Ultra Wideband Technology Update at Spring 2003 IDF

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Overview

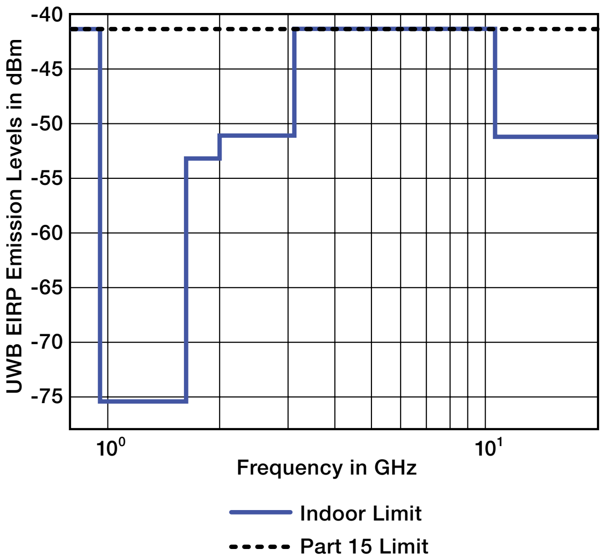
On February 14, 2002, the United States Federal Communications Commission (FCC) adopted the First Report and Order that permitted the marketing and operation of certain types of new products incorporating ultra wideband (UWB) technology. This rule change allows the use and subsequent study of commercial ultra wideband communications equipment. This governmental act, to enable the commercialization of ultra wideband technology, has created a great deal of interest in the wireless community.

Much of the industry's focus on UWB research and development during 2002 has centered on standardization. UWB represents fresh opportunities with respect to defining a new standardized physical interface for wireless technology. To a great degree, the success of UWB is in the hands of the industry. With much interest and many different industry views, there will be many proposed approaches to the standardization of UWB. Choosing a single worldwide universal standard that can coexist peacefully with existing spectrum users (other RF technologies) while providing scalability for future technologies will be the most important step in ensuring the success and future of UWB.

This article will explore UWB technology, some of the opportunities it presents, and some of the challenges that lie ahead. A more thorough ultra wideband discussion on these topics will be presented this February at Spring 2003 IDF (Intel Developer Forum) in San Jose, California.

What is UWB (Ultra Wideband) Technology?

UWB is defined as any radio technology having a spectrum that occupies a bandwidth greater than 20 percent of the center frequency or a bandwidth of at least 500 MHz. The FCC spectral mask (operating restrictions for UWB in the U.S.) specifies 7.5 GHz of usable spectrum bandwidth between 3.1 GHz and 10.6 GHz for communications devices (different masks exist for imaging and vehicular radar applications). To protect existing users operating within this spectrum, UWB transmit power is limited. UWB signals may be transmitted at power spectral density levels up to–41dBm/MHz. **Figure 1** shows the usable spectrum permitted under Part 15 of the Commission's rules. The primary difference between indoor and outdoor operation is the higher degree of attenuation required for the out-of-band region for outdoor operation. This further protects GPS receivers, centered at 1,600 MHz.



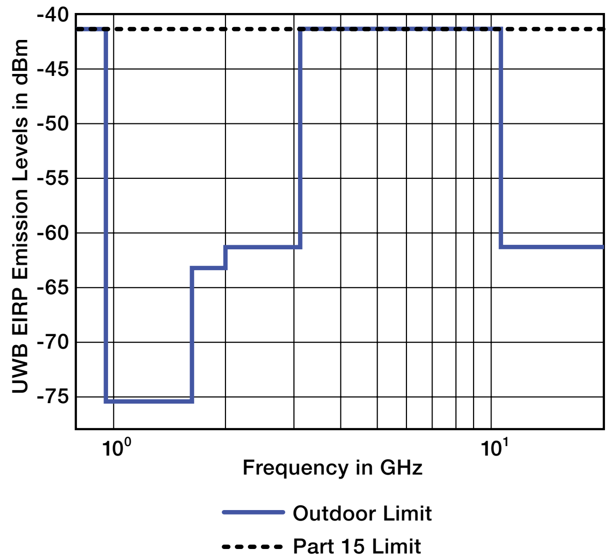


Figure 1. FCC Part 15 Spectral Mask

UWB differs from narrowband technology where single-frequency or multiple single-frequency carrier waves are used for information modulation. Ultra wideband transmission uses impulses to modulate information across a very wide frequency spectrum. Impulse duration, in the time domain, determines the bandwidth occupied in the frequency domain [1/duration ~ bandwidth].

