CHANNEL CHARACTERIZATION AND MODULATION SCHEMES OF ULTRA WIDEBAND SYSTEMS

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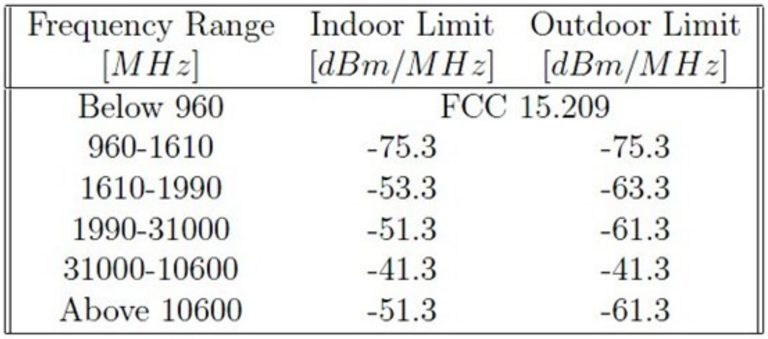
ABSTRACT

Channel measurements are generally the basis for channel models. Strictly speaking, channel models do not exclusively require measurements, but it is a fact that all standardized models are derived from measurements. This licentiate paper is focused on the characterization of ultra-wideband wireless channels. The paper presents the characterization of ultra wide band system with their benefits and drawbacks within the telecommunication industry. Furthermore with the advantages of Ultra wideband several modulation techniques for UWB are discussed in this paper.

1. INTRODUCTION

The interest on ultra-wideband (UWB) communications was initiated in the mid 90's with the pioneering work of Win and Scholtz [1, 2]. UWB-based technology had already been developed several decades before, but its use was restricted to military purposes, much like code division multiple access (CDMA) schemes. In 2002 FCC approved the frequency band from 3.- to 10.6 Ghz. This was unlicensed use among different bands operating in same range. According with FCC, a signals to be UWB needs to have at least one of the two following properties: a bandwidth larger than 500 MHz (large *absolute* bandwidth) or a bandwidth 20% larger than its center frequency (large *relative* bandwidth). Signals covering the frequency band 3.1-10.6 GHz hold both these properties.



Frequency Range $[MHz]$	Indoor Limit $[dBm/MHz]$	Outdoor Limit $[dBm/MHz]$
Below 960	FCC 15.209	
960-1610	-75.3	-75.3
1610-1990	-53.3	-63.3
1990-31000	-51.3	-61.3
31000-10600	-41.3	-41.3
Above 10600	-51.3	-61.3

Table 1.1: FCC mask limits

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The main purpose of UWB is to transferred data into computers with in given range and limit. But due to the chance of interference between other devices in a range the FCC also make some unpredictable rules to avoid them. These rules and regulations are shown in figure 1.1. indeed use of -41.3dBm/MHz above 960MHz, in-between GPS and PCS a notch is placed between them to handle receiver sensitivities.

One of the most important issues of UWB techniques has always been its relatively simple implementation. The fact that UWB was initially a carrierless modulation scheme rapidly promoted the construction of low-cost commercial hand-held radar receivers. As an example, a simple UWB receiver could be built at 1978 by purchasing the basic parts from the Tektronix Inc. catalogs, and using the published schematics for a UWB radar design by Benett & Ross [4]. The generation of extremely short pulses (also known as monopulses) was produced by means of solid state devices such as avalanche transistors [5, 6], or tunnel diodes, providing a minimum rise time of approximately 25 picoseconds. Once the implementation of UWB systems was not a problem, the emphasis was placed on the improvement of existent technology, and understanding the implications of transmitting wideband pulses in a world plenty of non-interfering radio-frequency communications.

