Analysis of FDSS Ultra-Wideband Six-Port Receiver

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Abstract - Ultra Wideband (UWB) radio system is an emerging wireless radio technology. It can transmit digital data over a wide spectrum of frequency band with very low power. This paper presents an analysis of UWB technology on direct millimeter wave six-port receiver, to be designed as an application-specific integrated receiver using Frequency Diversity Spread Spectrum (FDSS) technique. With wideband six-port circuits and other analog circuit, the proposed receiver provides a simple means to obtain a multi-chip module (MCM) for QPSK communications. Simulation results of BER and noise performance of the UWB six-port based receiver are shown and discussed.

I. INTRODUCTION

Ultra Wideband (UWB) technology is a transmission technology currently being investigated as a good means for wireless communication. It holds great promise for a vast array of new applications that have the potential to provide significant benefits for consumers in a variety of applications such as radar imaging and high-speed data transmissions. Its low transmission power, resistance to multipath interference and low implementation complexity make UWB technology a great opportunity to solve a number of communication problems that exit today.

UWB systems use signals that are based on trains of short duration pulse shapes, such that the spectrum of UWB signal can be several GHz or more in bandwidth. Short pulses spread RF power across a wide bandwidth and the power density decreases with increased frequency. The energy of radio signal is spread over a very wide bandwidth exceeding 25% of the center frequency. On February 14, 2002, the Federal Communications Commission (FCC) issued a First Report and Order for UWB technology, which authorizes the commercial deployment of UWB technology, within the power limit allowed under current FCC regulations, Ultra wideband can carry huge amounts of data over a short distance at very low power, and in addition, it has the ability to carry signals through doors, walls and other obstacles that tend to reflect signals which limited bandwidths and higher power. This paper presents recent results obtained on the analysis of UWB technology in direct millimeter wave frequency diversity six-port receiver designed as an application specific circuit (ASC) for QPSK communications.

II. RECEIVER ARCHITECTURE AND OPERATING PRINCIPLE

A direct digital six-port receiver is used for this UWB analysis. The receiver architecture is chosen to satisfy requirements of hardware receiver used in high speed QPSK communications. Figure 1 shows the proposed FDSS receiver architecture with a number of circuit functions to provide I&Q data directly from received QPSK signals.

The receiver is designed to operate at center frequency 27GHz and working wideband over 23GHz – 31GHz with BER of less than 1.0E-6 for E_b/N_0 greater than 12 dB. The RF design of six-port junction is such that only one of four possible modulation states is correctly identified, at any one time, by analogue decoder (item “a” in Fig.1).

In general, UWB signals are produced by pulsed emissions, where a very wide RF bandwidth is related provided by a narrow pulse and the transmitted power is spread over the whole wide bandwidth. Since the frequency range is highly populated, the UWB radio
must contend with a variety of interfering signals, and it must not interfere with narrowband radio systems operating in dedicated bands. These requirements necessitate the use of spread spectrum techniques. There are two main spread spectrum systems: frequency hopping spread spectrum (FH-SS) system, which is vulnerable to partial-band interference, and direct sequence spread spectrum system (DS-SS) which is vulnerable to band limited partial-time (or burst) jamming. However, the performance of each system can be improved by introducing time or frequency diversity technique.

Figure 1. Architecture of direct six-port receiver

In UWB communication, a short duration pulse generator provides pulses in the order of nanoseconds (to produce bandwidth of several GHz) is hard to achieve. In this paper Frequency Diversity Spread Spectrum (FDSS) method is introduced to simulate and translate the UWB narrow pulse performance [6]. Multi-carriers are used to transmit QPSK signal at same time and the transmitted power is spread to each carrier. FDSS system offers the advantage of coherent reception with coherent diversity combining [7]. No frequency hopping or time hopping is used for this FDSS method. Fast hopping makes the synchronization of the carrier phase difficult, and consequently imposed the use of a non-coherent receiver.

Frequency diversity can also be used to counter band-limited interference [8]. Such diversity allows us to avoid non-coherent signal combination losses. In FDSS system, the communication frequency band is partitioned into N disjoint subbands on which N replicas of the signal are simultaneously transmitted. The bandwidth of the composite transmitted signal and, consequently, its resistance to interception, increase with N. Since there is no hopping, coherent reception is possible.

Figure 2 shows the spectrum of FDSS signal and interference. N subbands are simultaneously transmitted while each subbands occupies the frequency interval F was modulated by a frequency \( f_n \). Because the signal spectrum spread from F to NF, The proposed FDSS receiver erases the replicas hit by the jammer, and it performs as in usual unjammed AWGN channel, but deprived from a fraction of its energy.
FDSS technique is easy to implement with the direct six-port receiver. This receiver bypasses intermediate frequency (IF) stages, and the high cost of frequency allocation of IF stage is avoided. Furthermore, due to the linear characteristic of the designed six-port at working wideband, no extra six-port circuit is needed when number of carriers is increased. Thereby it reduces complexity and cost.

![Fig. 2 Spectrum of FDSS signal and interference](image)

Frequency diversity is obviously a repetition code. In a practical system, more performance improvements can be gained by using channel coding. A repetition code implies no coding gain (on the Gaussian channel), and we consider it as a part of the modulation. Thus, for simplicity, the system analyzed here is uncoded.

### III. Results and Discussion

Within the operating frequencies band of the receiver (23 GHz – 31 GHz), Four carriers with different frequencies are selected ($f_1=24$GHz, $f_2=26$GHz, $f_3=27$GHz, $f_4=29$GHz) for QPSK modulated signals.

Simulated BER vs. $E_b/N_0$ results are presented in Figure 3 for single carrier (27GHz) six-port receiver and four carriers six-port receiver, where $E_b$ is the average energy of a modulated bit and $N_0$ is the noise power spectral density. The carrier power and local oscillator power for single carrier modulation is -21dbm and for four-carrier modulation, the carrier power and local oscillator power is -27dbm each. Five QPSK signals with different Bit rate (1Mb/s, 5Mb/s 10Mb/s, 20Mb/s 40Mb/s) are been used to analyze the BER performance of the FDSS receiver. It is seen that at high bit rate, four carriers frequency diversity receiver has obviously improved BER performance compared to single carrier receiver. On the other hand, while at low bit rate (1Mb/s) the BER performance improvement of frequency diversity receiver is marginal. Figure 3(a) and 3(b) shows that FDSS six-port receiver improves BER at high data rate.

Figure 4 shows simulated BER vs. $E_b/N_0$ of FDSS receiver for different LO phase noise level. Figure 5 shows simulated BER of FDSS receiver when none, one or more carrier missing. From Figure 5, it is seen that when one carrier is lost (25% signal power lost), the BER is less than 1.0 E-6 for $E_b/N_0$ level higher than 12 dB. When three carriers are lost (75% signal power lost) BER is less than 1.0 E-6 for $E_b/N_0$ higher than 16 dB.
Simulated results proved the robustness of the proposed receiver. The bit error rate of the receiver didn’t change much under strong phase noise or when one or more carriers are missing due to bad transmission.

IV. CONCLUSIONS

The impact of UWB technology on FDSS six-port receiver was simulated using an actual hybrid integrated six-port circuit. The results of BER vs. E_b/N_0 of FDSS UWB receiver compare with single carrier modulation receiver have been described. LO phase noise performance and carrier loss performance of the proposed FDSS receiver were also presented. Work is underway on developing the simulation platform for the multipath interference analysis and suitable coding technologies appropriate for UWB communication system.

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