Chapter 2
Fundamentals of UWB Impulse Systems

2.1 Introduction

In this chapter, the basic concepts and features of UWB impulse systems are presented. Different types of UWB impulse signals and commonly used modulation topologies for UWB impulse systems are described. The chapter also provides the core topologies of UWB impulse transmitters and receivers as well as brief overview of the UWB antennas for UWB impulse systems. These are essential for the design and understanding of UWB impulse systems.

2.2 UWB Overview

2.2.1 UWB Basics

Over the unlicensed frequency range of 3.1–10.6 GHz, the FCC has defined UWB signals as those that occupy a 10-dB bandwidth of greater than 500-MHz bandwidth or larger than 20% fractional bandwidth as defined by

$$\text{Fractional Bandwidth} = \frac{2(f_H - f_L)}{f_H + f_L} \geq 20\% \qquad (2.1)$$

where f_H and f_L are the upper and lower frequency limits, respectively, of the 10-dB bandwidth.

The FCC also requires that the power emission levels of the UWB signals within the UWB spectrum of 3.1–10.6 GHz must be sufficiently low to avoid interference with other existing communication systems, technologies and services operating in the same UWB allocated bands, hence enabling them to exist together. Specifically,

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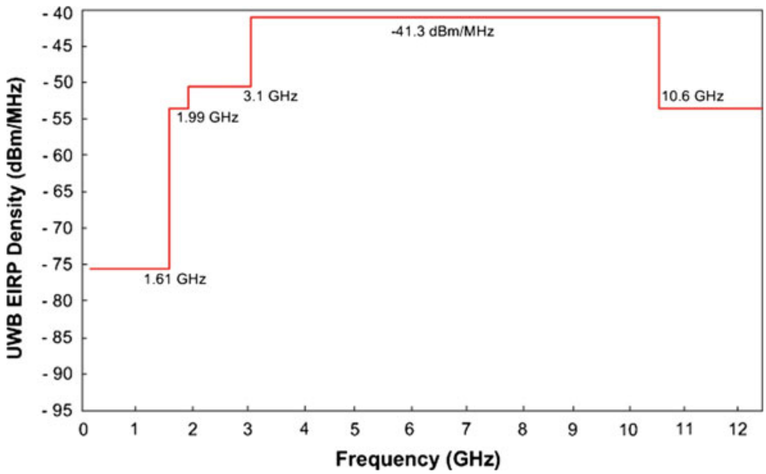


Fig. 2.1 Spectrum mask of the UWB effective isotropic radiated power (EIRP) from transmitting antenna

the FCC requires that the maximum allowed power spectral density (PSD) not to exceed −41.25 dBm/MHz as designated in the UWB spectrum mask shown in Fig. 2.1. This kind of power is low enough not to cause interference to other services, such as Wireless Fidelity (WiFi) operating under different rules that share the same bandwidth within the UWB frequency range. The limited emitting power presents a serious challenge to these unlicensed UWB systems because other RF systems or services sharing the same band of operation on licensed or unlicensed bands are likely to have a much higher transmitting power and, therefore, would subject the UWB receivers to considerable interference. This low RF emitting power requirement inevitably limits these unlicensed UWB systems to work only within short ranges, making it suitable to employ miniature CMOS RFICs whose RF power capability and dc power consumption are relatively small. It is noted that in UWB impulse systems, the transmitting pulse spreads the energy over a wide frequency band as compared to narrow-band signals as illustrated in Fig. 2.2.

2.2.2 UWB Advantages

Compared to CW based systems, UWB impulse systems have many advantages as following:

1. **Fine Resolution and Long Range**

UWB impulse systems typically have much wider instantaneous bandwidths than those of CW based systems due to the extremely wideband nature of the

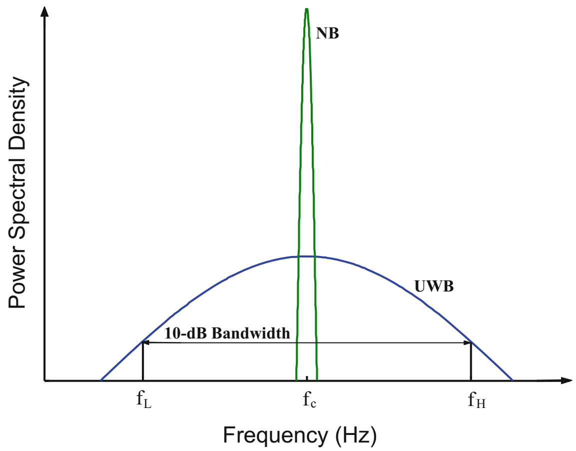


Fig. 2.2 Power level of a UWB signal with respect to a typical narrowband (NB) signal

impulse-type signals. These signals contain both low and high frequency components, making impulse systems very suitable for applications requiring fine range-resolution and/or long range. An ultra-wide bandwidth directly leads to fine range-resolution due to the fact that the range resolution is inversely proportional to the bandwidth. An ultra-wide frequency range spanning across low and high frequencies enables long range as compared to a CW frequency range containing only comparable high frequencies due to small attenuation at low frequencies and hence long propagating distance of low-frequency signals. It is noted that, while similar range-resolution and range can also be achieved for CW based systems operating with same bandwidth and frequencies, respectively, it is very difficult (if not impossible) to realize an extremely wide-band CW system.