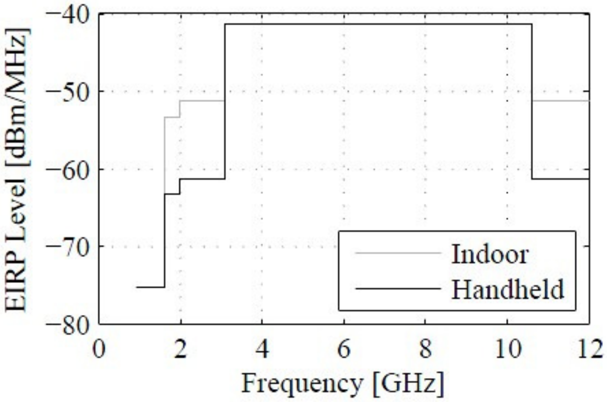


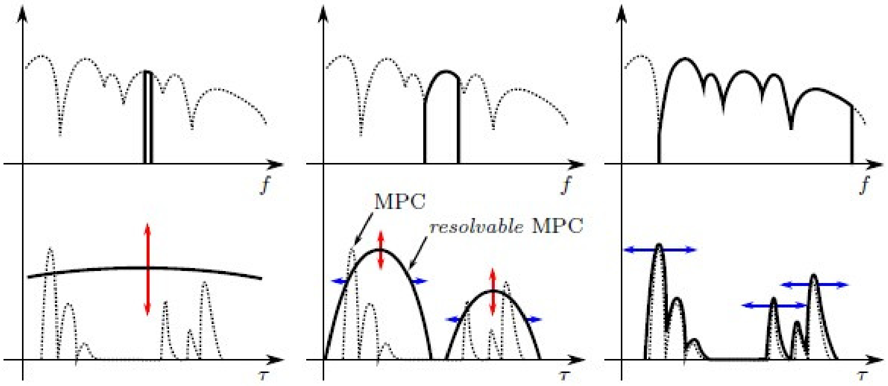
Figure 1.1: FCC assigned rules for outdoor and indoor UWB communication

2. UWB Channel Characteristics

The main purpose of any communication system is to convey a message from the transmitter to the receiver. In the case of digital communication systems, the message to be sent is initially described by a group of information bits, which are then mapped into some type of physical signal to enable the transmission. The medium over which the message is transmitted is designated as “channel.” In the delay-domain, the received signal, $y(\tau)$ is related with both the transmitted signal, $x(\tau)$, and the channel impulse response, $h(\tau)$ by the convolution operation, such that the input-output relation of the system can be described by

$$y(\tau) = h(\tau) * x(\tau) + n(\tau) \qquad \rightarrow \qquad 2.1$$

where $n(\tau)$ denotes the receiver noise. Due to channel limitations, and the need for simultaneous transmission of different messages over the same channel, signals are usually modulated onto specific carrier frequencies before transmission. Such transmitted signals are denoted band-pass signals. In this part we describe the properties of the channel impulse response $h(\tau)$, more specifically we focus on how its properties vary with the bandwidth [6]. Strictly speaking, the channel is not influenced by the bandwidth, as a physical channel does not depend on the signals that propagate through it. However, we are only interested in the part of the channel within the same bandwidth as the transmitted signal, since only this part actually plays a role. It is therefore common practice to refer to the "channel where UWB signals propagate," as the "UWB channel."



(a) Narrowband (b) Wideband (c) Ultra-wideband

Figure 2.2: Representation of the frequency-domain (upper plots) and delay-domain (lower plots) of the wireless channel for different bandwidths. The solid lines correspond to the different band-limited channels and the dashed lines correspond to the hypothetical infinite bandwidth channel. The arrows indicate the variations experienced by the channel when one of the antennas is moved.

2.1. Channel Bandwidth

The different mathematical models used to describe the impulse response $h(\tau)$ for the different bandwidths are presented in this section in their most general form. Fig. 2.2 shows a representation of the same wireless channel for three different transmission bandwidths (solid lines), in both the frequency and the delay domain.

