Ultra Wide Band Technologies

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Abstract

The paper covers Ultra Wide-Band technology. General description, implementation issues, methods to design and use this technology and their applications are covered. Special emphasize will be done on the applications in communications technologies, providing just a brief description for the other possible applications (like penetrating radars, etc). Modulation and demodulation techniques will be described along with the mathematical background. Similarities and differences between spread spectrum techniques and UWB techniques are also presented.

KEYWORDS: UWB

1 Introduction

This technology has many synonyms in technical literature as baseband, carrier-free or impulse. The term "ultra wideband" not being applied until approximately recently.

The system emerged from the need to fully describe the transient behavior of a certain class of microwave networks through their characteristic impulse response. Briefly, instead of characterizing a linear, time-invariant (LTI) system with the conventional means of frequency analysis (i.e., amplitude and phase measurements versus frequency, Fourier transforms, etc), an LTI system could be also investigated by its response (impulse response h(t)) to an impulsive excitation (ideally the Dirac pulse). In particular, the output y(t) of such a system to any arbitrary input x(t) could be uniquely determined using the Digital signal processing basic formula:

$$y(t) = \int\limits_{-\infty}^{\infty} h(u)x(t-u)du$$

Note that the characterization is done now in TIME DOMAIN, and not anymore in frequency domain (as highlighted above). That is why the technology is also known as Impulse radio technique. The description of the technology will refer to spectrum just for evaluating purposes, but the significant variables in the analysis are time domain dependent functions.

2 Ultra Wide Band Technology

2.1 Ultra Wide Band Technology Description

Ultra wide band radio communicates with baseband signal pulses of very short duration. The duration of the signal is usually few nanoseconds. The "shape of the signal" has a frequency characteristic starting from near very low frequency (few Hz) to Gigaherthz range. The energy "spreaded" (dependent on the frequency spectrum distribution and amplitudes) of the radio signal has very low power spectral densities values; typically few microW per MHz. Briefly, what result it is a signal with a very broad spectrum, rather uniform and with low power. The center frequency is now typically between 650 MHz and 5 GHz. Normally few kilometers range are obtained with miliWat (or below miliWat) power level, even using lowGain antennas.

So, with this technology the signal has high bandwidth even if no modulation is performed. As we shall see later, time hopping will be used to allow the multiple access needed by the mobile communication. In this way, the logic is the same like spread spectrum where the users share the same wide band, and coding will be used to separate the individual information from the users. The general modulation technique is the "Time Modulation". Many equipment providers might use sometimes specific issues for their particular implementation, but the general technique is the same.

2.2 Time Modulation Technique

The modulation consists of emitting ultra-short monocycles. The systems use pulse position modulation. *The interval between two pulses is controlled according to an input information signal (user data) and a user assigned sequence called channel code.* The sequence is needed to separate the users in the multiaccess environment. It is the "code" of the user. The widths of the monocycle pulse ranges between 0.20 and 1.50 nanoseconds. The interval between two pulses is between 25 and 1000 nanoseconds. These short monocycles are obviously ultra-wideband.

The demodulator directly converts the received wideband signal into the needed output signal. A front end cross-correlator coherently converts the electromagnetic pulse train to a baseband signal in one stage. There is no intermediate frequency stage, greatly reducing complexity.

A single bit of information is generally spread over multiple monocycles. This is the assumption that we deal with a wide sense stationary random process. This is important, since the correlator in the demodulator will use a technique that is based on this assumption to function properly. The receiver coherently sums the proper number of pulses to recover the transmitted information.

The monocycle shape is not restricted, only its characteristics are restricted. Any signal obeying the rules is a suitable candidate. This allowed multiple designers to choose the shape of the monocycle according to their particular preference, at least in theory. In practice, in the future, a standardization will be needed since multivendor markets must ensure interoperability.