2. **High Multi-Path Resolution and Low Interference with Other Existing Signals**

The transmitting energy spectral density of UWB impulse systems is typically much lower than that of CW based systems for the same input power since the total energy is spread over a wide range of frequencies of the impulse signal. This effectively produces much smaller interference to the signals of other existing or co-operating RF systems. Typical impulse signals have a very narrow pulse width and hence the transmission duration of impulse signals is very short in most cases. The signals returned from targets, in turn, have a very short time-window of opportunity to collide with the line-of-sight signals and less likely cause signal degradation, hence very high multi-path resolution can be achieved. The large frequency diversity of the ultra-wide spectrum of an impulse signal makes impulse signal relatively resistant to intentional and unintentional jamming or interference, because it is difficult to jam every frequency component in the ultra-wideband spectrum at once. Even if some of the frequency components are jammed, there is still possibly a large range of frequencies that remains untouched. UWB impulse systems offer excellent immunity to interference from other existing signals, while also causing minimum interference to these signals.

3. **Low Probability of Interception or Detection**

The lower-energy spectrum density of impulse signals also makes unintended detection more difficult than CW systems, hence resulting in low probability of interception or detection, which is desirable for secure and military applications.

4. **Reduced Signal Diminishing**

The ultra-wide bandwidth of UWB impulse systems leads to high frequency diversity that reduces the chance of signal diminishing in certain operating environments with severe multi-path fading at some frequencies, such as indoors, urban settings or mountainous terrains, or when signal attenuation at some frequencies are excessively high, which hinder the sensing capabilities, or where noise exists in a narrow-frequency range within the operating band, resulting in better immunity to destructive environments.

5. **Reduced Signal Diminishing**

The accuracy of locating and tracking for UWB impulse systems is higher due to the narrow time-duration of pulse signals typically used for transmission which causes much better timing precision than CW systems such as global positioning system (GPS).

6. **Simple and Low-Cost Architecture**

UWB impulse systems can be implemented with a simpler architecture than their wideband CW counterparts including multi-band OFDM systems, in which the core signal generator of the transmitter can be realized with a simple pulse generator without an up-conversion circuit and the core mixer of the receiver can be implemented with a simple direct-conversion (to baseband) sampling circuit, that does not require an intermediate Frequency-conversion stage, as compared to more complicated wideband signal source and mixer typically used in CW based systems. Moreover, a complex frequency synthesizer (or even simple oscillators) needed for the transmitter and receiver in CW systems is avoided. Additionally, a simple impulse UWB system with no frequency synthesizer or oscillator consumes less power, thereby extending the operating life, which is attractive for battery-operated portable devices.

UWB impulse systems of course also have several disadvantages as compared to CW systems. For instance, the receiver's noise figure of UWB impulse systems is much higher than that of CW systems, which in turn limits the sensitivity and hence the dynamic range of the receiver, preventing their use for applications requiring very high sensitivity and/or large dynamic range. It is also much more complicated to design antennas for UWB impulse systems due to wide bandwidths and the need to maintain signal fidelity across such bandwidths.

2.2.3 UWB Applications

UWB impulse systems find numerous applications for military, security, civilian, commerce and medicine. The following are some of the existing and emerging applications of UWB impulse systems:

Military and Security Applications: detection, location and identification of targets such as aircrafts, tunnels, concealed weapons, hidden illegal drugs, buried mine and unexploded ordnance (UXO); locating and tracking personnel; detection and identification of hidden activities; access control; through-wall imaging and surveillance; building surveillance and monitoring.

Civilian and Commercial Applications: detection, identification and assessment of abnormal conditions of civil structures such as pavements, bridges, buildings, buried underground pipes; detection, location and identification of objects; asset and inventory management; radio-frequency identification (RFID); monitoring of personal properties such as cars, homes and valuable items; intrusion detection; asset tracking; measurement of liquid volumes and levels; inspection, evaluation and process control of materials; geophysical prospecting, altimetry; collision and obstacle avoidance for automobile and aviation.

Medical Applications: detection and imaging of tumors; health monitoring of elders; health examination of patients; medical imaging.

It is particularly noted that the major application of UWB impulse systems operating within 3.1–10 GHz is for short-range communication due to its inherently very high data transfer rate for short distances. UWB impulse systems can send and receive high-speed data with very low power at relatively low cost and hence are attractive for short-range wireless communication areas. Specifically, the UWB technologies primarily target indoor short-range high-bit-rate applications such as home networking, high-speed wireless local area network (LAN), and personal area network (PAN) communications.

