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A Fully-Integrated Low Power PAM/PPM Multi-Channel UWB Transmitter

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Abstract— A new transmitter for ultra-wideband (UWB) impulse radio is described in this paper. The proposed architecture features the simple design, low-power operation, and enables the pulse-shape generation for 2 modulation schemes for a multi-channel UWB. The average power calculation is presented for pulse trains using Pulse-Amplitude Modulation (PAM) and Pulse-Position Modulation (PPM). The design is based on a 0.18-µm CMOS process. The core layout size is only 0.35 mm². The simulation results show that the generated signals satisfy the FCC spectrum mask, and the average power consumption is less than 1.7mW for these two types of signaling at a 1.8 V supply voltage. Pulses are transmitted at a PRF (Pulse Repetition Frequency) of 52MHz in 520 MHz bandwidth channels equally spaced within the 3.1-10.6 GHz ultra-wideband band.

Index Terms—Transmitter, modulator, Gaussian pulse, pulse generation, switches, UWB.

I. INTRODUCTION

Ultra-wideband (UWB) transceivers are attractive to short range wireless applications because of the low power spectral density, high data rate, and robustness to multi-path fading. The Federal Communications Commission (FCC) has defined an international UWB device by its operating bandwidth of 500MHz or wider in the 3.1–10.6 GHz band [1]–[2]. Pulse based transmitter architectures have been commonly proposed [3], [4].

The idea behind the multi-channel operation is to efficiently utilize the UWB spectrum by facilitating the frequency division multiple access operation, and to ease the demands in the hardware implementation in CMOS. The channel selection is accomplished by modulating the required carrier with the UWB impulse. The carrier frequency determines the center frequency of the channel, while the impulse shape and duration controls the bandwidth.

There are several challenges for multi-channel UWB. The power consumption is one of the important challenges for the multi-channel UWB. The most recent low power transmitters are reported in [5-7]. The Gaussian pulse is often used for the multi-channel UWB because of its low side-lobes. Another challenge is the design of the approximated Gaussian pulse shaping circuit. This paper will show the theory and proposed circuit for the pulse shaping. Several modulation schemes have been used for the multi-channel UWB, such as pulse amplitude modulation (PAM), pulse position modulation (PPM), and binary phase-shift keying (BPSK), etc. As UWB transceivers are intended for short range and low power applications, simple modulation schemes such as PAM and PPM are the preferred choices for their easy implementation. This paper proposes a PAM/PPM multi-channel UWB transmitter, which has the low power consumption and small size.

II. THE PULSE GENERATION METHOD

The shape of a UWB pulse should be designed to have low side-lobes and the transmitted power must satisfy the FCC regulation. For indoor UWB communication systems, the maximum equivalent isotropically-radiated power (EIRP) is restricted to -41.3dBm/MHz over the frequency range from 3.1 GHz to 10.6 GHz [8].

The most common wideband pulse shape is the Gaussian pulse. The Gaussian monocycle was used as a pulse shape in [9-11]. Thus the first attention of this paper is directed to the approximated shape of the Gaussian pulse in the CMOS process.

The desired step response of the pulse-shaping filter is a Gaussian-shaped pulse and the corresponding frequency response. A well-known technique for approximating a delayed Gaussian waveform is to use a CR-(RC)n filter [12]. The Gaussian pulse can be approximated by a realizable CR-(RC)n quasi-Gaussian filter of the form [13]:

\[ y(t) = \left[ t^n / n! \right] e^{-t} \]  \hspace{1cm} (1)

The (RC)n+1 filter shown in Fig.1 has the transfer function

![Fig. 1. The low-pass section of the (RC)n+1 filter](image)

given by

\[ H(f) = \frac{1}{(1 + jwRC)^{n+1}} \] \hspace{1cm} (2)

where n+1 is the number of the RC sections and \( w = 2\pi f \). Its step response is given by
\[
y(t) = \frac{1}{n!} \cdot \left(\frac{t}{RC}\right)^n \cdot e^{-\left(\frac{t}{RC}\right)}
\]

where \( K = \left(\frac{t}{RC}\right)^n / (RC) \) is constant. Equation (3) is similar to equation (1), so the pulse Gaussian pulse can be approximated by a realizable \((RC)^n\) filter.

I. SYSTEM ARCHITECTURE

Fig. 2. Block diagram of the proposed UWB transmitter

The proposed UWB transmitter block diagram is shown in Fig.2. The Gaussian shaping filter produces a pulse train. In this pulse train, the pulse width is inversely proportional to the bandwidth of the required signal. The clock and data input are synchronized by the D-flip-flop (DFF). The output of the DFF Q is the synchronized data input. The outputs P1 and P2 of the Gaussian shaping filter are modulated by the synchronized data to produce the impulse trains S1 and S2. P1 and P2 have the same pulse shapes, but different pulse positions in the time domain. In Fig.2, Vc1 is the control signals which control the types of the modulations, such as PAM and PPM. The switches perform a multiplication between the impulse train S1 or S2 and the signal generated by the voltage control oscillator (VCO). The output can be directly fed to an antenna of 50 ohm load.

