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A SiGe HBT Low-Power Pulse Generator for Impulse Radio Ultra-wide Band Applications

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Abstract—In this paper a compact ultra-wide band (UWB) pulse generator using SiGe HBT technology is presented. The proposed circuit uses a simple circuitry to generate a current spike on chip, which in turn triggers an under-damped resonant circuit. The generated pulses, whose shape is similar to the fifth order derivative of a Gaussian pulse with $\sigma = 60$ ps, have a short time-domain extension of 200 ps FWHM (full width at half maximum), allowing very high repetition rates up to 1.5 GHz (200 MHz is used in the experiments). The spectrum of the generated pulse train is centered around 6 GHz with a 10-dB bandwidth of 5.6 GHz, which complies well with the FCC spectral mask for indoor UWB devices. In the time domain, pulses have a peak-peak amplitude of 120 mV. The power consumption is 4.6 mW at 200 MHz, and 6 mW at 1.5 GHz pulse repetition rates. This compact design occupies a chip size of 0.18 mm^2 including pads.

I. INTRODUCTION

Impulse-radio UWB (IR-UWB) systems transmit data through carrier-less sub-nanosecond time-domain pulses, occupying a large 10-dB bandwidth in compliance with the spectral mask. The Federal Communications Commission (FCC) allocated the 3.1-10.6 GHz band with a equivalent isotropically radiated power (EIRP) less than -41.3 dBm/MHz for UWB systems. In the frequency band of 0.96-1.61 GHz, the radiated EIRP was defined below -75.3 dBm/MHz to avoid interference to existing systems such as Global Positioning System (GPS). The main challenge in circuit implementations for IR-UWB systems is to generate extremely short pulses and make optimum use of the available spectral mask, using a simple circuit topology, while achieving low power consumption - an often claimed main advantage of IR-UWB systems, e.g. to be used in medical implants.

Any pulse with a shape fitting the allocated spectral masks can be used for UWB applications. According to [1], the fifth-order derivative of a Gaussian pulse can make very efficient use of the FCC spectral mask for indoor devices. Until now, many types of UWB pulse generator implementations have been reported, e.g. in [2], a popular technique is the up-conversion of base-band pulses to the allocated UWB frequency band using an oscillator and mixer. [3] shows a cross-coupled oscillator being turned off and on by digital pulses using low power CMOS circuitry. In [4] an under-damped

resonant circuit is triggered by a current spike to generate impulses with a pulse shape similar to the fifth derivative of the Gaussian bell shape.

This work follows the latter approach, with significantly reduced power consumption due to a novel spike generation circuit to trigger a resonant circuit. The proposed circuit, realised in a Si/SiGe HBT technology, can be directly controlled by either a digital or a sinusoidal input signal. The output pulse repetition rate can be as high as 1.5 GHz with a low power consumption of 6 mW. Albeit realised by a purely bipolar process, this low power consumption is competitive with CMOS circuits. The pulse shape of the generated pulses, whose spectrum meets the emission restrictions for indoor UWB systems well without the need of complex filter structures, is an excellent approach of fifth derivative of the Gaussian pulse.

II. TECHNOLOGY

The pulse generator is realised in the Telefunken Semiconductors GmbH SiGe2RF $0.8 \mu\text{m}$ HBT technology [5]. Two kinds of transistors, with high f_T ($f_T = 80 \text{ GHz}$, $BV_{CEO} = 2.4 \text{ V}$) and with high breakdown voltage ($f_T = 50 \text{ GHz}$, $BV_{CEO} = 4.3 \text{ V}$) are available simultaneously. The process incorporates three metallization layers, four different types of resistors and dielectric MIM capacitors together with nitride capacitors. All the devices were fabricated on a low resistivity $20 \Omega \text{ cm}$ substrate.

III. CIRCUIT DESIGN

The complete pulse generator circuit is shown in Fig. 1, it can be divided into two function blocks: A current spike generation circuit and a pulse shaper circuit. A Schmitt trigger incorporating a current mirror generates current spikes with a shape approximating a Gaussian pulse. The functionality of the following pulse shaper, implemented as an under-damped LC resonator, is to generate higher order derivatives of the Gaussian pulse by its exponentially decaying sinusoidal response.

A. Spike generation circuit

The Schmitt trigger is implemented by a comparator incorporating positive feedback through resistor R_7 . The transistor

Fig. 1. Complete circuit of the proposed pulse generator including current spike generation and pulse shaper circuits.

