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ULTRA-WIDEBAND (UWB) WIRELESS TECHNOLOGY FOR APPLICATION

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Abstract: Ultra-wideband (UWB) transmission has recently received great attention in both academia and industry for applications in wireless communications. It was among the CNN’s top 10 technologies to watch in 2004. A UWB system is defined as any radio system that has a 10-dB bandwidth larger than 20% of its center frequency, or has a 10-dB bandwidth equal to or larger than 500 MHz, The recent approval of UWB technology by Federal Communications Commission (FCC) of the United States reserves the unlicensed frequency band between 3.1 and 10.6 GHz (7.5 GHz) for indoor UWB wireless communication systems. It is expected that many conventional principles and approaches used for short-range wireless communications will be reevaluated and a new industrial sector in short-range (e.g., 10 m) wireless communications with high data rate (e.g., 400 Mbps) will be formed. Further, industrial standards IEEE 802.15.3a (high data rate) and IEEE 802.15.4a (very low data rate) based on UWB technology have been introduced.

I. INTRODUCTION

UWB is a wireless technology that transmits binary data—the 0s and 1s that are the digital building blocks of modern information systems. It uses low-energy and extremely short duration (in the order of pico seconds) impulses or bursts of RF (radio frequency) energy over a wide spectrum of frequencies, to transmit data over short to medium distances, say about 15—100 m. It doesn’t use carrier wave to transmit data. UWB is fundamentally different from existing radio frequency technology. For radios today, picture a guy watering his lawn with a garden hose and moving the hose up and down in a smooth vertical motion. You can see a continuous stream of water in an undulating wave. Nearly all radios, cell phones, wireless LANs and so on are like that: a continuous signal that's overlaid with information by using one of several modulation techniques. Now picture the same guy watering his lawn with a swiveling sprinkler that shoots many, fast, short pulses of water. That's typically what UWB is like: millions of very short, very fast, precisely timed bursts or pulses of energy, measured in nanoseconds and covering a very wide area. By varying the pulse timing according to a complex code, a pulse can represent either a zero or a one: the basis of digital communications. Wireless technologies such as 802.11b and short-range Bluetooth radios eventually could be replaced by UWB products that would have a throughput capacity 1,000 times greater than 802.11b (11M bit/sec).

II. UWB OVERVIEW

UWB radio, operating with extremely large bandwidths, must coexist with many other interfering narrow-band signals(TV, GSM, UMTS, GPS, etc). In the same time, these narrow-band systems must not suffer intolerable interference from the UWB radios. Regulatory considerations over such a wide bandwidth limit the radiated power. The low transmit power levels together with the ultra-fine time resolution of thesystem can increase considerably the synchronization acquisition time and the complexity of the receiver.

The Federal Communications Commission in USA (FCC) has defined an UWB device as any device with a – 10 dB fractional bandwidth, greater than 20% or occupying at least 500 MHz of the spectrum [1]. Most narrowband systems occupy less than 10% of the center frequency bandwidth, and are transmitted at far greater power levels. For example, if a radio system were to use the entire UWB spectrum from 3.1-10.6 GHz, and center about almost any frequency within that band, the bandwidth used would have to be greater than 100% of the center frequency in order to span the entire UWB frequency range. By contrast, the 802.11b radio system centers about 2.4 GHz with an operating bandwidth of 80 MHz. This communication system occupies a bandwidth of only 1% of the center frequency.

The FCC also regulated the spectral shape and maximum power spectral density (-41.3 dBm/MHz) of the UWB radiation in order to limit the interference with other communication systems. The power spectral density is the average power in the signal per unit bandwidth and hence provides important information on the distribution of power over the RF

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spectrum. The ETSI regulations in EU are expected to follow the FCC but with a more restrictive spectral shape, motivated by a different management of the available spectrum [2]-[3]. For the antenna this means that only one 500 MHz band need to be active at a time. The UWB spectral power density mask is shown in Fig.1.

