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Challenges in the Design of an Impulse Radio Based Ultra Wide Band Transceiver

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Abstract: **Ultra Wide Band (UWB) is one of the key emerging short-range wireless technology that can answer many of the problems faced by narrow band technologies. UWB offers all the advantages of spread spectrum including GHz of RF bandwidth and high data rate. UWB signals are virtually undetectable operating at noise like low power levels. UWB offers very fine range resolution and also immune to multipath fading. Conventionally UWB is defined as carrier free, impulse based radio, which communicates in time domain by only using sharp rising pulses of the order of fraction of nano seconds. In this paper challenges in the design and development of Impulse Radio based Ultra Wide Band transceiver is explained. Antennas that work in time domain, UWB impulses that meet the required FCC mask on EIRP and digitizer that has to sample and process at the rate of Gigasamples per second are some of the key challenges.**
Keywords: **UWB Ultra Wide Band, FCC Federal Communication Commission, EIRP Effective Isotropically Radiated Power, OOK On Off Keying, BPM Bi Phase Modulation**

I. INTRODUCTION

The growing demand for wireless data capability in portable devices at higher bandwidth, the growth of high-speed wired access to the Internet in enterprises, homes, and public spaces, shrinking semiconductor cost and power consumption for signal processing are some of the recent trends that are driving the wireless technology for short range applications.

Ultra Wide Band (UWB) is one of the key emerging short range wireless technology that can answer many of the problems faced by narrow band technologies viz. limited bandwidth and hence the data rate, multipath fading, susceptibility for interference, etc. UWB offers all the advantages of spread spectrum including GHz of RF bandwidth and high data rate. UWB signals are virtually undetectable operating at noise like low power levels. UWB offers very fine range resolution and also immune to multipath fading.

Conventionally UWB is defined as carrier free, impulse based radio, which communicates in time domain by only using sharp rising pulses of the order of fraction of nano seconds (Fig 2).

Alternatively UWB can be defined as a wireless technology, which offers large fractional bandwidths greater than 25% and greater than 500MHz (see Fig 1).

$$F_u - F_l > 0.25fc \quad (1)$$

Where, fc is the center frequency,Fu and Fl are the upper and lower 10dB points respectively.

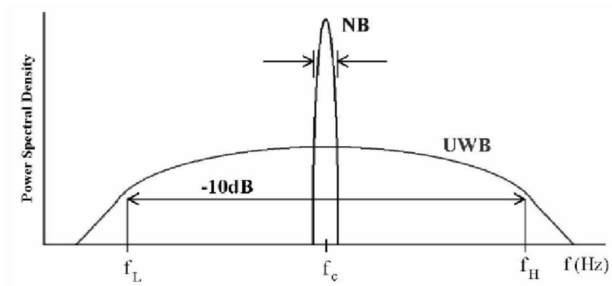

Fig. 1. UWB Fractional Bandwidth

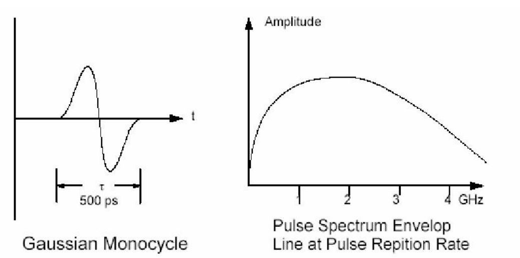

Fig. 2. UWB Impulse and the Corresponding Spectrum

UWB finds applications in Communication, Radar and Precision Geo location areas. The applications include wireless Audio, Data &Video Distribution; RF Tagging & Identification; Collision/Obstacle Avoidance; Precision Altimetry ;Intrusion Detection; Ground Penetrating Radar; Asset Tracking etc.,

As per FCC, UWB signals has to meet the stringent specifications on emission as given in the spectrum mask See Fig3 & Table1. These Effective Isotropic Radiated Power (EIRP) levels are established by considering the power spectrum of emitting sources in each frequency range and keeping it low enough to avoid any interference.

