Direct synthesis of WiMedia UWB signals

Although UWB promises high data rates, creating these signals in the lab and preserving their signal integrity is a highly complex process. One unique method of creating UWB-WiMedia signals uses an arbitrary waveform generator (AWG), yet retains the simplicity of using a dedicated UWB chipset. RF design engineers who use this unique method of AWG-based WiMedia signal generation will have several options, including IQ-baseband, IF and direct-RF-synthesis signal-generation techniques.

By Iqbal Bawa, K. A. Muralidharan and Joan Mercade

To provide high data rates, the Federal Communications Commission (FCC) in 2002 approved the unlicensed usage of UWB devices in the spectrum of 3.1 GHz to 10.6 GHz, provided that the bandwidth (BW) of the signal is greater than 25% of the carrier frequency (i.e., fractional bandwidth = (FH - FL)/FC > 25%, or the total BW > 1.5 GHz. One approach to this is the UWB-WiMedia protocol, which uses a multiband-OFDM technique. The WiMedia specification divides the UWB frequency spectrum into six band groups, with five different band groups (band groups 1 to 4 and band group 6) consisting of three frequency bands, and the sixth band group (band group 5) consisting of two frequency bands. Each of the frequency bands has a bandwidth of 528 MHz.

The physical layer uses OFDM technology with 122 tones in each of the 528 MHz bands. The OFDM packets are then spread using a time-frequency code (TFC). Two types of spreading are defined: one uses frequency hopping over the three bands and is referred to as time-frequency interleaving (TFI). The other is transmitted in a single band and is referred to as fixed-frequency interleaving (FFI). For band groups 1, 2, 3, 4 and 6, 10 different TFCs are defined, with seven TFIs and three FFIs. For band group 5, three FFIs are defined, thus bringing the total number of channels to 53.

The transmitter WiMedia RF signal is defined in eq. 1:

$$S_{RF}(t) = \mathrm{Re}\left\{ \sum_{n=0}^{N_{packet}-1} s_n(t - nT_{SYM}) \exp(j2\pi f_c(q(n))t), \right\} \quad \text{eq. 1}$$

Where Re{ . . .} represents the real part of the signal. T_{SYM} is the symbol length, N_{packet} is the number of symbols in the packet, $f_c(m)$ is the center frequency for the mth frequency band, q(n) is a function that maps the nth symbol to the appropriate frequency band, and $s_n(t)$ is the complex baseband signal representation for the nth symbol, which must satisfy the following property: $s_n(t) = 0$ for $t < 0$, and $t \geq T_{SYM}$. The exact structure of the nth symbol depends on its location within the packet.

Unique logical channels are defined by using up to 10 different TFC codes for each band group. TFCs and the associated base sequences for band group 1 are shown in Table 1. A symbolic representation of band hopping among three bands, as defined by TFC 1, is shown in Figure 1.

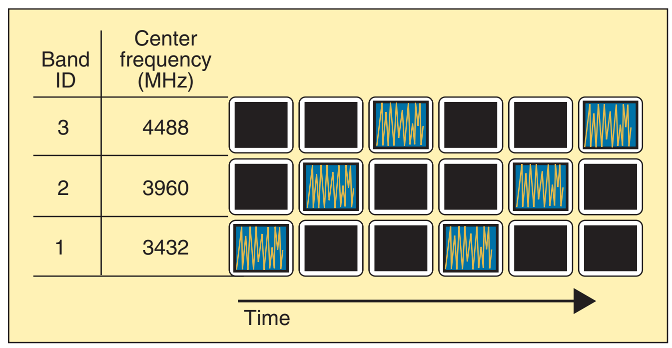

Figure 1. This diagram represents the frequency band-hopping sequence assigned to band group 1, as defined by TFC No. 1.

TFC Number	Base Sequence/ Preamble	Band ID for TFC					
1	1	1	2	3	1	2	3
2	2	1	3	2	1	3	2
3	3	1	1	2	2	3	3
4	4	1	1	3	3	2	2
5	5	1	1	1	1	1	1
6	6	2	2	2	2	2	2
7	7	3	3	3	3	3	3
8	8	1	2	1	2	1	2
9	9	1	3	1	3	1	3
10	10	2	3	2	3	2	3

Table 1. TFCs and the associated base sequences for band group 1.