Fig.1 shows the UWB spectral power density mask limited to –41.3 dBm by FCC and ETSI to ensure that the UWB emission levels exceedingly small. The summary of emission levels for indoor and handheld UWB devices defined by FCCis listed in Table 1. The emissions shall not exceed the average limits when measured using a resolution bandwidth of 1 MHz. UWB handheld devices are relatively small devices that do not employ a fixed infrastructure. Antennas may not be mounted on outdoor structures such as the outside

of a building or on a telephone pole. Antennas may bemounted only on the handheld UWB devices. HandheldUWB devices may operate indoors or outdoors [4].

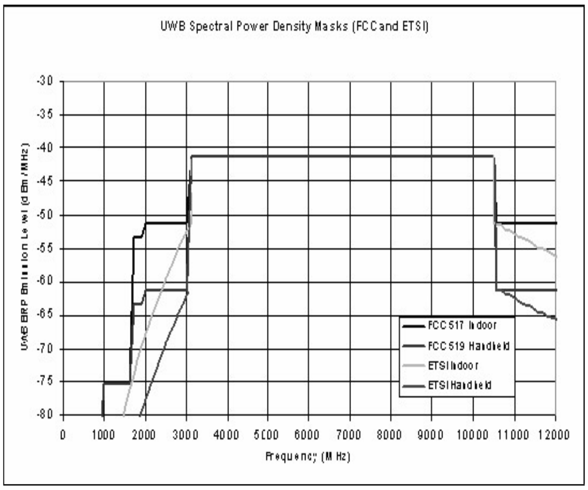

Fig.1. UWB spectral power density mask (FCC and ETSI) [1], [5] Table 1. FCC limits for indoor and handheld systems

Frequency (MHz)	Indoor EIRP (dBm)	Handheld EIRP (dBm)
960 - 1.610	-75.3	-75.3
1.610 - 1.990	-53.3	-63.3
990 - 3.100	-51.3	-61.3
3.100 - 10.600	-41.3	-41.3
Above 10.600	-51.3	-61.3

The bandwidth is measured at -10 dB points on either side of the peak emission. If these upper and lower points are represented by f_H and f_L, respectively, the fractional bandwidth and center frequency can be derived as in (1), (2) [4].

A. Regulations Worldwide

The regulatory bodies outside United States are also actively conducting studies to reach a decision on the UWB regulations now. They are, of course, heavily influenced by the FCC's decision, but will not necessarily fully adopt the FCC's regulations. In Europe, the Electronic Communications Committee (ECC) of the Conference of European Posts and Telecommunications (CEPT) completed the draft report on the protection requirement of radio communication systems from UWB applications [6]. In contrast to the FCC's single emission mask level over the entire UWB band, this report proposed two sub-bands with the low band ranging from 3.1 GHz to 4.8 GHz and the high band from 6 GHz to 8.5 GHz, respectively. The emission limit in the high band is -41.3 dBm/MHz. In order to ensure co-existence with other systems that may reside in the low band, the ECC's proposal includes the requirement of Detect and Avoid (DAA) which is an interference mitigation technique [7]. The emission level within the frequency range from 3.1 GHz to 4.2 GHz is -41.3 dBm/MHz if the DAA protection mechanism is available. Otherwise, it should be lower than -70 dBm/MHz. Within the frequency range from 4.2 GHz to 4.8 GHz, there is no limitation until 2010 and the mask level is -41.3 dBm/MHz. The ECC proposed mask against the FCC one are plotted in Fig. 2.

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$BW = 2(f_H - f_L)$

$f_C = (f_H + f_L)\,2$

$(f_H + f_L)$

(1)

(2)

This bandwidth greatly exceeds that of other radio transmitters, which are generally confined to a narrow frequency band allocated for a specific service. As a consequence of occupying a large bandwidth, UWB devices can span a number of bands. However, as the level of emissions from UWB is very low and below the power floor of existing frequency users, they are able to share spectrum with existing services. The large transmission bandwidth, from near d.c. to a few GHz, has as result a higher immunity to interference effects and improved multipath fading robustness.