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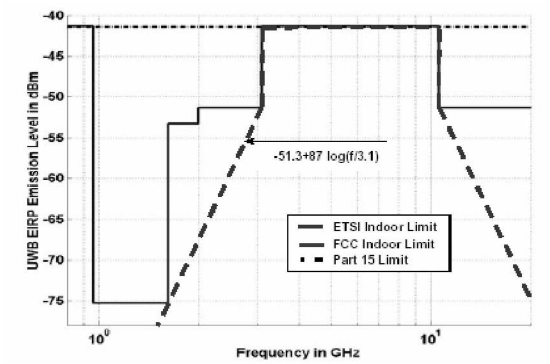

Fig. 3. FCC Spectrum Mask

Table I: FCC Specifications on EIRP Levels

Operating frequency range	3.1 GHz to 10.6 GHz
Average radiated emissions limit	
Frequency range (MHz)	Mean EIRP in dBm/MHz (indoor / handheld)
960-1610	–75.3 / –75.3
1610-1900	–53.3 / –63.3
1900-3100	–51.3 / –61.3
3100-10600	–41.3 / –41.3
Above 10600	–51.3 / –61.3
Peak emission level in band	60 dB above average emission level
Max. unacknowledged transmission period	10 seconds

Traditionally antennas are designed and simulated in frequency domain. In UWB systems, antennas have to process Gaussian shaped impulses without distorting the characteristics of the impulses. Similarly the receiver has to process ultra high bandwidth signals that operate at a very low power levels like noise. Development of UWB transmitter calls for development of impulse generator that can generate very narrow pulses with sharp rise & fall times. The digital signal processing unit design incorporates high sampling rate digitizer and real time processing of high bandwidth signals.

The key challenges in designing UWB systems include

- Ultrawide band impulse generator with front-end receiver
- Generation of UWB pulses such as Singlet, doublets, monocycles, wavelets etc
- Shaping of spectrum of the TX signal (impulse radio, multi-band OFDM based UWB etc.) to confine to FCC regulations
- Synchronization /Coherent or non-coherent receiver design;
- High bandwidth high sampling rate digitizer and signal processing unit
- Wideband RF components like LNA with flat gain and constant phase characteristics
- Ultra wide Band Antenna that can process time domain signals

II. IMPULSE GENERATION

Bandwidth and the center frequency of the spectrum will be decided by the type (singlet impulses, doublets, monocycles, wavelets),rise and fall time of pulses. Conventional method of generating ultra short pulses use spark gap and carbon discharge electrodes. With the evolution of technology various devices are used to generate these ultra short pulses, which include Gallium Arsenide photoconductive switches, mercury switches, avalanche transistors, step recovery diodes, tunnel diodes and avalanche diodes etc. Avalanche diodes, GaAs photoconductive switches or mercury switches are usually employed for high power radar applications. Tunnel diodes, avalanche transistors and step recovery diodes have very fast rise time, therefore they are used for low power and low cost applications.

The principle of ultra short pulse generation is based on the charge storage and discharging of these devices with a triggered input signal. The avalanche effect in either a transistor or some kind of discharge/switching diode produces non-linear characteristics. The non-linearity results in very fast rise time for step or pulse generation, resulting in very narrow pulses. An SRD based impulse generator is designed and developed to generate a very narrow pulse of the order of nano second or fraction of nano second. SRDs are capable of achieving higher amplitude of output voltage and satisfy rapid rise time requirements.

Input trigger that drives the series SRD generates a step like pulse. It is further sub divided to deliver two equal step like pulses to the short circuited stub and the load. The reflected step like pulse from the short –circuited stub, which is 180 degree out of phase with the incident pulse combines with the next step like pulse propagating toward the load to form a positive impulse at the out put. The generation of sub nano seconds pulse is mainly governed by the snap/transition time and junction capacitance of an SRD. Hence choice of the semiconductor plays a critical role in the development of the impulse generator. In many applications, there is the need of shaped impulses to fulfill the FCC spectrum regulations. The generated pulse is passed through pulse shaping network to produce the desired pulse.

There are two approaches to cover the desired frequency spectrum: 1) Shaping of the pulse to achieve the desired spectrum 2) Up-conversion of the baseband signal. Shaping circuits become complex for a given center frequency and bandwidth. In such circumstances the second approach by up-converting the base band is followed.

