A Fully Integrated CMOS Transmitter for Ultra-wideband Applications

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Abstract – In this paper, a fully integrated CMOS UWB transmitter is presented. The transmitter consists of a band-notched UWB antenna and a transmitter IC which integrates a pulse generator, a gating signal generator and driver amplifiers. The drive amplifier employs a 2-stage amplifier – a Class-E amplifier and a Class-A amplifier with switch control, to significantly reduce power consumption. Fabricated using a 0.18-μm CMOS process, the generated pulse is then passed through the driver amplifier (DA) which not only drives the antenna but also shapes the generated digital pulse in the FCC spectral mask.

Index Terms – Ultra-wideband (UWB), pulse generator, driver amplifier, transmitter, CMOS, antenna

I. INTRODUCTION

The ultra-wideband (UWB) technology has received considerable attention since the U.S. Federal Communications Commission (FCC) released an unlicensed spectrum of 3.1-10.6GHz for commercial wireless applications. UWB systems have many advantages over traditional narrowband wireless systems, such as noise/interference immunity, low probability of undesired detection, interception, low-power consumption, high data rates, and coexistence with other wireless communication systems [1]. In impulse UWB systems, the pulse generator is a key component for both the transmitter and receiver.

The methods of generating a particular pulse signal for UWB systems is one of the fundamental considerations in the design of UWB circuits and systems, because the pulse waveform determines the spectrum characteristics of the UWB signal and constraints for component and system design. Recently, several pulse generating approaches were proposed for UWB communications, such as to generate the 1st and 2nd derivative of the Gaussian pulse [2] or a precise UWB pulse whose frequency spectrum satisfies the FCC regulation [3].

Antenna is another critical component in UWB systems. The ultra-wideband requirement brings great challenges to the antenna design. In accordance with the regulations released by the FCC, ultra-wideband (UWB) systems have been collocated to the bandwidth from 3.1 to 10.6GHz. However, the use of the 5.15–5.825GHz band is limited by IEEE 802.11a and HIPERLAN/2. Therefore, in order to avoid interfering with nearby communication systems, a UWB antenna with frequency notched function is desirable.

In this paper, the transmitter proposed generates narrow pulses using a simple digital circuit. To minimize power consumption and circuit complexity, a class E amplifier and switched class-A amplifier is proposed, which not only drives the antenna but also shapes the generated digital signal to fit the FCC spectral mask. Moreover, a novel hybrid shape notch antenna is proposed which can not only satisfies all UWB bands but also rejects the limited band in order to avoid possible interference with the existing 5.15–5.825GHz band.

In the following section, the transmitter system architecture is described. The building blocks of the proposed transmitter are then explained in detail in Section III. The measurement results of the fabricated transmitter are reported in Section IV.

II. SYSTEM ARCHITECTURE

The block diagram of the proposed UWB transmitter architecture is shown in Fig. 1. The transmitter system is accomplished by a transmitter IC which integrates a pulse generator, a gating signal generator, a driver amplifiers and a band-notched UWB antenna.

Fig. 1. Architecture of the UWB transmitter system.

The input data signal \( v_{in} \) triggers the pulse generator to generate positively-peaked narrow pulses at the output of the pulse generator and the gating pulse generator. These narrow pulses are only generated at the rising edges of the input clock \( v_{clk} \) \( v_{pulse} \) which is generated by pulse generator and then passed through a two-stage driver amplifier, while gating signal is used to activate the class-A amplifier only when there is a pulse transmission. The driver amplifier will amplify and shape the generated pulses \( v_{pulse} \) to meet the FCC spectral mask. It also drives the antenna for pulse transmission. The band-notched UWB antenna transmits...
the modulated pulse which is the key element deciding the transmitted and received pulse shape and amplitude.

Due to the fact that pulse-shaping will be achieved in a later stage through the driver amplifier, the pulse widths of the pulses generated at this stage do not have to be stringently controlled. For the gating signal generator, since generated pulse ($V_{\text{pulse}}$) has to travel through a longer circuit delay as compared to the gating signal ($V_{\text{control}}$), more delay elements are used to produce the gating signal window larger than the generated pulse.

The advantage of the both pulse generators are that current is consumed only when the pulse is generated, hence power consumption is greatly reduced and it decreases with decreasing data rate.

B. Driver Amplifier

The driver amplifier is used to shape the frequency spectrum of the generated signal $V_{\text{pulse}}$ into the FCC spectral mask, to amplify the UWB pulse and also to drive the antenna.

As shown in Fig. 2, the transmitter employs a 2-stage amplifier – a Class-E amplifier and a Class-A amplifier with switch control, to significantly reduce power consumption. Using the gating signal, the 2-stage amplifier consumes current only when a pulse has to be transmitted.

The generated pulse is first amplified with a class-E amplifier consist of M1, C1-C3 and L1-L3. The pulse will cause the transistor M1 to turn on, and result in a large current flowing through the LC shaping network [4]. The shaping network is designed to satisfy the FCC spectral mask requirement for the 3-5GHz bands. The class-E amplifier consumes no power when there is no transmitted pulse.