2.3 UWB Impulse Signals

The selection of impulse-signal types for UWB impulse systems is one of the fundamental considerations in designing UWB impulse systems, antennas, and circuits because the type of an impulse determines the UWB signal's spectrum characteristic. Many types of impulse signals such as step pulse, Gaussian-like (or monopolar) impulse, Gaussian-like single-cycle (or monocycle) pulse, Gaussian-like doublet pulse, and multi-cycle pulse can be used for UWB impulse systems. Among those, Gaussian-like impulse, doublet pulse, and monocycle pulse are typically used in UWB impulse systems. Particularly, the monocycle pulse is preferred in most UWB impulse systems because of its spectral characteristics (having no dc) that facilitate easier wireless transmission than the impulse, wider bandwidth than the multi-cycle pulse, and easier to realize than the doublet pulse.

2.3.1 Gaussian Impulse

Figure 2.3 shows the time-domain waveform of a Gaussian impulse that has a shape of the Gaussian distribution, along with its frequency-domain waveform or spectral response. The impulse is assumed to have 200-ps pulse duration (or pulse width). The Gaussian impulse can be expressed as

$$y(t) = Ae^{-a^2t^2} \tag{2.2}$$

where A is the maximum amplitude of the Gaussian impulse and a is the constant that determines the slope of the Gaussian pulse. The spectral response containing the spectral components of the Gaussian impulse is obtained by taking its Fourier transform as

$$Y(\omega) = \frac{A}{a\sqrt{2}} e^{-\frac{\omega^2}{4a^2}} \tag{2.3}$$

The frequency corresponding to the peak value of the impulse in the frequency domain is $f_o = 0$. The 3-dB bandwidth of the Gaussian impulse can be derived by letting the amplitude of the impulse at the 3-dB band-edge equal to the $1/\sqrt{2}$ of the maximum value at $f = 0$ as

$$\Delta f = 0.8326 \frac{a\sqrt{2}}{2\pi} \tag{2.4}$$

2.3.2 Gaussian Monocycle Pulse

Gaussian monocycle pulse is the first derivative of the Gaussian impulse signal. Figure 2.4 shows a Gaussian monocycle pulse having the same 200-ps pulse duration as the Gaussian impulse shown in Fig. 2.3 and its spectrum. The Gaussian monocycle pulse is described by

$$y(t) = -2a^2Ate^{-a^2t^2} \tag{2.5}$$

The spectral response of the Gaussian monocycle pulse is given as

$$Y(\omega) = \frac{i\omega A}{a\sqrt{2}} e^{-\frac{\omega^2}{4a^2}} \tag{2.6}$$

The frequency corresponding with the peak value of the Gaussian monocycle pulse in the spectrum is obtained as

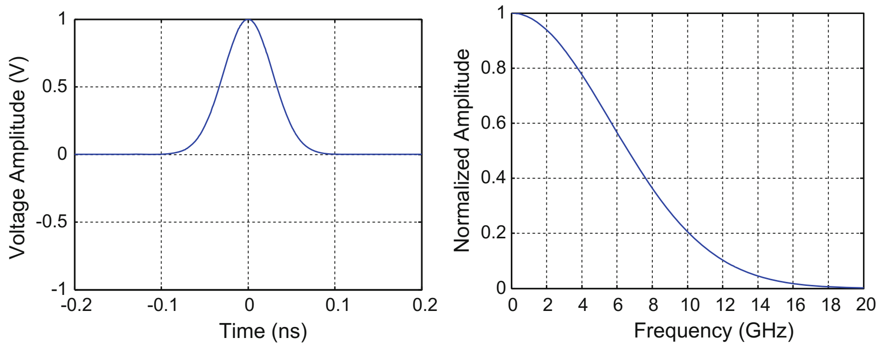


Fig. 2.3 Gaussian impulse with 200-ps pulse duration and its frequency spectrum

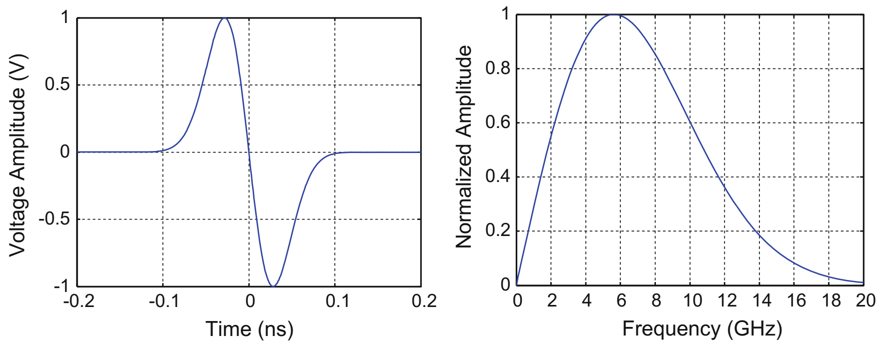


Fig. 2.4 Gaussian monocycle pulse with 200-ps pulse duration and its frequency spectrum

$$f_o = \frac{a\sqrt{2}}{2\pi} \tag{2.7}$$

and the 3-dB bandwidth can be derived as

$$\Delta f = 1.155\frac{a\sqrt{2}}{2\pi} = 1.155 f_o = \frac{1.155}{T_p} \tag{2.8}$$

where $T_p = 1/f_o$ is the pulse duration, which shows that the 3-dB bandwidth of the Gaussian monocycle pulse is approximately equal to 115% of the pulse's center frequency f_o. Figures 2.5 and 2.6 show the waveforms and spectrums of various Gaussian monocycle pulses having different pulse durations.

