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Silicon Integration of UWB: Choices and Challenges

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1. Introduction

Ultra Wide Band (UWB) based wireless transmissions by definition occupy a very wide frequency bandwidth compared to the more conventional narrowband schemes. According to the definition introduced by Defense Advanced Research Projects Agency (DARPA, USA) in 1990, UWB signals occupy bandwidth that is at least 25% of the center frequency of the band. It is worth noting that early wireless transmissions by Guglielmo Marconi using spark gaps would fall into the UWB category [1].

With the favorable ruling of spectral mask by the Federal Communications Commission (FCC, USA), UWB presents an intriguing opportunity to rethink the way commercial wireless communication is accomplished in the modern era. FCC ruling allows UWB operating range of 3.1 to 10.6 GHz at -41.25dBm.

UWB has several applications, including ground penetrating radars, medical imaging, surveillance devices, vehicular radar systems, and data communications systems. In this paper I will focus on use of UWB for short range wireless data communications for Personal Area Network (PAN). UWB based PAN could provide single hop communication distance below 10m with data rate of at least 100Mbps. Power consumption of the entire transceiver is targeted to be below 300mW.

Silicon integration

With 90nm silicon MOSFETs reaching f_{max} of 80GHz [2], it is an ideal choice for building UWB systems that are low cost, low power, and mainstream. As per Shannon's law, data rate is proportional linearly to the bandwidth and logarithmically to the power level. In UWB, 100Mbps+ data rates are achieved by the 7.5GHz bandwidth and hence do not necessitate high transmission power. Also, low transmission power is required to meet the FCC spectral mask in order to coexist with present and future standards in the 3.1 to 10.6 GHz frequency range. The power level requires the signal swing to a 50Ω antenna to be below ±250mV, suitable for antenna drivers built with scaled CMOS technologies. Furthermore, baseband digital signal processing to approach Shannon law's theoretical data rate limit is best accomplished in high performance CMOS. These unique characteristics of UWB make low voltage, high performance sub-100nm silicon CMOS an ideal vehicle for integrated implementation of UWB.

2. Spectrum usage choices

Impulse transmission

Traditional UWB made use of the allocated spectrum by coding symbols using sub-nano-second pulses (impulses). Such impulses, by definition, span short time duration and thereby occupy wide frequency spectrum. To meet spectral compliance, filtering is accomplished between the output driver and the antenna. The advantage of such impulse based transmission is its simplicity, achieved merely through digital circuits for both pulse generation and modulation. However, the shortcomings of this spectrum usage model arise from the fact that the entire available bandwidth is occupied at the same time. A more flexible usage of the spectrum can be achieved by transmitting discrete tones or combination of discrete tones within the allocated spectrum at any given time, details of which are presented in the next section.

Tone transmission

Impulse based transmission of a symbol that contains the entire frequency spectrum cannot be immediately followed by another symbol. This is due to the inter-symbol interference at the receiver, especially for high data rates. Conversely, tonal transmission of a symbol that contains a discrete frequency can be immediately followed by another symbol that uses a different frequency, resulting in higher data rates. This protocol requires a transmitter capable of generating discrete tones and a receiver that can distinguish between tones. Additionally, in this transmission scheme it is possible to avoid narrow band interferers that may co-exist. This is accomplished by deciding periodically what set of tones to use based on presence or absence of interferers. Furthermore, this scheme permits frequency division multiplexing allowing multiple UWB connections to co-exist.

In the next section, I will cover the key on-chip analog front end circuit components for a typical UWB transceiver. I will focus on the key components for the tonal spectrum usage method; however some components are common to both spectrum usage methods. Back end digital signal processing and modulation schemes are not covered in this paper. More details on modulation and achievable throughputs can be found in [3]. Note that several off-chip components such as wide band antennas and band-pass filters are required for a functional transceiver. These components can either be incorporated on the package substrate or on the printed circuit board.

3. Main transmitter components

I discuss selected transmitter components below.

Tone generation

As described earlier, tonal transmission has several advantages, but it requires additional circuitry for generating the various tones. This results in trading additional power consumption and silicon area for higher data rates. The spectral purity requirement of the tones will dictate the circuit complexity and the resulting increase in power and area. For this purpose, novel low power frequency synthesizers are under active investigation. Generation of these tones can be accomplished through various schemes including the use of (1) dedicated or shared PLLs and (2) programmable DLLs with frequency synthesizers. Technique that can be used to minimize power consumption includes generators that can be turned on/off within few nanoseconds.

Tone shaping and antenna driver

Ideally, the tones generated should not overlap in the frequency spectrum and the receiver should be able to distinguish between the tones perfectly. In reality neither of the above is possible. Additionally, the channel is non-ideal resulting in multipath related interference between spectrally impure tones. To minimize the impact of the resulting interference, tone shaping prior to transmission might help. Typical tone shaping will involve gradual increase and decrease of the tone strength within the allocated time slot. The rate at which a tone's strength is modulated will depend on the time duration of the slot and the amount of interference improvement required. Following shaping, the tone based symbol is driven to the antenna. As mentioned earlier, the power level requirements are such that the signal swing is small enough to be compatible with standard CMOS process.

4. Main receiver components

I discuss selected receiver components below.

Wide Band Low Noise Amplifier (WBLNA)

The very first gain stage of the receiver plays a key role in minimizing the impact of noise introduced by the devices. Achieving low noise figure and sufficient signal gain is essential for the first stage. For UWB it is also necessary that the first stage Low Noise Amplifier (LNA) exhibit these characteristics for the wide frequency band spectrum of 3.1 to 10.6 GHz. Due to this reason the Wide Band LNA (WBLNA) cannot be a traditional narrow-band tuned LNA. But, the WBLNA can be several tuned LNAs in parallel, where each tuned LNA targets a different part of the spectrum. Having several tuned LNAs provides the flexibility of disabling reception of tones where a strong interferer may co-exist. However, this comes at the expense of power and area. If the bias currents for the tuned LNAs can be turned on/off within few nanoseconds the expense of power can be mitigated.

A better design choice is to use an untuned WBLNA. Such an amplifier would need to satisfy the following for the entire frequency band – have constant input impedance, exhibit sufficient gain, and low enough noise figure. Additionally, to deal with strong interferers, the WBLNA also needs to exhibit exceptional linearity. One implementation of a WBLNA could be achieved through a common gate amplifier stage. A common gate amplifier can provide sufficient gain and a near constant wide band input impedance. However it suffers from the absence of current gain resulting in noise of the load current to appear directly at the input [4]. Current gain attenuates the input referred noise due to the current load, and is therefore preferred. WBLNA topologies that can meet these stringent requirements with automatic gain control are under active investigation. WBLNA design challenges are common to both impulse and tone based spectrum usage.

Data extraction

Following amplification of incoming tone the next step is to extract the symbol and data stream. This step can be accomplished by correlating the incoming tone with an expected tone in a given time slot. Correlation results in an analog voltage, whose amplitude will indicate the level of correlation, and will change at the base data rate. This can then be converted to a digital stream by an Analog-to-Digital Converter (ADC) followed by digital signal processing. An alternative to correlation is the use of high speed samplers and high speed ADCs to digitally reconstruct the tone, followed by digital signal processing. In both cases, the receiver can be designed to have parallel modules to capture energy from multipath related time dispersion of tones at the receiver end.

5. Summary

A basic overview of UWB, its opportunities and challenges were presented. Silicon integration of UWB physical layer was motivated and design requirements of some of the key components were described. UWB presents both prospects and tribulations that are hard to resist!

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