Ultra-wideband as a short-range, ultra-high-speed wireless communications technology

Ultra-wideband technologies have been proposed to provide ultra-high speed data rates for short-range communications. In the United States, the systems have been approved for use in the frequency band 3.1 GHz to 10.6 GHz. It supports bit rate greater than 100 Mbps within a 10-meter radius. UWB communications coexist with other wireless networking standards such as 802.11 LAN, 802.16 MAN and WAN.

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Ultra-wideband (UWB) technology is considered a wireless air interface for high-speed data transmission, such as the IEEE 802.15.3a standard. Recently, UWB communications have received great interest from the research and industry communities. The reason for the increasing interest is because of its potential to offer high data rates, low-power transmission, robustness for multipath fading, and low power dissipation [1-3]. UWB is defined as any signal whose fractional bandwidth is equal to or greater than 20% of the center frequency [4], or that occupies bandwidth equal to or greater than 500 MHz. The fractional bandwidth *(FB)* is expressed as:

$$FB = \frac{2(f_H - f_L)}{(f_H + f_L)} \tag{1}$$

where f_H and f_L are the upper and lower bounds that are at 10 dB below the highest radiated emission. The Federal Communications Commission (FCC) approved the use of 7500 MHz of spectrum for UWB devices for communications applications in the 3.1 GHz to 10.6 GHz frequency band. Because of the low power transmissions, UWB communications are best suited for short-range communications, including sensor networks, and wireless personal-area networks (WPANs).

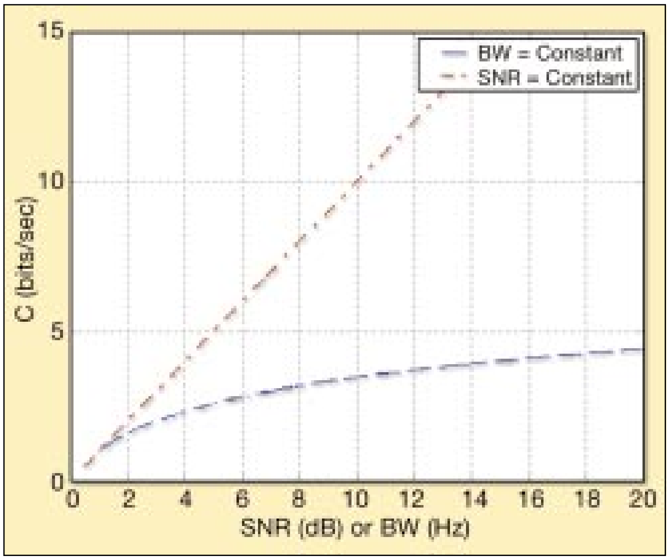

Figure 1. Capacity as a function of bandwidth or SNR.

Since the capacity [5] of a communications channel in a non-fading environment is expressed as:

$$C = B \cdot \log_2 (1 + S/N) \tag{2}$$

where

C = channel capacity (bit/s)

B = channel bandwidth ‘BW’ (Hz)

S = signal power (watts)

N = noise power (watts)

According to Equation 2, the capacity can be increased by either increasing B or S/N. It is obvious that the capacity can be increased more by increasing B rather than S/N (see Figure 1). Therefore, one might argue that UWB technology has the highest data rate capability of all the present wireless technologies.

One way of generating UWB signals is to transmit short duration pulses [6-7] called Gaussian monopulses, which are generated at baseband and transmitted without a carrier. The Gaussian function

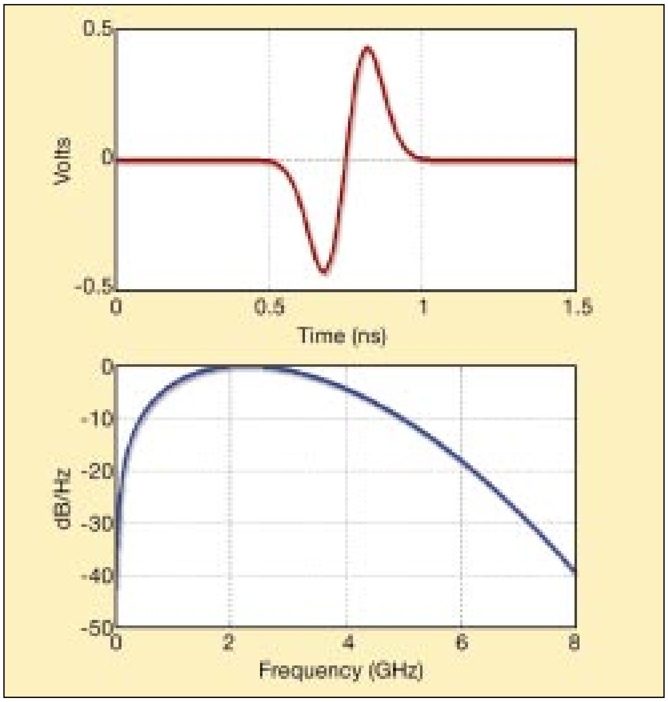

Figure 2. Time and frequency domains of a UWB pulse waveform.