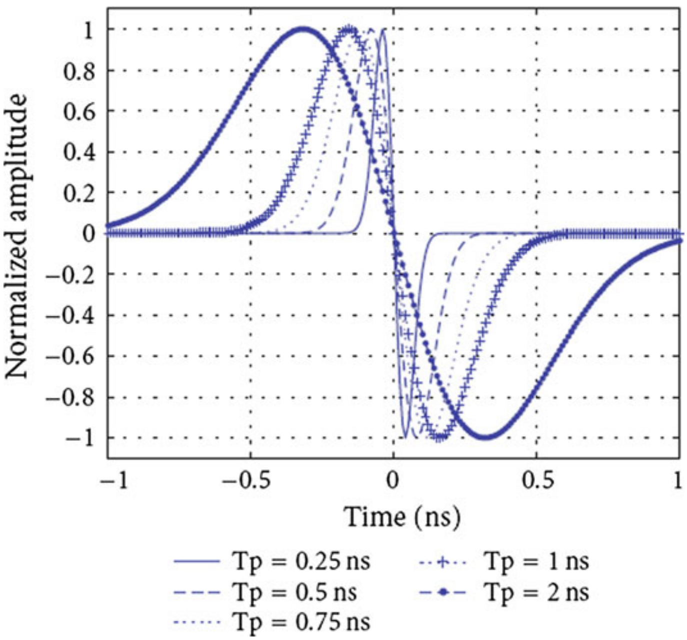
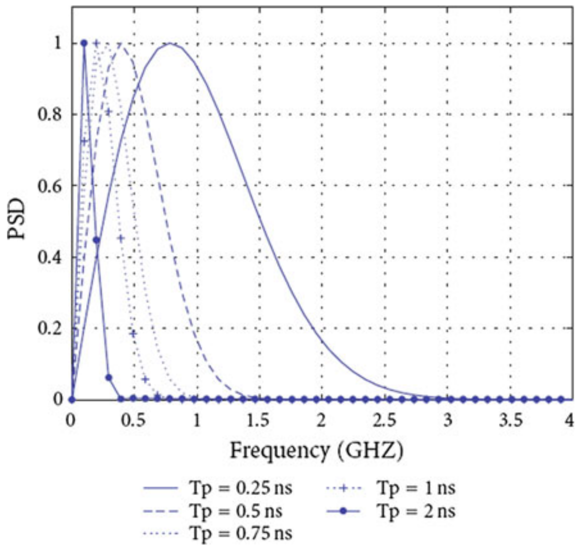


Fig. 2.5 Gaussian monocycle pulses with different pulse durations

Fig. 2.6 Spectrum of Gaussian monocycle pulses with different pulse durations



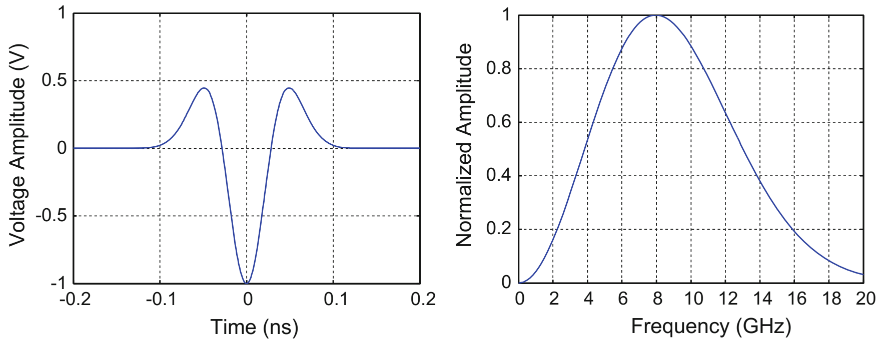


Fig. 2.7 Gaussian doublet pulse with 200-ps pulse duration and its frequency spectrum

2.3.3 *Gaussian Doublet Pulse*

Figure 2.7 shows a Gaussian doublet pulse having 200-ps pulse duration and its spectrum. The Gaussian doublet pulse is the second derivative of the Gaussian impulse signal and hence can be expressed as

$$y(t) = -2a^2 A e^{-a^2 t^2}(1 - 2a^2 t^2) \tag{2.9}$$

The spectral response of the Gaussian doublet pulse is

$$Y(\omega) = \frac{-A\omega^2}{a\sqrt{2}} e^{-\frac{\omega^2}{4a^2}} \tag{2.10}$$