Another direct consequence of the large bandwidth is the possibility to accommodate many users, even in multipath environments. Furthermore, the very low frequencies have good penetration properties through different materials, improving the coverage of the UWB radios.

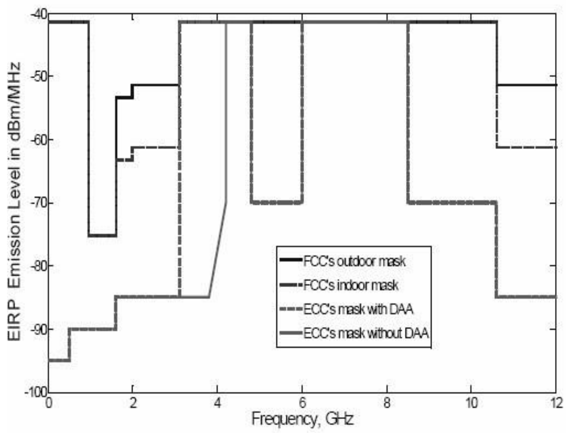

Fig.2. Proposed spectral mask of ECC [5]

In Japan, the Ministry of Internal Affairs & Communications (MIC) completed the proposal draft in 2005 [8]. Similar to ECC, the MIC proposal has two sub-bands, but the low band is from 3.4 GHz to 4.8 GHz and the high band from 7.25 GHz to 10.25 GHz. DAA protections is also required for the low band.

In Korea, Electronics and Telecommunications Research Institute (ETRI) recommended an emission mask at a much lower level than the FCC spectral mask.

Currently in Singapore the Infocomm Development Authority (IDA) permits UWB with a special experimental license. The UWB Friendly Zone (UFZ) is located within Science Park II, amidst the research, development, and engineering community in Singapore [4].

The UWB proposals in Japan, Korea and Singapore against the FCC one are illustrated in Fig. 3. In order to facilitate experimentation and encourage innovation, IDA issues trial licenses to companies permitting them operate UWB devices within the UFZ, subject to the emission limits given in Table

2. The emissions of Table 2 are measured in a resolution of 1 MHz. The limits are 6 dB less stringent, and have an expanded lower frequency band edge than what is permitted by the FCC.

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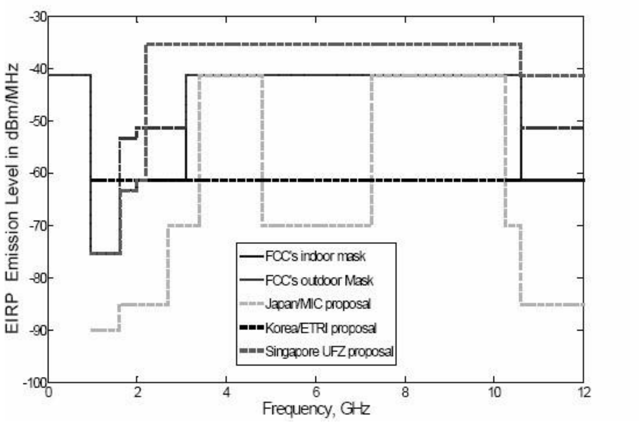

Fig.3. Proposed spectral mask in Asia [5]

Table 2. UWB limits for the Singapore UFZ

Frequency (MHz)	EIRP (dBm)
960 - 1.610	-75.3
1.610 - 1.990	-63.3
1.990 - 2.200	-61.3
2.200 - 10.600	-35.3
Above 10.600	-41.3

III. APPLICATION OF UWB TECHNOLOGY

UWB short-range wireless communication is different from a traditional carrier wave system. UWB waveforms are short time duration and have some rather unique properties. In spreading signals over very wide bandwidths, the UWB concept is especially attractive since it facilitates optimal sharing of a given bandwidth between different systems and applications. Recent years, rapid developments have been experimented on the technologies using UWB signals. UWB technology offer major enhancements in three wireless application areas: communications, radar and positioning or ranging. UWB technology can be delivered also over wire lines and cables such as CATV application. Each of these applications illustrates the unique value of UWB [9].