2.1.1. Narrow Band

Narrowband systems are flat over frequency, as illustrated in Fig. 2.2 a, such that their impulse response can be simply defined by a complex coefficient α, and a delay τ_0 as

$$h_{NB0}(\tau) = \alpha\delta(\tau - \tau_0) \qquad \rightarrow \qquad 2.2$$

The delay resolution (inverse of the bandwidth) of narrowband systems is very small, and therefore no individual MPCs can be resolved (here, each MPC is characterized by an amplitude and phase, and is considered to be flat over frequency as well). Thus, all MPCs contribute to α, which can make $|\alpha|$ to vary strongly within a small-scale area. On the other hand, the variations of the delay $h_{NB0}(\tau)$ within the same area is so small in proportion to the delay resolution, that they are always neglected. An example of a narrowband communication system was the Nordic mobile telephony NMT-900, which used 25 kHz of bandwidth.

2.1.2. Wideband

For wideband systems, the profile of the frequency spectrum varies significantly and cannot be considered flat (it is said to be frequency-selective), see Fig. 2.2 b. This varying frequency-response is translated into a delay dispersive impulse response which can be described by a tapped delay line representation as:

$$h_{NB0}(\tau) = \sum_{k=1}^{L} \alpha_k \delta(\tau - \tau_k) \qquad \rightarrow \qquad 2.3$$

where α_k is the complsex amplitude of the k:th *resolvable* MPC and τ_k the corresponding delay (Fig. 2.2b shows two resolvable MPCs). The amplitude variations of α_k can still be large, however, the number of MPCs contributing to each α_k is less than for the narrowband case. An example of a wideband communication system is Long Term Evolution (LTE) which can use a bandwidth up to 20 MHz. LTE-Advanced is expected to reach 100 MHz, but it still falls within the wideband category.

2.1.3. Ultra-Wideband

Channels having an ultra-wide bandwidth, as illustrated in Fig. 2.2c, have unique properties. Besides the frequency variations of the "complete" channel, each resolvable MPC is frequency selective as well, and to account for this *per-path* distortion, the channel must be described in equation 2.4. Table 2.1 qualitatively summarizes the characteristics of the different band limited channels.

$$h_{NB0}(\tau) = \sum_{k=1}^{L} \alpha_k \vartheta_k \delta(\tau) \times \delta(\tau - \tau_k) \quad \rightarrow \quad 2.4$$

	Delay resolution	No. of MPCs per tap	Small-scale fading per tap	MPC's frequency
Narrowband	low	large	large	flat
Wideband	medium	medium	medium	flat
Ultra-Wideband	high	small	small	selective

Table 2.1: Comparison of the channel characteristics for different bandwidths.

2.2. Frequency Dependence

The understanding of the frequency dependence of single MPCs is important from a channel description perspective because such MPCs become smeared in the delay domain, possibly leading to correlation between the delay taps, which may in turn, violates the uncorrelated scattering (US) assumption. The frequency dependence of a single MPC can be caused by different propagation effects. In the following subsections, five of these effects are described and corresponding example expressions are given.

2.2.1. Free Space Loss

In the case of two antennas transmitting in free-space, assuming that the antennas are lossless and matched in both impedance and polarization, the power at the receiver antenna, P_{RX}, is well described by Friis's law as [7].

$$P_{RX}(f) = \frac{P_{TX}(f) G_{TX}(f) G_{RX}(f)}{L_0(f)} \quad \rightarrow \quad 2.5$$

Here, P_{TX} is the transmitted power, G_{TX} is the gain of the transmitter antenna and G_{RX} is the gain of the receive antenna. The free-space path loss is

$$L_0(f) = \left(\frac{4\pi f d}{c_0}\right)^2 \quad \rightarrow \quad 2.6$$

where c_0 is the speed of light in vacuum and d is the distance between the antennas.

2.2.2. Dielectric Layer Transmission and Reflection

Dielectric materials influence both the attenuation and the propagation speed of electromagnetic waves. Real propagation scenarios often include layered materials, e.g., wooden doors, concrete walls and glass windows, and therefore the transmission through, and reflection of, dielectric layers becomes of interest when evaluating and modeling propagation effects. The transmission coefficient through a dielectric layer of length L surrounded by air is defined by [8]

$$\gamma(f) = \frac{2\pi f}{c_0}\sqrt{-\rho_r(f)} \quad \rightarrow \quad 2.7$$

The transmission and reflection coefficients can be measured by frequency domain techniques which provide a way to determine the dielectric constant of unknown sample materials.

