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SURVEY TO ULTRA-WIDEBAND SYSTEMS

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Abstract - In this document a short description to the idea of ultra-wideband and impulse radio systems has been given. Due to ultra-wide frequency band the transmitted signal is noiselike and does not substantially interfere with other existing radio systems which allows overlay schemes. Ultra-wideband systems also offer high accuracy for positioning and ranging applications. Impulse radio utilizes extreamly short pulses that makes the spectrum of the transmitted signal ultra wide. Pulse position modulation is applied to data modulation. Although the use of ultra-wideband systems and impulse radio in military and civil communications has recently achieved a large interest among the research groups in communications area, the technique is known for more than three decades and the first applications were impulse radars.

1 INTRODUCTION

Scope of this document is to present some basic features of ultra-wideband (UWB) systems. This effort is based on the literature survey concerning the topic.
Signal is defined to be an ultra-wideband if the fractional bandwith B_f is greater than 0.25 [1]. The fractional bandwidth can be determined using formula [1]

$$B_f = 2\frac{f_H - f_L}{f_H + f_L} \tag{1}$$

where f_L = lower and f_H = higher -3 dB point in a spectrum, respectively.

Impulse radio communication systems and impulse radars both utilize very short pulses in transmission which results in an ultra-wideband spectrum. For radio applications, this communication method is also classified as a pulse modulation technique because the data modulation is introduced by pulse position modulation (PPM). UWB signal is noiselike which makes interception and detection quite difficult. Due to the low power spectral density, UWB signals do not interfere with existing narrowband radio systems, and they are not necessarily regarded as radio transmission according to the requlations. This would allow licence free operation of radio systems

Time-modulated impulse radio signal is technically seen as a carrierless baseband transmission. The absence of carrier frequency is the very fundamental character that differs impulse radio and impulse radar transmissions from narrowband applications and, on the other hand, from DS spread spectrum multi-carrier transmissions, which also can be characterized as an (ultra)wideband technique. Fast slewing chirps are the third method to generate UWB signals.

At the end of this document there is a reference list for some additional reading of the UWB, impulse radio and also on the impulse radar systems. Sources from [1] to [15] are referred in this document.

2 TECHNOLOGY BASICS OF THE EXISTING SYSTEMS

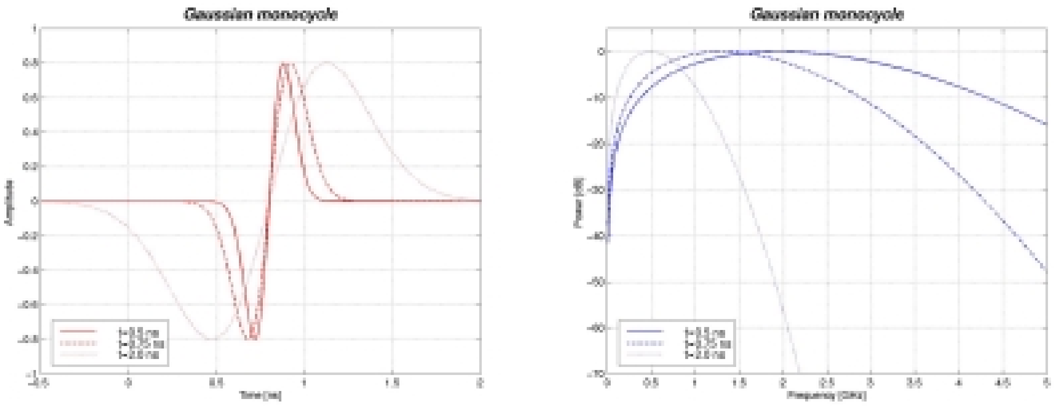
2.1 Impulse Radio

Time-modulated ultra-wideband (TM-UWB) communication is based on the emission of very short Gaussian monocycles (Fig. 1a) that makes the signal ultra wide in frequency domain (Fig. 1b).