Challenges of waveform generation

It is a challenge to generate WiMedia signals capable of testing the wide variety of UWB device types. This testing must not only establish conformance with protocol definitions, but must establish operating margins. Currently, there are two ways to generate WiMedia signals. Both of these methods have their own sets of advantages and disadvantages, providing the designer with options that can be applied for different test requirements.

The first method is shown in the upper portion of Figure 2. This first method provides all the advantages of an arbitrary waveform generator, such as creating real-world signals, including distortions and impairments, and frequency hopping at RF (which is mandatory as per WiMedia specifications, and involves the use of costly and complex arrangements such as external frequency hoppers). Though the second method—which uses a dedicated UWB chipset to feed the device under test (DUT), as shown in the lower half of Figure 2—provides the ability to band hop signals, it does not offer the functional flexibility and RF agility provided by an AWG. It is, therefore, desirable to develop a hybrid method for generating WiMedia-based UWB waveforms having the power of the first method, while retaining the simplicity

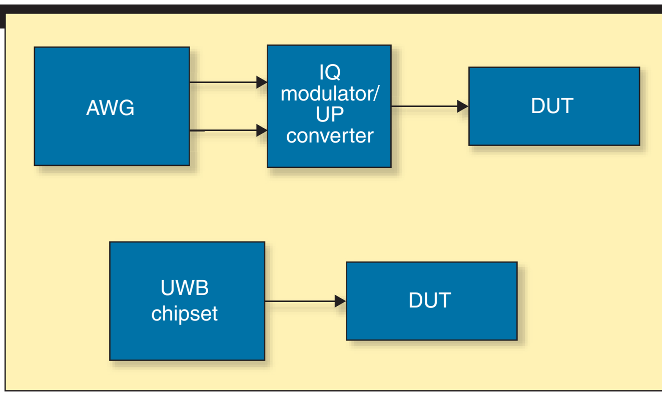

Figure 2. The two basic methods for generating WiMedia UWB signals.

of the second method. The implementation for a unique method having these characteristics is outlined in the following discussion.

The synthesis of signals with bandwidths exceeding 1.5 GHz at carrier frequencies up to 10 GHz exceeds the capability of traditional vector signal generation architectures used in wireless communication testing. The necessary modulation and baseband bandwidths, the frequency-hopping nature of the UWB-WiMedia signals and the influence of any amplitude, timing, and frequency response misalignments of the I and Q components of the signal requires additional effort to achieve the signal quality needed for UWB-WiMedia signals. In addition to the following descriptions for potential architectures for UWB signal generation, Table 2 lists several additional details on the AWG requirements for different configurations.

	Quadrature Modulation	Upconversion	Direct-RF Synthesis
AWG number of channels	2	1	1
Non-hopping signal			
Sampling rate	750 Msps(1)	1.5 Gsps	7.5 Gsps(2)
Modulation BW	500 MHz	500 MHz(4)	N/A
Oversampling (SR/BWBB)(5)	3	3	15
Hopping signal	YES/NO	YES/NO	YES/NO
Sampling rate	2 Gsps	4 Gsps	10 Gsps(3)
Modulation BW (hopping)	1.5 GHz	1.5 GHz(4)	N/A
Oversampling (SR/BWBB)(5)	6	8	20
Calibration requirements	Very High	High	Low
Signal quality	Fair	Good	Good
General setup complexity/cost	Complex/very expensive	Simple/ expensive	Simple/ expensive

Note 1: I and Q baseband signal bandwidth is 264 MHz for a combined channel bandwidth of 528 MHz
Note 2: Frequency band 1 only
Note 3: Band group 1 only
Note 4: Bandwidth of a single sideband
Note 5: BWBB: Bandwidth for a single UWB band (528 MHz)

Table 2. Instrument specifications.