For example, a "Gaussian" monocycle can be used. The mathematical description is listed below [11]:

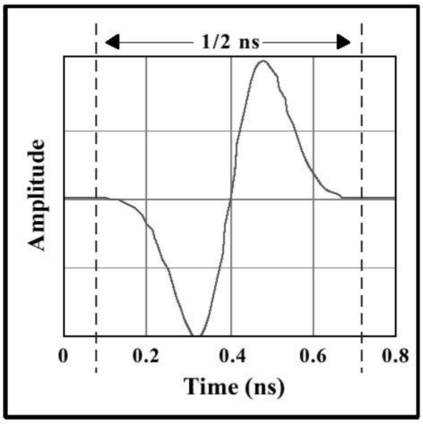
$$V(t) = \left(\frac{t}{\tau}\right) e^{-\left(\frac{t}{\tau}\right)^2}$$

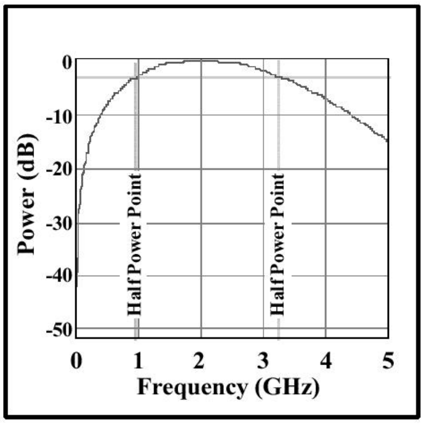
It has the shape similar to the first derivative of the Gaussian function.

The spectrum for this type of monocycle is:

$$V(f) = -j\, f\, \tau^2\, e^{-f^2\tau^2}$$

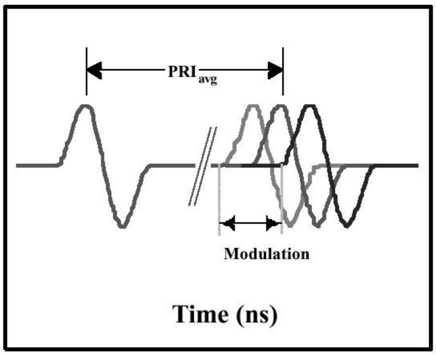
The graphical plot is presented below. Note the center frequency is $1/\tau$ and in this case is about 2 GHz.

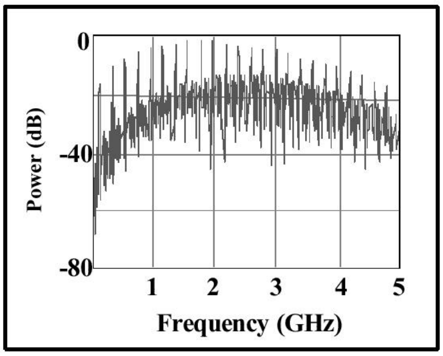




As stated before, the modulation is performed by varying the timing for transmission of the next monocycle with respect to its nominal unmodulated position. Note that the unmodulated signal is in fact a sequence of pulses equally spaced at the predefined time interval. And the modulation in fact reduces or increases the time interval between two successive pulses in the train according to its modulation rules.

The time-modulated signal shape can be easy understood using the picture below.





As noticed in the picture, the logical "0" determines the next pulse to be advanced in time (send earlier) by a predefined amount of time (say 10 percent of the time interval between the pulses), while a logical "1" determines the pulse to be delayed with respect to the neutral position with the same amount of time. Note! The neutral position (reference pulse position) does not correspond to any of the two levels, since both logical 0 and 1 are displaced with respect to the "reference" position. This description is referenced from [11] implementation.

For reasons of clarity and simplicity, the above description does not include the effect of introducing the additional channel code (next part will take it also in consideration).

The rigorous mathematical description is presented next, and uses the assumption of having a multi-access environment[14]:

$s_{tr}{}^{(k)}$ ($t^{(k)}$)= $\sum_{j=-\infty}^{\infty}$ w_{tr}($t^{(k)}$ - jT_f -$c_j^{(k)}T_c$ - $\delta d^{(k)}{}_{j/Na}$)

where w_{tr}(t) represents the transmitted monocycle waveform; superscript k denotes the user k assumed in multiuser environment. So, the signal emitted by user k consists of monocycles shifted to different times, the j-th monocycle nominally beginning at time jT_f+ $c_j^{(k)}T_c + \delta d^{(k)}[j/Ns]$. [9]

The component structure and meaning is:

*** **Uniform Pulse Train** of the form $w_tr(t - jT_f)$ consists of monocycle pulses spaced Tf seconds apart in time. The pulse repetition period T_f must be at least a hundred times the monocycle width. If multiple-access signals would have been composed only with uniformly spaced pulses then collisions from the train of pulses coming from the signals coming from the other user simultaneously using the system can corrupt irreversibly the message. That's also why the channel code is needed (the channel code is used also to provide the privacy of the transmission).

