Intel Research & Development

Ultra-Wideband / a Disruptive RF Technology?

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Introduction

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 technology (UWB). This rule change will allow the use and subsequent study of commercial ultra-wideband communications. UWB is a new radio technology that promises to revolutionize high-speed data transfers and enable the personal area networking industry leading to new innovations and greater quality of services to the end user.

This governmental act to enable the commercialization of ultra-wideband technology has created a great deal of interest in the wireless community. This paper will provide a basic understanding of this new technology while explaining the fundamental benefits, interesting usage scenarios and industry challenges.

What is UWB (ultra-wideband) technology?

UWB is defined as any radio technology having a spectrum that occupies a bandwidth greater than ¼ the center frequency or a bandwidth of greater than 500 MHz. Simple examples of an ultra-wideband transmission would be an RF (Radio Frequency) transmission with a bandwidth of at least 250 MHz having a center frequency of 1GHz or a transmission with a bandwidth of greater than 500 MHz having a center frequency of 6 GHz. This differs from narrow band technologies where the bandwidth is typically 10% or less of the center frequency. An example of a specification using narrow band technology is 802.11b WLAN where the bandwidth is 22MHz with a center frequency in the range of 2.4GHz.

The first pulse based UWB radio was the Spark Gap radio. Spark Gap radios were first developed by Guglielmo Marconi in the late 1800's and were used to transmit Morse code. Spark Gap technology remained dominant until narrowband (continuous wave) radios were proven to be better for voice communication in the early 1900's. By 1924, Spark Gap radios were forbidden in most applications due in part to their unregulated RF emissions that were disruptive to narrowband, carrier based radios. [1]

With the development of the sampling oscilloscope by Hewlett-Packard in 1962, the impulse (pulse based) response of microwave networks could be directly observed and measured. In the 1960's, the study of impulse measurement revealed the potential for using pulse based transmission for both radar and communications. In 1973, the Sperry Research Center was awarded the first wideband patent and wideband technology began to re-emerge. Between 1960 and 1999 over 200 papers were published and over 100 patents were awarded on topics related to wideband technology. [2]

Through the late 1980's, UWB technology was referred to as baseband, carrier-free or impulse technology. It was not until 1989 that the U.S. Department of Defense applied the term "ultra wideband". By that time, development of techniques using this technology had been under development for nearly 30 years. Until recently, UWB applications were permissible only under special license.[3]

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[1] John S. Belrose. The Sounds of a Spark Transmitter: Telegraphy and Telephony. Adventures in CyberSound.
[2] Dr. Robert J. Fontana. A Brief History of UWB Communications. Multispectrum Solutions, Inc.
[3] Dr. Tarance W. Barrett. History of Ultra Wideband (UWB) Radar & Communications: Pioneers and Innovators

Regulations and Commercialization

On April 22, 2002, the FCC issued UWB Regulations, under Part 15 of the Commission's rules, permitting ultra-wideband intentional emissions subject to certain frequencies and power limitations that will mitigate interference risk to those sharing the same spectrum. Still, UWB faces the additional challenge of world wide regulatory approval. The US is currently the only country where UWB based consumer products are legal. Intel is working closely with local governing bodies to promote and facilitate UWB regulations similar to those adopted by the FCC. Intel believes UWB to be a valued technology for personal connectivity, however, there is much more work to be done.

Figure 1 shows the usable spectrum permitted under Part 15 of the Commission's rules. UWB signals may be transmitted between 3.1 GHz and 10.6 GHz at power levels up to – 41dBm/MHz. The primary difference between indoor and outdoor operation is the higher degree of attenuation required for the out of band region for outdoors operation. This further protects GPS receivers, centered at 1600MHz.

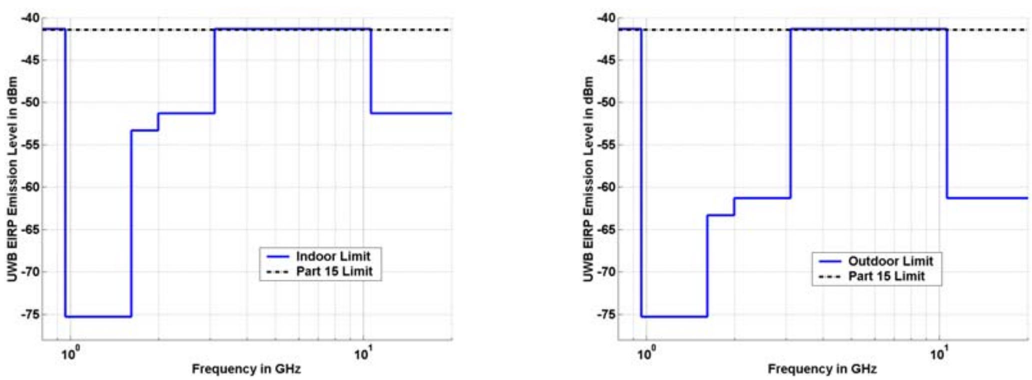

Figure 1

Part 15 applies the same power limitations to UWB as it does for unintentional emissions, similar to existing equipment like PC's (personal computers). UWB innovation and product development under Part 15 rules will promote global harmonization as other countries adopt regulatory changes to support the new technology.