UWB offers many advantages over narrowband technology where certain applications are involved. Improved channel capacity is one major advantage of UWB. The channel is the RF spectrum within which information is transferred. Shannon's capacity limit equation shows that increasing channel capacity requires linear increases in Bandwidth while similar channel capacity increases would require exponential increases in power.

Shannon's Capacity Limit Equation:

$$C = BW*\log 2\,(1+SNR)$$

C = Channel Capacity (bits/sec)
BW = Channel Bandwidth (Hz)
SNR = Signal to noise ratio

Where SNR = P/BW*No

P = Received Signal Power
No = Noise Power Spectral Density (watts/Hz)

This is why UWB technology is capable of transmitting very high data rates using very low power. **Figure 2** compares practical UWB implementations with present wireless technologies.

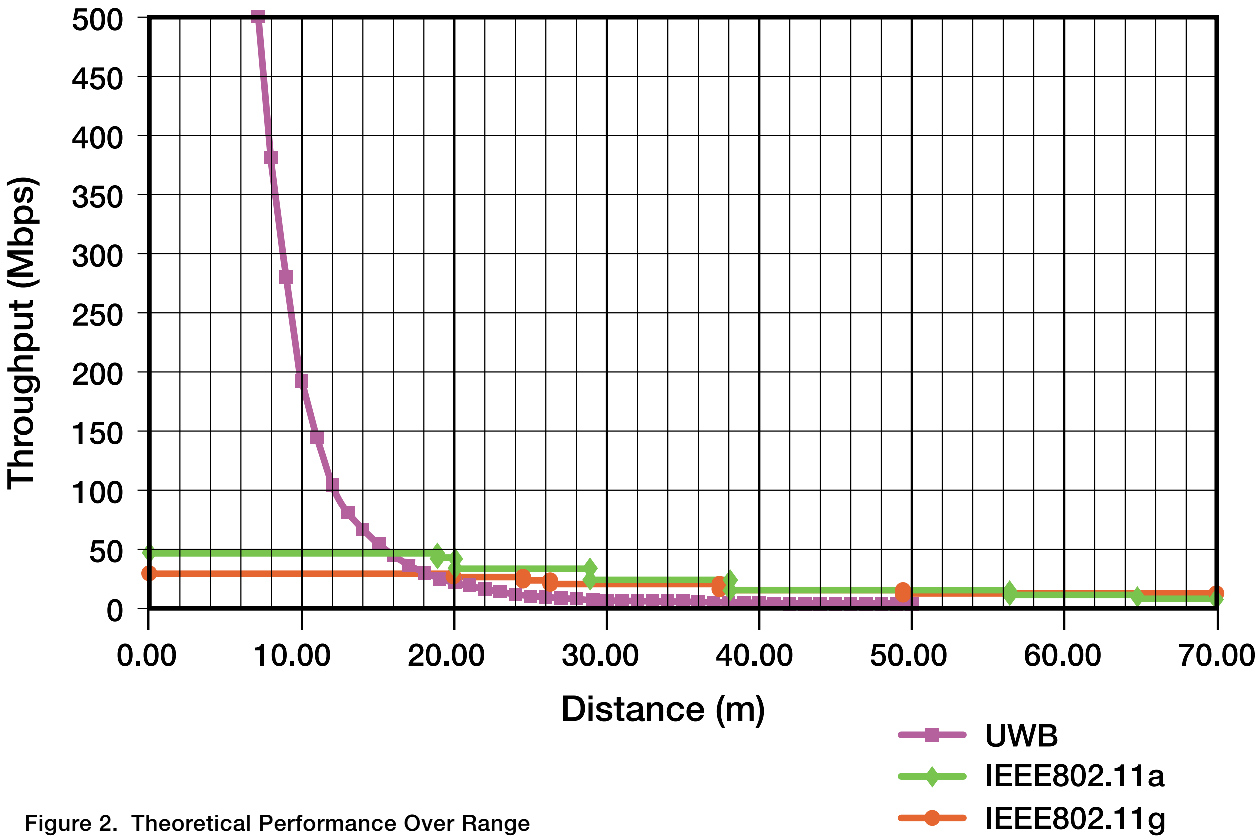


Figure 2. Theoretical Performance Over Range

It is important to notice that while UWB may provide dramatic channel capacity, it can do so only at limited range. This is due mainly to the low power levels allowed by the FCC for legal UWB operation. UWB technology, when used for high-rate applications, is most useful at short-ranges (less than 10 meters). Longer-range flexibility is better served by WLAN (wireless local area network) technologies like 802.11a.

Coexistence and Sharing Spectrum

As stated earlier, the FCC spectral mask specifies 7.5 GHz of usable spectrum (between 3.1 GHz and 10.6 GHz), which is shared with existing radio solutions. When the FCC adopted new Part 15 rules permitting the marketing and operation of products incorporating UWB, it was felt that initial restrictions were quite conservative and that some relaxing may be possible once UWB was better understood by the industry.

Although UWB out-of-band attenuation requirements are quite restrictive and average in-band power levels are kept very low, interference is still a concern where certain applications are involved. Testing performed by the FCC determined 2–3 meters or greater was adequate for interference separation. This is true for applications typically unrelated to short-range communications like satellite and radar.

However, personal computing and consumer entertainment applications may require closer device proximity for use models. The most obvious technology that will need to coexist at close proximity to UWB is WLAN, since the allocated spectrum for UWB completely overlaps the 5 GHz U-NII bands. Personal computers and possibly consumer electronic equipment may employ both Wireless LAN and UWB peripheral connectivity. This implies the possibility of UWB-connected peripherals in very close proximity to networked systems (within 1 meter, for example) using 802.11a in the 5 GHz spectrum.