The frequency at which the peak value of the Gaussian doublet pulse occurs in the spectrum is

$$f_o = \frac{a}{\pi} \tag{2.11}$$

This frequency is higher than that given in (2.7) for the Gaussian monocycle pulse. The 3-dB bandwidth can be derived as

$$\Delta f = 1.155 \frac{a\sqrt{2}}{2\pi} = 1.155 \frac{f_o}{\sqrt{2}} \tag{2.12}$$

Compared to the bandwidth of the Gaussian monocycle pulse given in (2.8), the absolute bandwidth of the Gaussian doublet pulse is same, yet the fractional bandwidth is larger assuming the same pulse duration. This result is due to the second-derivative performed upon the Gaussian impulse. Additional derivatives taken on the Gaussian impulse would produce other pulses having the same pulse duration but with progressively increasing fractional bandwidth and frequency corresponding to the peak pulse-magnitude. This phenomenon further implies that UWB impulse signals generated using higher derivatives of the Gaussian impulse may be attractive for high-frequency UWB impulse systems since they have higher frequencies and larger fractional bandwidth for the same pulse duration, which may be useful for some applications. It is noted that using a Gaussian monocycle pulse, which is the first derivative of a Gaussian impulse, at high frequencies requires very narrow pulse duration, which may be difficult to realize with sufficient amplitude in practice.

As can be seen from the pulse waveforms, the Gaussian impulse has no zero crossing point, while the Gaussian monocycle pulse and Gaussian doublet pulse have one and two zero crossings, respectively, which help define the bandwidth characteristics of these pulses. It is also observed that the spectral responses of these pulses contain no side-lobes beyond the zero-crossing frequency points which are desirable for signal transmission. For pulses whose spectral responses have side-lobes, such as a rectangular or sinusoidal pulse, these side-lobes are always outside the pass-band, which at most extends across the zero-crossing frequency ends, and hence produce unwanted radiation, leading to possible false-target detection and/or interference to other existing systems, especially when they have sufficiently high energy.

It is particularly noted that, as the peak spectral amplitude of the Gaussian impulse occurs at dc and as seen in Fig. 2.3, the bulk of its energy is contained at dc and low frequencies near dc. The monocycle and doublet pulse signals, on the other hand, contain no dc component and have much lower low-frequency energy. In general, the monocycle and doublet pulses have similar energy distributions in the low- and high-frequency regions around the center frequency. It is the difference in the spectral shapes of these signals at dc and low frequencies that greatly affects the transmission of signals via antennas and the propagation of signals though components, and ultimately the design of UWB antennas, components and systems. Impulses are not transmitted and received effectively through practical antennas due to their large portion of low-frequency spectral components which cannot be transmitted (or is transmitted with very low efficiency) by practical antennas. Monocycle and doublet pulses, on the other hand, can be transmitted more efficiently due to no dc component and less low-frequency content. Furthermore, using monocycle or doublet pulse facilitates the design of components including antenna in UWB impulse systems due to no design consideration at dc and less design emphasis at low frequencies, leading to simpler and more compact design. It is further noted that signal fidelity is of utmost important for UWB impulse systems, which require signals to be transmitted and received with minimum distortion. With no dc component and less low-frequency spectral amplitudes contained in monocycle pulses, antennas and other system components can be more conveniently designed to cover desired bandwidth, hence minimizing the distortion of signals traveling through these components and, consequently, producing better fidelity for transmitting and receiving signals.

UWB impulse systems always transmit a train of pulses (typically periodically) instead of a single pulse. Consequently, according to Fourier analysis, the spectrums of UWB impulse signals are not continuous and contain discrete spectral lines (corresponding to discrete frequencies) spaced apart by 1/T, where T is the period of the UWB signals. Fourier analysis also shows that a UWB impulse signal consisting of a train of pulses is not substantially distorted by passive components including antennas having a bandwidth approximately equal to the reciprocal of the pulse width, because of most of the energy is contained within such bandwidth. According to the Parseval's theorem, the average power in a periodic pulse train is equal to the sum of the powers in its spectral components including dc and harmonics. Therefore, transmission of a UWB impulse signal consisting of periodic high-voltage pulses would be similar to simultaneous transmission of strong CW signals at different frequencies. The results of the Parseval's theorem also suggest an alternate way of generating a UWB impulse signal of periodic pulses by combining various CW signals having appropriate amplitudes and frequencies.

