ISSN 2229-5518

Analysis and Future Approach of Ultra Wideband Technology

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Abstract— Ultra-wideband (UWB) technology is a revolutionary wireless technology used to transmit large amounts of digital data short distances (up to 230 feet) over a very wide bandwidth (from 1 gigahertz [GHz] up to 10 GHz [17]) and at very low power levels (less than 0.5 milliwatt). Unlike typical radio frequency broadcasts that use continuous sine waves to transmit data, UWB uses precisely positioned pulses at specific time intervals to transmit the signals across a wide spectrum. 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) [1] 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 Technical note we explain the concepts behind UWB technology, its unique hardware and software architectures, and future applications.

Index Terms— Arbitrary Waveform Generators, Digital Phosphor Oscilloscopes, Narrowband Communication, Power Spectral Density, Radio Free technology, Ultra Wideband, Universal Serial Bus.

1 INTRODUCTION

Ultra Wideband was traditionally accepted as pulse radio, but the FCC and ITU-R now define UWB in terms of a transmission from an antenna for which the emitted signal bandwidth exceeds the lesser of 500 MHz or 20% of the center frequency. Ultra wideband (also known as UWB or as digital pulse wireless) is a wireless technology for transmitting large amounts of digital data over a wide spectrum of frequency bands with very low power for a short distance. UWB uses precisely positioned pulses at specific time intervals to transmit the signals across a wide spectrum [7].(Figure 1.)

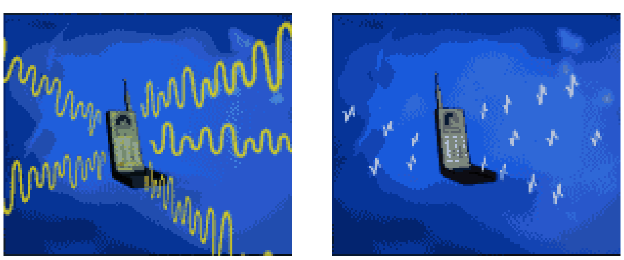

Figure1. Continuous Sine Waves vs. Time Modulated Pulses

Ultra wideband radio not only can carry a huge amount of data over a distance up to 230 feet at very low power (less than 0.5 milliwatts), but has the ability to carry signals through doors and other obstacles that tend to reflect signals at more limited bandwidths and a higher power.Ultra wideband can be compared with another short-distance wireless technology, Bluetooth, which is a standard for connecting handheld wireless devices with other similar devices and with desktop computers.

Ultra wideband broadcasts digital pulses that are timed very precisely on a carrier signal across a very wide spectrum (number of frequency channels) at the same time. Transmitter and receiver must be coordinated to send and receive pulses with an accuracy of trillionths of a second. On any given frequency band that may already be in use, the ultra wideband signal has less power than the normal and anticipated background noise so theoretically no interference is possible. Time Domain, a company applying to use the technology, uses a microchip manufactured by IBM to transmit 1.25 million bits per second, but says there is the potential for a data rate in the billions of bits per second.

2 CONCEPT

This concept doesn't stand for a definite standard of wireless communication (the standard is being developed now is still far from completion); this is a method of modulation and data transmission which can entirely change the wireless picture in the near future. Before going on future view let's take a look at the diagram that demonstrates the basic principle of the UWB:

