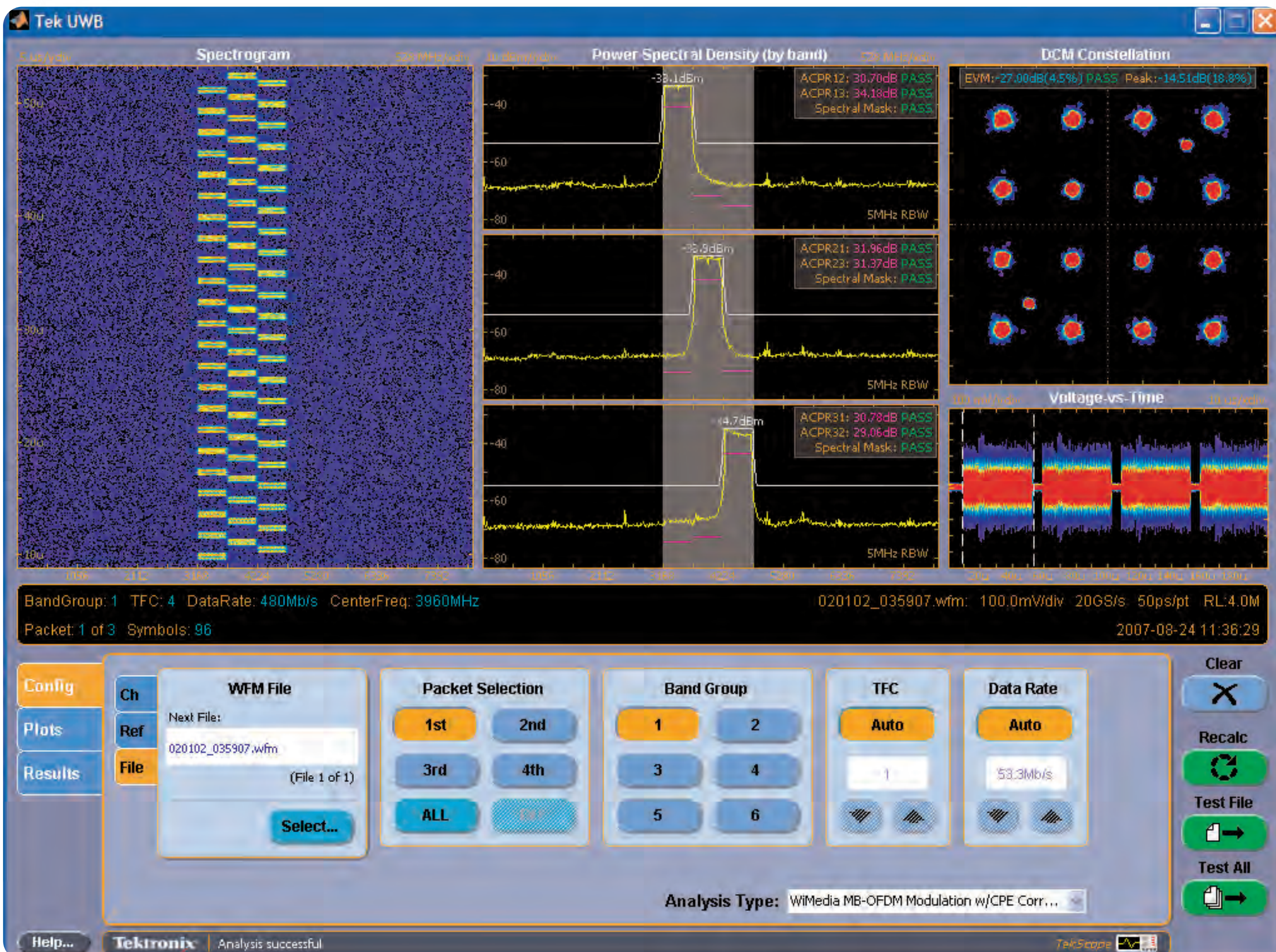
Ultra-Wideband Technology and Test Solutions



Abstract

Ultra-Wideband (UWB) wireless is a rapidly growing technology that promises to revolutionize low power, short-range wireless applications. UWB has quickly emerged as the leading technology for applications like wireless Universal Serial Bus (USB) and short-range ground penetrating radars. UWB radios differ from conventional narrow-band radios, with a variety of specialized test demands. Enormous signal bandwidths, short duration pulses and transmit Power Spectral Densities (PSDs) near the thermal noise floor, make UWB testing difficult. Fortunately, leading instruments like the Tektronix Arbitrary Waveform Generators (AWG), RFXpress waveform creation software and Digital Phosphor Oscilloscopes (DPO) with UWB measurement software offer solid solutions to UWB test challenges. In this Tech Brief we explain the concepts behind UWB technology, its unique hardware and software architectures, and some of the associated test issues engineers encounter.

Tektronix
Enabling Innovation

Introduction

UWB technology is quickly gaining acceptance as a wireless technology with outstanding characteristics. To understand UWB, we begin with a look at its origins and its growth to date.

History

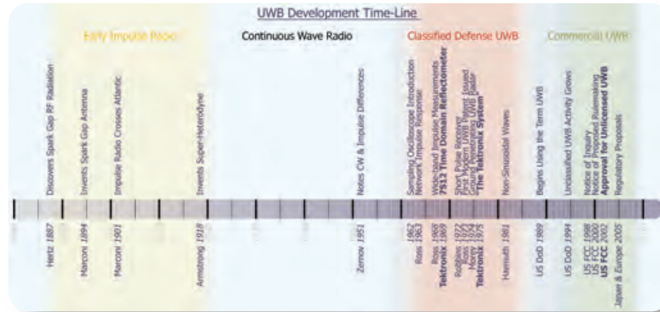
Early radios like Guglielmo Marconi's spark gap design (1896) marked the beginning of Impulse Radio (IR) communications. Inspired by Heinrich Hertz's (1888) experimental apparatus that proved James Clerk Maxwell's theoretical electromagnetic waves (1865), the first wireless telegraph signals used short impulses to transmit information. These impulse signals were the forerunners of modern UWB communications.

The spark gap designs were simple and easy to build with primitive components. However, early impulse radios were subject to interference from atmospheric sources and other transmitters.

In 1918 Edwin Armstrong's super-heterodyne radio design enabled outstanding interference rejection of narrowband Amplitude Modulated (AM) signals. Continuous wave, narrowband wireless radio also excelled at long transmission distances and quickly replaced early impulse radios.

Impulse radio development languished for decades until modern test equipment technology ultimately rekindled interest. In 1962 the invention of the sampling oscilloscope made it possible for Gerald Ross to use transient impulses to characterize wideband radar components (1963). Sub-nanosecond pulse generation capability enabled previously difficult characterization of microwave component mismatches inside phased array coupler networks.

By the 1970s, ultra wideband impulse characterization techniques were being applied to short-pulse radars and communications links, which rekindled interest in IR, but now with ultra wide bandwidth.

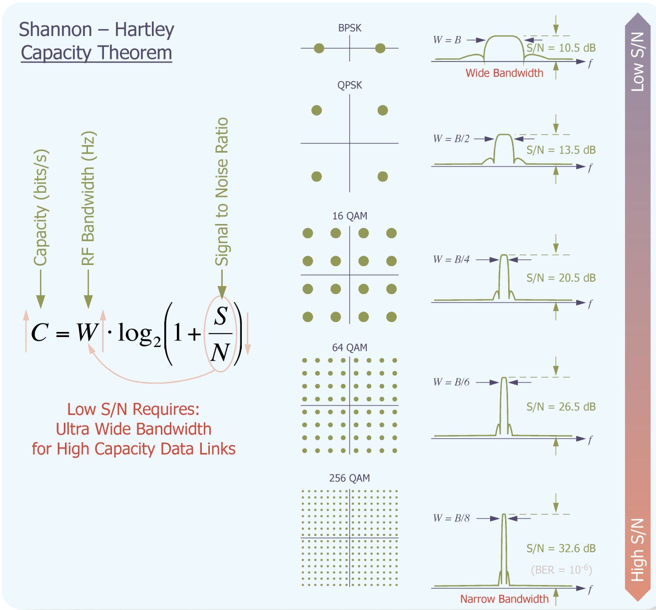


▶ **Figure 1.** *The UWB development timeline illustrates the long history of impulse radio development that ultimately grew into today's UWB technology.*

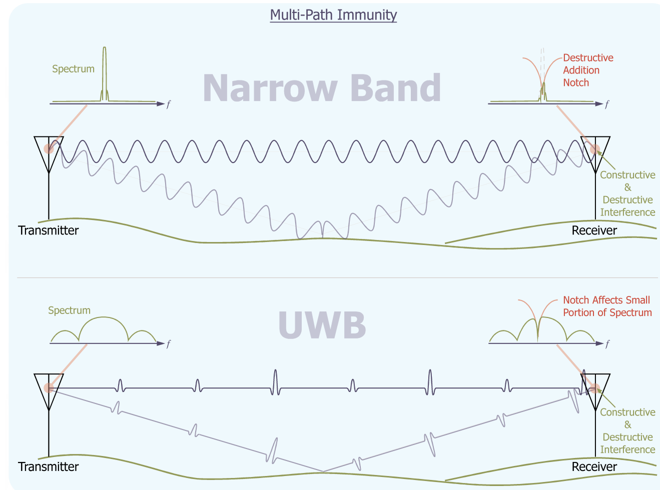
Precision short-range radar and Low Probability of Detection (LPD)/Low Probability of Interception (LPI) communication systems for government use, kept much of the work in the 1960s and 1970s classified.

