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Ultra-wideband transmitter design based on a new transmitted reference pulse cluster☆

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Abstract

This study presents an energy efficient ultra-wideband (UWB) transmitter based on the novel transmitted reference pulse cluster (TRPC) modulation scheme. The TRPC-UWB transmitter integrates wideband active baluns, a wideband IQ modulator based on up-conversion mixers, and a differential-to-single-ended converter. The integrated circuits of the TRPC-UWB front end are designed and implemented in a low-cost 130-nm CMOS process. The measured worst-case carrier leakage suppression is 22.4 dBc, whereas the single sideband suppression is greater than 31.6 dBc, operating at a frequency from 3.1 to 8.2 GHz. With an adjustable data rate of 10 to 300 Mbps, the transmitter achieves good energy efficiency of 38.4 pJ/pulse and a maximum current consumption of 24.5 mA from a 1.2-V power supply.

Keywords: Ultra-wideband (UWB); Transmitted reference pulse cluster; IQ modulator; CMOS

1. Introduction

Spectrum has become an increasingly scarce resource as the wireless communication market has grown at an unprecedented pace. The spectrum below 6 GHz becomes very crowded. Ultra-wideband (UWB) technology has emerged as a candidate solution to short-range high data rate communications thanks to its ultra-wide spectrum in the unlicensed 3.1–10.6 GHz band allocated by the Federal Communications Commission (FCC). Impulse radio (IR) is widely used for UWB communications. IR-UWB transmitters were realized by the structures in [1,2] or without a carrier [3]. In these IR-UWB designs, simple modulation schemes such as on–off keying (OOK), binary phase-shift keying (BPSK), and pulse-position modulation (PPM), were employed and demonstrated very good energy efficiency. IR-UWB can be categorized into coherent and non-coherent schemes. Non-coherent schemes generally have much lower complexity, power consumption and cost than coherent schemes. In non-coherent schemes, estimating the long multipath UWB channels at a minimal price of error performance or data rate is not required. Of the non-coherent (NC) schemes, transmitted reference pulse cluster (TRPC) leads in error rate performance, data rate, robustness and ease of implementation [4]. Furthermore, it provides robust performance to time variation and immunity to pulse distortion caused by frequency dependent antenna and channel effects. The baseband equivalent TRPC transmitted signal is:

$$\tilde{s}(t) = \sqrt{\frac{E_b}{2N_P}} \sum_{m=-\infty}^{\infty} \sum_{i=0}^{N_f-1} [g(t - mT_s - 2iT_d) + b_m (t - mT_s - 2iT_d)] \quad (1)$$

where N_p denotes for the number of total pulses in one cluster, E_b is the average energy per bit, $g(t)$ denotes the component pulse of width T_p in a single pulse cluster, T_s denotes the symbol duration, and T_d is the delay among the pulses in a single cluster. Usually $T_d = T_p$ or some multiples of T_p, and

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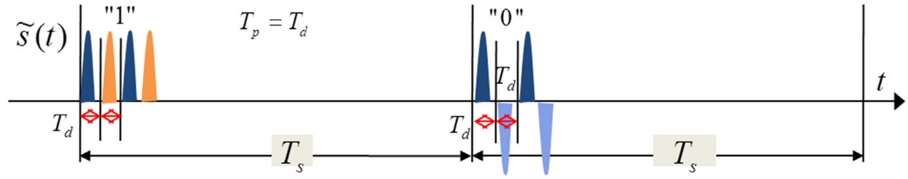

Fig. 1. TRPC structure.

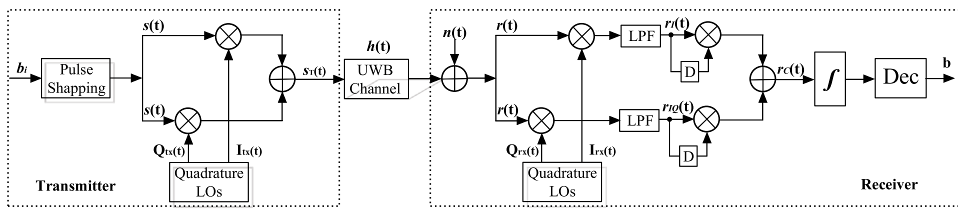

Fig. 2. Block of the proposed TRPC-UWB transceiver.