2.2.3. Diffraction

Diffraction effects are also dependent on frequency. Various diffraction models can be used to describe these propagation phenomena. Since the wavelength of the FCC allowed UWB frequencies (which ranges from 28 mm to 96 mm) is generally much smaller than the objects causing the diffraction, e.g., corner walls, it is reasonable to use high-frequency approximations as the geometrical theory of diffraction (GTD) or the uniform theory of diffraction (UTD). GTD describes in a rigorous way the diffracted rays emanating from edges and corners, but it is unable to describe the field at the shadow boundaries [9].

2.2.4. Rough Surface Scattering

A rough surface is considered to be a surface with small-scale random fluctuations on the local height. In cases when the surface height can be well described by a Gaussian distribution, the scalar reflection coefficient of the rough surface becomes [10]

$$R_r(f) = R_s e^{-2\left[2\pi\left(\frac{f}{c_0}\right)\sin(\rho)\right]} \quad \rightarrow \quad 2.8$$

2.3. Signal processing for UWB

The distinctive propagation characteristics of ultra-wideband also influence the signal processing required at both transmitter and receiver. In this section, we give an example of the signal processing needed to transmit (or reciprocally, receive) a signal in a certain direction, assuming multiple antennas. We consider the uniform linear array (ULA) case, where the antennas are equally spaced along a specific direction.

For narrowband systems, beam forming a signal $s(t)$ in a specific direction ρ from the array, is achieved by applying *steering phases* to $s(t)$ before the antennas elements. This can be interpreted as a frequency-domain approach since the steering phases affect the phase of the carrier frequency. In accordance, the signal transmitted from the nth antenna (using complex base-band representation) is defined as:

$$x_n(t) = s(t)e^{-2\left[2\pi\left(\frac{f}{c_0}\right)\sin(\rho)\right]} \quad \rightarrow \quad 2.9$$

In ultra-wideband systems, especially in the case of impulse based communications systems with large relative bandwidths, there is no single carrier frequency, and therefore the beam forming approach of (equation 2.9) cannot be used.

3. Advantages of UWB systems

As compare to other technologies in the circle UWB have various silent features. Some of them are illustrated below.

1. Bandwidth and channel capacity. The use of UW frequency makes it possible to gain huge bandwidth from Mbps or Gbps. It also provides a distance of 1-10 meter [11].
2. During transmission low power consumption
3. As of low power transmission; frequency spectrum is lower than accepted noise floor [10]. As shown in figure 2.3.

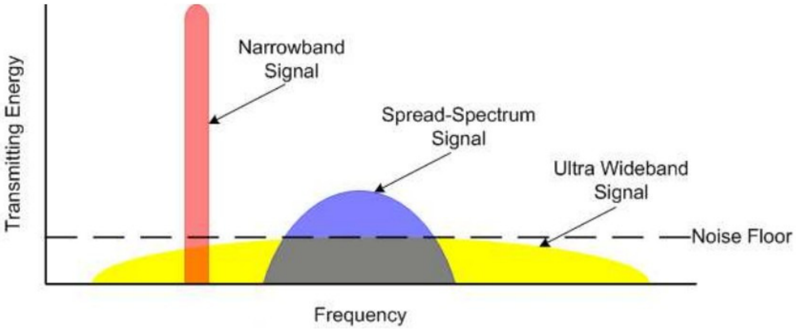


Figure 2.3: Ultra wideband communications spread transmitting energy across a wide spectrum of frequency

For example, 1 watt of power spread across 1GHz of spectrum results in only 1 nano watt of power into each hertz band of frequency. Thus, UWB signals do not cause significant interference to other wireless systems.