UWB technology development continued, however, with the help of legendary measurement equipment like the Tektronix 7S12 Time Domain Reflectometer (TDR) and the 'Tektronix System' (a collection of laboratory instruments that could be interconnected to create a UWB data link or UWB radar).

More recently, modern computers have created a strong demand for high speed, short-range Personal Area Networks (PANs) to interconnect high data rate peripherals. In 2002, recognizing UWB as an ideal technology for expanding short-range communications and precision location applications, the United States Federal Communications Commission (US FCC) granted the first commercial spectrum allocations for unlicensed low power UWB transmissions. Manufacturers have been racing to fill a host of short-range low power applications like Certified Wireless USB with new UWB products that can deliver outstanding performance. Now, as wireless UWB products enter the consumer market, the winning designs and applications will begin to revolutionize our world.



▶ **Figure 2.** *The Shannon–Hartley theorem illustrates the ideal relationship between channel capacity (C), RF bandwidth (W) and minimum signal-to-noise (S/N) ratio. UWB is attractive because high channel capacities or data rates can be supported with low S/N ratios. Comparing the RF bandwidth and S/N requirements for the illustrated modulations with identical bit rate capacity, it is easy to see bandwidth can be traded for S/N Ratio.*



▶ **Figure 3.** *Destructive multi-path, where a reflected signal cancels the desired signal at the receiver's antenna, affects narrowband signals differently than UWB signals. The frequency notch created by destructive multi-path can completely eliminate a narrowband signal. However for the UWB signal, it will only affect a small percentage of the total energy transmitted, resulting in little disturbance. Similarly, narrowband signals disturb such a small percentage of the redundantly coded UWB signal that interference is minimal.*

Why UWB?

What are UWB's unique features and why is UWB seen as an enabling technology for many short-range wireless applications?

Ultra-Wideband signals offer the data capacity needed to support many of today's high data rate applications like wireless video. Greatly simplified, the Shannon–Hartley theorem says there are only two ways to achieve higher data rates through a wireless link: 1) expand the bandwidth of the RF signal (W), or 2) use a more complex multi-level constellation that requires a higher Signal to Noise (S/N) ratio for a given error rate.

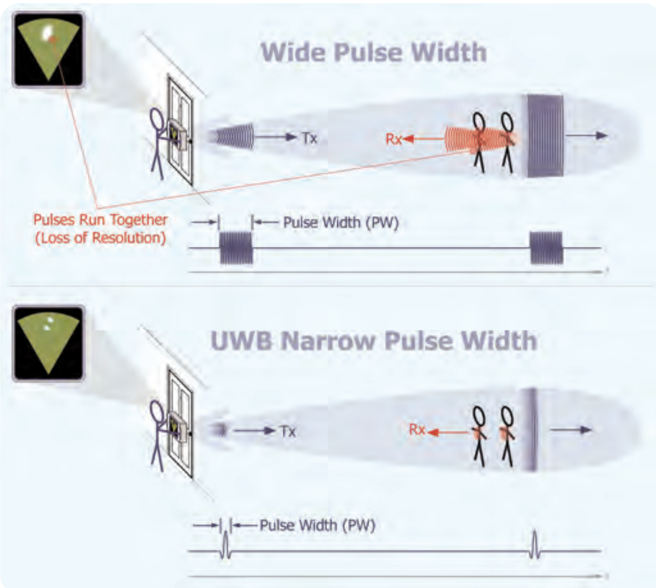
Using ultra wide bandwidths enables high data rates much more easily than trying to add symbols to the constellation. More importantly, adding bandwidth allows reliable data transmissions at low S/N ratios close to the thermal noise floor. Low S/N transmissions are a key factor, enabling UWB to avoid unwanted interference with other wireless signals.

Since UWB signals can occupy many gigahertz (GHz) of RF spectrum, coordination with existing wireless services cannot rely on traditional frequency duplexing. In today's crowded wireless world, there simply isn't enough available spectrum bandwidth to allocate ultra-wide bands to single purpose applications. Thus another means of interference mitigation must be employed to allow UWB to coexist with current wireless spectral allocations.

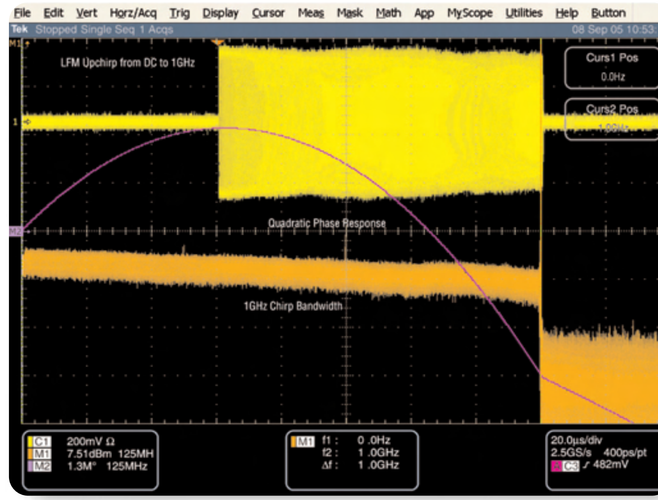
The two basic interference cases are: 1) UWB signals interfering with existing narrowband communications, and 2) narrowband signals interfering with UWB transmissions.

To achieve harmony between existing spectrum allocations and UWB signals that occupy the same frequency, UWB signals must have low power spectral densities just above the thermal noise floor. This is possible if the UWB transmitter power is restricted to low levels and spread out over many gigahertz of bandwidth. Transmitter power restrictions prevent significant interference with existing narrowband signals, but this limits UWB to short-range applications.

Fortunately, the redundancy built into UWB signals gives them outstanding interference immunity to strong narrowband signals, the other case to be considered. This same redundancy also gives UWB devices premier multi-path capabilities.



▶ **Figure 4.** *Longer radar pulse widths can run together, being interpreted as a single echo return or object. Short UWB pulse-widths improve the radar's resolution by returning distinctly separate echoes.*



▶ **Figure 5.** *A 1 GHz radar chirp is captured with the DPO7000 oscilloscope using its 20 GHz of bandwidth. The oscilloscope can convert the time domain signal (yellow) to a spectral plot (orange) and phase (purple).*

Destructive addition of multi-path signals with the desired signal can create dispersive frequency notches, canceling out certain frequencies entirely. Narrowband signals can be completely engulfed by this phenomena, eliminating all receive power which causes the signal to fadeout, while UWB signals only experience a small percentage power loss since they are much wider than the frequency notch. The redundant coding used in UWB signals renders this narrowband loss of energy insignificant, giving the UWB signal outstanding multi-path performance.

In a similar fashion, a strong narrowband interference source has little impact on a UWB signal since it affects only a small portion of the total signal energy. UWB's tolerance to multi-path and interference makes it ideal for challenging indoor transmission environments that are filled with reflected signals and RF interference sources.

Thus UWB's high data rate capability, multi-path immunity and robustness to interference make it an attractive enabling wireless technology for today's bandwidth-hungry computer peripherals. UWB's Low power spectral densities are ideal for LPD communications systems too. Furthermore, the spreading techniques used to create ultra wide bandwidths render UWB signals difficult to intercept, providing outstanding LPI communications for military applications.