Ultra-Wideband Advantages

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 capacity increasing as a function of BW (bandwidth) faster than as a function of SNR (signal to noise ratio).

$$C= BW*\log2 (1+SNR)$$

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

SNR = P/BW*No
P = Received Signal Power

No = Noise Power Spectral Density (watts/Hz)

Shannon's equation shows that increasing channel capacity requires linear increases in Bandwidth while similar channel capacity increases would require exponential increases in power. 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.

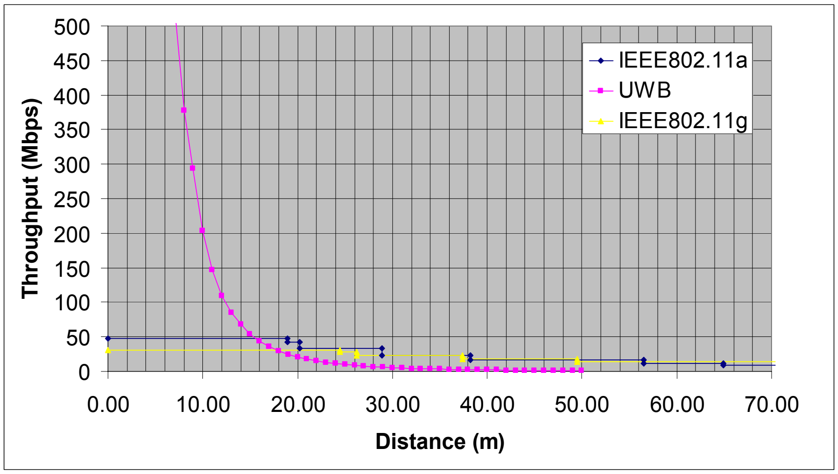

Figure 2[4]

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 mandated by the FCC for legal UWB operation. UWB technology is most useful in short-range (less than 10 meters) applications. Longer-range flexibility is better served by WLAN applications like 802.11a.

An 802.11a narrowband radio might occupy a BW of 20MHz with a transmit power level of 100 mWatts. The power mask, as defined for UWB by the FCC, allows up to –41 dBm/MHz, where dBm is a measure of Power and dBm/MHz is a measure of Power Density (power/spectrum used).

UWB radios may also provide lower cost architectures than narrow band radios. Narrow band architectures use high quality oscillators and tuned circuits to modulate and de-modulate information. UWB transmitters, however, can directly modulate a baseband signal eliminating components and reducing requirements on tuned circuitry. UWB receivers, on the other hand, may require more complex architectures and may take advantage of digital signal processing techniques. Reducing the need for high quality passively based circuits and implementing sophisticated digital signal processing techniques through integration with the same low cost CMOS processes used for microprocessors will enable radio solutions that scale in cost/performance with digital technology.

Another key advantage of UWB is its robustness to fading and interference. Fading can be caused when random multipath reflections are received out of phase causing a reduction in the amplitude of the original signal. The wideband nature of UWB reduces the effect of random time varying amplitude fluctuations. Short pulses prevent destructive interference from multipath that can cause fade margin in link budgets. However, another important advantage with UWB technology is that multipath components can be resolved and used to actually improve signal reception. UWB also promises more robust rejection to co-

[4] Ben Manny & Kevin Kahn. Ultra-Wide-Band, a Disruptive RF Technology? Spring'02 Intel Developer Forum Conference.

channel interference and narrowband jammers showing a greater ability to overlay spectrum presently used by narrowband solutions. [5]

Usage Scenarios

UWB offers some unique and distinctive properties that make it more suitable for some applications and less suitable for other applications. As shown earlier in this paper, UWB has the potential for very high data rates using very low power, however only at very limited range. This will lead to applications well suited for WPAN (Wireless Personal Area Networking). UWB will not be suitable for applications such as WLAN (Wireless Local Area Networking) or WWAN (Wireless Wide Area Networking, cell phone radios), both of which having greater range expectations.

UWB will provide enhanced value for WPAN in three areas. First, peripheral connectivity through cable-less connections to applications like storage and I/O devices will improve the ease and value of using PC's (Personal Computers) and Laptops. Second, enabling high-speed content transfers between computers and consumer electronics like digital cameras, video cameras, MP3 players, projectors, televisions and automobile applications will present new experiences in home and personal entertainment. Third, as data becomes an integral part of daily communication, mobile users will grow to expect higher performance low power solutions from WPAN leading to new freedom and expectations.