One transmitted data bit is spread over multiple Gaussian monocycles. The data modulation is based on pulse position modulation (PPM). The receiver used is a homodyne cross correlator receiver that utilizes a direct RF-to-baseband conversion. No intermediate frequency conversion is needed.

Because the transmission is not continuos, the UWB communication is resistant to the severe multipath propagation and thus there is no ISI. Due to the short pulse width and relative slow pulse repetition frequency, the transmitted pulse is attenuated before the next pulse is sent which reduces inter-pulse interference.

In the time domain, a Gaussian monocycle can be defined as the first derivative of the Gaussian function. An example of the monocycle in time and frequency domain is presented in Figures 1a and 1b.



a) *b)*

Figure 1. Gaussian monocycle in time domain (a) and in frequency domain (b).

The nominal center frequency and the bandwidth of the monocycle depends on the monocycle pulse width. Bandwidth is about 116 % of the monocycles nominal center frequency [2]. Using the monocycle duration of 0.75 ns, as used in the Figure 1 (dashed line), the center frequency can be found in 1.33 GHz and the half power bandwidth is 1.55 GHz. One can see from Fig.1b that the spectrum of UWB signal is asymmetrical.

A Gaussian monocycle has a single zero crossing. If additional derivates of the Gaussian function are taken the relative bandwidth decreases, and the center frequency increases for a fixed time decay constant. Also the number of zero crossings of the pulse will increase due to the additional derivates, which all reduces the resolution of the system.

2.1.1 Modulation and Transmitter

As mentioned before, in TM-UWB systems data modulation is based on the pulse position modulation. This approach allows matched filter technique to be used in the receiver. PPM varies the precise timing of transmission of a monocycle about the nominal pulse position. If the transmitted digital bit is “0” the pulse is transmitted some time shift before the nominal time and in the case of “1” the timing is delayd. Time shift is about one-quarter of a pulse width [3].

PPM spreads the signal RF energy across the frequency band and makes the signal less detectable. When using pseudo random (PR) code to determine random transmission time over a large time frame, the spectrum of the transmitted pulse appears like a white noise. This time hopping randomizes the signal in both time and frequency domains. Time hopping eliminates also collisions in multiple accessing systems, where each user has a distinct pulse shift pattern [4]. Due to the PR time-modulation, the detector needs accurate knowledge about the PR code phase. One can imagine impulse radio systems as time hopping spread spectrum (SS) systems. UWB waveforms are, however, generated without modulation with an additional spreading code which simplifies the transmitter structure compared to SS systems [5]. The bit rate of the transmission can be chosen by changing the number of pulses to modulate a single data bit [6].

The transmitted power level can even be less than 1 mW, thus the transmitter does not need a linear power amplifier due to the good signal penetration capability. This reduces cost and power consumption of UWB devices. A critical component in the UWB systems is antenna which acts like a filter. Generation of a very short pulse is also a key issue in transmitter implementation. This all demands high performance of the digital switches. Also accurate time references are needed to satisfy the coherence requirements.

2.1.2 Receiver

Optimal receiver for single-user UWB system (without ISI) is cross correlation receiver, whose structure is based on matched filter consisting of an analog multiplier bank followed by an integrator. Integration time at the correlator is the duration of the pulse. This means time slots less than a nanosecond for the multiply and integrate process. Due to the modulation scheme, the receiver is an early/late detector [3]. TM-UWB radios (and also impulse radars) utilize coherent receivers in both frequency and phase.

Because of noisy propagation environment and low pulse energy, detection of one and single pulse is rather impossible. During the pulse integration process, numerous correlator samples are added coherently together to solve the problems of low SNR. The output of the correlator is an estimator of the time of arrival (TOA) of the received noisy pulse [3]. Effect of noise can be suppressed when multiple values of outputs of the correlator are combined coherently.

The TM-UWB systems have high processing gains that result from the duty cycle gain and the pulse integration gains. Processing gains are typically as high as 50 dB [3].