UWB Radar

The short pulse width of many UWB signals also provides outstanding radar resolution benefits. Closely spaced targets illuminated with long radar pulses can create overlapping radar returns that obscure the nature of the target, while very narrow pulses provide distinct echo returns.

Ultra short UWB pulses are naturally suited for short-range low power imaging of small, closely spaced targets. Applications like ground penetrating radars, in-building special operations radars and terminal proximity fuses, which all operate over short distances detecting small targets, can benefit from UWB.

Short UWB pulses require ultra-large bandwidths that enable outstanding multi-path immunity. In some cases instead of extremely short pulses, UWB pulse compression techniques (pulse modulation) can improve radar resolution. Frequency chirps or Bi-Phase Shift Keying (BPSK) are common approaches to modulating radar pulses for improved resolution. Some of the pulse compression modulations used today require ultra-wide bandwidths and fit the definition of a UWB signal.

Coding techniques used to spread UWB signals also allow precision radiolocation of transceivers much like conventional spread spectrum designs. The short pulses enhance precision over shorter ranges.

High data rate channel capacity, unlicensed low PSD transmissions, outstanding multi-path performance, robust interference immunity, high resolution radar capability and precision radiolocation potential are important traits that make UWB ideal for many short-range wireless applications. However, these UWB benefits come with the price of some technological challenges.

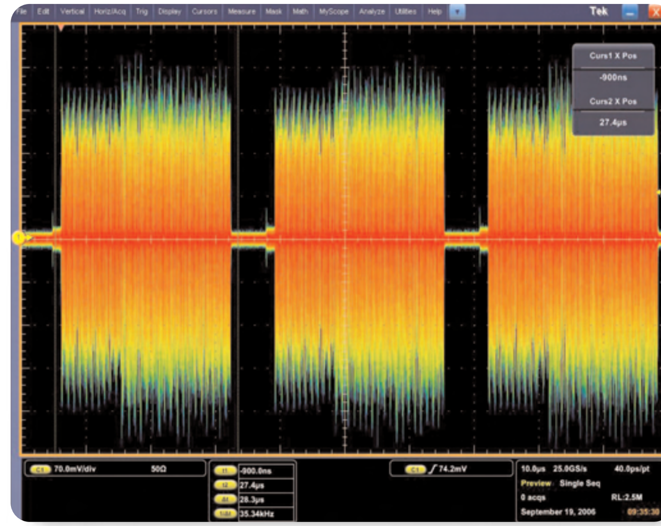
A Challenging Test Problem

UWB signals pose many challenging test and measurement issues that demand special test instrument capabilities.

Generating and analyzing ultra broadband test signals for UWB requires high performance arbitrary waveform generators like the Tektronix AWG7000 series and very broadband digital phosphor oscilloscopes like the DPO70000 series that can support the enormous bandwidth requirements of the UWB signal.

UWB signal requirements present broadband amplitude and phase flatness challenges. Transient UWB pulses can be distorted by the spectral amplitude and phase flatness from both the test signal generator and measurement instruments. Pulse distortion effects in turn alter the spectral properties of UWB signals.

For narrowband signals, test equipment is typically selected such that its bandwidth is significantly larger than the desired signal bandwidth to be measured, minimizing flatness issues. However, for UWB signals it is not possible to have a vastly wider test equipment bandwidth.



▶ **Figure 6.** *Powerful UWB test instruments Like the AWG7000 series and DPO70000 can generate and capture complex ultra-wideband signals.*

Another problem encountered when testing UWB signals is the limited measurement bandwidth options available. Even simple power spectral density measurements can be difficult, as regulations require a 50 MHz resolution bandwidth (RBW) few spectrum analyzers support.

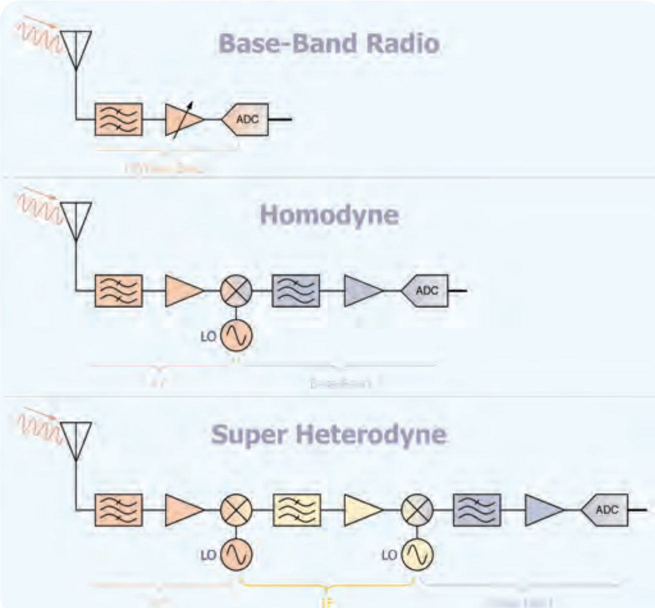
Add to these challenges Time Frequency Codes (TFC) that spread the UWB signal, and device test can be a major challenge without the right test equipment.

To understand which test solutions are appropriate for UWB, let us briefly review what UWB technology is all about and what makes up these fascinating signals.

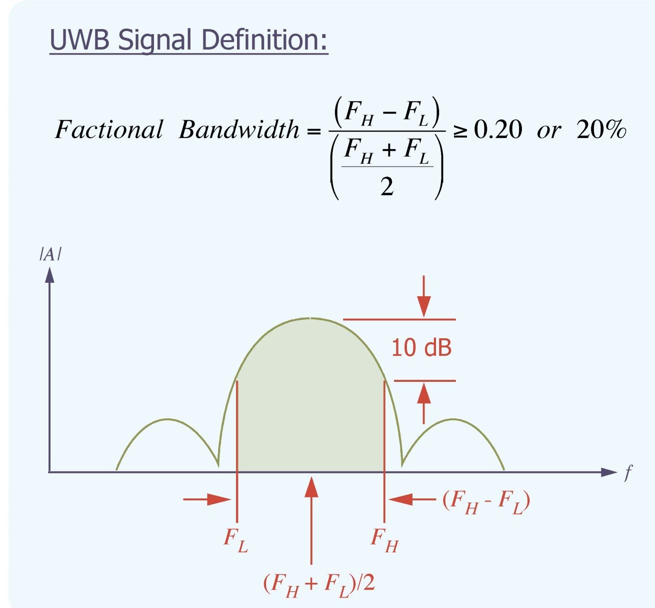
UWB Technology

UWB technology encompasses a broad range of signal types and design topologies. So great are the differences between UWB signal types, seemingly the only thing they all have in common is their enormous bandwidth.

What exactly differentiates a UWB signal from a traditional narrowband signal?



▶ **Figure 7.** *Three receiver architectures have been popular at different times in history: base-band radio, such as an early spark gap receiver, is simple but lacks interference immunity; the homodyne is more complex, and allows reception at higher frequencies where less interference might be present; the ubiquitous super-heterodyne receiver has an Intermediate Frequency (IF) conversion with a narrowband high Quality factor (Q) filter capable of eliminating interferers close in frequency. The super-heterodyne has dominated radio designs for the last 80 years.*



▶ **Figure 8.** *US FCC defined a UWB signal as any signal with a bandwidth at the 10 dB attenuation points (? 90% spectral power bandwidth) greater than 20% of the modulation frequency.*

What is UWB?

UWB communications signals initially went by other names, such as impulse radio, base-band communications, carrier-free transmission and impulse modulation. In fact, it was not until the late 1980s that the term UWB began to be applied to this unusual class of signals, which had grown vastly in bandwidth.

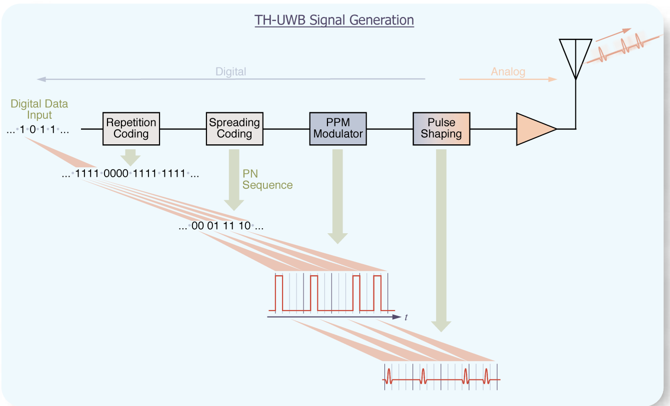
Many UWB design approaches differed substantially from conventional wireless links by not employing the ubiquitous super heterodyne frequency conversion architecture.

