A Low-Power SiGe Impulse Radio-UWB Transmitter with Biphase Modulation Function

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***Abstract*—In this paper a compact and low-power IR-UWB transmitter is presented. The transmitter is based on a cross-coupled LC oscillator core which is transiently turned on and off by current spikes generated on-chip. A simple phase control circuit enables biphase modulation by controlling the start-up phase condition of the oscillator. The UWB transmitter has a low power consumption of 9.8 mW when biphase modulated with a 200 MHz impulse sequence. The transmitter IC occupies an area of 0.3 mm^2 including bond pads.**

***Index Terms*—UWB, transmitter, biphase modulation, differential, LC oscillator.**

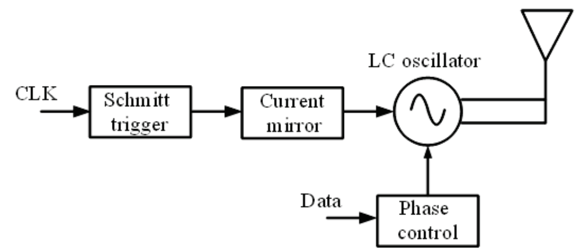

Fig. 1. Block diagram of the proposed differential UWB transmitter.

I. Introduction

Impulse radio-UWB (IR-UWB) uses sub-nanosecond impulses occupying a wide allocated bandwidth (3.1-10.6 GHz by FCC) to transmit information. Owing to the large spectral bandwidth, it is a promising technology for high speed communications. The carrier-less nature allows a simple transceiver architecture and results in an increased robustness to multipath fading and a low power consumption. To generate short time-domain impulses, making optimum use of the available spectral mask, is the main challenge in circuit implementations for IR-UWB systems. Many techniques have been reported to generate and modulate UWB impulses. [1] presents a UWB transmitter based on an on-off LC oscillator controlled by an all digital pulse generator, which achieves a maximum data rate of 2 Mbit/s. This transmitter can realize on-off-keying (OOK) and pulse position modulation (PPM). Regarding modulation schemes for UWB impulses, biphase modulation (BPM), precisely speaking binary phase shift keying, performs better in terms of bit error rate than OOK and PPM in additive white Gaussian noise (AWGN) environment, since BPM constitutes antipodal signalling and has the greatest distance between symbols [2]. In previous works [3]-[5], the BPM function was realized by the use of an extra UWB modulator circuit, however, this method significantly increases the complexity and power consumption of the system.

Here we demonstrate a novel and low-power technique for the generation of biphase modulated impulses through controlling the start-up phase condition of the LC oscillator which is transiently turned on and off. Fig. 1 shows the block diagram of the UWB transmitter. Current spikes, which are generated by the Schmitt trigger in conjunction with the following current mirror, shortly turn on the LC oscillator to generate impulses of sub-nanosecond duration and with a large 10 dB bandwidth. The BPM function is achieved by a simple phase control circuit which sets the start-up phase of the LC oscillator, without increasing the circuit complexity. Differential configuration is favourable to UWB systems because differential UWB antennas avoid feed-line radiations. Additionally, on-chip virtual ground makes the packaging easier. The active circuit is realized in 0.8 μm SiGe HBT technology (f_T = f_{max} = 80 GHz, BV_{CEO} = 2.4 V), while on a standard 20Ωcm Silicon substrate.

II. Circuit design

A cross-coupled LC oscillator is chosen as core due to its simple circuit topology and the inherent convenience of achieving BPM. The complete schematic of the proposed UWB transmitter can be seen in Fig. 2. The Schmitt trigger eliminates the time-domain influence of the input CLK signal by steepening the rising and falling edges. Thus the CLK signal, whose exact shape does not matter, is transferred to a square wave signal with extremely short transition time in picosecond range.

A current spike is generated at every rising edge of the square wave as the output of the Schmitt trigger is connected to the current mirror. When the Schmitt trigger provides a high voltage level close to V_1, the diode-configured transistor T_1 will bring that potential down to the built-in base-emitter potential of T_2, with a time constant determined by R_1 and the base-emitter capacitance C_{BE1} of T_1. So the collector potential of T_1 has a spike-like shape before it settles, this correspondingly generates a collector current spike in T_2 as it is connected in current mirror configuration to T_1. During the rest of the period, the collector current of T_2 is too low to turn the cross-coupled oscillator on because of a suitable area ratio of T_1 and T_2. The amplitude of the current spike can easily be adjusted by changing the size of T_2. The repetition rate of