The following are modulation schemes (Fig.4) generally used for UWB applications: Pulse Position Modulations

(PPM), Pulse Amplitude Modulation (PAM), On-OFF Keying (OOK) and Bi-Phase Modulation (BPM). Out of these schemes OOK is simpler to implement and BPM offers better BER performance.

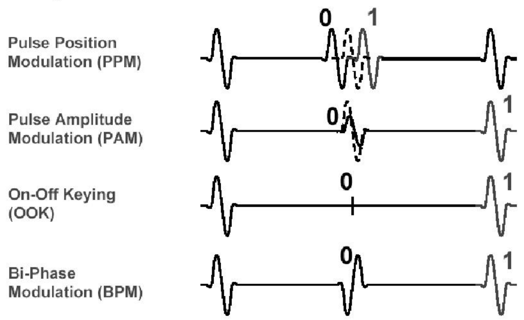

Fig. 4. UWB Modulation Schemes

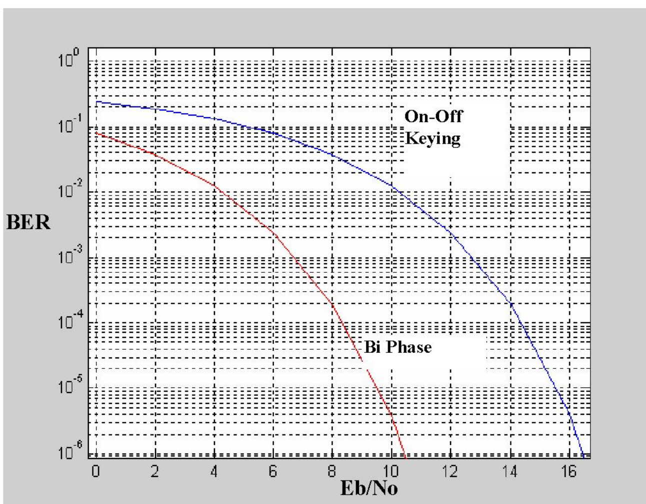

Fig. 5. Simulation BER Performance for OOK and Biphase Modulation Schemes

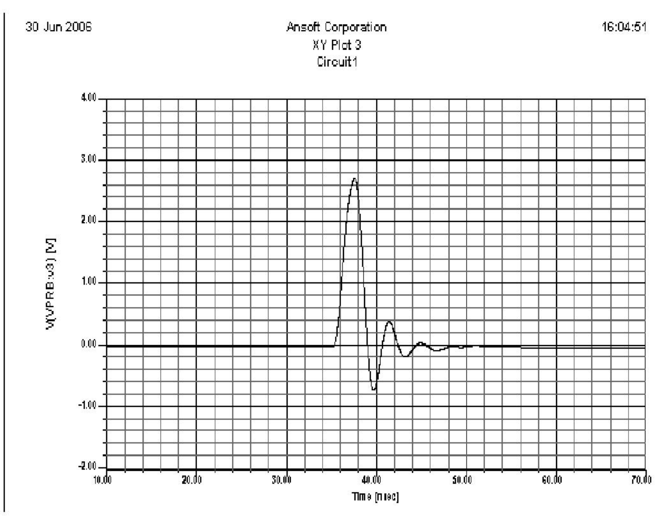

Fig. 6. Simulation Result of UWB Impulse

The following Fig.5 shows the simulated BER performance of the transceiver for the two modulation schemes viz On Off Keying and Biphase modulation.

The following is the simulation result (Fig 6) of the Ultra Wide band Guassian Pulse generated by an SRD based impulse generator. The corresponding spectrum in frequency domain is shown in Fig 7.