However, modern super heterodyne radio architectures can now produce signals of comparable bandwidths to direct base-band modulation with very short pulses.

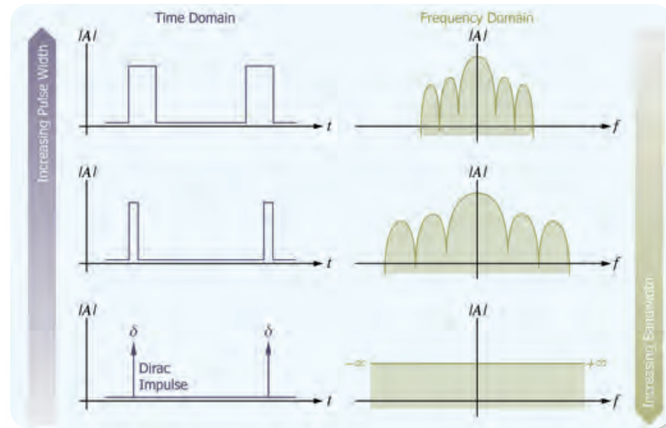
Since UWB signals can be generated in a variety of ways, the US FCC spectral regulatory agency has selected a definition of UWB based on bandwidth rather than radio architecture or modulation format. UWB signals have been defined as signals with a percentage bandwidth greater than 20%.

Percentage bandwidth allocations this wide are not available in today's crowded radio spectrum, so UWB signals are forced to overlap other allocated service bands, creating the potential for interference. As we mentioned earlier, the solution for this has been to limit UWB signals to low power short-range communications and rely on inherent UWB interference immunity with narrow-band signals.

The result of the US FCC definition is that a variety of different UWB modulation techniques and hardware architectures are in use today.



▶ **Figure 9.** *TH-UWB generation with PPM is a simple process of coding, spreading, modulating and shaping the short impulses that make up the signal. Notice how the signal creation is all done at base-band with no frequency up-conversion.*



▶ **Figure 10.** *Pulsed signal bandwidth is inversely related to pulse width in the time domain. Thus changing the time domain impulse shape can control the power spectral density of a UWB signal.*

Popular UWB Approaches

There are several different approaches to generating ultra-wideband signals. Let's consider three popular methods of modulating the ultra-wideband signal: Time Hop UWB (TH-UWB), Direct Sequence UWB (DS-UWB) and Multi-Band Orthogonal Frequency Division Multiplexing UWB (MB-OFDM).

TH-UWB

Time hop UWB signals are composed of a series of very short impulses at pseudo-random intervals.

The TH-UWB signal begins by taking the data to be transmitted across the wireless link and repeating each bit multiple times. This repetition block coding adds signal redundancy and spectral diversity, increasing our signal's immunity to multi-path variation and interference.

Each coded bit is then assigned a pseudo-random value for signal spreading prior to being time hopped with Pulse Position Modulation (PPM).

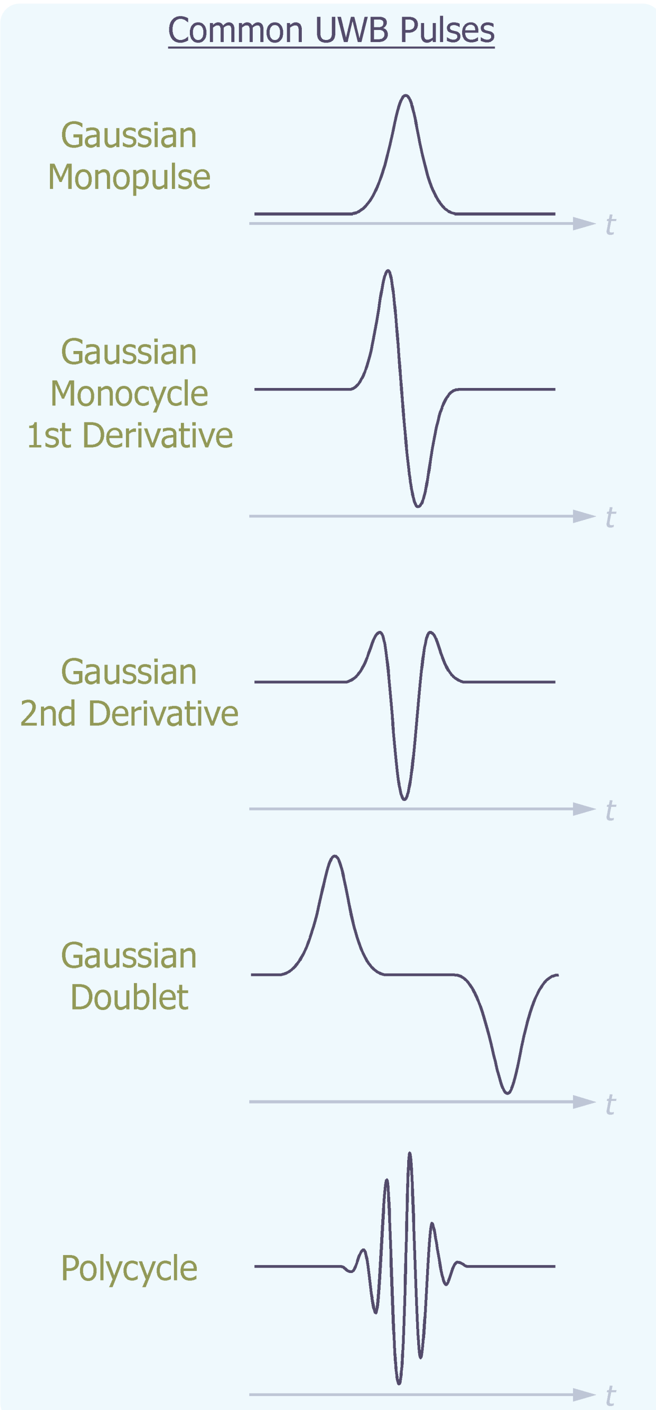
Using the pseudo-random transmission spreading code, the pulse position modulator selects a time slot proportional to the assigned pseudo-random value and generates a pulse. This modulates the position of each pulse that is sent, generating a pseudo-random stream of pulses. Of course there are many variations possible, but this is the basic process used for time hopping UWB signals.

Finally, the TH pulses are shaped and amplified into the desired impulse for transmission across the wireless channel.

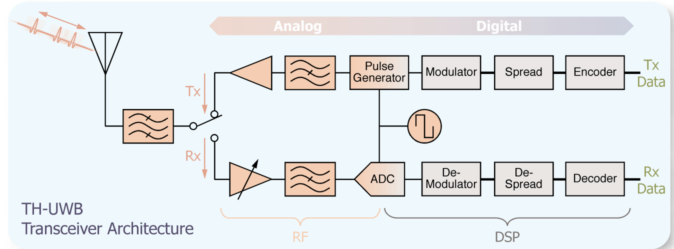
Pulse Shaping

Pulse shaping is important because it affects the spectral properties of the UWB modulation. To avoid interference, regulations limit the power spectral density of the UWB signal, but the frequency domain spectral shape is directly related to the time domain impulse shape.

The theoretical Dirac impulse, or infinitely narrow pulse width in the time domain, creates an infinitely wide spectral response in the frequency domain. By carefully changing the impulse shape, the power spectral density of the TH-UWB signal can be controlled.



▶ **Figure 11.** *A variety of Gaussian impulse shapes are commonly used with UWB signals. The simple Gaussian monopulse is shown for reference only, and is rarely used because it introduces a DC offset.*



▶ **Figure 12.** *TH-UWB transceiver architectures can be very simple and lack many traditional analog RF components. TH-UWB signals can be created and processed almost entirely at base-band with digital hardware.*

Pulse shaping is also important because it can affect the Inter Symbol Interference (ISI) and multi-path characteristics of a TH-UWB signal. Unlike many traditional narrowband digital modulations that use raised cosine filtering and controlled symbol timing to avoid ISI, UWB signals often favor Gaussian pulse shapes, which retain their shape better when confronted with dispersive channel effects. The Gaussian pulse shape does introduce some ISI, but since UWB signals have plenty of bandwidth, timing can be adjusted to minimize inter symbol interference.