2.2 Multi-Carrier Spread Spectrum Schemes

The other approach to UWB communication is direct sequence spread spectrum scheme (DS-CDMA) with optional multi-carrier (MC) technique. There are three different kinds of techniques to realize SSMC transmission; multi-carrier CDMA, multi-carrier DS-CDMA and multitone (MT) CDMA [7]. Using all these techniques, the spectrum of transmission is wider than needed. Depending on the case, assumption of Eq. 1 is or is not satisfied.

Multi-carrier systems are more complex to implement than impulse radio systems. The data rate in each subcarrier is lowered to ease synchronization of spreading sequence and to avoid ISI. MC-CDMA scheme spreads the signal in frequency domain, MC-DS-CDMA and MT-CDMA schemes apply the spreading in the time domain.

The spreading factor of MT-CDMA scheme is much higher than of MC-CDMA and MC-DS-CDMA schemes. However, the total bandwidth of MT-CDMA is nearly the same as it is in the normal DS-CDMA scheme (without multi-carrier properties). When MC-CDMA or MC-DS-CDMA is used the total bandwidth is about 1.5 times wider than in basic DS-CDMA scheme [7].

2.3 Impulse Radar

The first application of UWB was impulse radar, especially ground penetrating radar (GPR). In [8 - 11] there are good overviews of UWB radar technologies. Due to the wide bandwidth the resolution of the radar is good and because of the relatively long wave length the penetration ability of the signal is also good. UWB radars offer simultaneously the possibility to low-frequency surveillance with high resolution [10]. Also the passive discrimination and imagining of target is possible [11]. Good penetration ability can also be utilized in the foliage which is also true for low frequency non-impulse (UWB) radars. The implementation of impulse radar is, however, cheaper and it is possible to make light and small impulse radar devices [10].

The UWB radar receiver can be based on the treshold or correlation detection [11]. The receiver type and construction depends on the application.

3 ADVANTAGES OF THE UWB

Due to the low energy density and the PR characteristics the transmitted UWB signal is noiselike, which makes its detection difficult. Low power UWB systems are not classified as a radio equipments as the low power spectral density of the transmission does not interfere existing radio systems. That allows licence free operation.

Time-modulation systems offer high data rates for communication; tens to hundreds of Mb/s has been proposed for communication links [W13]. In [2, 6] it is estimated that the number of users in an impulse radio communication system is much larger than in conventional systems. The estimation is claimed to be valid for both high and low data rate communications. However the range of the system will decrease when increasing the number of users to retain low spectral density towards other systems.

Because of the ultra-wide bandwidth of the transmitted signal, a very high multipath resolution is achieved. Large bandwidth offers (and also requires) huge frequency diversity, which together with the uncontinuos transmission, makes TM-UWB signal resistant to the severe multipath propagation and jamming/interference. TM-UWB systems offer good LPI and LPD (low probability of interception/detection) properties for, especially, military applications.

The penetration of TM-UWB signals through matter is better than that of conventional narrowband radio signals, which added to a precise target resolution suggests profitable applications for rescue and anti-crime operations, as well as in surveying and mining industry. One can also achieve better timing precision using UWB radios than GPS [2].

The TM-UWB systems can be implemented in low cost, low power integrated circuit processes [2]. TM-UWB technique offers also grating lobe mitigation in sparse antenna array systems without weakening of the angular resolution of the array [13]. Grating lobes are problem in conventional narrowband antenna arrays.

4 RESEARCH CHALLENGES IN UWB

One of the important issues in UWB communication is the frequency allocation. There are no allocated bands for UWB systems but there are lots of restricted bands in the UWB signal band. Companies in the USA are working towards removing those restrictions from the FCC's regulations when UWB technologies are used. Similar discussion on frequency allocation and radio interference should also emerge in Europe. Currently, there are no dedicated frequency bands for UWB in the ETSI and ITU recommendations.

Accurate radio channel models are not currently available for UWB communication systems design. The channel models widely used are generated using much smaller bandwidths than what UWB requires. UWB channel modelling for mobile communications would be a brand new research area.