*** **Pseudorandom noise code** is needed to protect from collisions in multiple accessing, each user k is assigned a distinct channel code $c_j^{(k)}$ (in fact a pattern that will provide its own influence in shifting the monocycles. These hopping codes $c_j^{(k)}$ are periodic. Since ideally random chosen pattern was wished, but the requirement for periodicity made the codes to be pseudorandom with period Np. Only a receiver operating with the same sequence code can decode the transmission.

Thus, this code provides an additional time shift to each pulse in the pulse train, with the j-th monocycle additionally shifted with $c_j^{(k)}$ Tc seconds. Hence the added time shifts caused by the code are discrete times between O and NhTc seconds. Normally, c_j^k is an integer value in the range 0 to a predefined value Nh. Also the greatest shift generated by the code (NhTc seconds) is required to be less than the length of the basic train pulses period Tf. One effect of the hopping code is to reduce the power-spectral density from the line spectral density (1/Tf apart) of the uniformly spaced pulse train down to a spectral density with **finer** line spacing 1/Tp apart (Tp = NpTf, where Np is the period of the time hopping sequence). That is because the spectrum is not continuous (even if it might look continuous). Practically the signal is periodic, the period is large, and hence, the frequency spacing is very small. We assumed the data to be quasi-stationary (variation rate very small compared with the other rates).

There are some papers that uses a slight different notation of the same concepts presented above. They consider a **frame** to be the interval between two basic pulses (Tf). In this frame (time period) multiple users are sharing the medium. The frame is also logically split in **compartments**. The number of compartments is equal to the maximum value of possible shifting due to time hopping code. So, Nh compartments will be in a frame. And a pulse for a particular transmitter, at a particular time must be **in a particular compartment within the frame**. The compartment position within the frames will vary in time according to time hopping sequence of values. Refer to [8] for a detailed description (with examples).

*** **Information Data To Be Modulated:** The data sequence $d_i^{(k)}$ of transmitter k is a binary (logical 0 or 1) symbol stream. The modulation system uses Ns monocycles transmitted for each symbol (oversampling) and considered as wide-sense stationary random process from statistical view. In this modulation method, when the data symbol is 1 a time shift of δ is added to a monocycle, and when the data is 0 either a backwards shift of δ is performed to the monocycle in some implementation. Some other implementations may choose that for the 0 symbol not to shift the monocycle. This is implementation decision, and no restriction can be imposed. Other forms of data modulation can be employed to benefit the performance of the synchronization loops, interference rejection, implementation complexity, etc. The data modulation further smoothes the power spectral density of the pseudorandom time-hopping modulation.

The picture below provides the description for the transmitter. Note that the transmitter does not contain a contain a power amplifier. As will be described later, the power required is easily obtained without power amplifiers. A very important issue remains the output filters. Some implementations uses the **antenna itself as a filter**, others uses standalone filters and the antenna designs requirements are not very strict. Below it was presented the solution in which the filtering is done by the antenna element itself[9].

Note the advantage of having no carrier modulation, greatly simplifies the scheme.

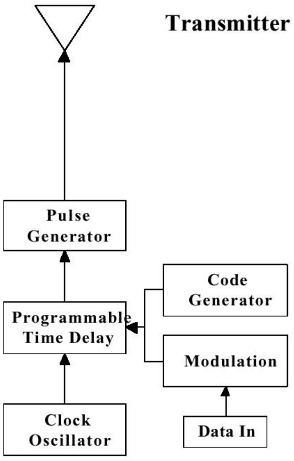


Figure The Block Diagram of the Transmitter

The transmitter will simply be a circuit that will control the timing of monocycles transmission, based on above rules. The resulted signal is directly fed into the antenna.

2.3 Demodulation Techniques

So, having all the above information explained, we can proceed further to describe the signal from which the receiver must recover its correct information. Considering Nu users in the multiple access channel, the composite signal received by the antenna for each receiver is:

r(t) = $\sum s^{(k)}$ (t - τ_k) + n(t)

The received signal is a superposition of the transmitted signals from each user. n(t) introduces the effect of additive white gaussian noise (AWGN) from the multishared communication channel.