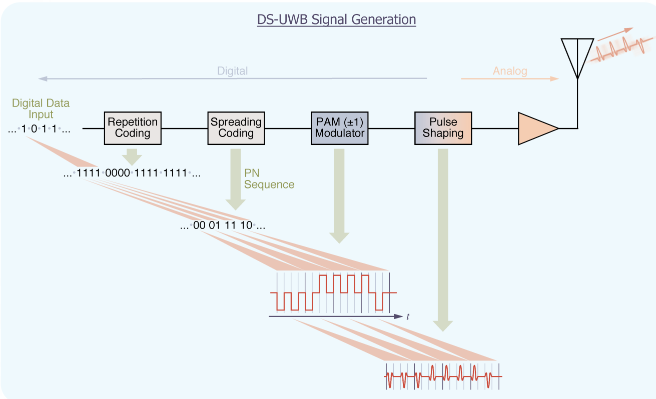
Spectrum shape is also affected by impulse type. Carefully manipulating impulse shape and width allows selection of impulses that fit spectral and ISI requirements.

Initially, early UWB impulse signals were created with avalanche diodes and appropriate matching networks for pulse shaping. Now, many UWB pulses are created with high-speed Complementary Metal Oxide Semiconductors (CMOS).

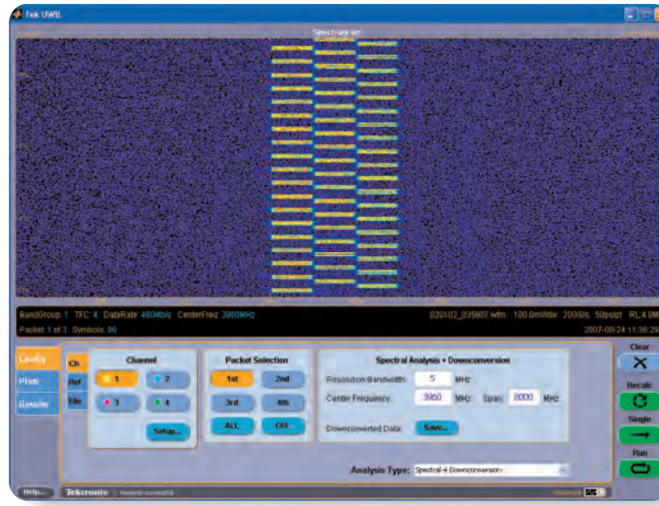
Base-band UWB IR

It is important to note that almost the entire TH-UWB IR process can be accomplished at baseband.

Baseband generation of the transmitted signal eliminates the need for many conventional super heterodyne components, such as up- and down-converters, IF filters, amplifiers, mixers and LO sources. This makes IR UWB designs significantly less complex and costly. It also allows the many benefits of Digital Signal Processing (DSP) to be applied extensively.



▶ **Figure 13.** *DS-UWB PAM signal generation is similar to TH-UWB. A key difference is in the pulse modulator that inverts the phase of the pulse.*



▶ **Figure 14.** *A WiMedia MB-OFDM signal with frequency hop spreading is captured with a DPO7000 series oscilloscope and displayed as a spectrogram of the band group.*

DS-UWB

Direct Sequence UWB (DS-UWB) is another modulation approach used to create ultra-wideband signals. DS-UWB employs techniques similar to Direct Sequence Spread Spectrum (DSSS). DSSS techniques spread the impulse radio spectrum over ultra-wide bandwidths.

Starting with a repetition block coder, each bit is replicated and assigned a positive or negative value. Again, this increases redundancy and improves spectral diversity for robust transmission characteristics.

The coded data is then fed to a Pseudo Noise (PN) transmission channel encoder that assigns a pseudo-random value to each redundant bit. The output of the direct sequence transmission channel encoder is a spread sequence of positive and negative values.

The signal is then fed to a PAM modulator that generates positive and negative pulses.

The PAM modulator output pulses are subsequently pulse shaped into the desired impulse and amplified for transmission.

Though this process is similar to the DSSS BPSK modulation commonly used with continuous waveforms, pulse phase modulation or inversion is accomplished digitally prior to pulse generation and shaping.

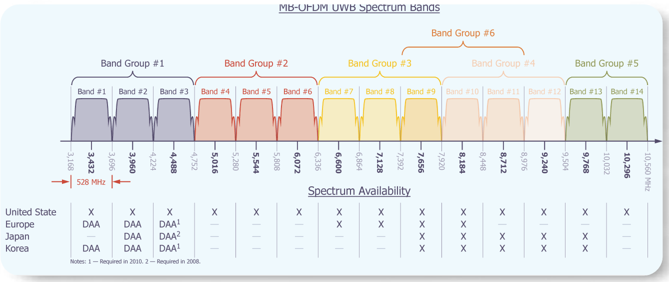
DS-UWB like TH-UWB can also use base-band and zero-IF or homodyne architectures for signal generation and reception, allowing many hardware architectural simplifications.

MB-OFDM

Generating UWB signals with MB-OFDM is another important approach. Since the US FCC regulations stipulate only that bandwidth and power spectral density requirements are met, the regulations thus allow conventional modulations like orthogonal frequency division multiplexing as long as the spectrum is spread over sufficient bandwidth.

In order to achieve the UWB regulatory status, Multi-Band (MB) OFDM uses a frequency hopping technique to further spread the bandwidth of a conventional OFDM signal. Current low cost OFDM modulators can 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 signal can achieve over 1.5 GHz of bandwidth. At typical center frequencies, this bandwidth is sufficient for classification as a UWB application.

The OFDM signal is prized for its outstanding multi-path rejection. Since OFDM is composed of many signal carrier modulations closely spaced together yet still remaining orthogonal, each signal carrier has a much slower data rate than the combined set of signals. Simultaneously sending many carriers that are ultimately combined for high data rate capacity, allows corresponding longer symbol times, versus a single carrier modulation's short symbol duration. This eliminates ISI caused by time spreading from multi-path. OFDM thus provides very robust performance when channel characteristics are poor.



▶ **Figure 15.** *The WiMedia band group structure provides several band groups for its MB-OFDM signal structure. Not all bands are available worldwide and some require a DAA for interference mitigation.*

Since short-range communications are often accompanied with poor transmission channel conditions, such as indoor environments, MB-OFDM is a particularly attractive modulation.

The WiMedia Signal

The WiMedia Alliance has selected an MB-OFDM signal as its high-speed multi-media UWB data link standard. The WiMedia signal is composed of an OFDM modulation with 128 carriers, using either Quadrature Phase Shift Keying (QPSK) or Dual Carrier Modulation (DCM) on each carrier. This modulation format allows at least eight data rates ranging up to 480 Mb/s.

The WiMedia OFDM modulation is frequency hopped over a band group composed of 528 MHz wide bands. The hopping of the OFDM signal across the band group is controlled by one of ten Time Frequency Codes (TFC). Relative to most Frequency Hop Spread Spectrum (FHSS) signals, the MB-OFDM WiMedia signal is hopped slowly with an uncomplicated hopping pattern, with many bits transmitted during each hop.

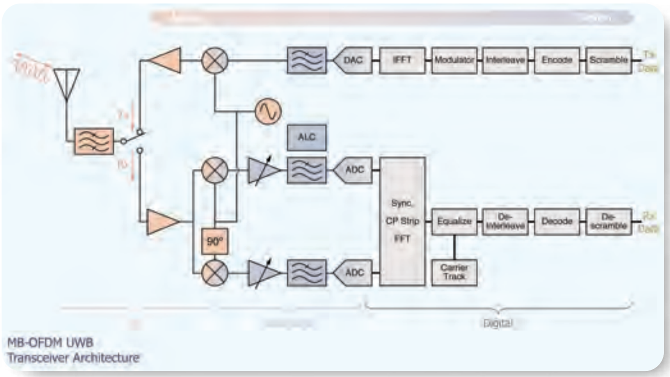
The US FCC was the first to open up radio spectrum for UWB use. Other countries have quickly followed the US FCC initiative, however, not all bands are available worldwide for UWB applications. Some countries require or will require Detect And Avoid (DAA) schemes where transceivers listen to the band for other signals before transmitting to help mitigate interference.

Though WiMedia's MB-OFDM signal is in many ways similar to conventional narrowband wireless signals, it is still possible to employ many of the architectural savings other UWB designs benefit from. For example, MB-OFDM does not require the sharp IF filtering of a super heterodyne architecture to eliminate interference.

Zero-IF transceivers do not use an IF conversion, but rather go directly from baseband to RF or vice versa in a single conversion, eliminating many components. The zero-IF or homodyne architecture is appealing for highly integrated semiconductor designs. Some integrated circuits that support WiMedia's modulation format with uncomplicated zero-IF architectures are now becoming available.