2.4 Basic Modulation Topologies

Several modulation techniques can be used to create modulated UWB signals, which modulate the information bits directly into very short UWB impulses [1]. Since there is no intermediate frequency (IF) processing in systems employing such signals, these systems are often called "base-band" or "impulse radio systems." Typical modulations in UWB impulse systems can be divided into the mono-phase and bi-phase techniques. The three most popular mono-phase UWB modulation approaches are the pulse position modulation (PPM), pulse amplitude modulation (PAM), and on-off keying (OOK). In these techniques, the data signal "1" is differentiated from the data "0" either by the size of the pulse signal or the time when it arrives with all the pulses essentially having the same shape. For the more efficient bi-phase case, the bi-phase shift keying (BPSK) is one of the most popular topologies. This modulation transmits a single bit of data with each pulse, with the positive pulse representing "1" and the negative pulse signifying "0". A brief description for each of these modulation topologies is gen as follows.

2.4.1 PPM

PPM is one of the common modulation technologies used in UWB impulse systems. In this technique, both the pulses that indicate digital data bits "1" and "0" have the same amplitude but at different times. The system transmits the same pulse at different positions in the time domain to represent a "1" or "0". This method may require a complex receiver in order to determine the precise position of the received pulse in order to recognize corresponding 1 or 0. An example of the PPM is shown in Fig. 2.8, where a (time) position of the pulse representing "1" leads that of the pulse representing "0".

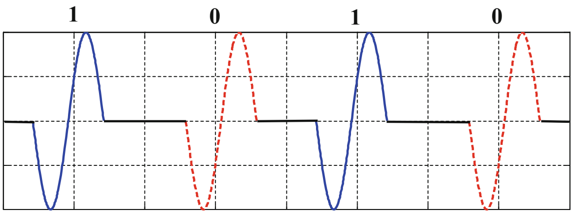


Fig. 2.8 An example of PPM with pulses representing 1 and 0

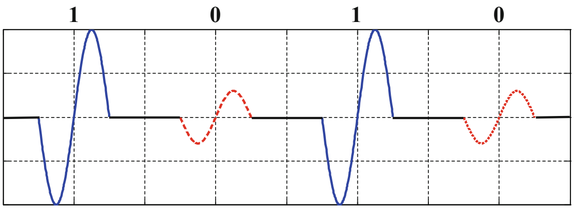


Fig. 2.9 An example of PAM with high- and low-amplitude pulse representing respective 1 and 0

2.4.2 PAM

PAM works by separating the high-amplitude and the low-amplitude pulses. In the PAM, the amplitude of the pulse is varied according to different digital data information, where high-amplitude pulse represents "1" and small-amplitude pulse designates "0". Figure 2.9 illustrates an example of the PAM technique.

2.4.3 OOK Modulation

In OOK modulation, information bits "1" and "0" are represented with the full-amplitude and zero-amplitude of the UWB pulse, respectively, which are obtained by turning the UWB pulse on and off, respectively. By setting the UWB pulse on and off, binary information bits "1" and "0" are sent out. An example of the OOK modulation is shown in Fig. 2.10, where "1" is obtained when there is a pulse and "0" corresponds to no pulse.

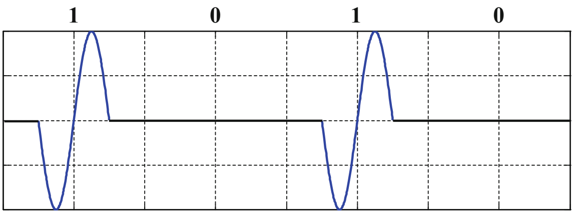


Fig. 2.10 An example of OOK modulation where 1 and 0 are represented with and without pulse, respectively

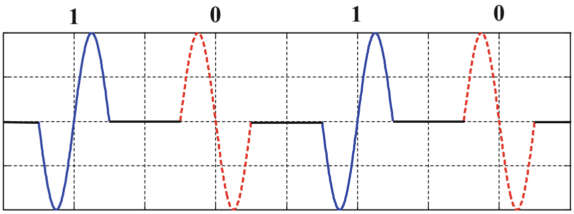


Fig. 2.11 An example of BPSK modulation with 1 and 0 represented by pulses of opposite polarities

2.4.4 BPSK Modulation

The most common bi-phase modulation approach used in impulse UWB systems is BPSK. Bi-phase modulation differentiates "1" with a pulse (e.g., positive pulse) and "0" with another pulse of opposite polarity (e.g., a negative pulse). Comparing with the PPM, where a series of ultra-wideband circuits is needed to generate very accurate time steps, the bi-phase modulation approach is simple, requires only two kinds of pulses to be generated, and imposes less processing at the receiver side. The BPSK modulation offers several advantages such as power efficiency and smooth spectrum with smaller-amplitude spikes over the above-mentioned mono-phase techniques of PPM, OOK, and PAM that have larger amplitude spikes. These spikes are caused by the multi-pulse occurring periodically. The most significant advantage is an improvement of two times in the overall power efficiency as compared to the OOK or PPM [2]. This makes the bi-phase UWB approach extremely efficient for high-data-rate portable applications. An example of the BPSK modulation is shown in Fig. 2.11.