The receiver demodulation functionality is based on the **correlation receiver**. The correlation receiver is normally used in **coherent** detection of the signal. This means that a local signal to be correlated to the received signal must be generated.

A general correlator based decoder for a particular user (see also the picture) is simply a multiplier circuit(mixer) followed by an integrator circuit. The output of the integrator is fed to a decision device (that might also have another integrator in its box) that monitors the output of the integrator and performs the decision for the receiving bit.

Note ! The PN code is assumed to be already known at the receiving entity. A procedure for prior PN code distribution must exist before the communication can begin. Normally, transceivers have already the codes distributed by multiple means (SIM cards, etc).

Next in the presentation we shall use w_{rec}(t) as a notation for the received time dependent waveform. Why is difference between w_{tr}(t) and w_{rec} (t) monocycles? Ideally, there should not be any difference if considering perfect transmission medium. But that is not the practical case. So in order to model the modifications of w_{tr}(t) we introduce w_{rec}, although the basic shape and ratios must be preserved. In practical implementations it is possible to estimate this wave form if training sequences are sent initially by the transmitters.

Logically, the receiver must decide whether the transmitted bit d_i is 0 or 1. Using mathematical notations, this can be reformulated as having two hypotheses Ho and H1, and we must decide which hypothesis is valid. The available information is the received signal r(t), the PN code and τ. Synchronization is assumed to be already performed. Practically, the received signal is investigated over an interval bit duration. Note the bit duration interval is Ts = NsTf.

The pulse correlator will correlate (multiply and integrate) the received signal r(t) with time shifted versions of the template signal v(t) over a period Tf. v(t) is a locally generated signal(the difference between a received monocycle and a time shifted version of the same monocycle):

v(t) = w_{rec}(t) - w_{rec} (t - δ)

Inside the correlator module, the multiplied signal is applied to an integrator submodule, that performs the integration over a Tf duration of the signal obtained from multiplier subunit..

The pulse correlator out will be:

$$\alpha_j(u) = \int_{\tau+jT_f}^{\tau+(j+1)T_f} r(t)v(t-\tau-jT_f-c_j^kT_c)dt$$

Continuing, the output of the correlator (integrator) is supplied to the test module(also known as pulse train integrator in some schemes) (**that will sum up the integrator output (correlations) α_j along a duration of a bit (Ts) and will compare the final result to 0**).

Mathematically, this can be expressed as :

$$\sum_{j=0}^{N_s-1}\alpha_j(u) = \sum_{j=0}^{N_s-1}\int_{\tau+jT_f}^{\tau+(j+1)T_f} r(t,u)v(t-\tau-jT_f-c_j^kT_c)dt$$

The result of upper evaluation is compared with the value 0! If the value is greater than 0 we can assume the considered hypothesis is true.

Briefly, we can state that the bit d_0 == 0 if and only if the expression evaluated above is greater than O. That will mean the validation of the Hypothesis Ho.

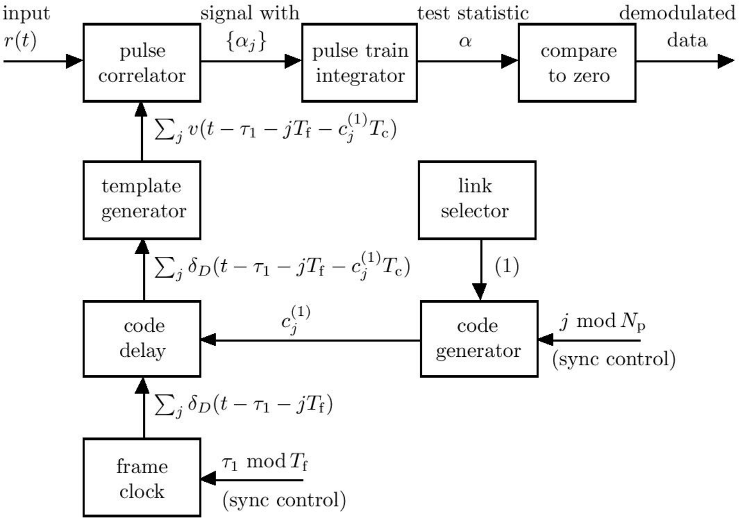


Figure The DSP Logical Diagram of the Receiver [13]

*Important:*It was assumed that the combined effect of the other user transmissions can be viewed statistically as white noise. And with this assumption, the previous described correlator decoding scheme is valid.[5]

Also, all the discussion above was meant under the assumption that binary symbols are envolved (i.e 0 and 1). Still, it is possible to extend over bigger M-ary alphabets. A detailed description of this case can be found in [15].