The zero-IF homodyne does present some technical challenges. Common issues include DC offsets in the down conversion process and circuit stability.

As amplifier gain increases, circuit stability becomes more difficult. The risk of a small amount of the amplifier output signal reaching the input of the amplifier to create regenerative oscillations increases with gain. This becomes a paramount concern as gain exceeds 70 – 75 dB, the typical amplifier internal output to input isolation level.



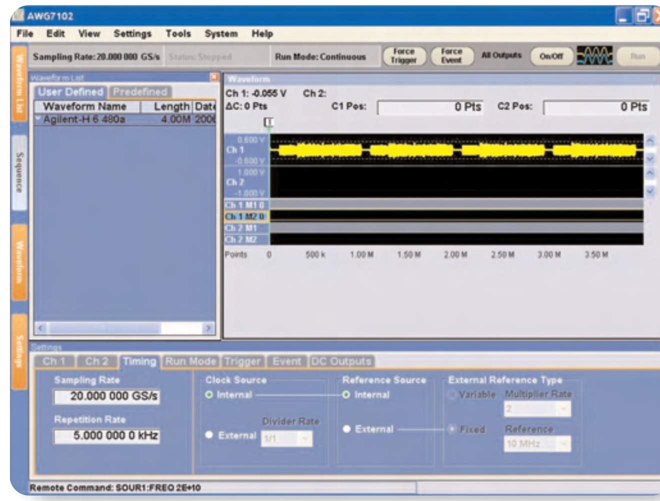
▶ **Figure 16.** *The MB-OFDM transceiver architecture shows the benefits of a homodyne zero-IF design. The high levels of digital implementations eliminate many expensive IF and RF components.*

The super heterodyne receiver architecture is generally preferred for stability because the total receiver gain can be spread over three different frequency ranges, RF, IF and base-band. Zero-IF architectures require greater gain at RF and base-band since they lack an intermediate frequency range. Fortunately, modern highly integrated zero-IF designs now employ substantial digital signal processing where gain is intrinsically stable, thereby minimizing stability issues.

WiMedia® signals that rely on complex protocols, like many UWB signals, can be difficult to test with older traditional instruments. The unusual nature of the UWB signal combined with radically different hardware architectures that often lack traditional test-points, present unique challenges for the engineer.

Testing UWB Devices

There are many wireless test instruments on the market, but only a few are suitable for UWB devices. Let's look at some common problems and the test solutions that are available for UWB applications…



▶ **Figure 17.** *The Tektronix AWG7000 arbitrary waveform generator can directly generate many UWB signals with its 20 GS/s capability.*

Wide Bandwidth UWB Signal Generation

UWB test signal generation requires enormous bandwidth dictating specialized signal generation equipment. Most common laboratory signal generators are capable of generating only a few tens or hundreds of megahertz (MHz) of bandwidth – far short of the one and a half gigahertz of bandwidth necessary for most UWB signals.

Depending on the UWB modulation to be generated, different signal generation approaches may be needed. Signals like TH-UWB and DS-UWB are typically generated entirely at baseband and require many gigahertz of baseband bandwidth. Other signals like MB-OFDM are more typically upconverted to the appropriate RF band. Upconversion methods require less baseband bandwidth, but add the complexity of an external upconverter or modulator.

For many years, the Tektronix AWG series has led the industry in bandwidth capability. Models like the AWG7000 achieve up to 20 GS/s or 5.8 GHz of base-band bandwidth using nearly four times over-sampling. This is sufficient BW to directly generate RF for BG1 and BG2 of the WiMedia MB-OFDM signals.

The versatile AWG can perform either direct base-band arbitrary waveform generation or the convenient I–Q outputs can drive an external modulator for modulation and upconversion to higher frequencies. With 8 to 10 bits of dynamic range, the AWG7000 can directly generate UWB signals up to 5.8 GHz with no external components. Applications such as the upper WiMedia band groups #3–6 can be generated using an external up-converter or an I–Q modulator.

The AWG7000 series is also equipped with differential outputs for direct interface with popular balanced amplifier and mixer components that offer the improved noise immunity of common mode rejection.

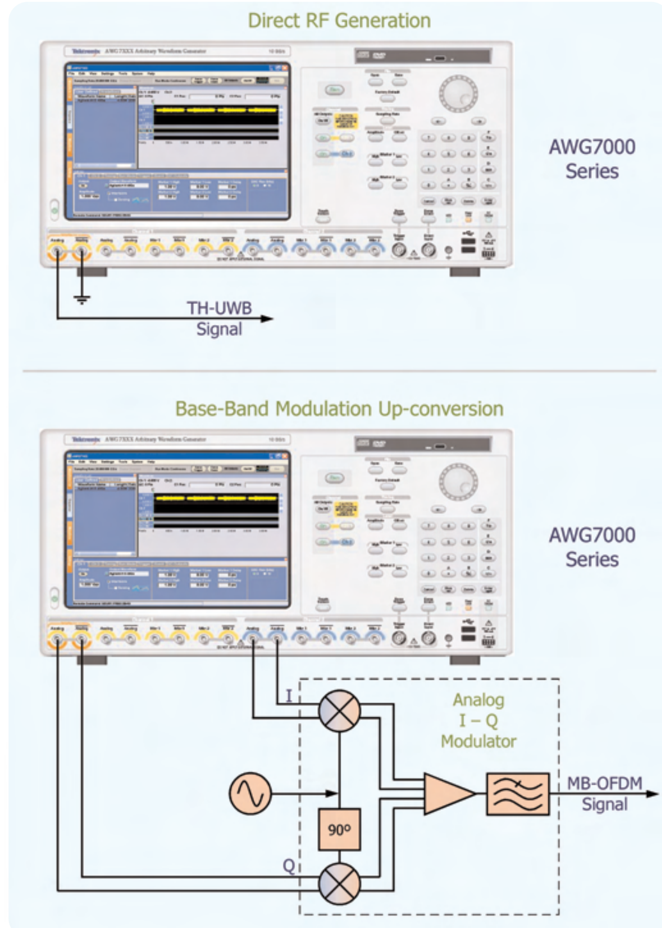
Since a great deal of the UWB signal creation is accomplished digitally from software algorithms, the flexibility of an arbitrary waveform memory for playing back a variety of signals is particularly attractive to the UWB engineer.

The arbitrary waveform memory can be programmed either from the front panel of the instrument or on a PC using one of several programming options.

Tektronix offers RFXpress, a powerful software tool that can synthesize complex UWB modulated waveform files. In addition, Tektronix AWGs also support the importing of many common file types for playback, such as .pat, .seq, .wfm, MATLAB®, Mathcad® or Excel®. This flexibility in file formats allows engineers to download waveform data directly from their software defined radio design tools, often without format conversion.

Waveform Creation with RFXpress

To efficiently build a UWB system, a variety of stimulus test waveforms are needed. Compiling complicated UWB signal structures has been difficult in the past. Often, the most readily available source of exotic UWB waveforms comes from the system's own software defined signal code. This is why Tektronix AWG signal generators offer such a wide range of compatible file types for popular software defined radio design tools.



▶ **Figure 18.** *AWG7000 supports direct base-band and external I–Q modulator/upconverter UWB signal generation approaches.*

However, using the UWB's own system software to generate test signals can present issues. The primary problem with this approach is it pre-supposes that system waveform designs are working correctly. Early in the development cycle, this may not be the case. In addition, the radio system software usually lacks the ability to add impairments and can be cumbersome to manipulate for test purposes, as it is typically not designed with a human interface in mind.

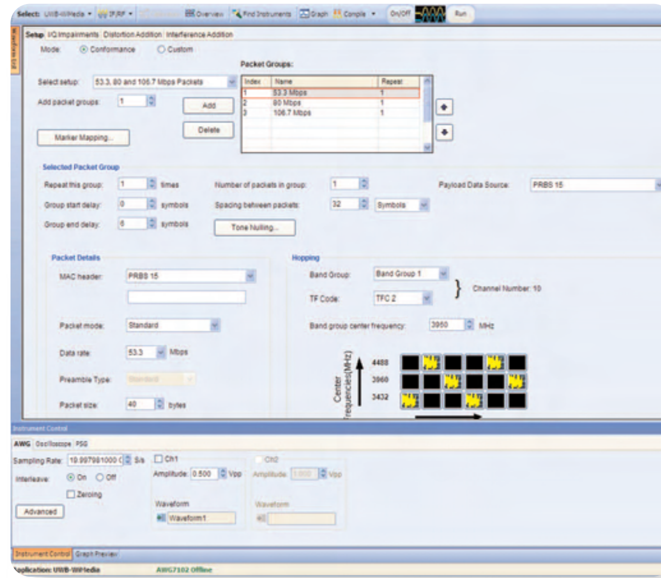
A more preferable approach is to use a known good software tool that can reliably synthesize both general purpose and standards based signals, with or without impairments. This eliminates uncertainty with the test signal and provides an easy-to-use human interface, accelerating the design and debug process.