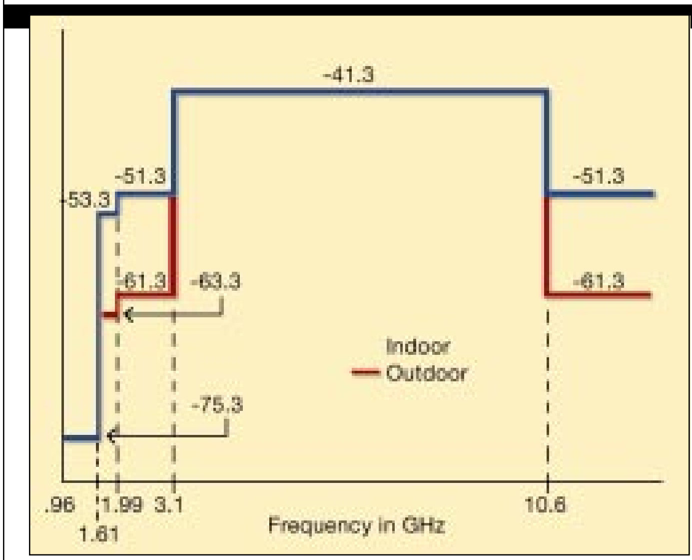

Figure 3. FCC spectral masks for indoor and outdoor applications.

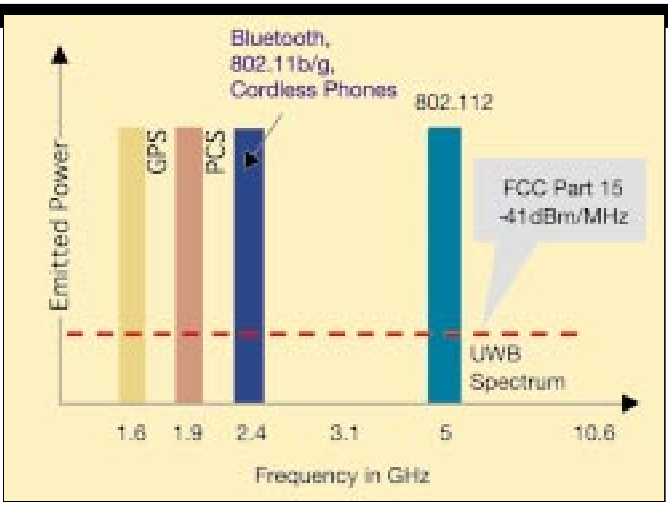

Figure 4. Some wireless technologies that would co-exist with UWB.

of a UWB monopulse in time domain can be expressed as:

$$v(t) = \frac{t}{\tau} e^{-(t/\tau)^2} \qquad (3)$$

where τ is the time-decay constant that determines the duration of the monopulse. Applying Fourier transform to Equation 3, the frequency domain of the Gaussian pulse can be determined. Figure 2 shows the time and frequency domains for a monopulse of duration 0.5 ns.

The width of the monopulse determines the center frequency of the UWB signal. For example, if the pulse width is 320 ps, the pulse would have a center frequency of 3.12 GHz. For a shorter pulse such as 95 ps, the center frequency is 10.6 GHz. Low power transmission is a key characteristic that could allow UWB technology to coexist with other wireless technologies. Figure 3 shows the typical FCC power spectral density masks for indoor and outdoor UWB communication systems.

From Figure 3, the emissions limit is equivalent to a transmission level of 75 nW/MHz between the 3.1 GHz to 10.6 GHz band. Figure 4 shows different wireless technologies that coexist with the UWB technology.