$T_s \geq N_p T_d + \tau\text{max}$, where τmax denotes the maximum channel delay. Fig. 1 illustrates TRPC signal structures, where "1" represents a single pulse cluster that consists of all "positive" pulses, and "0" represents one pulse cluster containing both positive and negative pulses. A simple auto-correlation receiver with short delay lines and a low analog-to-digital sampling rate can successfully collect the transmitted energy that is spread into multipaths without explicit channel estimation. It was shown in [4] that TRPC achieves a 2–3 dB and 1.3–2 dB power gain over conventional TR and NC-PPM schemes. In this study, we present a novel TRPC-UWB transmitter design based on the CMOS transmitter front end [5].

The remainder of this paper is organized as follows. Section 2 describes the transceiver system architecture and derives the transmitter specifications to comply with the FCC UWB emission limit. In Section 3, a detailed circuit design is presented. Section 4 presents experimental results that demonstrate good radio frequency (RF) and energy efficiency performance. A conclusion is provided in Section 5.

2. TRPC-UWB transmitter specification

Fig. 2 shows the main function blocks of a TRPC-UWB transceiver. After pulse shaping, the identical TRPC pulse train *s(t)* is sent to both I and Q branches at the transmitter end. At the receiver end, the UWB signal is down-converted through an IQ demodulator, followed by low-pass filters (LPFs) and auto-correlators. After signal combining, pulse integration, and decimation, the baseband signal is successfully recovered. The mathematical derivation proves that the constant carrier frequency is successfully canceled by using the TRPC scheme and IQ modulation/demodulation architecture [6]. Therefore, the TRPC UWB system is not sensitive to frequency and phase mismatch. Another benefit of using the direct-conversion topology is that it has very pure output without undesired frequency products [7]. These advantages derived from the system level largely alleviate the complexity and difficulty of implementation.

Furthermore, FCC regulates that the effective isotropic radiated power (EIRP) should not exceed −41.25 dBm/MHz, and that the peak EIRP density level should be below 0 dBm in a 50-MHz bandwidth. This prevents the unlicensed UWB signals from interfering with another spectrum. For the TRPC signaling structure, it remains to be discovered whether the component pulse amplitude enables EIRP to comply with the FCC regulation. In a UWB system that employs a single pulse having a pulse width of T_p and a pulse repetition frequency (PRF) of R_p, the relationship between the entire full bandwidth (FBW) peak power and the average power of the UWB signal is indicated by the following equation:

$$P_{ave} = P_{peak} \cdot \delta \tag{2}$$

where P_{peak} is the FBW peak power and $\delta = T_p \cdot R_p$ is the pulse duty cycle. However, because of limited resolution bandwidth (RBW) in the spectrum analyzer measurements, the measured peak and average power vary from the aforementioned theoretical calculations. According to [8], a RBW filter with bandwidth BR leads to the following.

$$P_{ave}^{m} = P_{peak}^{m} = (R_P \cdot \tau_R)^2 \cdot P_{peak} \cdot T_p^2 \cdot B_R^2 = P_{peak} \cdot T_p^2 \cdot B_P^2 \quad R_P \gg B_R \tag{3}$$

where P_{ave}^m and P_{peak}^m are the measured average and peak power, respectively, and τ_R is the reciprocal of B_R. Eq. (3) implies that when $R_p \gg B_R$, the RBW filter in the spectrum analyzer effectively sums $R_p \cdot \tau_R$ pulses. Consequently, the amplitude increases by $R_p \cdot \tau_R$ times, and the power by $(R_p \cdot \tau_R)^2$ times. By contrast, TRPC signaling has a unique structure consisting of N_p contiguous pulses, and the cluster repeats at a rate of R, which is much greater than B_R. Following a similar argument in [9], the output of the spectrum analyzer is the sum of the $N_p \cdot R \cdot \tau_R$ component pulses. Thus, the measured average and peak power are given by

$$P_{ave}^{m} = P_{peak}^{m} = (N_P \cdot R \cdot \tau_R)^2 \cdot P_{peak} \cdot T_p^2 \cdot B_R^2 = N_p^2 \cdot P_{peak} \cdot T_p^2 \cdot R^2 R \gg B_R. \tag{4}$$

In this study, the designed data rate ranges from 10 to 300 Mbps, which is much larger than the RBW of 1 MHz. Moreover, (4) indicates that the measured power will increase by