2.5 UWB Impulse Transmitters and Receivers

2.5.1 UWB Impulse Transmitters

One of the major advantages of impulse UWB transmitters, as compared to CW transmitters, is the simplicity of their circuits, in which complex components typically employed in CW transmitters, such as frequency synthesizers that contain various circuits like phase-locked-loop (PLL), voltage-controlled oscillator (VCO) and mixers, are not needed. Impulse UWB transmitters are thus relatively easier to design and implement and less expensive.

Figure 2.12 shows a block diagram of an UWB impulse transmitter, which is relatively simple and does not contain many components as seen in typical CW

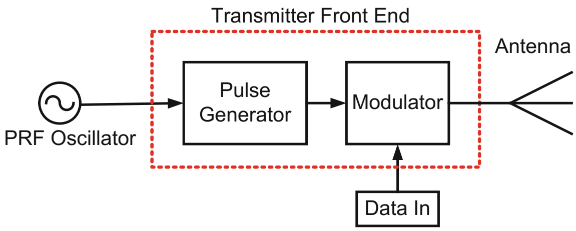


Fig. 2.12 Block diagram of an impulse UWB transmitter

transmitters. It consists of a pulse generator and a digital-controlled modulator circuit that controls the timing or polarization of the transmitted pulse signal corresponding to digital data bit 1 or 0. The local oscillator, which typically employs a simple and inexpensive topology such as a crystal oscillator, determines the pulse repetition frequency (PRF) of the UWB impulse signal (and hence the corresponding UWB impulse system). The pulse generator produces a pulse signal with a desired waveform such as impulse or monocycle pulse, etc. The modulator circuit modulates the transmitting pulse signal with incoming digital data information using a particular modulation such as the BPSK, PAM, OOK or PPM described in Sect. 2.4, depending on the timing or polarization modulation requirement for the UWB impulse system.

The main component of the UWB impulse transmitters is the pulse generator. There are various ways to generate narrow-pulse signals in the pulse generator. Existing methods for generating sub-nanosecond pulses are generally based on hybrid circuits using discrete components, therefore resulting in relatively large size and high cost. These existing pulse generators are normally not optimized for minimum power consumption and feasibility of integrating them into wireless portable devices. Some of the pulse generators were developed using spark gaps [3], which are not an option for consumer electronics due to their size. One method of generating sub-nanosecond impulse and monocycle pulses involves hybrid circuits using Schottky barrier diodes and step recovery diodes (SRD) [4–6], which are also not very suitable for RFIC applications.

A periodic impulse can also be generated indirectly from individual concurrent sinusoidal signals having appropriate amplitudes and phases at different frequencies according to the Fourier series. A UWB impulse system employing such an impulse generator can be considered as equivalent to a frequency-domain system. Generation of impulse waveforms based on Fourier series is very accurate in theory [7, 8]. This technique, however, is very difficult to be implemented in practice at microwave frequencies due to the difficulty in generating and transmitting individual sinusoidal waveforms at different frequencies with precise amplitudes and phases as well as receiving them, especially when a large number of harmonics is needed to obtain an accurate waveform. A transmitter that can generate many harmonic components with certain phases and amplitudes is very difficult to design and could be bulky. In addition, the receiver design is also very complicated because the receiver needs to receive all of the returned signals from the transmitted harmonics for accurate results. Due to the complex nature of the transmitter and receiver design implementing this approach, it is not suitable for most wireless UWB applications, especially those requiring miniature and low-cost UWB impulse systems.

All of the foregoing mentioned impulse-generator designs have two common drawbacks: relatively large circuit size and possibly high cost (at least for mass production). These problems make them not desirable for compact UWB applications involving small-space and low-cost deployment. Using CMOS RFICs could resolve these issues because of their miniaturization, low cost, low power consumption, and easy integration with digital circuits (for complete single-chip systems).

Detailed design of UWB impulse transmitters is described in Chap. 3. Particularly, a RFIC pulse generator based on a commercial CMOS technology that produces both Gaussian impulse and monocycle pulse with tunable durations is presented. This pulse generator is integrated together with a BPSK modulator to form a UWB impulse transmitter module.

2.5.2 UWB Impulse Receivers

As for UWB impulse transmitters, one of the major advantages of UWB impulse receivers, as compared to CW receivers, is the simplicity of their circuits, in which mixers with intermediate-frequency (IF) stages typically employed in CW receivers are not needed. UWB impulse receivers directly convert received RF signals into a baseband output signal without an intermediate stage and are thus relatively easier to design and implement and less inexpensive.

Figure 2.13 shows a block diagram of a UWB impulse receiver, which consists of a low-noise amplifier (LNA), a correlator (correlation circuit), and a (template) pulse generator. The oscillator drives the pulse generator and determines the pulse repetition frequency (PRF) of the UWB impulse system. To maximize the processing gain and signal-to-noise ratio (SNR), the template waveform generated by the pulse generator should have a similar shape to that of the received pulse signal. After passing the LNA, the received pulse signal is coherently correlated with the template pulse through the correlator and the input pulse is then converted into a baseband signal. The conversion process can be done in a single stage (correlator) and, hence, no intermediate-frequency-conversion stage is needed, which greatly reduces the system complexity.