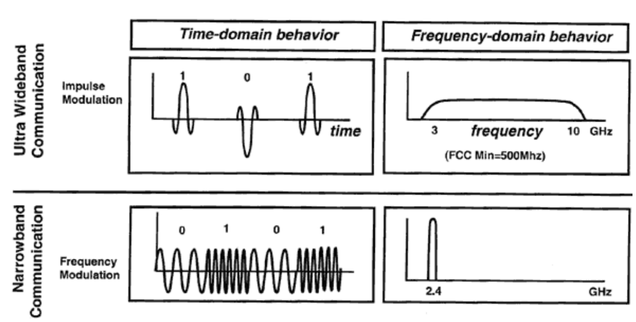

Figure 2: an approach on Narrowband and UWB Communication

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The UWB is above and the traditional modulation is below which is called here Narrow Band (NB), as opposed to the Ultra Wideband. On the left we can see a signal on the time axis and on the right there is its frequency spectrum, i.e. energy distribution in the frequency band. The most modern standards of data transmission are NB standards - all of them work within a quite narrow frequency band allowing for just small deviations from the base (or carrier) frequency. Below on the right you can see a spectral energy distribution of a typical 802.11b transmitter. It has a very narrow (80 MHz for one channel) dedicated spectral band with the reference frequency of 2.4 GHz. Within this narrow band the transmitter emits a considerable amount of energy necessary for the following reliable reception within the designed range of distance (100 m for the 802.11b). The range is strictly defined by FCC and other regulatory bodies and requires licensing. Data are encoded and transferred using the method of frequency modulation (control of deviation from the base frequency) within the described channel.

Now take a look at the UWB - here the traditional approach is turned upside down. In the time space the transmitter emits short pulses of a special form which distributes all the energy of the pulse within the given, quite wide, spectral range (approximately from 3 GHz to 10 GHz). Data, in their turn, are encoded with polarity and mutual positions of pulses. With much total power delivered into the air and, therefore, a long distance of the reliable reception, the UWB signal doesn't exceed an extremely low value (much lower than that of the NB signals) in each given spectrum point (i.e. in each definite licensed frequency band). As a result, according to the respective FCC regulation, such signal becomes allowable although it also takes spectral parts used for other purposes:

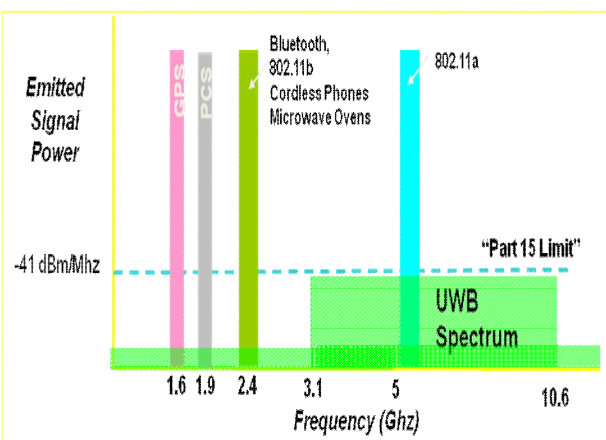

Figure 3: Different Standards in terms of Emitted Signal Power

So, the most part of energy of the UWB signal falls into the frequency range from 3.1 to 10.6 GHz, and the energy spectral density doesn't exceed the limit determined by the Part 15 of the FCC Regulations (-41dBm / MHz). Below 3.1 GHz the signal almost disappears, its level is lower than -60. The more ideal the form of a pulse formed with the transmitter, the less the energy goes out of the main range. But however that may be, the permissible deviation of the pulse from the ideal form must be limited, hence the second purport. The spectral range lower than 3.1 GHz is avoided not to create problems for GPS systems whose accuracy of operation can suffer a lot from outside signals even if their density is lower than -41. That is why 20 dBm (up to -60) were reserved in addition at the spectral range up to 3.1 GHz; it is not obligatory but it seems to be welcomed by military bodies.

The total energy of the transmitter which can fit into this band is defined by the area of the spectral characteristic (see filled zones on the previous picture). In case of the UWB it's much greater compared to the traditional NB signals such as 802.11b or 802.11a [14]. So, with the UWB we can send data for longer distances, or send more data, especially if there are a lot of simultaneously working devices located close to each other.