A. Communication Systems

Using UWB techniques and the available large RF bandwidths, UWB communication links has become feasible. The exceptionally large available bandwidth is used as the basis for a short-range wireless local area network with data rates approaching gigabits per second. This bandwidth is available at relatively low frequencies thus the attenuation due to building materials is significantly lower for UWB transmissions than for millimeter wave high bandwidth solutions. By operating at lower frequencies, path losses are minimized and the required emitted power is also reduced to achieve better performance.

Computer peripherals offer another fitting use of UWB, especially when mobility is important and numerous wireless devices are utilized in a shared space. A mouse, keyboard, printer, monitor, audio speakers, microphone, joystick, and PDA are in wireless, all sending messages to the same computer from anywhere in the given range [4].

UWB also is used as the communication link in a sensor network. A UWB sensor network frees the patient from the tangle of wired sensors. Sensors are being used in medical situation to determine pulse rate, temperature, and other critical life signs. UWB is used to transport the sensor information without wires, but also function as a sensor of respiration, heart beat, and in some instance for medical imaging.

UWB pulses are used to provide extremely high data rate performance in multi-user network applications. These short duration waveforms are relatively immune to multipath cancellation effects as observed in mobile and in-building environments. In addition, because of the extremely short duration waveforms, packet burst and time division multiple access (TDMA) protocols for multi-user communications are readily implemented [10].

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B. Radar Systems

For radar applications, these short pulses provide very fine range resolution and precision distance and positioning measurement capabilities. The very large bandwidth translates into superb radar resolution, which has the ability to differentiate between closely spaced targets. This high resolution is obtained even through lossy media such as foliage, soil and wall and floor of the buildings. Other advantages of UWB short pulses are immunity to passive interference (rain, fog, clutter, aerosols, etc) and ability to detect very slowly moving or stationary targets [11]. UWB antennas arrays are especially important, to have both fine range and angular resolution in radars.

In radar cross-section (RCS) range, a single UWB antenna replace a large set of narrow band antennas that are normally used to cover the whole frequency band of interest. UWB signals enable inexpensive high definition radar. Radar will be used in areas currently unthinkable such as; automotive sensors, smart airbags, intelligent highway initiatives, personal security sensors, precision surveying, and through- the wall public safety application [4].

Operation of vehicular radar in the 22 to 29 GHz band is permitted under the UWB rules using directional antennas on automobiles. These devices are able to detect the location and movement of the objects near a vehicle, enabling featuressuch as near collision avoidance, improved air bag activation,and suspension systems that better respond to road conditions

C. Positioning Systems

For Global Positioning Satellite System (GPS), location and positioning require the use of time to resolve signals that allow position determination to within ten of meters. Greater accuracy is enhanced with special techniques used. Since there is a direct relationship between bandwidth and precision, therefore increasing bandwidth will also increase positional measurement precision, with UWB techniques extremely fine positioning becomes feasible, e.g., sub - centimeter and even sub-millimeter [10]. In satellitecommunications where wide band feeds save space and weight by supporting many communication channels with justone antenna.
Therefore, the emission of UWB will greatly boost the performance of intrusion detection radar precision geolocation systems, proximity fuses and secure ground communications for troops which far outweigh the impact of UWB may have on other systems.

D. UWB over Wires

UWB technology is also delivered over wire lines and cables. This could effectively double the bandwidth available to cable television (CATV) systems without modification to the existing infrastructure. Over wire technology for coaxial cable provide up to 1.2 Gbps down-stream and up to 480 Mbps upstream of additional bandwidth, at low cost, on differing CATV architectures. The wire-line UWB technology does not interfere with or degrade television, highspeed internet, voice or other services already provided by theCATV infrastructure [4].

IV. SHORT-PULSE GENERATION

In general, UWB radio systems transmit and receive single band or multi-band pulses. Single-Band (SB) based, employing one single transmission frequency band, and Multi- Band (MB) based, employing two or more frequency bands, each with at least 500 MHz bandwidth.