Studies performed by Intel and the IEEE (Institute of Electrical and Electronics Engineers) have determined that some form of interference mitigation will be required for these types of scenarios to succeed. UWB technology is expected to share the approved spectrum with existing technologies. It will be the responsibility of the industry (through the establishment of responsible standards) to avoid interference with existing spectrum users if UWB is to be successful. The multi-band modulation scheme shown below, which is currently part of a focused research project within the Intel research and development network, is an example of a UWB waveform design that can coexist with IEEE 802.11a at very close ranges.

Ultra Wideband Design Opportunities

UWB represents fresh opportunities with respect to defining a new standardized physical interface for wireless technology. With much interest and many different industry views, there will be many proposed approaches to the standardization of UWB. Choosing a single worldwide universal standard that can coexist peacefully with existing spectrum users while providing scalability for future technologies will be the most important step in ensuring the success and future of UWB. The following sections give a high-level overview of a couple of different approaches to UWB waveform design that take advantage of the FCC allocation for UWB devices.

UWB Modulation

Single impulse generation is the traditional approach for generating UWB waveforms (see **Figure 3**). By varying the impulse *chakracteristics*, the characteristics of the energy in the frequency spectrum may be defined. There are three parameters of interests when defining the properties of energy filling a specified frequency spectrum. The first is in defining the intended bandwidth of the transmitted energy. The second is in limiting energy to within the specified spectrum. The third is defining where generated energy should center within the spectrum of interest (i.e., center frequency). Impulse duration, in the time domain, determines bandwidth in the frequency domain [1/duration ~ bandwidth].

Impulse frequency is one characteristic that may determine the center frequency of a band of transmitted energy. Impulse shape determines the characteristics of how the energy occupies the frequency domain. Traditional impulse technology is designed to use required bandwidth with respect to the intended application. Where highest performance is the objective, as much bandwidth as is practical will be used to take advantage of the capacity made available when bandwidth is very large.