Fig. 3. The Gaussian Shaping Filter

A. Gaussian Shaping Filter

The proposed Gaussian shaping filter (in Fig.3) is used to approximate a Gaussian pulse and to smooth the sharp edge of the clock pulse as explaining in Section II. A CMOS transistor can be modeled as a switch with infinite off-resistance and finite on-resistance. The on-resistance and the capacitance of transistor determine the transient behavior of an inverter. The additional capacitors of the transistor drains reduce the slope of the rising edge and falling edge of the clock (rectangular) pulse further. The clock pulse is the rectangular pulse \( x(t) \),

\[
x(t) = A \cdot \text{rect}(t / T_o)
\]

Its step response is given by

\[
X(f) = AT_o \cdot \sin c(f \cdot T_o)
\]

where \( A \) is the amplitude of the clock pulse and \( T_o \) is the width of the clock pulse. The step response of the output is,

\[
Y(f) = X(f) \cdot H(f) = \frac{AT_o \cdot \sin c(f \cdot T_o)}{(1 + jwRC)^{n+1}}
\]

Equation (6) shows that in the frequency domain, the output of the Gaussian shaping filter has very small side-lobes with the increasing number \( n \). This is very useful to the multi-channel UWB operation.

B. VCO

The frequency of the VCO determines the center frequency of the channel. Fig4. shows a typical cross-coupled complementary LC oscillator. A PMOS transistor has lower flicker noise than an NMOS counterpart, so a p-tail np-core structure is often used in LC VCO. The np-core structure has lower phase noise than that of n-core or p-core structure because of the symmetry between rise time and fall time of the oscillation waveform [14]. VB controls the current consumption of LC VCO and optimize the noise versus power performance. The output LO signals define the center frequency of the channel.

C. Modulation scheme selection and Modulator

Fig5. shows the arrangement for the selectable Modulation schemes including PAM and PPM. P1 and P2 are the outputs of the Gaussian Shaping Filter. They have the same pulse shape, but different positions in the time domain. S1 and S2 are the
modulated signals for PAM and PPM respectively by controlling Vc1 and Vc2. In Fig.6, C and R are used to filter the dc values of the two outputs LO+ and LO- of the VCO, yielding io+ and io-. The switches facilitate the modulation of the carrier by the pulse trains S1 and S2.

**PAM**

From Fig.5, when Vc1 is high, then the Gaussian pulse trains P1 or P2 cannot be transferred to P3, and there is no output pulses at S2. The synchronized data input Q is either high or low. P1 is transferred to S1 when Q is high, but it is isolated and S1 is grounded when Q is low. So P1 is modulated by Q to form S1. M2 and M5 are used to reduce the noise when M1 and M4 are turned off. In Fig.6, io+ shifts the pulses of S1 into the desired frequency. C1, C2 and the antenna load (50 ohm) form a high pass filter. For this modulation scheme, the pulses are only produced at the output only when Q = 1.

**PPM**

In Fig.5, when both Vc1 is low, the pulse train P2 is transferred to P3. Q is used to select either P1 or P2. The pulses in P1 have the different positions from those in P2. When Q is high, P1 passes through M1 to reach S1. Then io+ shifts the pulse of S1 to the desired frequency in Fig.6. When Q is low, P2 passes through M4 to reach S2. After modulating, the different position pulses are shifted by io- to the desired frequency. For this modulation scheme, the pulse positions are different for pulses “1” and “0”.

### II. Simulation Results

The design was implemented using the Chartered 0.18-µm RF CMOS technology with 1.8V power supply and simulated in the Cadence environment using Spectre simulator. In the design process, a purpose Gaussian shaping filter was used to shape the pulses into the approximated Gaussian pulses. Fig.7 shows the single output pulse waveform and it has the approximate Gaussian pulse shape. The Peak-to-Peak voltage of one single pulse is about 49mV. In Fig.7, T1 is 1.6ns, which is the pulse width at 0.707A (A is the amplitude of the pulse). And T2 is the pulse duration at 0.5A, which is 2.1ns. The result of PAM is shown in Fig.8. The pulse is only transmitted when the data input is “1”. Fig.9 shows two approximate Gaussian pulse trains. These two trains are used to produce pulses of different positions for data bit “1” and data bit “0” respectively in the time domain. Fig.10 shows the transmitted pulses of different positions according to PPM for the same data string used in the PAM. As an example, all the modulated pulses were up-converted to a 4-GHz center frequency. The max power spectra density of the output pulse is -41.3dBm/MHz as permitted by the FCC limit. By changing the carrier frequency, the transmitter can be used for multi-channel UWB communication. Table I gives a summary of the performance of this design along with the performance of other reported UWB transmitters. Based on Table I, the power consumption of our proposed transmitter is much smaller than that of transmitters in [5] and [6]. Although the power consumption of this transmitter is just a little lesser than that of [7], its Pulse Repetition Frequency (PRF) is much higher than that of [7]. The proposed transmitter layout is shown in Fig.11. The core layout size is only 0.35 mm². This design has been sent out for fabrication.

### III. Conclusion

In this paper, we have proposed a low power dual-modulation scheme multi-channel UWB transmitter. A technique for generating pulses that accurately approximates a Gaussian shape has been presented. The whole transmitter is fully-integrated, performing up-conversion and shaping in one simple circuit.

This transmitter communicates with 2 types of modulations and a variable PRF up to 52MHz. Pulses are up-converted to channels of 520MHz bandwidth. The carrier frequency is can be tuned from 3.5 GHz 4.5 GHz. For all simulations, the average power (including VCO) is less than 1.7mW for the 1.8V supply.

### REFERENCES


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Fig. 7. One of the output pulses of the transmitter

Fig. 8. Input data (above) and the output pulse waveform of the transmitter for PAM (below)

Fig. 9. The approximate Gaussian pulse waveforms for data “0” and data “1”

Fig. 10. Input data (above) and the output pulse waveform of the transmitter for PPM (below)

Fig. 11. The layout of the transmitter