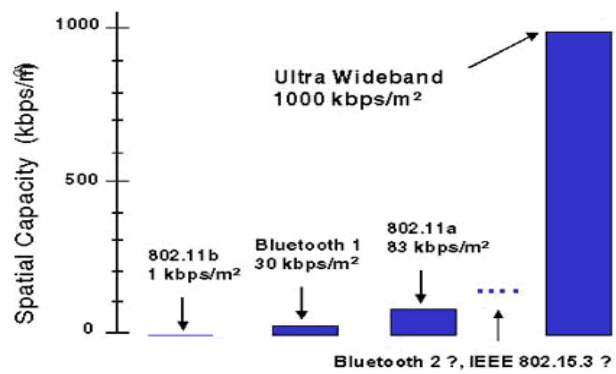

Figure 4: Spatial Capacity Comparison

A The UWB actually tries to solve the problem of inefficient spectrum utilization, like the Hyper Threading solves the problem of idle time of functional processor units. Frequency bands dedicated for different services remain unused for the most part of time - even in a very dense city environment - at each given point of time the most part of the spectrum is not used, that is why the radio spectrum is used irrationally:

1. Most frequencies are not used all the time. That is a low frequency effectiveness of the spectrum utilization.
2. Guard channels necessary for NB modulations (gaps between channels to eliminate pickups). That is a low frequency effectiveness of the spectrum utilization.
3. Excessive and, as a rule, uncontrolled power of transmission (and, therefore, transmission range) of signals even if a distance is quite short. That is a low spatial effectiveness of the spectrum utilization.

Whatever direction we are looking into nothing seems to be good - so, it's high time to start improving methods of radio communication and division of the air. In case of the NB a frequency and width of the dedicated spectral range for the most part (though the real situation is much more complicated) defines a bandwidth of the channel, and the transmitter's power defines a distance range. But in the UWB these two concepts interwine and we can distribute our capabilities between the distance range and bandwidth. Thus, at small distances, for example, in case of an interchip communication, we can get huge throughput levels without increasing the total trans-

ISSN 2229-5518

ferred power and without cluttering up the air, i.e. other devices are not impeded. Look at how the throughput of data transferred in the UWB modulation depends on distance:

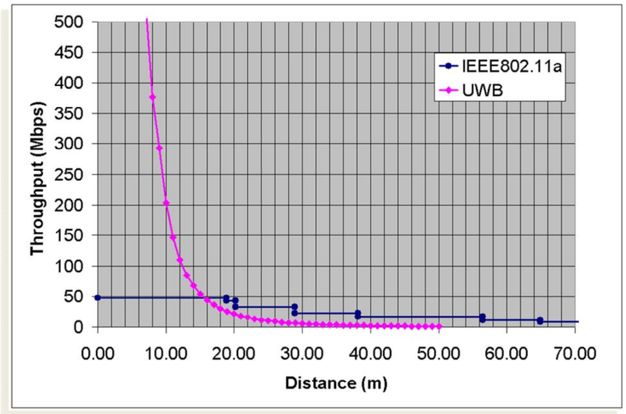

Figure 5: Throughput vs Distance

While the traditional NB standard 802.11a uses an artificially created dependence of throughput on distance (a fixed set of bandwidths discretely switched over as the distance increases), the UWB realizes this dependence in a much more natural way. At short distances its throughput is so great that it makes our dreams on the interchip communication real, but at the longer distances the UWB loses to the NB standard. Why? On the one hand, a theoretical volume of the energy transferred, and therefore, the maximum amount of data, is higher. On the other hand, we must remember that in a real life information is always transferred in large excess. Beside the amount of energy, there is the design philosophy which also has an effect. For example, a character of modulation, i.e. how stably and losslessly it is received and detected by the receiver.

3 Transmitter and Receiver Configurations

The earliest radio transmissions by Marconi were UWB in the sense that Marconi's spark-gap transmitter in effect generated short pulses and occupied a relatively large bandwidth, but means for using spreading gain to enable multiple access were not available. Soon after the potential of radio as a medium for communication was understood, efficient methods for sharing the medium were sought and found that involved heterodyning and narrowband, tuneable transmitters and receivers. An example super heterodyne receiver diagram is given in Figure 6. that features double conversion to reject harmonic images of the signal that are unwanted by products of the heterodyning (multiplication) operations. With the proliferation of narrowband wireless devices today and the continual development of new devices for the wireless market, the trend is for the transmitters and receivers to become smaller and simpler.