Architecture 1: IQ baseband generation and quadrature modulation

This is the traditional vector-signal generation architecture. Frequency hopping may be implemented in two ways: by synthesizing a baseband IQ pair with the required frequency shift for each symbol, or by changing the LO frequency at the IQ modulator. Practical implementations for the baseband generation of the hopping signal require dual-channel AWGs with sample rates around 2 Gsps and analog bandwidths in the 1 GHz range. The implementation of frequency hopping by controlling the carrier frequency at the IQ modulator requires the capability of hopping more than 1 GHz in less than 70 ns.

Current implementations, given their limitations in sample rate and hopping speed, are limited to the generation of non-hopping signals. As two independent signal paths are used for I and Q baseband components, their alignment is extremely critical to obtain satisfactory results. Careful and long calibration procedures requiring additional high-performance analysis equipment are necessary and may have to be carried out frequently (due to the associated thermal and time-delay drifts).

Architecture 2: IF generation feeding upconverter

In this method, a single-channel AWG is used to generate a UWB signal to feed an upconverter covering the required frequency range. Practical requirements for the AWG depend on the implementation of the hopping frequency operation. A sampling speed of 1.5 Gsps is the minimum requirement to generate a non-hopping signal. Generating a hopping signal would require twice rate (greater than 3.2 Gsps). Upconverters used in such a system would require a minimum of 750 MHz or 2 GHz upconversion bandwidth for non-hopping and hopping signals, respectively.

Although this method also requires careful magnitude and phase calibration procedures to reach the highest levels of modulation and spectral accuracy, its requirements are much less demanding, as the I and Q components are by definition aligned, and share the same signal path. The main limitation of this strategy is handling the signal images that will show up in the spectrum. This effect may be minimized by using an analog bandpass filter covering the target band. The

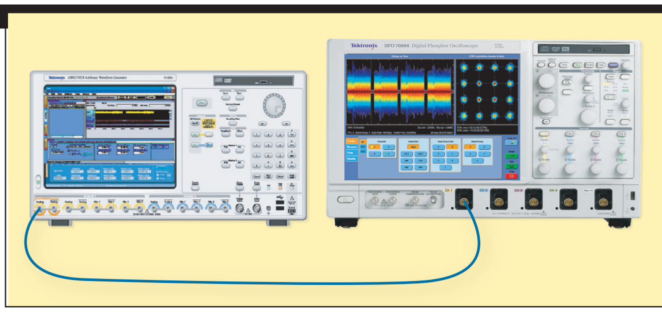

Figure 3. Test setup of UWB-WiMedia signal generator, featuring a Tektronix AWG7102 with 20 Gsps when interleaved and a Tektronix DPO70804 with WiMedia analysis software.

amplitude and group-delay distortions introduced by the bandpass filter may be compensated as part of the calibration procedure.

Architecture 3: direct RF synthesis

In this arrangement, a single-channel AWG generates the UWB signal directly at the final frequency. 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. For band group 1 (max. frequency 4.752 MHz) a minimum of 10 Gsps sampling rate and 5 GHz analog bandwidth are necessary. Band group 2 requires 15 Gsps sampling speed and 7 GHz analog bandwidth.

The Tektronix AWG7102 is capable of generating 5.8 GHz bandwidth waveforms at 20 Gsps, so it is possible to generate hopping signals in band group 1 with sufficient performance margin. Direct RF synthesis requirements for calibration are low. Controlled thermal behavior, low drift, and the elimination of additional external equipment allow this setup to maintain an acceptable signal quality for extended time periods, using only factory-level calibration.

Instrument setup and evaluation

Experimental data has been gathered using the test setup shown in Figure 3, which is an implementation of the direct RF synthesis architecture. All the WiMedia signals were generated using a Tektronix AWG. The AWG7000 series AWG has an extremely high sample rate, bandwidth and signal fidelity. For example, the unit features sample rates from 5 Gsps to 20 Gsps (10 bits), together with one or two output channels. The instruments also run on open Windows (Windows XP), enabling connectivity with peripherals, and compatibility with third-party software.

All tests were performed using a high-bandwidth digital sampling oscilloscope (DSO) with a sampling rate of 40 Gsps and a 15 GHz bandwidth, a 64 megasample record length, and UWB-analysis capability. Amplitude and phase distortions introduced by the oscilloscope are extremely low due to built-in real-time, DSP-based compensation techniques, and time-domain calibration procedures performed during the manufacturing process. The oscilloscope's high accuracy and traceability, therefore, makes it suitable for waveform-generator calibration procedures.