In a technological field there are also some challenging areas. One is the ultra wideband antenna technology. UWB antenna aspects have been considered in [11]. Digital signal processing has to be very fast in the receiver due to sub-nanosecond pulse length. Multipath combining will imply more complexity in receiver structure. Coherent detection of the TM-UWB signal can be difficult due to the very short pulse time. In radar applications, the higher the target location accuracy for the system is needed, the shorter pulses are required. This is appropriate in geolocation, too. Taking into account the rapidly developing component technology, implementation issues will not be the limiting factors for commercial UWB applications.

Research for receiver algoriths in severe multipath environment and studies on multiple-access schemes are needed. There are also interesting topics in the fields of system design and implementation of ultra wideband communication systems. UWB systems also call for time hopping codes that have good cross- and autocorrelation properties. Codes for UWB system is one important research topic, especially in radar applications.

5 APPLICATIONS

Due to a good resistence against the severe multipath fading, TM-UWB can be used in wireless LANs and inbuilding communications [W13]. High target resolution of TM-UWB systems can be utilized in geopositioning, ranging, tracking, navigation and security systems. Good penetration properties can be utilized, e.g., in surveillance, through-wall radars and ground penetrating radars. Applications of GPR are e.g. landmine or buried obstacle detection.

In [W3] one can find information about the centimeter accuracy localizer. UWB video link has been used, e.g., between an unmanned helicopter and a ground robotic vehicle [W9]. Also UWB applications for altimeter, collision/obstacle avoidance radar and low VHF band packet radio can be found in [W9].

6 UWB ACTIVITIES IN THE WORLD

In the area of ultra wideband techniques, the Ultra Wideband Working Group (UWBWG) has been founded in USA. UWBWG discusses the UWB issues with FCC. The UWBWG Internet pages [W1] offer a large number of documents around the UWB conversation with FCC.

At the University of Southern California, UltRaLab contributes significant research on the area of UWB. At the end of May 1998 there was an UWB Communication Workshop at the University of Southern California. There will be an Ultra-Wideband Conference in the Washington, DC in Sept. 28-30, 1999 sponsored by the UWB industry [W1], and the IEEE MILCOM'99 conference in Atlantic City, NJ, USA (Nov. 1999) will also include an UWB session (www.milcom1999.com).

For further introduction to UWB industry, the references include Internet addresses to a number of companies acting on this arena.

At the CWC (at the University of Oulu, Finland) the UWB research has already been started. It should be noted that there is not a single article on UWB systems written by a European research organization. Therefore, it would be very important to become active in this field to make the gap between USA and Europe smaller.

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7.2 WEB Pages and Companies in UWB area

There are some Internet addresses and companies presented below (list is not complete). These pages might also contain links to the other ultra wideband web pages. (* = member of UWBWG)

[W1]	Ultra Wideband Working Group (UWBWG)	www.uwb.org
[W2]	UltRaLab, University of Southern California *	ultra.usc.edu/ulab
[W3]	Aether Wire & Location, Inc *	www.aetherwire.com
[W4]	Arthut D.Little, Inc	www.arthurdlittle.com
[W5]	Com21, Inc *	www.com21.com
[W6]	Honeywell Technology Center *	www.htc.honeywell.com
[W7]	Impulse Radio Communications	www.sss-mag.com/impulse.html
[W8]	Interval Research *	www.interval.com
[W9]	Lawrence Livermore National Laboratory	www.llnl.gov
[W10]	Multispectral Solutions, Inc	www.multispectral.com
[W11]	Pulson Medical, Inc. *	
[W12]	Sensors & Software, Inc. *	www.sensoft.on.ca
[W13]	Sparta, Inc.	www.sparta.com
[W14]	Time Domain Corporation *	www.time-domain.com
[W15]	T.N.Cokenias Consulting *	
[W16]	TRW, Inc. *	www.trw.com
[W17]	Tuscon Amateur Packet Radio (TAPR) *	www.tapr.org
[W18]	Xtreme Spectrum, Inc. *	www.xtremespectrum.com
[W19]	Zircon Corporation *	www.zircon.com