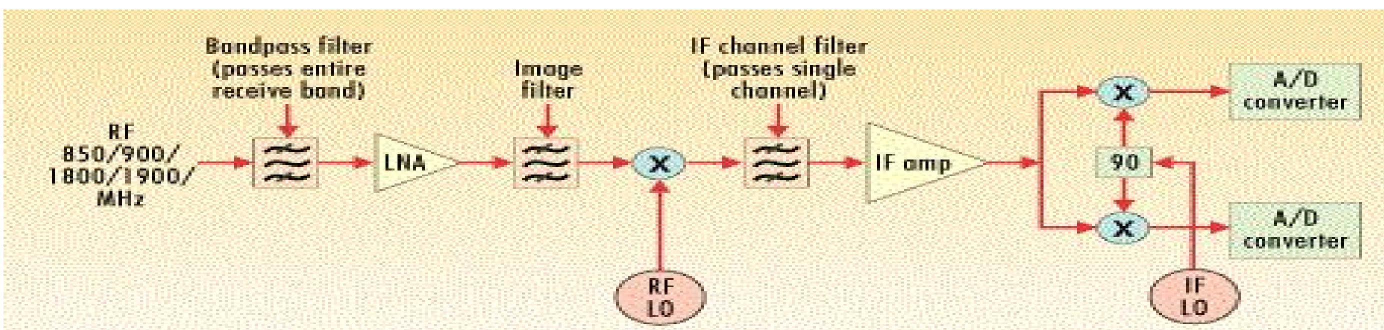

Figure 6: Double-conversion super heterodyne receiver

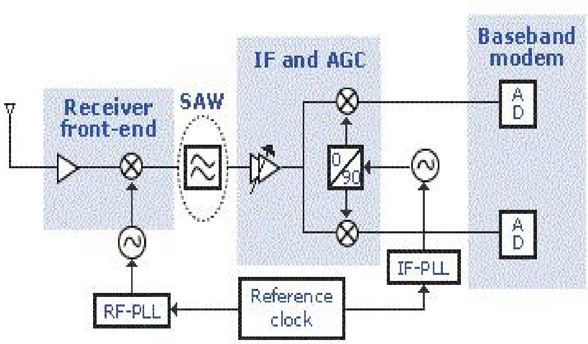

Figure 7: Typical Digital Heterodyne receiver

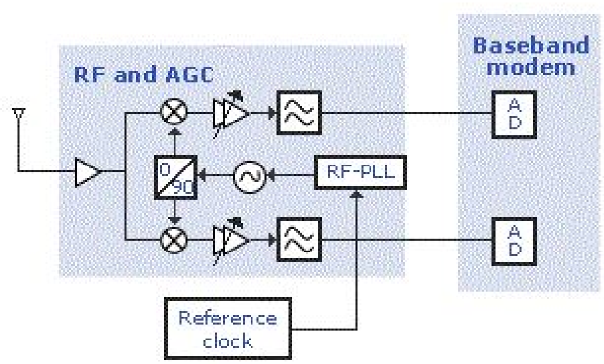

Figure 8: single-chip direct conversion receiver (right) that integrates RF and IF without a SAW filter

Figure 9: Concept of UWB baseband system implementation

For example, Figure 7 shows a typical digital heterodyne receiver using a surface acoustic wave (SAW) filter and a "one chip" receiver based on direct conversion to baseband that does not require the SAW filter. As such advances in digital processing became cheaper and more efficient; the use of UWB waveforms in radar and communication applications also has become feasible.

Ideally in carrierless (baseband) transmission, as illustrated in Figure 8, the radio system can operate without local oscillators and the sometimes complex filtering needed to control emissions and spurious radiations that accompany heterodyning. It is almost, but not quite, as simple as utilizing the same kind of transmissions as those that are unintentionally emitted by the printed circuit board of digital devices, with the antenna connecting directly to the integrated circuit containing the baseband processing logic.

4 UWB Applications

UWB technology can enable a wide variety of WPAN applications. Examples include:

■ Replacing cables between portable multimedia CE devices, such as camcorders, digital cameras, and portable MP3 players, with wireless connectivity

■ Enabling high-speed wireless universal serial bus (WUSB) connectivity for PCs and PC peripherals, including printers, scanners, and external storage devices

■ Replacing cables in next-generation Bluetooth Technology devices, such as 3G cell phones, as well as IP/UPnP-based connectivity for the next generation of IP-based PC/CE/ mobile devices

■ creating ad-hoc high-bit-rate wireless connectivity for CE, PC, and mobile devices

5 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.