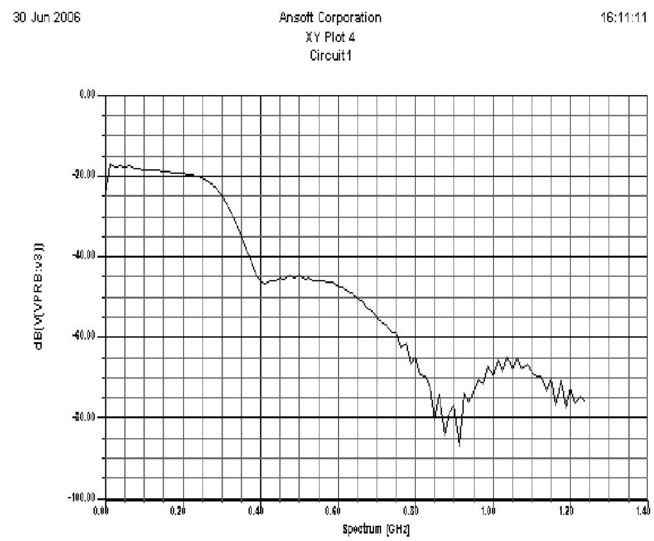

Fig. 7. Power Spectral Density of the Simulated Impulse

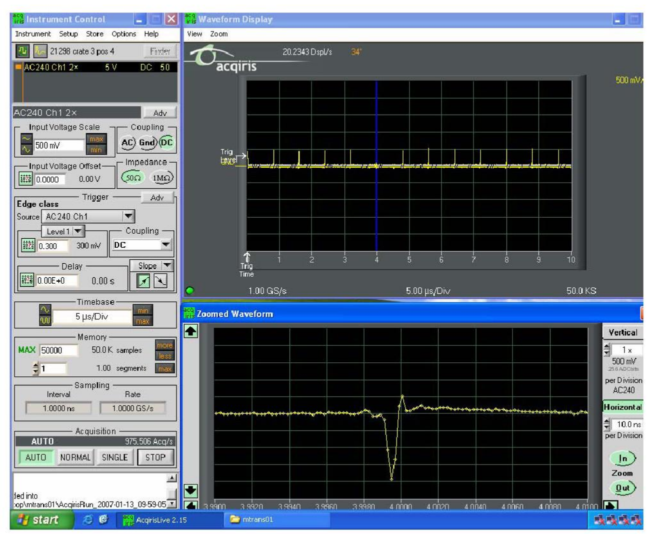

Fig. 8. Measured Result of the Generated UWB Impulse

The above figure (Fig 8) shows the measured result of an UWB impulse using a high-speed digitizer platform

III. ANTENNA

UWB systems operate over a very large instantaneous bandwidth (~ 500MHz to 7.5GHz). Hence antennas with special electrical properties such as constant group delay, wide instantaneous impedance, gain and radiation pattern bandwidth are desired for reliable reception of pulses. Time Domain response of UWB antenna is also very important because it plays an important role on pulse shaping that is being radiated or received.

Different types of wideband antennas have been reported in the literature. Among those some of them have desired wideband characteristics in terms of phase linearity. Majority of the reported antennas operate in monopole mode to achieve the wide band operation.

Although stacked patch antennas may give the desired fractional bandwidth of 25%, the configuration will not be compact. Thorough literature study lead us to choice of CPW fed monopole antenna and Single ended elliptical antenna due to their compact nature and easy feeding mechanism.

The first one uses a CPW feeding with band notch characteristics provided by the slits and the second one uses MMCX adaptor type of feeding. Parameters of both these antennas were chosen such that they provide no interference to sensitive GPS systems while operating in the desired band of frequencies. For CPW fed monopole antennas, simulations showed a gain and beam width of 1.2dBi-1.8dBi and 55° in one plane while the other plane being omni directional.

IV. FRONT END AND DEMODULATION

The RF front end would require wideband LNAs, filters, gain blocks and an AGC circuit. An overall gain of around 70 to 80 dB may be required to boost the signal voltage to the ADC sensitivity level. The front-end should present linear phase and constant gain characteristics over the wide signal bandwidth to preserve the pulse shape.

Detection of received pulses: There are two approaches that can be used to detect the pulse modulated RF signal.

Down–conversion Method: Received signal is down converted to base band by mixing with the chosen center frequency of the required band. This method requires a mixer, frequency synthesizer and a frequency correction loop to correct the offset frequencies. Appropriate care to manage harmonics, spurious and leakage is vital.

Diode-detection Method: Tunnel or Schottky based diode detector would give the envelope of the pulse modulated RF signal. Since it is a non-coherent detection, choice of modulation techniques will be limited.