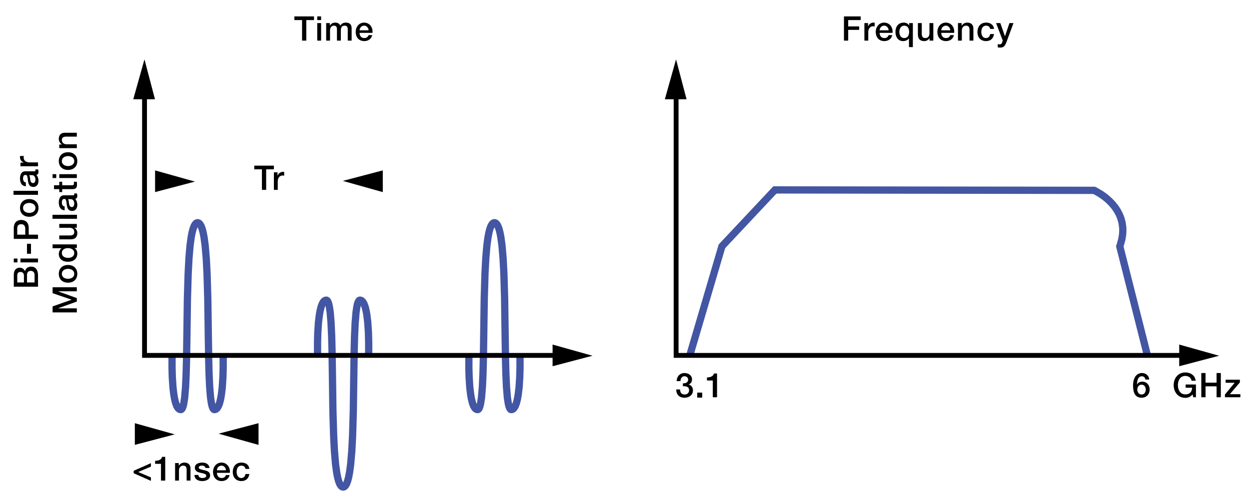


Figure 3. Single Impulse 180-Degree Phase Modulation

As with traditional radio architectures, data can be modulated on the impulses in a number of ways, including amplitude, phase, time position, or any combination of these.

Single impulse architectures offer relatively simple radio designs, but provide little flexibility where spectrum management is an objective. Examples of scenarios where managing the spectrum might be desirable are: matching different regulatory requirements in different international regions, dynamically sensing interfering technologies and suspending usage of contending frequencies, or choosing to use narrower bands of spectrum to either share spectrum in a local area or to enable lower cost devices that don't require large bandwidth for a specific application.

Another area where managing the spectrum might be desirable is in managing performance. Increasing the performance of existing designs may require completely redesigning a radio for higher performance implementations, forgoing backward compatibility with earlier implementations. These considerations have led Intel to investigate the feasibility of a more flexible multi-band approach, which is described next.

Multi-band modulation

Multi-band modulation is another approach to modulating information with wideband technology. Multi-band UWB modulation provides a method where the 7.5 GHz of new spectrum may be split into multiple smaller frequency bands. This could be accomplished by choosing to implement a few large bands or many small bands, all of which would be stacked across the legally available frequency spectrum.

As stated previously, ultra wideband technology uses impulses to modulate information over a wide band of frequencies. Impulse shape is the primary characteristic that determines the distribution of energy within the frequency domain, and properly shaping the impulse will concentrate more of the energy in the center lob of the energy band, reducing side lob energy and reducing chances for adjacent band interference.

To effectively fill the specified spectrum, multiple frequency bands of energy must be generated with different center frequencies and spaced across the spectrum. A method for shaping an impulse that enables center frequency definition is shown in **Figure 4**. Center frequency selection is accomplished when using a pseudo carrier oscillation in generating and shaping the required UWB impulse. The frequency of the pseudo carrier oscillation determines the center frequency of the band, while the impulse shape as prescribed by the outline of the oscillation defines the impulse shape, and thus defines the bandwidth.