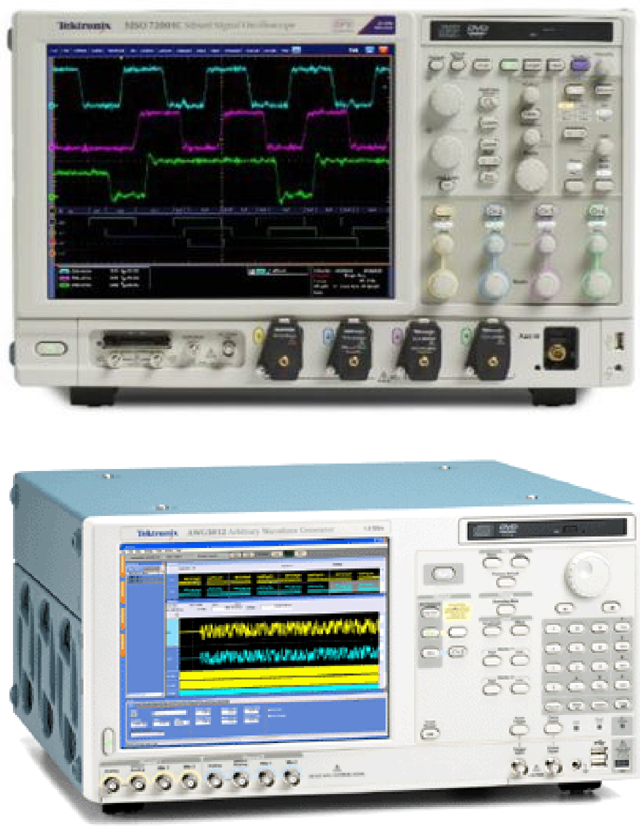

Figure 10: Typical Instruments like AWG7000 series and DPO70000 can generate and capture complex ultra-wideband signals.

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.

6 Technology Considerations

For UWB technology to become a widely adopted radio solution, a few key areas need to be resolved:

■ Interoperability
■ Ease of product integration and certification
■ Overall solution cost (to the OEM)
■ Global spectrum allocation

Many Industries are addressing a number of these issues through investment strategies, research, participation in wired and wireless communications initiatives, and product development. Some are also developing protocols that will take full advantage of the strengths of UWB technology. The WUSB specification developed through the Wireless USB Working Group and the UPnP work done through the Digital Home Working Group (DHWG) is examples of industrial contributions.

7 The Future: Radio Free

UWB Technology envisions a future in which all devices are connected by smart radios. The vision is called Radio Free, and it embodies the concept of a smart radio that can reprogram and reconfigure itself based on available spectrum, the desired application, and the device at hand. Configurations would include an 802.11 radio for communicating with a WLAN hotspot, a Bluetooth Technology radio for communication with a cell phone, or a UWB radio for participation in a WPAN. To promote this vision, it is involved in all areas of the RF space. In wireless wide area networks (WWAN), it could be the case of WiMAX. Now, with support of UWB technology for the WPAN space, the concept of Radio Free technology is one step closer to reality.

8 Conclusion

UWB and the associated networking protocol efforts are in the early stages of development, and several key deployment scenarios are being defined and evaluated. UWB complements currently deployed wireless networks in the WLAN environment, plus it extends high bit-rate, multimedia connectivity to WPANs supporting PC, CE and cellular devices. This combination will enable true convergence of computers, consumer electronics and mobile communications. A common radio platform that connects seamlessly with the existing networking protocols and cost effectively enables connectivity solutions among CE peripherals will shift the home entertainment environment. It will enable multiple usage models from cable replacement to the streaming of video, audio, and other entertainment media [3]. Many UWB components and systems are already in the testing and demonstration phases, with actual release dates for final consumer products expected in early 2005. Many Corporations are working with the industry to enable this exciting technology and help ensure its success.

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