In order to achieve sufficient output power and avoid spectral re-growth, the output pulse is further amplified by a high linearity class-A amplifier consists of M2. To reduce the power consumption, transistor M3 together with the gating signal is used to activate the class-A amplifier only when there is a pulse transmission. Since $V_{\text{pulse}}$ has to travel through a longer circuit delay as compared to $V_{\text{control}}$, the positive pulse of $V_{\text{control}}$ is designed to extend nearly 2 times wider to ensure that all pulses can be amplified and transmitted during the operating stage.

Another LC shaping network consists of L4-L5 and C4-C5 is employed to further shape the transmitted pulse and provides the desired 50Ω impedance matching to the antenna. Given that the pulse duration is very short (<1ns) compared to the data rate (5μs-0.5μs) and the driver amplifiers only operate when there is a pulse transmission, the overall power consumption for the transmitter can be reduced significantly.
C. Band-Notched UWB Antenna

Due to the overlap of the currently allocated UWB frequency band with the existing wireless local area network (WLAN), a UWB antenna with band-notched characteristic is desirable for reducing the interference between the two communication systems. A novel hybrid shape band-notched antenna is proposed, as shown in Fig. 4. Antenna part is formed by two ellipses with a rectangle to smooth out the discontinuity of the overlap parts. By inserting a rotated E-shape slot into the planar monopoles, a notched band can be achieved. The notched frequency can be adjusted by tuning the length of E-shape slot and the notched depth can be slightly adjusted by optimizing the length of middle slot. By selecting optimum parameters of the proposed antenna, it is found that except for a sharp frequency-band notch in the 5-6GHz WLAN band, return loss has good impedance matching over the entire 3.1–10.6GHz UWB frequency band.

Fig. 4. Photograph of the proposed UWB antenna.

IV. MEASUREMENT RESULTS

A UWB transmitter is implemented in a Chartered’s 0.18-μm CMOS technology. The chip microphotograph is shown in Fig. 5. The chips are mounted on a Rogers PCB using the chip on board technique and tested. The die size is 1.25mm by 0.9mm.

Fig. 5. Microphotograph of the transmitter.

Fig. 6 shows the measured UWB transmitter pulse at the TX output. The date rate is set to 20Mbps. At each rising edge of the input data v_in, a UWB pulse is generated. As a result, a UWB pulse is transmitted for each data bit. The voltage swing of the pulse is around 600mVp-p, and the pulse width is around 0.5ns. The pulse repetition rate can be changed by varying the input clock rate since each pulse is generated by each rising edge of the clock. An example of high data rate 50Mbps is also shown in Fig. 7.

Fig. 6. Measured UWB pulses (20Mbps).

Fig. 7. Measured UWB pulses (50Mbps).

Fig. 8 shows a measured spectrum of the DA output pulse sequence, where the data transmission rate is 50Mbps. It can be seen that the pulse spectrum are shaped such that the major energy occupies in the FCC UWB low-band of 3.1GHz to 5GHz and the power spectrum density is less than -41.3dBm/MHz. The proposed UWB transmitter IC can also be used for other data rate. The measured transmitter IC performance is summarized in Table I.

The reflection coefficient of the antenna is measured using an HP 8510 Network Analyzer. In Fig. 9, the simulated and measured results are displayed and a sharp frequency-band notch is created in the 5-6GHz WLAN.
Table I: Summary of TX performance

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Pulse Width</td>
<td>~0.5ns</td>
</tr>
<tr>
<td>BW (-10dB)</td>
<td>~1.9GHz</td>
</tr>
<tr>
<td>TX Rate</td>
<td>1-100Mbps</td>
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<tr>
<td>Average Power</td>
<td>522μW</td>
</tr>
<tr>
<td>Consumption</td>
<td></td>
</tr>
<tr>
<td>Technology</td>
<td>0.18-μm CMOS</td>
</tr>
<tr>
<td>Supply Voltage</td>
<td>1.8V</td>
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</tbody>
</table>

Fig. 8. Measured spectrum of DA output pulse sequence.

Fig. 9. Measured and simulated return loss of the antenna.

Fig. 10. Measured pulse signal transmitted by the UWB transmit module.

V. CONCLUSION

A fully integrated CMOS UWB transmitter is presented. The transmitter consists of a band-notched UWB antenna and a transmitter IC which integrates a pulse generator, a gating signal generator and driver amplifiers. The UWB pulse generator proposed is novel, all-digital, low-complexity and has low power consumption. A dedicated new drive amplifier including a Class-E amplifier and a Class-A amplifier with switch control has been proposed to amplify and shape the generated digital signal to fit the FCC spectral mask. The transmitter has been demonstrated in a 0.18-μm CMOS technology in a very average low power consumption.

REFERENCES