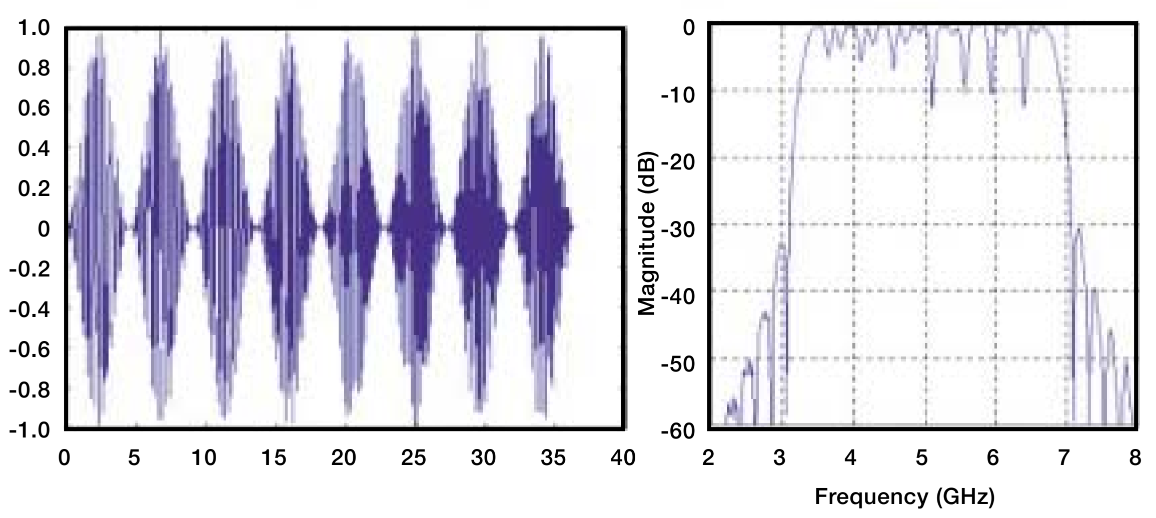


Figure 4. Eight Frequency Bands (time domain left, frequency domain right)

There are several advantages when using multi-band UWB modulation. One advantage is the ability to efficiently use the entire 7.5 GHz of new spectrum made available by the FCC. Choosing appropriate multi-band widths can ensure full usage of the entire spectrum. **Figure 4** shows how multiple bands of wideband energy might efficiently fill the specified spectrum. Notice rapid attenuation at the band edges.

Another compelling advantage is that separate bands stacked across the available spectrum may be treated independently, creating a new level of flexibility for UWB.

Coexistence and interference are other interesting areas that could benefit from a multi-band approach. UWB will be expected to share the approved spectrum with existing technologies. It is important first to protect existing technologies (UWB interfering with narrowband) using mitigation techniques. Overlay concepts must then be developed to ensure UWB is robust (narrowband interfering with UWB). It will be the responsibility of UWB developers to avoid interference with existing spectrum users if UWB is to be successful.

Some form of interference mitigation will be required for very close operation (i.e., inside 3 meters). The most obvious technology that will require coexistence next to UWB is WLAN in the 5-GHz spectrum. A multi-band implementation would be able to identify potential interference and either reduce power in the contending band or turn it off completely (see **Figure 5**).