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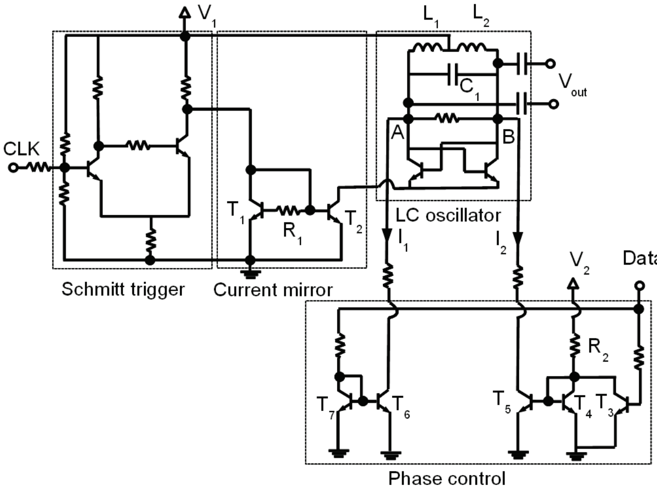

Fig. 2. Complete circuit schematic of the differential transmitter.

the current spike train is equal to the input CLK frequency, which can extend into GHz range in our design.

The generated current spikes turn on the LC oscillator once the collector currents of the cross-coupled pair are high enough to create a negative real part of the impedance at the collector terminals. The phase control circuit is introduced to determine the phase condition as the oscillator starts up. When the input data signal is low, transistor T_7 is off, and the collector current I_1 of T_6 is zero because of the current mirror configuration to T_7. Meanwhile, the applied voltage V_2 will generate a collector current I_2 of T_5 through the current mirror configuration of T_5 and T_4, because T_3 is off. So the voltage potential at point A is larger than that at B, as I_2 causes a voltage drop through the DC series resistance of L_2. When the data signal is high, T_4 is off, since a high voltage drop is generated at R_2 by the collector current of T_3, which causes I_2 to be zero. At the same time, the high potential at the base of T_7 introduces a collector current I_1 in T_6. In this state, the voltage potential at point A is smaller than that at B. Thus the start-up phase conditions are opposite at different data signal levels. Additionally, the asymmetry of different voltage potentials at points A and B shortens the start-up time, which in turn minimizes the required current spike width for a given duration of the generated UWB impulse, reducing the power consumption.

A parallel resistor is inserted into the oscillator core to quench off the oscillator quickly immediately after the current spike has disappeared. Thus, short-time domain impulses with a repetition rate equal to the input signal frequency are generated. The orientation of the generated impulses is directly controlled by the simple phase control circuit for biphase modulation. The center frequency of the UWB impulses is determined by L_1, L_2, C_1 as well as the parasitic capacitance, which is designed to be around 6 GHz in this work.

The IC is mounted on a 0.81 mm thick Rogers RO4003C substrate where a dipole fed circular slot antenna is realized and wire-bonded to external microstrip transmission lines, as shown in Fig. 3. The IC is a quite compact design with an area of 0.56 X 0.53 mm^2 due to a simple circuit topology. This UWB transmitter can also be used for OOK and PPM schemes.

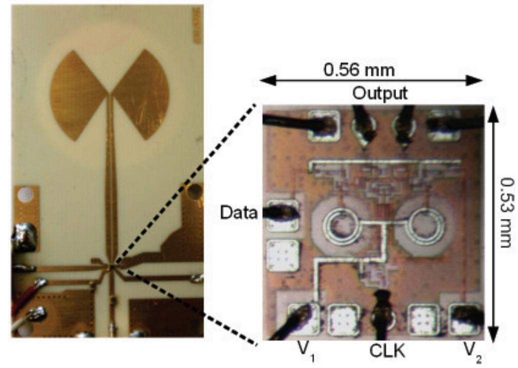

Fig. 3. The realized transmitter and the microphotograph of the IC.

III. Measurement results

A real time oscilloscope with a bandwidth of 13 GHz is used to record the output waveform, with the outputs fed to two different channels of the oscilloscope. The differential signal is then displayed using the scope's waveform subtraction feature. First the IC is characterized on-wafer using microwave ground-signal-ground (GSG) and ground-signal-signal-ground (GSSG) probes with 100 μm pitch. The CLK port is fed either with a 200 MHz or a 1 GHz sinusoidal signal, while the data port is connected to ground. The time domain results can be seen in Fig. 4. The results show a peak-peak amplitude of 260 mV and an envelope width of 0.3 ns FWHM. The complete circuit has a low power consumption of 8.7 mW at 200 MHz and of 14 mW at 1 GHz. The transmitter can realize OOK and PPM schemes with this set-up.

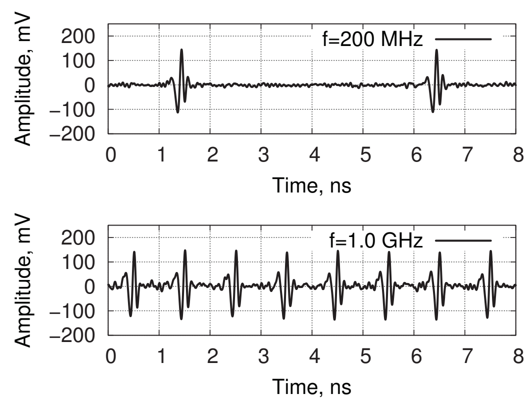

Fig. 4. Measured impulse trains in time domain.