The above figure (Fig 9) shows the measured result of an the received and detected UWB impulse using a high speed digitizer platform

V. BASE BAND PROCESSING

The first step before Base band processing involves High bandwidth high sampling rate digitization. This is generally done using high bandwidth ADCs which sample the signal on the order of Giga Samples per second. The following are major blocks of signal processing architecture: Timing and Synchronization, coarse acquisition, tracking loop and base band demodulation or detection. The following figure Fig.10 shows typical base band architecture. Base-band processing for the UWB transceiver is completely implemented in an FPGA. Due care has to be taken while designing the high sampling rate signal-processing platform.

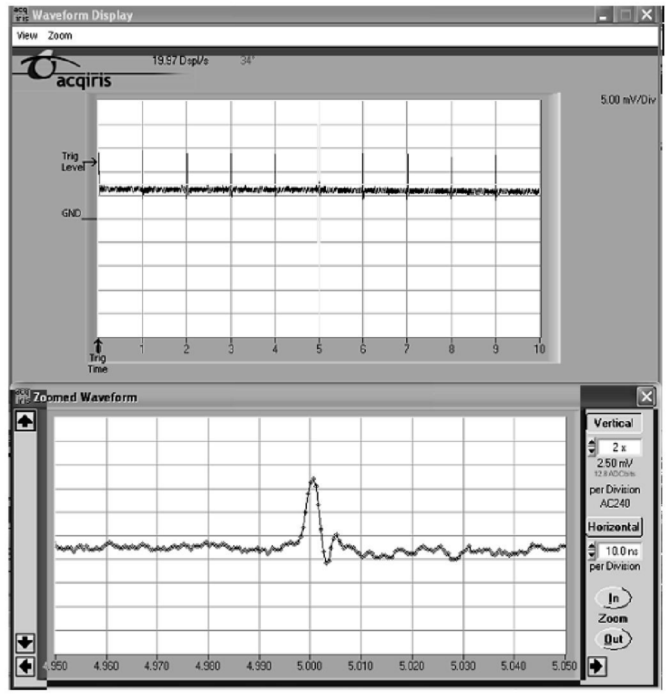

Fig. 9. Measured Result of the Received UWB Impulse

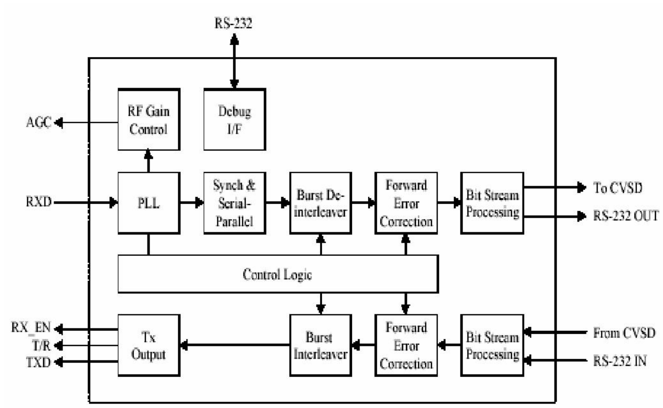

Fig. 10. Typcial UWB Base Band Processing Blocks

Timing Synchronization: The first signal-processing step to be performed in the receiver is estimating the coarse timing of the received waveform. This is performed using

Matched filtering and threshold detection. Once the coarse estimate or acquisition of the pulse (waveform) is done, fine synchronization and maintaining the lock is carried using the tracking Loop.

Acquisition: The incoming received signal is correlated with a reference waveform template and the resultant energy is compared with a threshold to determine the presence or absence of the waveform (pulse). Each of these samples is then threshold detected to determine the phase of the received waveform. The estimated phase is sent to tracking loop for finer synchronization.

Tracking Loop: Traditionally, many of the wideband systems like direct sequence spread spectrum employs one form or the other of Early-Late synchronizer. The most widely employed one is delay lock loop (DLL). It employs two correlators namely early and late which uses advanced and delayed template waveforms. The difference in the energy of the two arms is fedback to the clock generator which clocks the prompt template and there by correcting the timing errors.

Demodulation: Once the tracking loop gets locked, the energy in the prompt (synchronized) branch of the DLL reflects the presence or absence of the pulse in the case of ON-OFF keying scheme. Threshold detection gives the raw data bits.

VI. CONCLUSION

Various building blocks of a typical Impulse Radio based UWB Transceiver is explained. The design challenges of the realizing the functional sub modules are discussed.

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