Basic experimental results are grouped by EVM data sets gathered for different bit rates and modulation schemes (QPSK and DCM). All data generated by this setup suggest that direct-RF synthesis would yield an EVM of around -30 dB better than the -19.5 dB EVM specified in the standard, as reflected in the data in Table 3. This setup also has the ability to frequency hop without the necessity of an external frequency hopper, due to the high sampling rate and bandwidth of the AWG.

The setup is easy to control and configure. A good frequency-response flatness is achieved without any predistortion in band group 1 using the Tektronix AWG 7102. Figure 4 provides the frequency spectrum of the signal captured on the Tektronix oscilloscope. This direct-synthesis implementation method provides a unique yet simple setup to generate clean, high-quality UWB-WiMedia frequency-hopping band group 1 waveforms. This implementation also provides the flexibility to add controlled interference and distortions to the UWB-WiMedia waveforms. Therefore, it has the sophistication of other AWG-based methodologies, yet retains the simplicity of using a dedicated UWB chipset to feed the device under test. RFD

Data Rate	TFC (chosen randomly)	EVM rms measured
53.3 Mbps	1	-30.50 dB
53.3 Mbps	10	-29.86 dB
80 Mbps	2	-30.43 dB
106.7 Mbps	3	-30.36 dB
160 Mbps	4	-30.12 dB
200 Mbps	1	-30.24 dB
320 Mbps	1	-31.20 dB
400 Mbps	3	-30.04 dB
480 Mbps	4	-30.94 dB

Note: Signals were generated using AWG7102 in interleaving mode
Note: All measurements conducted for band group 1; RF center frequency of 3960 MHz
Note: Sampling rate in the AWG set at 20 GHz

Table 3. Measurement results for direct-RF synthesis.

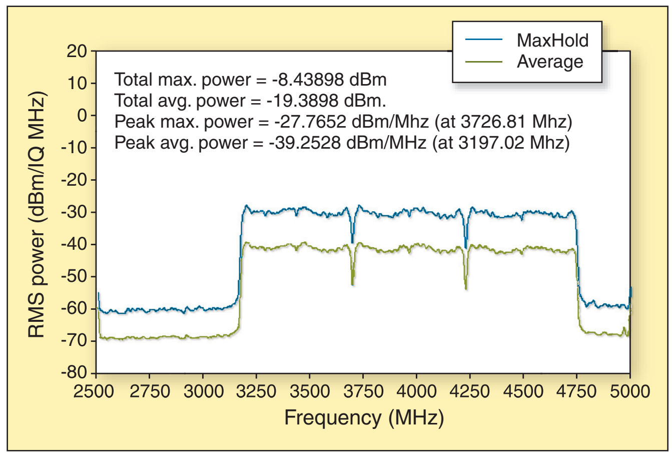

Figure 4. Spectrum of band group 1 (direct RF synthesis architecture).

References

1. Standard ECMA -368, 1st edition, December 2005.
2. Multiband OFDM Physical Layer specifications release 1.1.
3. Tektronix case study—Getting Ultra Wide Band Radio Signals to Hop: TZero Technologies Takes Advantage of Powerful Tektronix Instruments, November 2005.

ABOUT THE AUTHORS

Iqbal Bawa is an engineer in electronics and communications, currently a technical lead in Tektronix' signal sources product line. He has more than eight years of experience in the fields of digital signal processing, embedded systems and communication.

K. A. Muralidharan is an electronics & communication engineer with a post graduate diploma in marketing. He works as a marketing manager for SW applications in Tektronix' signal source product line. He has 12 years of experience in sales and marketing and has been in the T&M industry for more than five years.

Joan Mercadé is a telecommunication engineer trained by the Polytechnic University of Catalonia (UPC), Barcelona, Spain. He has worked in different areas of the T&M industry for more than 20 years in companies including Philips and Tektronix. Currently, he runs his own R&D and consulting company, Arbitrary Resources.