2.4 Performance in Multi-Access Environments

First, the UWB channel capacity relation are presented. The maximum Channel capacity C (bits/sec) can be related to channel bandwidth B (hertz), signal power S (watts) and noise power N watts) using the following relation (The Shannon theorem):

C = B log (1 + $\frac{S}{N}$)

As the upper relation shows, the capacity increases linearly with the bandwidth B (2GHz for current implementations), but logarithmically with the signal to noise ratio!

The requirement criteria for the system is to keep the bit error rate (BER) controlled. One possible factor to affect the BER is the signal to noise ratio. It was proven that in the multiple access environment with aggregate additive white noise channel, the number of users Nu that can use simultaneously the system is provided with the following relation (result is truncated to be integer) [13]:

Nu(P) = $M^{-1}SNR_{spec}^{-1}(1 - 10^{-P/10})$ +1

where M is the modulation coefficient, P is the fractional increase in required power (in dB) to maintain a signal-to-noise ratio at a level SNR_{spec}, where there are Nu users.

Considering the maximum number of users, we can evaluate using the following relation:

N_{max} = $M^{-1}SNR_{spec}^{-1}$ +1

obtained using the assumption that Nu(P) < $lim_{P->\infty}$ Nu(P)

3 Spread Spectrum Techniques vs Ultra Wide Band

The natural question " why Spread spectrum and UWB are different?" will be tried to be answered below.

Although there are many similarities between the Direct Sequence Spread Spectrum and the Ultra Wide Band techniques like the existence of PN code needed to spread and separate the data from multiple users, Direct Sequence Spread Spectrum **modulates the resulted spread spectrum signal** after the multiplication with the PN pseudorandom noise **with a fixed frequency carrier**. This will move the already spreaded signal to the most suitable band required for transmission. [6] As stated before in UWB, carrier modulation does not take place. Of course, there is a type of modulation (time -hopping) in UWB, but the modulation is done to extremely short duration pulses and does **not** involve carriers. The rest of the time is idle (considering the point of view for one transmitter). In spread spectrum systems the carrier is always present => a 100 percent duty cycle. For UWB the duty cycle can be as low as 0.5 percent.[10] And this low duty cycle in UWB is a key for low power consumption.

Considering the other types of spread spectrum techniques like Frequency Hopping Spread Spectrum in which the frequency is hopped according to a predefined code, comparisons can be done in somehow subjective matter, since the UWB and FHSS have very few elements in common.

So, UWB provides the advantage of a simpler circuitry, especially in the receiver ends where it is not needed to locally generate the carriers, provide several stage mixing (multiplier) circuits, sharper filtering, etc[12].

But, still, there are advantages of Spread Spectrum (using carrier) over the Ultra Wide Band techniques. And this is the range that the applications can be used. UWB can be viewed as a sort of baseband signal (although the spectrum ranges to several gigaherthz). In this case the propagation properties of near DC, medium range, and upper range of the spectrum will have different propagation characteristics, that will make the technology rather restricted to short range communications. For long range communication and especially relaying, the spread spectrum techniques are more suitable.

4 Applications of Ultra Wide Band Technologies

4.1 Communication Systems

A typical scheme of the receiver is described using the following picture:

Currently, the today's ideal requirements for a performant system should employ high data traffic at high speeds for as many as possible users located far away between them. Of course all together is hard to obtain, so trade-off are needed to be identified. Today's trend is to have as much data as possible very fast, without having the distance as a main requirement. In fact, shorter distances mean spectrum reuse, with benefits for the numbers of users being simultaneously served. Also the cell radio techniques (like GSM and W-CDMA), makes hardly visible for the end user the short distance his mobile is actually performing, by having a very dense coverage. So, it seems high capacity over short ranges is going to be the chosen solution, at least for highly populated urban areas. Sometimes the capacity can be measured as *bits/sec/square-meter*. Also the power required for transmissions is going to be smaller and smaller, allowing small low power circuits to be used. Also the price will be smaller to this kind of devices, and also the sizes.

Before continuing the discussion, for the sake of completeness, the block schematic of a UWB practical receiver is presented in the next picture.