In the SB solution, the UWB signal is generated using very short, low duty-cycle, baseband electrical pulses with appropriate shape and duration. Due to the carrier-less characteristics, no sinusoidal carrier to raise the signal to a certain frequency band, these UWB systems are also referred to as carrier-free or impulse radio (IR-UWB) communication systems [12]. Such systems are capable of providing low system complexity and low cots because of their direct transmission and reception of pulsed signals and the least RF devices in their front-ends as against conventional narrow-band radio systems [13].

The MB UWB systems is implemented carrier less (different pulse shapes/lengths are used according to the frequency band) [14] or carrier based (multi-carrier like) [15] known as UWB orthogonal frequency division multiplexing (UWB-OFDM). In UWB-OFDM bandwidth is split into many sub-bands applying communication techniques well- known from narrowband systems.

The requirements for UWB antennas can vary for different schemes. In the multiband scheme, the consistent or flat gain response of the UWB antennas is more important than a constant group delay or a linear phase response, which is conversely more important in the single band scheme. Therefore, the performance of UWB antennas can be assessed in terms of the system transfer function and group delay together with conventional frequency-domain parameters such as return loss, gain, radiation patterns, and polarization matching path loss as well as the time-domain parameters such as

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pulse waveforms, and fidelity [16].

In the IR-UWB, typically the radiated pulse signals are generated without the use of local oscillators or mixers, thus potentially a simpler and cheaper construction of the transmitter (TX) and receiver (RX) is possible, as compared to the conventional narrow-band systems. The characteristics of the pulse used (shape, duration), determine the bandwidth and spectral shape of the UWB signals. The most common pulse shapes used in IR-UWB are: gaussian monocycle (and its derivatives) and hermitian pulses [17].

The impulse radio technology has been widely used in radar applications due to its spatial resolution, detectable material penetration, easy target detection and feature extraction and low probability of intercept signals [18]-[20]. Military and government multi-user networking and high precision localization applications rely on the UWB communication systems [21].

The basic properties of the impulse radio systems make the UWB technology ideal candidate also for commercial, short-range, low power, low cost indoor communication systems such as Wireless Local Area Network (WLAN) and WPAN [22]-[24].

V. ADVANTAGES AND DISADVANTAGES OF UWBSYSTEMS

The benefits of UWB technology are derived from its unique characteristics that are the reasons why it presents a more eloquent solution to wireless broadband than other technologies. The unique characteristics are listed below [9]:

Firstly, an inherent capability for integration in low cost, low power IC processes. UWB system based on impulse radio features low cost and low complexity which arise from the essentially baseband nature of the signal transmission. UWB does not modulate and demodulate a complex carrier waveform, so it does not require components such as mixers, filters, amplifiers and local oscillators. Secondly, UWB has an ultra wide frequency bandwidth; it can achieve huge capacity as high as hundreds of Mbps or even several Gbps with distances of 1 to 10 meters [25].

Thirdly, UWB system is extremely fine time and range solution even through lossy, opaque media. Fourthly, UWB system has immunity from multipaths Fifthly, non-interfering operation with existing services. UWB systems operate at extremely low power transmission levels. By dividing the power of the signal across a huge frequency spectrum, the effect upon any frequency is below the acceptable noise floor [26].

Lastly, UWB has low probability of detection and interception. UWB provides high secure and high reliable communication solutions. Due to the low energy density, the UWB signal is noise-like, which makes unintended detection quite difficult. Hence UWB is perhaps the most secure means of wireless transmission ever previously available [27].

As with any technology, there are always applications that may be better served by other approaches. For example, for extremely high data rate (10’s of Gigabits/second and higher), point-to-point or point-to-multipoint applications, it is difficult today for UWB systems to compete with high capacity optical fiber or optical wireless communications systems.

The high cost associated with optical fiber installation and the inability of an optical wireless signal to penetrate a wall dramatically limit the applicability of optically-based systems for in-home or in-building applications. In addition, optical wireless systems have extremely precise pointing requirements, obviating their use in mobile environments.

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