The correlator is the heart of UWB impulse receivers. It consists of a multiplier, an integrator, and a sampling/holding (S/H) circuit. The multiplier mixes or, precisely, multiplies the received pulse signal from the LNA with the (template) pulse signal from the pulse generator. The result (output signal) of the multiplier is integrated over several periods of the received pulse train to maximize the power and minimize the noise of the received signal. Due to the integration performed over a train of pulses, more correlated energy is integrated over the duration of each

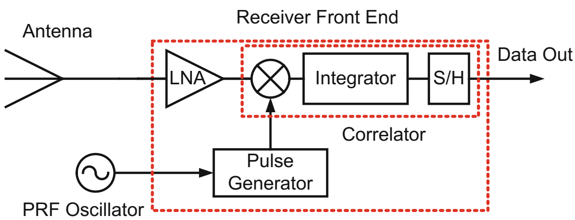


Fig. 2.13 A UWB impulse receiver block diagram

symbol (or received signal corresponding to the symbol) and hence the correlated signal is raised from the noise. Consequently, if more pulses (i.e., a longer pulse train) are used to transmit each symbol (essentially, the transmitting signal of the transmitter) or, in turn, contained in each symbol (essentially, the received signal of the receiver), then better SNR will be obtained.

Considering the unique feature of UWB impulse receivers described above, there is a stringent requirement for the correlation speed, which demands that both the multiplier and integrator must be fast enough to process each pulse. This inevitably brings great challenge to the correlator design for UWB impulse receivers.

Like most spread-spectrum systems, where energy generated in a particular bandwidth is deliberately spread over the operating spectrum in the frequency domain, resulting in a signal with a wider bandwidth, the processing gain (PG) is also an important characteristic in UWB impulse systems. To combat the unavoidable noise in and interference to the signal, a group or train of N pulses is used to transmit each symbol (signal), hence the energy of the symbol is spread over N pulses and the processing gain can be achieved. The processing gain (in dB) derived from this procedure can be defined as

$$PG_1 = 10\ \log_{10}(N) \tag{2.13}$$

Furthermore, the pulse signal only occupies a very small part of the entire period, which means the duty cycle of the pulses can be extremely small, sometimes even less than 1%. Therefore, the UWB impulse receiver is only required to work for a small fraction of the period between the pulses, and the impact of any continuous source of interference is hence reduced so that it is only relevant when the receiver attempts to detect a pulse. The processing gain due to a low duty cycle is given by

$$PG_2 = 10\ \log_{10}\left(\frac{T_f}{T_p}\right) \tag{2.14}$$

where T_f is the period and T_p is the pulse width.

The total processing gain PG is the sum of the two processing gains:

$$PG = PG_1 + PG_2 = 10\ \log_{10}(N) + 10\ \log_{10}\left(\frac{T_f}{T_p}\right) \tag{2.15}$$

As an example, consider a UWB impulse receiver operating with a pulse train having a pulse period of 100 ns and a pulse width of 200 ps, the processing gain due to the low duty cycle (PG_2) would be about 27 dB. Since the UWB impulse system uses multiple pulses to recover each bit of information (symbol), if one digital bit is determined by integrating over 100 pulses, then the processing gain PG_1 would be another 20 dB. The total processing gain PG for the UWB impulse system is then about 47 dB. Since the PRF of the pulse is 10 MHz and each bit covers 100 pulses, the resulting data rate is 100 Kbps as obtained from (2.15).

Detailed design of UWB impulse receivers is given in Chap. 4. Particularly, the designs of a UWB LNA, correlator and receiver on RFIC using a commercially available CMOS technology are described.

2.6 UWB Antennas

UWB antennas capable of radiating and receiving faithfully UWB impulse signals are crucial for high-performance UWB impulse systems. As all of the frequency components contained in an impulse signal needs to be transmitted or received concurrently, UWB antennas used in UWB impulse systems have more stringent requirements than UWB antennas employed in UWB CW systems, which only need to transmit or receive one frequency component at each time. These strict requirements, such as minimum dispersion and loss (and hence distortion), make the design of UWB impulse antennas more difficult, particularly on planar circuits that enable direct and low-cost integration with UWB impulse transmitters and receivers. Chapter 5 discusses UWB antennas for UWB impulse systems and presents the detailed design of a uniplanar UWB antenna implemented on microwave integrated circuits, that is suitable for UWB impulse systems.

2.7 Summary

This chapter covers the fundamentals of UWB impulse systems operating across or within the unlicensed UWB frequency band of 3.1–10.6 GHz. It provides the essence of UWB impulse systems including the spectrum mask, advantages and applications of UWB impulse systems, UWB impulse signals including Gaussian impulse, doublet pulse and monocycle pulse, modulations including PPM, PAM, OOK and BPSK, UWB impulse transmitters and receivers, and UWB antennas.

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