Fig. 5 shows the measured spectrum of the corresponding 200 MHz impulse train. It is centered around 6 GHz with a 10-dB bandwidth of 6.7 GHz from 3.1 - 9.8 GHz, which well complies with the FCC spectral mask for indoor UWB systems.

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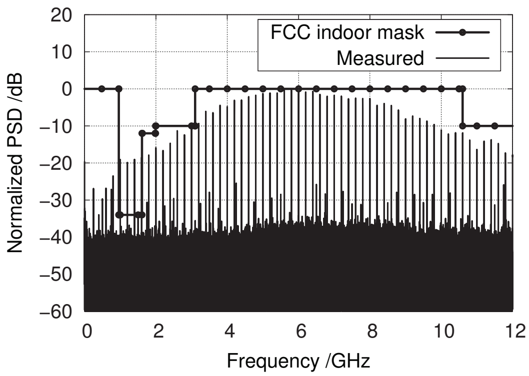

Fig. 5. Normalized spectrum of the 200 MHz impulse train

Then different voltage potentials are applied to the data port to show the biphase modulation performance. Measured results are given in Fig. 6. The orientation of the impulses is clearly reversed, showing a perfect biphase modulation.

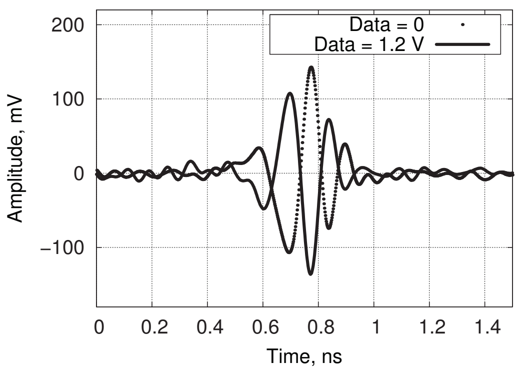

Fig. 6. The measured biphase modulated impulses

At last, the packaged transmitter module is tested in connection with a correlation type IR-UWB receiver to validate the wireless transmission of the modulated impulses. The fully integrated receiver front-end includes the LNA, template impulse generator, multiplier and low pass filter and is mounted at the feedpoint of another antenna, which is placed at a distance of 20 cm from the transmitter. Receiver and transmitter are manually synchronized, adjusting the phase difference between the two CLKs of the receiver and transmitter. The TX CLK, data signal, measured modulated impulse sequence and demodulated signal from the RX are shown in Fig.7. The total power consumption, including the biphase modulation action is 9.8 mW at this data rate, slightly higher than that when generating a 200 MHz unmodulated impulse train.

IV. Conclusion

A UWB transmitter, targeting the FCC spectral mask, applicable for biphase modulation has been demonstrated. The realized circuit uses on-chip generated current spikes to transiently turn on and off a cross-coupled oscillator. The BPM function is achieved by a simple phase control circuit,

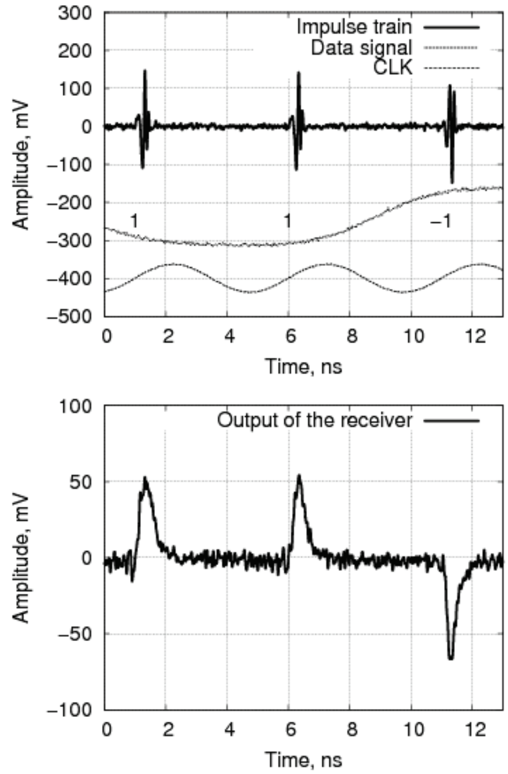

Fig. 7. Measured results of the (top) modulated 200 MHz impulse train, including the data signal and CLK and (bottom) the demodulated signal from the RX with the TX and RX placed with a distance of 20 cm.

thereby avoiding a complex UWB modulator and saving power consumption. The realized transmitter generates impulses with a 10 dB bandwidth of 6.7 GHz well fitting the FCC mask. The generated impulse repetition rate can be up to 1 GHz depending on the input CLK frequency. It features a low power consumption of 9.8 mW at a modulated 200 MHz impulse sequence.

Acknowledgment

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