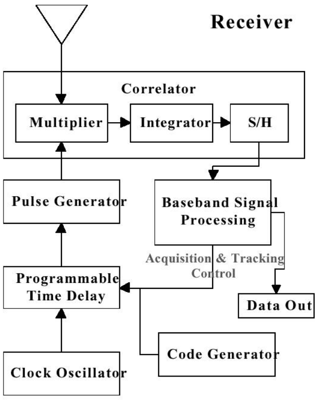


Figure The Block Diagram of the Receiver[11]

Currently, there are several competing technology in highRate-shortRange sector. Bluetooth, Wireless LANs (802.11a and 802.11b), W-CDMA, GSM, etc. Much closer to our interest will be still Bluetooth and WLANs.

IEEE 802.11b has a typical operating range of 100 meters. In the 2.4GHz band, there is about 80MHz of useable spectrum.In the covering area (radius 100 meters) can operate three 22MHz 802.11b systems,each having 11Mbps.The total speed is 33Mbps per cell, (hence the spatial capacity of approximately 1Kbs/square-meter). And this rate is shared by the total number of users in the covering area. Same assumption about the number of users will apply for the next descriptions on Bluetooth and UWB. Note , when computing the area we assume a circle(=> area = πr^2). The same formula applies for the next evaluation also, noting that π is roughly truncated to 3 for easier to read values.

IEEE 802.11a is a derived system meant for higher speed and shorter ranges. The range is 50 meters and speeds up to 54Mbps. The available spectrum is 200 MHz, running in the 5GHz band. 12 simultaneous systems can run within the 50 meters range area obtaining a total speed of 650Mbps (83 Kbs/square-meter).Considering technical implementation issues, we can also summarize:

- 8 frequencies 4 cell frequency re-use pattern,
- the transmitter should have 16 dBm;
- MAC efficiency is 0.6
- Receiver (10 percent PER for t rms < 200ns): 0 dBi
- antenna, 10 dB noise figure, 5 dB multipath

Bluetooth,in its low-power mode,has a rated 10-meter range and a rate of 1Mbps. It was shown that approximately 10 Bluetooth "piconets "can operate simultaneously in the same 10-meter circle yielding a total speed of 10Mbps. Hence for Bluetooth we get 30 Kbs/ square-meter. Normally, a typical Blotooth transmitter needs about 1mW power in antenna.

One UWB technology developer has measured peak speeds of over 50Mbps at a range of 10 meters and projects that six such systems could operate within the same 10-meter radius circle with only minimal degradation.Following the same procedure,the projected spatial capacity for this system would be over 1 Mbs /square-meter. [3]

Capacity Model for UWB

- Transmitter: < 10 uW average power in antenna (-16 dBm)(! compare to 1mW needed in Bluetooth)
- MAC efficiency: 0.9 (compare to 0.6 MAC efficiency for Bluetooth)
- Receiver: 7 dB SNR, 0 dBi antenna, 10 dB noise figure + implementation loss

Still, depending on the technology used UWB can provide rates starting 50Mbps per cell up to 300 Mbps per cell.

An important issue to be mentioned is the capability of UWB technology to coexist with the other technologies without disrupting each over(eg like Bluetooth and wireless LANs devices). The power transmission levels are very low (considered below the noise level for most applications that uses narrowband) and the broad spectrum allows high robustness to interference and jamming, even if locally the narrowband signals are powerful(like radiostations etc). As stated, the UWB signal will provide almost undetectable interference with other signals, and morevover, by requiring to filter the GPS 2GHZ band, it proves to be a reliable technology.

4.2 Location and Radar Systems with High Resolution

Radar and motion detection application are natural applications for this technology. The operation is similar to the other radar systems. A train of pulses is directed to a target, and the reflections are measured. Thus position can be determined, and naturally the distance and speed. Since the util band reaches gigaHerthz ranges, the resolution can be as precise as few centimeters. This is a particular important advantage.[2] Of course, special design antennas are needed to provide the directionality of the transmitted signal. High directive antennas are required for a proper operation.

One important drawback comes from directive antenna designs to cover such a broad spectrum. Compromise designs are needed, but still feasible. Also the range of these radars can not be high. Since the powers are restricted, only short range radars can be developed. If power is increased, it will interfere with the other useful signals in the band.