The RFXpress waveform synthesis software supports general-purpose signal creation, as well as standard specific signal creation like the WiMedia format. Thus, RFXpress is useful for both spectral environment simulation and functional test of WiMedia devices.

RFXpress is a modern PC based software tool with a graphical user interface that allows visual confirmation of waveforms and setups. RFXpress makes waveform synthesis fast and easy auto calibration for RF and IF signal creation. It also incorporates an 'auto detect instruments' feature that eliminates the drudgery of manual instrument setup. To simplify the waveform creation process for either general purpose or standards based waveforms, RFXpress also incorporates automatic wrap around corrections and normalized waveform amplitude. Automatic wrap around corrections eliminate the spectral glitches that can occur when the waveform is repeated continuously with a large signal amplitude difference at the beginning and end of the waveform being replayed. Normalizing the waveform amplitude maximizes the signal's dynamic range by scaling the waveform's amplitude to best fit the dynamic range of the AWG's Digital-to-Analog Converter (DAC).

Using conformance mode, complicated MB-OFDM WiMedia signals can be synthesized with the click of a mouse. RFXpress incorporates adopted WiMedia signal standards, allowing the user to select signal properties at the highest level. This eliminates the complexity of manually programming signal features that are dictated by the standard. It also reduces the possibility of inadvertent errors when composing WiMedia signals.

RFXpress can program a wide latitude of WiMedia signal features. For example, though WiMedia defines RF



▶ **Figure 19.** *RFXpress offers both general purpose multi-channel modulation synthesis and standards based synthesis like WiMedia's UWB signals.*

band-groups and center frequencies, Tektronix realizes many engineers may wish to test at IF. RFXpress allows the user to define signals at IF frequencies as well as the standard RF frequencies adopted by WiMedia that are within the AWG's capability.

RFXpress's flexibility in configuring WiMedia signals extends far beyond output frequency. Many UWB parameters can be defined at the packet group level.

WiMedia UWB signals use a complex PLCP Protocol Data Unit (PPDU) that define the protocol needed for transmission. The The PLCP Preamble, PLCP Header and PSDU make up the PLCP Protocol Data Unit (PPDU). The PLCP includes a preamble for packet synchronization and channel estimation as well as a PLCP header for PHY characteristics, such as rate, packet length, Media Access Controller (MAC) information, encoding and other signal protocol properties. The PSDU portion of the packet includes the data payload, among other functions such as tail bits and pad bits.

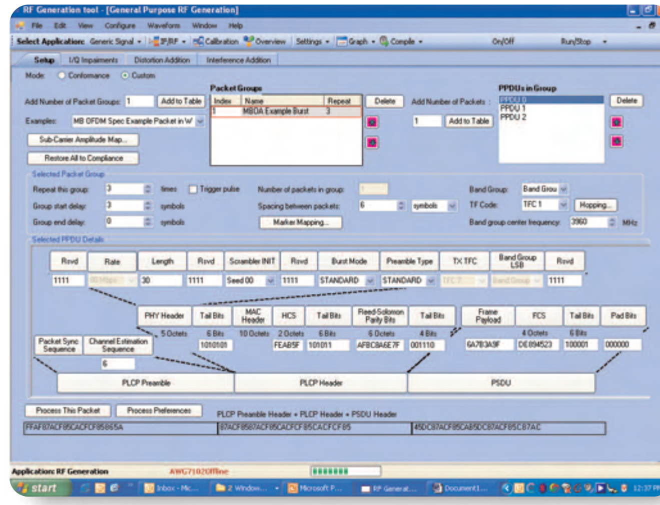
RFXpress enables extensive control of PLCP and PSDU elements to generate waveforms from the digital packet group level. Test engineers can easily create different packets to test functional performance of WiMedia devices with a simple graphical PPDU interface that includes a visual pattern indicator and Hexadecimal display of the packet to be sent. Additionally, one can select and graphically view all TFC codes along with the spacing between packets.

RFXpress provides the flexibility to create complete stimulus packets for the Device Under Test (DUT), including setting the MAC header and data payload. Even OFDM tone nulling is possible, allowing independent flexibility of the power level of each carrier. To test basic acquisition circuits and equalizers, RFXpress also has the ability to generate only the WiMedia preamble without the PLCP header and data payload, which is helpful in certain troubleshooting scenarios.

The ability of UWB modulations to robustly withstand signal impairments is an important capability many UWB applications rely upon. To evaluate the performance of UWB devices it is often desirable to provide stimulus signals with added impairments.

RFXpress will not only generate complicated WiMedia MB-OFDM signals, but it can add common signal impairments. With the ability to add signals digitally, both in-band and out-of-band interferers of all types can be synthesized and added to the desired signal to access the robustness of RF data links. Similarly, gated noise can be added to signals at exactly the right timing. Even distortion and I–Q Impairments can be added to test receiver performance with less than perfect transmitters to assure RF interoperability.

Achieving a flawless air interface between RF devices can be challenging. One way to accomplish this is to record the UWB RF transmissions from a host of wireless devices in different environments, and then play them back to the targeted wireless device to evaluate its response.



▶ **Figure 20.** *RFXpress can synthesize WiMedia packet waveforms from the packet group level controlling PLCP preamble, header and PSDU data payload.*

With both custom and in-depth compliance synthesis of digital waveform files for playback on the AWG, RFXpress is clearly a powerful waveform synthesis tool.

Efficient Interference Testing

Testing a UWB receiver's interference susceptibility has been cited as a significant challenge by test experts, so let's take a closer look at this issue. The large bandwidth a UWB signal covers 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.

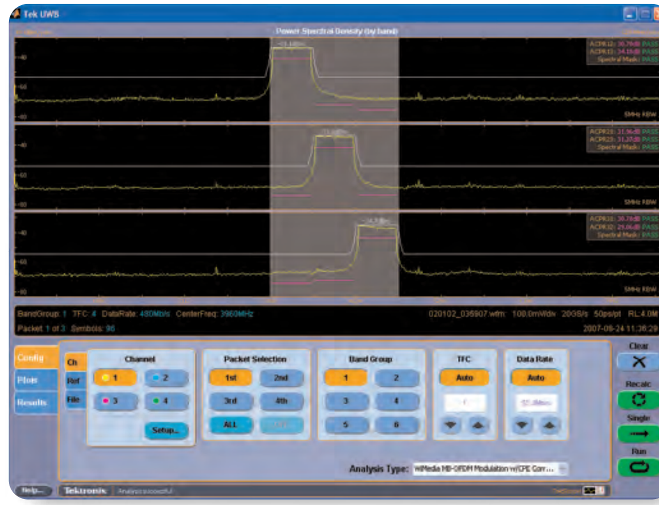
Simulating harsh interference-filled spectral environments that encompass large bandwidths can be expensive. The conventional approach of summing multiple signal sources together in order to generate a realistic interference environment typically requires a significant investment in signal sources.

A better approach to creating interference test signals is to use the AWG's ultra wide bandwidth and unique software tools like RFXpress to synthesize an entire spectral environment with a single AWG source.

A complex array of narrowband spectral interferers can be generated at random in RFXpress and stored in the AWG. Playing an entire spectral environment back along with the desired UWB signal from a single AWG source makes it easy to judge the effectiveness of design improvements on interference susceptibility.

RFXpress also controls Tektronix high-speed oscilloscopes, thus enabling broadband signal capture and playback. This allows precise playback of 'off-air' spectral environments to evaluate the performance of different designs under controlled conditions that replicate real world spectral environments.

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



▶ **Figure 21.** *The spectral mask for each band of the WiMedia band group along with the ACPR measurements are simultaneously tested on the DPO7000 series oscilloscope with UWB application software.*

UWB Spectrum Measurements

UWB spectral measurements present some unusual challenges for development and test engineers.

