification of frame contents. Receiver testing is also essential. Constructing a test signal, with properly controlled margins and accurately controlled amplitude is essential for Bit Error Ratio (BER) tests. In some cases, the receiver must be able to demodulate a known bit pattern from the test signal and so needs to have MAC layer structures included.

Summary

With RF signals increasing in complexity, it is becoming more essential to utilize tools that help RF designers correctly synthesize these signals. A modern AWG is fully capable of creating digitally modulated signals. When combined with signal synthesizing software, creation of standard specific signals, such as a WiMedia MB-OFDM signal, is possible. This signal creation includes both the PHY layer and the MAC layer, and allows injection of signal impairments such as interference or modulation errors. When combined with a modern oscilloscope, also with signal specific software, a full radio development or conformance test system can be created for signals with up to 500 Mb/s data rates at 4x oversampling. With the proliferation of new applications that utilize wireless transmission and digital RF systems, engineers need faster and easier ways to create intricate RF signal behaviors and interactions. There are now new choices for generating general-purpose digital signals, including frequency hopping Ultra-Wideband (UWB) signals.

Author bio:
Darren McCarthy is a Technical Marketing Manager for RF Test at Tektronix. Darren has worked extensively in various Test and Measurement positions for the last 18 years including R&D engineer, R&D management, Product Planning, and Business Development. During his career, he has also represented the US on several IEC Technical Committees for international EMC standards. He holds a BSEE from Northwestern University in Evanston, Illinois.

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