This technology provides an efficient mean for protection against jamming, and it is very difficult to intercept.[4]

4.3 Through-Wall Motion Sensing

These application requires the spectrum to have the center frequency to be as low as possible. Normally, wall (material) penetrating properties of electromagnetic waves exhibit an attenuation that increases with frequency. Microwave and RF spectrum signals have lower penetration abilities compared to lower frequency band, and they are more like light wave propagation patterns. So, low frequencies are better suited for penetrating needs. UWB fits very well, because it covers *naturally* the low frequencies spectrum. On the other hand, having too low frequencies might determine very poor resolutions. So, for normal through wall sensing devices, there is a requirement trade-off. UWB, by having a very wide spectrum from near DC to few Gigarths, with full range swap, it will be a flexible method to adapt to a multitude of wall materials, and will not need any special tuning to optimize the wall properties. Briefly, Through Wall motion sensing is basically a radar system, with the characteristic that lower frequency of the waves allows propagating through material that usual RF and Microwave waves can not.

5 Conclusions

Considering the indoor usage it was proven that UWB propagation have r^{-2} dependencies, while for sine wave carrier systems the variation is r^{-3}. (r is the distance between the transmitter and the testing place). So, UWB is a very efficient solution for indoor usage.

One important advantage of pulse technology is the possibility to almost eliminate the effect of multipath signal interference with the original signal [7]. **Generaly,** mutipath signals appear due to reflections of the original signal (since it is considered a quasi omnidirectional transmission) that will superimpose with the direct signal. As the reflected waves usually have a different propagation path, they will reach the receiver antenna with a different phase. Superposition of signals with same frequency but out of phase may provide even signal canceling if the phase if the reflected signal comes in anti-phase. In **Ultra Wide Bands** systems the very short pulses, the reflection pulses can be easily detectable and ignored. Of course special circuitry is needed for that, but the implementation is feasible. [1]

One main disadvantage of this technique is that the possibility to relay these signals are very costly. The possibility to relay by simply reamplifying the signal might require too large band amplifiers, and also the other signals can be distorted if a interfered (eg. local radio broadcast powerful signal) will be amplified too much and generate harmonics that might interfere with other traditional AM/FM transmissions. Still, due it its characteristics of white noise like spectrum with low power, it is very unlikely that the UWB can be affected by relays, but the other signals might be. So, it is possible that the usage to be targeted mainly to systems with medium/short range applications. It refers to multiuser access where a node on backbone network decodes the signal and transmits it classically (similar to UMTS networks), or have local coverage.

An important concern at the moment for UWB is the emissions level. Although the power levels in UWB are viewed almost as White Noise for most applications, there are still some demanding applications that are interfered by the UWB signal. Especially for Global Positioning System, there is a limiting requirement of spectral density for the frequencies below 2 GHz. Also, some studies made by Sprint Networks, claimed the CDMA based mobile traffic is disturbed by the presence of UWB. Of course, some filtering will be required to meet the new restrictions imposed. That will make the circuits more expensive.

To be noted the compromise between throughput and range. Throughput/range ratio needs to be tuned according to the particular requirements.

Since the signal transmitted is *periodic*, there is a limitation of the theoretical number of users that can concurrently use the system. Of course, the limitation is not a threat for today requirements, but as a theoretical issue, we can not increase infinitely the number of users. As seen in Chapter 2.4 Performance in Multiuser Environments, that the number of users is chosen based on the required Signal to noise ratio, required bit-rate, etc.

Currently, there are many device producers that develops devices for Ultra Wideband. One major example is TimeDomain (TimeOn), but as the technology will spread, it is expected that other munufactures will provide ICs suporting Ultra WideBAnd.

6 Abreviation List

AJ Anti Jamm

AWGN Additive White Gaussian Noise

BER Bit Error Rate

CDMA Code Division Multiple Access

DSP Digital Signal Processor

GPS Global Positioning System

HC Hybrid Coordinator

LAN Local Area Network

LTI Linear Time Invariant

MAC Medium Access Control

PCS Personal Communication System

PN PseudoNoise

PLL Phased Locked Loop

RF Radio Frequency

SNR Signal-to-Noise Ratio

SS Spread Spectrum

UWB Ultra Wideband

VCO Voltage Controlled Oscilator

WLAN Wireless Local Area Network

W-CDMA Wideband Code Division multiple Access

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