The impact of UWB interference depends on many factors,

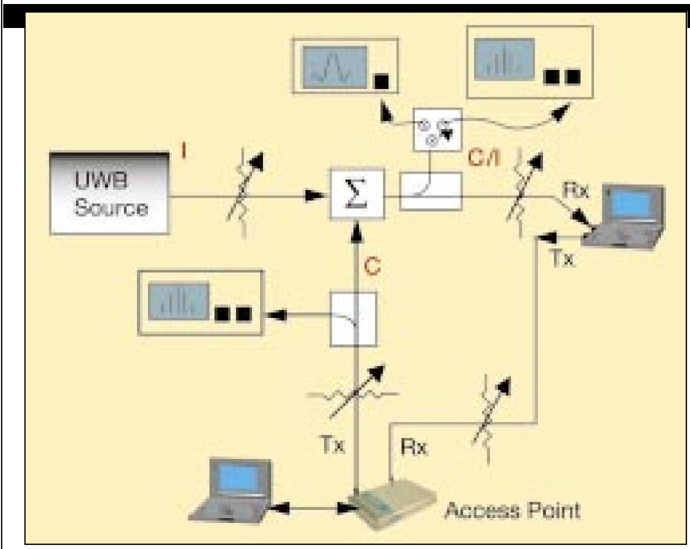

Figure 5. Test setup to estimate the impact of UWB interference.

including the distance between the UWB sources and the receivers of other wireless systems, modulation technique, the channel propagation losses, the pulse repetition frequency of the UWB signal, and the antenna gains of both the UWB transmitter and the other wireless system's receiver. The effect of UWB interference on other wireless technology such as WLAN 802.11a could be studied using a test setup as shown in Figure 5.

The test setup in Figure 5 enables the measurement of the throughput of the WLAN link as a function of the carrier-to-interference *C/I*, where the interfering signal is the UWB signal.

> *The three types of UWB systems are: imaging systems that include ground penetration radars (GPR), wall and through-wall imaging, medical imaging, and surveillance systems; vehicular radar systems; and communications and measurements systems.*

UWB systems could also suffer from interference from other wireless technologies that exist in the vicinity of operation, but this problem can be mitigated by using adaptive selection of frequency bands in multiband UWB systems.

UWB wireless systems

The main types of UWB systems are: imaging systems thatinclude ground penetration radars (GPR), wall and through-wall imaging, medical imaging, and surveillance systems; vehicular radar systems; and communications and measurements systems. These systems operate in the following frequency bands:

- GPR systems operate below 960 MHz or in the 3.1 GHz to 10.6 GHz frequency band. They are used by rescue organizations, law enforcement, mining companies and construction companies.
- Wall imaging systems operate below 960 MHz or in the 3.1GHz to 10.6 GHz frequency band. They are used to detect the location of objects through a wall.
- Through-wall-imaging operate below 960 MHz or in the 1.9 GHz to 10.6 GHz frequency band. They are used to detect movements of people or objects located behind walls.
- Medical systems operate in the 3.1 GHz to 10.6 GHz frequency band. They are used for health applications and research.
- Surveillance systems operate in the 1.9 GHz to 10.6 GHz frequency band.
- Vehicular radar systems operate in the 22 GHz to 29 GHz frequency band. They are used for near collision avoidance.
- Communications and measurement systems operate in the 3.1 GHz to 10.6 GHz frequency band.

Different system design approaches are implemented to use the 7500 MHz band that is allocated for UWB spectrum. These approaches include single-band UWB (uses the entire 7500 MHz), and multiband UWB, which divides the 7500 MHz into 15 sub-bands (500 MHz each). In a multiband system, the estimated noise power (kTB) is -87 dBm, where *k* is the Boltzman's constant 1.38×10^{-23} J/K, *T* is 290 degree Kelvin, and *B* is the bandwidth of 500 MHz. In a single-band system, the thermal noise is -75 dBm. The thermal noise of a single-band system is 12 dB higher than the multiband system. Such an increase in the thermal noise degrades the coverage range and requires higher transmission power. Other advantages of multiband systems are they allow for adaptive selection of frequency bands to mitigate the interference from other wireless technologies that are allocated in the same band. Also, the information can be processed over much smaller bandwidth, which reduces the complexity of the design. However, some design challenges for UWB systems include the extreme antenna bandwidth requirements, which can be difficult to achieve. The modulation techniques that are used in UWB systems include pulse position modulation (PPM), binary phase shift keying (BPSK), pulse amplitude modulation (PAM), on-off keying (OOK), and orthogonal frequency-division multiplexing (OFDM).

Conclusion

UWB provides an interesting new technology for short-range ultra-high-speed communications. It supports a bit rate greater than 100 Mbps within a 10-meter radius for wireless personal area communications. The advantages of UWB include low-power transmission, robustness for multipath fading and low power dissipation. The low power transmission of the UWB is the key characteristic that might allow it to coexist with other wireless technologies. However, there are still challenges to surmount before this technology performs up to its full potential. RFD

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