Another interesting application is very low power sensor networks. In most applications today, sensors are used for specific local applications. Sensor networks suggest the use of many low-cost low-powered sensors, on a wider more generalized scale, networked to provide ubiquitous access. Sensor networks such as this will provide information that can make life easier. Sensors in these types of networks will work together to provide information that could: maintain environmental conditions across large buildings or many buildings, identify empty conference rooms or help one find an empty parking place in a huge parking lot.[6]

The success of these kinds of applications will depend on industry adoption. As with any wireless technology targeted for consumer use, volume deployment will most likely require the cost advantages and interoperability enabled by open standards. Working with cross industry groups, Intel efforts focus on creating a UWB communication standard for WPAN to support interoperable connectivity for mobile, PC and CE platforms. For example, Intel is involved in the IEEE (Institute of Electrical and Electronics Engineers) 802.15 Working Group for WPAN. UWB is being addressed in SG3 (Study Group 3a), 802.15.3 High Rate WPAN. [http://www.ieee802.org/15/pub/SG3a.html]

Position and location detection is another unique property of UWB. UWB is basically RADAR (RAdio Direction And Ranging). Positioning and Locating were early focuses of wideband Research and Development. Short impulses (wideband signal) allow for very accurate delay estimates providing position and location capabilities within a few centimeters.

The RADAR like properties of UWB may also be applied to imaging applications. Some forms of imaging will be applicable in Surveillance Systems (i.e.Wall Imaging and Through-wall Imaging Systems or Intrusion Protection). Another example of imaging is a specialized Government application using UWB for GPR (Ground Penetrating Radar). This application was employed after the terrorist disaster on September 11th in New York to try and find survivors in the rubble. Other Military examples of UWB have been used to locate enemy objects behind walls and around corners in the battlefield. Imaging applications applied to commercial use find value in Medical Systems where X-ray Systems may be less desirable.

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[5] Jeff Foerster. Ultra-Wideband Technology for Short-Range, High-Rate Wireless Communications. Intel Technology Journal

[6] W. Steven Conner, Lakshman Krishnamurthy, Roy Want. Making Everyday Life Easier Using Dense Sensor Networks. Ubcomp 2001: 49-55

Specialized commercial applications have also been developed. Assets tracking through very low powered RF tagging have been employed commercially and in the military. These types of single radio applications do not necessarily require standards to be successful.[7]

Technical Challenges

Although UWB provides many advantages, it also presents many challenges. At Intel Research and Development, we are looking into addressing a number of these challenges. Efficient architectures for CMOS implementations will become more and more important in keeping cost down while enabling scaleable performance.

Intel Research Areas

At Intel Research and Development, efforts are underway to look at various aspects of UWB system and CMOS circuit designs. Channel compensation strategies need to be understood to develop techniques for capturing multipath energy and guarding against inter-symbol interference. Acquisition and Synchronization techniques need to be developed in ways that reduce sampling rate requirements over wide signal bandwidth. And capacity considerations will require the development of modulation, coding and multiple access schemes for achieving high data rates .

Interference mitigation techniques must be understood before industry development introduces problems that may ultimately inhibit the introduction and evolution of wideband technology. It is important first to protect existing technologies (UWB interfering with Narrowband) with coexistence techniques and regulations. Overlay concepts must then be developed to ensure UWB is robust (Narrowband interfering with UWB).

Ultimately, efficient architectures for CMOS implementation must be developed to enable low cost implementations throughout the industry. One Intel Research and Development goal is to demonstrate 500 Mbps. [8]

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[7] First Report and Order (FCC 02-48). Action by the Commission February 14, 2002. New Public Safety Applications and Broadband internet access among uses envisioned by FCC authorization of Ultra-Wideband Technology

[8] Ben Manny & Kevin Kahn. Ultra-Wide-Band, a Disruptive RF Technology? Spring'02 Intel Developer Forum Conference.

Summary

Wideband radio technology is not a new RF (radio frequency) technology, however work with wideband techniques over the last few years have developed new possibilities for personal computing. UWB (ultra-wideband) is a new nomenclature introducing new techniques for wideband radio technology.

On February 14, 2002, The United States Federal Communications Commission (FCC) adopted the First Report and Order that permits the marketing and operation of certain types of new products incorporating ultra-wideband technology under Part 15 of the Commission's rules subject to certain frequencies and power limitations. However, in spite of this, most countries have not yet recognized UWB as a spectrum friendly technology and therefore continue to disallow UWB use.

UWB technology is still very much in the research stage of development for the computer industry. There is much progress to be made in the development of radio solutions and industry specifications before compatible applications can be developed and deployed.

UWB technology will likely be most promising in WPAN (Wireless Personal Area Network) applications due to high data throughput capability, lower power requirements and short-range characteristics. Key application areas that will benefit from UWB technology will be PC (Personal Computer) peripherals, CE (Consumer Electronics) and Mobile Communications.