4. UWB high security and reliability best for communication industries. \

4. UWB Modulation Techniques

The pulse train need to be modulated before transmitting information. For UWB modulation there are several techniques such that PAM (pulse Amplitude modulation), PP (Pulse Position Modulation), On-Off keying (OOK), and Binary-phase shift keying (BPSK). BPSK has a 3dB performance improvement over OOK and PPM.

4.1.1. Pulse position Modulation PPM

The position of entire pulse or every pulse can be changed in accordance with information data in PPM. A digital zero is necessary for coding the entire bit sequence earlier then picoseconds; also this zero can be modulated on same rate with a same amount of time as shown in Figure 2.4. The number of symbols even for making M-array PPM can be done by several changing positions. The constant transmitting power is a main advantage of this type of modulation.

4.1.2. Pulse Amplitude Modulation PAM

The information data pulses can be encoded in train of amplitude of pulses in PAM. To change the power of pulses values need to adjust. For example eight levels of pulses amplitude are used for making 8-ary PAM. This can be illustrated in Figure 2.4.

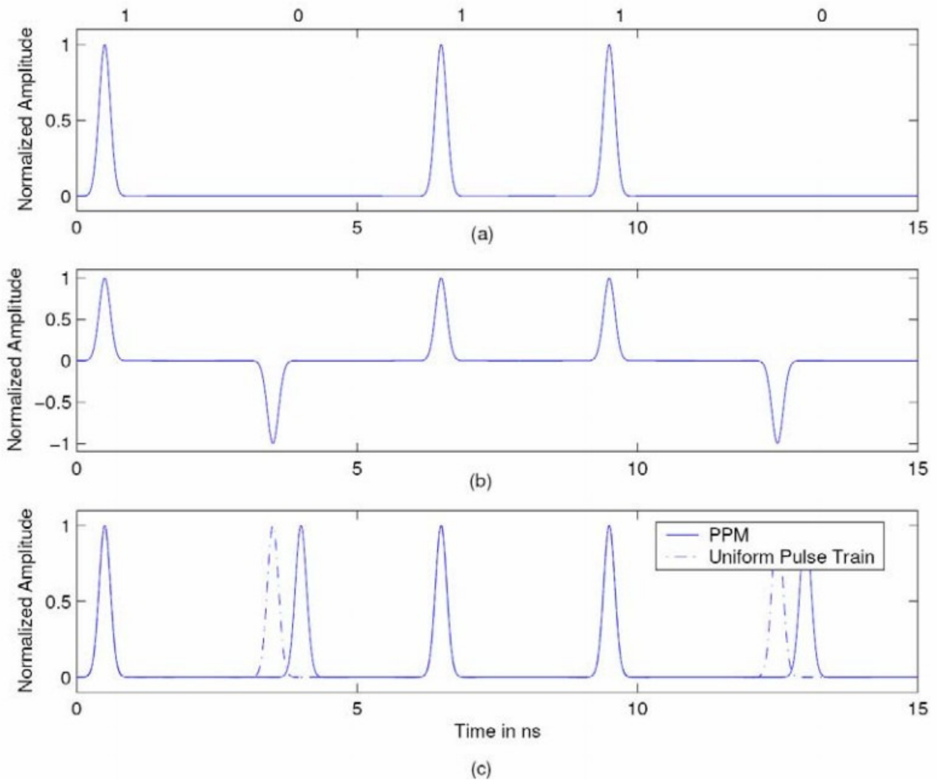


Figure 2.4 UWB Modulation schemes (a) OOK, (b) PAM, (c) PPM

4.1.3. On-Off Keying OOK

The presence of a pulse in OOK is represented by a value of 1, while the absence is represented by zero. Equation 2.10 shows the OOK modulation while figure 2.6 sow the OOK UWB waveforms.

$$s(t) = \sum_{n=-\infty}^{\infty} b_n p(\tau - n\tau_f) \qquad \rightarrow \qquad 2.10$$

Simple implementation is a main advantage of OOK upon other modulation techniques.

CONCLUSION

This paper main aimed is to explore the basic idea and concept related to characterization of UWB and its modulation techniques. We found that UWB have enough benefits rather on other technologies on the circle.

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