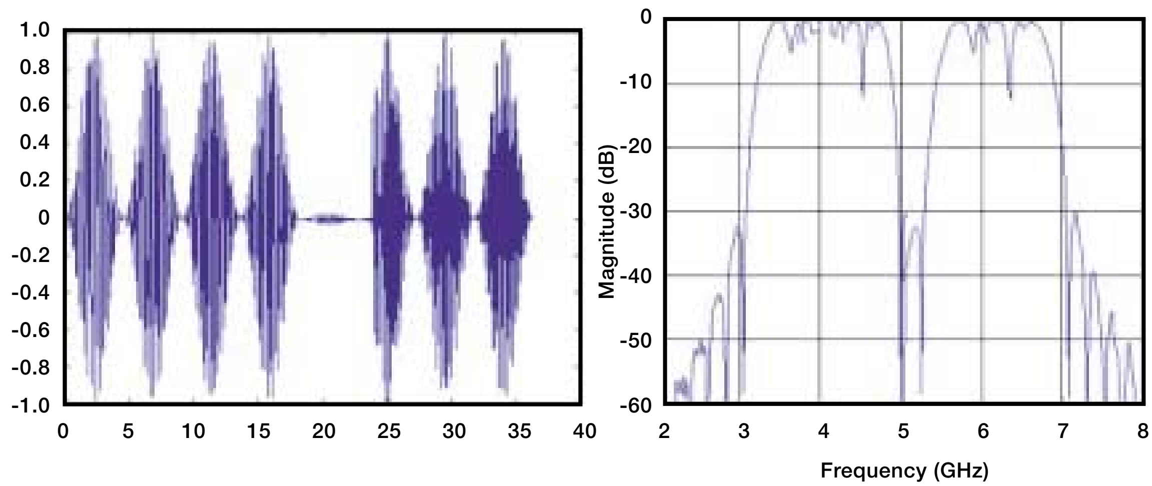


Figure 5. Eight Frequency Bands (notice the 5th band and 5 GHz range free)

Another opportunity to controlling the spectrum in this way is the ability to adapt to different environments. Different worldwide regions may have different regulatory requirements. Dynamic frequency control, made possible with multi-band modulation, could help enable global acceptance.

The ability to scale performance is yet another benefit of spectral control. Connection support could be scaled from very low-speed devices (that might use only one or two bands, keeping implementation costs down) to very high-speed devices (requiring the entire bandwidth of available spectrum). Another very compelling opportunity would be the ability to scale performance up as new spectrum becomes available while maintaining backward compatibility. Adding support for new spectrum simply requires designing additional frequency bands into the radio to support the new spectrum without impacting existing system functionality.

Summary

Currently, UWB is legal only in the United States. International regulatory bodies are considering possible rules and emission limits that would help enable worldwide operation of UWB devices. Intel is working with local regulatory efforts in Japan, Europe and China to achieve regulations similar to those provided by the FCC. Harmonized worldwide regulations would provide a significant benefit for UWB technology, allowing devices to be carried around the world without service interruption.

Many challenges exist when dealing with large bandwidths and the high instantaneous frequencies required with UWB technology. Initial implementations will be based primarily upon the SiGe (silicon germanium) process. In order to take advantage of the scalability of Moore's Law, UWB transceivers will need the advantages of CMOS integration.

At the Intel research and development network, efforts are underway to look at many aspects of UWB system and CMOS circuit design. Multi-band UWB modulation is only one area of interest. Channel compensation strategies need to be better understood to develop techniques for capturing multipath energy and guarding against intersymbol interference. Acquisition and synchronization techniques need to be developed in ways that reduce sampling rate requirements over wide signal bandwidth. And capacity considerations will further require the development of modulation, coding and multiple access schemes for achieving high data rates in multifaceted applications. Ultimately, efficient architectures for CMOS implementation must be developed to enable low-cost implementations throughout the industry.

There are many possible approaches to UWB implementation. To take full advantage of the frequency spectrum allocated by the FCC, the industry needs to agree on a single standard approach to ensure interoperability and peaceful coexistence among multiple UWB devices throughout the world. You can learn more about ultra wideband at the Spring 2003 IDF conference in San Jose this February. IDF will present a technology session to further explore ultra wideband technology and multi-band modulation and will show the first prototype of a UWB radio using multi-band modulation.

More Info

You can find out more about Intel's efforts in ultra wideband technology at the Intel Ultra Wideband site or at the Ultra Wideband Working Group Web site. An article in the Intel Technology Journal also highlights ultra wideband technology. Or, find more information about how the Intel research and development network is *Building the Wireless Tomorrow*. Learn more about the Intel Developer Forum conference at the IDF Web site.

Author Bio

James M. Wilson is a technical research engineer in the Communications and Interconnect Lab, part of the Corporate Technology Group, currently working on radio interconnect technologies for future applications. In his 20 years at Intel, he has worked on a variety of projects, including mixed signal component development and test engineering, PC chipset validations, platform development and product introductions. He received his B.S.E.E.T. in electrical engineering from DeVry Institute of Technology.

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