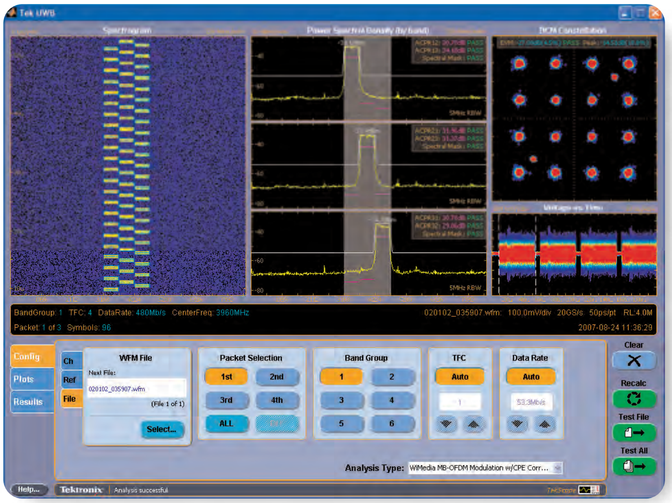
Highly integrated UWB devices often allow spectral measurements to be taken only from radiated signals. Internal test point connections may not exist or may not reflect the attenuation characteristics of an ultra-broadband antenna. Adding to these issues, the transmit signal is likely to be near the noise floor, requiring a very sensitive spectrum analyzer or external preamplifier.

Regulatory requirements for UWB signals dictate a 50 MHz spectrum measurement resolution bandwidth. UWB signals cover large swaths of spectrum and some of the licensed channels contained in this spectrum can be up to 50 MHz wide. Thus, RBWs of 50 MHz are needed to accurately access the potential for interference. This requirement eliminates many popular spectrum analyzers as only a few have internal bandwidths this wide.

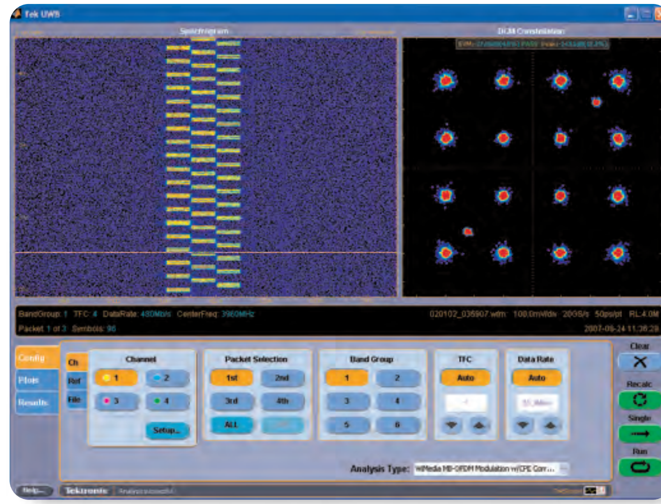
Oscilloscopes usually lack the dynamic range of the typical spectrum analyzer, making setup for some measurements more cumbersome. However, high-speed oscilloscopes like the Tektronix DPO7000 series have internal Fast Fourier Transform (FFT) capability that can generate spectral emission plots from the time domain signal capture. Further, the Tektronix DPO7000 oscilloscopes feature the UWB software that enables automatic spectral mask measurement for WiMedia UWB signals.

The UWB analysis software automatically identifies the TFC of the signal and selects the correct spectral mask to apply. The software then determines if the signal passes or fails the mask and measures the total integrated channel power.

Once a compliant UWB output spectrum is achieved, the next measurement concern is usually optimizing the modulation performance.



▶ **Figure 22.** *The DPO7000 oscilloscope and UWB analysis software automatically identifies the TFC of this MB-OFDM spectrogram as part of a complete set of measurements and plots for each analyzed packet.*



▶ **Figure 23.** *UWB analysis software measures the constellation of a single OFDM carrier as well as EVM, data rate and center frequency.*

UWB Modulation Measurements

WiMedia's MB-OFDM UWB modulation is complex and presents several challenges when characterizing performance.

Unlike many narrow band modulations that rely on outstanding component performance over narrow frequency ranges, UWB signals can be distorted by ultra-wideband component characteristics. For example, amplitude flatness, group delay variations and frequency hopping glitches can all degrade valuable link performance. Detecting these and other problems from a multi-band signal requires capabilities far beyond simply capturing the time domain waveform.

To begin with, the appropriate TFC for the given WiMedia signal to be tested must be identified. Identification of the correct code can be difficult if the operational mode of the device under test is not known. Fortunately, the Tektronix UWB analysis software takes the DPO7000 captured waveform and identifies the TFC for the signal, hopping sequence and data rate automatically. The UWB software and DPO7000 oscilloscope have sufficient bandwidth to identify MB-OFDM signals in all WiMedia band groups, simplifying testing of devices that might be bound for any region of the world.

The UWB analysis software then allows viewing of detailed modulation measurements. The software has powerful frequency domain capabilities and can determine if the signal passes or fails each of the three spectral masks. It also measures Adjacent Channel Power Ratio (ACPR) independently for each band in the band group, as well as number of mask hits in a band group, and number of mask hits out of band group.

After spectral compliance is determined, modulation quality can be accessed with Error Vector Magnitude (EVM), Peak EVM, data rate, center frequency, number of data symbols and Common Phase Error (CPE).

The UWB Error Vector Magnitude (EVM) computation is more complex than traditional continuous wave measurements. UWB EVM includes an initial Channel Estimation (CE) using the CE symbols to provide a phase and timing estimation. This allows corrections to be applied to the pilot tones frequency offset estimation for more precise measurements by simply selecting the CPE analysis type.

The Tektronix UWB analysis software can simply and easily measure complex UWB signal attributes to design and produce leading products.

Conclusion

As illustrated, UWB technology offers many benefits. High-speed connections, interference protection and simple hardware architectures are a few of the characteristics that are propelling the rapid growth of UWB devices. TH-UWB, DS-UWB and MB-OFDM techniques are reshaping short-range high-speed wireless data links and radars.

The measurement challenges of UWB are often very demanding; bandwidth requirements alone eliminate many test instruments. Tektronix, however, supports UWB design and production with AWG signal generators that are capable of producing UWB signals, additive impairments and broadband interference test spectrums.

Generating waveforms for playback on the AWG can be done using the RFXpress waveform synthesis tool that enables easy programming of complex waveforms. Signals like WiMedia's MB-OFDM can be quickly assembled from simple choices at the protocol bit level. RFXpress can also control Tektronix oscilloscopes for unmatched 'off-air' signal recording and playback bandwidth that is ideal for testing RF interfaces.

Tektronix real-time oscilloscopes complement the AWG signal sources. The DPO oscilloscopes offer not only the bandwidth to capture UWB signals, but a unique set of UWB modulation measurements on popular WiMedia signals. The UWB analysis software provides unmatched insight into MB-OFDM signal performance.

Testing UWB devices takes state of the art measurement instruments. Fortunately, advanced testing of UWB signals is now easier than ever with the right ultra-wideband tools. See how Tektronix continues to lead the industry in UWB test solutions by arranging for a demonstration today…

Contact Tektronix:

ASEAN / Australasia (65) 6356 3900
Austria +41 52 675 3777
Balkan, Israel, South Africa and other ISE Countries +41 52 675 3777
Belgium 07 81 60166
Brazil & South America (11) 40669400
Canada 1 (800) 661-5625
Central East Europe, Ukraine and the Baltics +41 52 675 3777
Central Europe & Greece +41 52 675 3777
Denmark +45 80 88 1401
Finland +41 52 675 3777
France +33 (0) 1 69 86 81 81
Germany +49 (221) 94 77 400
Hong Kong (852) 2585-6688
India (91) 80-22275577
Italy +39 (02) 25086 1
Japan 81 (3) 6714-3010
Luxembourg +44 (0) 1344 392400
Mexico, Central America & Caribbean 52 (55) 5424700
Middle East, Asia and North Africa +41 52 675 3777
The Netherlands 090 02 021797
Norway 800 16098
People's Republic of China 86 (10) 6235 1230
Poland +41 52 675 3777
Portugal 80 08 12370
Republic of Korea 82 (2) 6917-5000
Russia & CIS +7 (495) 7484900
South Africa +27 11 206 8360
Spain (+34) 901 988 054
Sweden 020 08 80371
Switzerland +41 52 675 3777
Taiwan 886 (2) 2722-9622
United Kingdom & Eire +44 (0) 1344 392400
USA 1 (800) 426-2200
For other areas contact Tektronix, Inc. at: 1 (503) 627-7111
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