T_1 is biased in off state, while the output voltage of the circuit is in the low state because T_2 is conducting. When a positive input base-band signal triggers T_1 to be on, the output voltage potential immediately switches to be high and close to V_{CC} , with T_2 off. The threshold input voltage for switching between the two states can be very low by suitable biasing. Therefore the pulse generator can operate with very low input power levels. After the positive input signal disappears, T_1 is open again and the output voltage is back to low state. A square-wave signal with extremely short transition time in picoseconds is generated by the Schmitt trigger because of the positive feedback through R_7 .

A current spike can be generated at every rising edge of the square-wave as the output signal of the Schmitt trigger is connected to a current mirror. When the Schmitt trigger provides a high voltage potential, the diode-configured transistor T_3 together with R_6 will draw that potential down to the built-in potential of the diode. So the voltage potential at the collector of transistor T_3 has a spike performance before it becomes stable, and this responds to a current spike at the collector of T_4 . The repetition rate of the generated current spike is equal to the frequency of the input signal. The width of the current spike will be mainly determined by the time constant of the charging circuit consisting of R_8 and the base-emitter capacitor C_{BE3} of T_3 . This time constant τ can be written as

$$\tau = R_8 C_{BE3}. \quad (1)$$

So the current spike width can be precisely controlled by the value of R_8 and the size of T_3 . In this work, a generated current spike with full-width at half maximum of 60 ps is achieved by suitable selection of the transistor size and the resistance value. The spike generation circuit draws 2.4 mA current under 1.5 V supply nearly independent of the input signal frequency. This spike generation circuit can even be operated with sinusoidal input signals, and offers significant freedom in terms of input amplitude and repetition rate.

B. Pulse shaper circuit

The second function block is the pulse shaper circuit. The targeted pulse is achieved by the RLC resonator powered by the generated current spike. The output voltage in the RLC resonator can be described by a second order differential equation with the spike current i_C from the collector of T_4 .

$$\frac{d^2 v_{out}}{dt^2} + \frac{R_o}{L} \frac{dv_{out}}{dt} + \frac{1}{LC} v_{out} = R_o \frac{d^2 i_C}{dt^2}. \quad (2)$$

The time needed for the oscillations to die out is proportional to the quality factor Q , which can be expressed as

$$Q = \frac{1}{R_o} \sqrt{\frac{L}{C}}, \quad (3)$$

where $R_o = 50\Omega$. Choosing an inductance of 1 nH and capacitance value of 0.2 pF, the resulting transient corresponds to a fifth derivative of the Gaussian pulse and $\sigma = 60$ ps with the properly chosen width of the stimulating current spike. Meanwhile the centre frequency is around 6 GHz for the optimum use of the FCC mask. The power consumption of this function block depends on the input signal frequency. It draws a current of 0.7 mA at 200 MHz and 1.6 mA at 1.5 GHz output pulse repetition rates. The microphotograph of the proposed

Fig. 2. Micrograph of the pulse generator circuit. The IC has a size of 0.41 x 0.43 mm².

pulse generator is shown in Fig. 2. Due to its quite simple circuit topology, the size of the chip is mainly determined by the RF pads and the inductor. It has a size of only 0.41mm x 0.43mm including bonding pads.

IV. MEASUREMENT RESULTS

All presented measurement results were performed on-wafer using a sinusoidal continuous-wave signal source generating the input signal to the pulse generator. Two ground-signal-ground microwave probes were used to connect the input and output ports of the circuit.

A. Time domain measurements

A real time oscilloscope with 13 GHz bandwidth is used to characterize the output signal of the circuit. First the pulse generator is tested with a 200 MHz sinusoidal input signal. The measured pulse with a peak-peak amplitude of 120 mV, and duration around 0.6 ns can be seen in Fig. 3. A more precise measurable figure is the FWHM of the envelope function, which for this pulse is 200 ps. It shows an excellent agreement between the mathematically derived fifth order derivative of a Gaussian pulse with $\sigma = 60$ ps with the measured pulse shape. Because of the high sensitivity of the Schmitt trigger, the circuit requires extremely low input power levels: -18 dBm at 200 MHz output repetition rate. This offers a large freedom regarding the operation of the pulse generator.

Fig. 3. Comparison of the measured pulse waveform with fifth order derivative of Gaussian pulse with $\sigma = 60$ ps and amplitude scaled to be the same as the measured pulse.

Secondly, in order to demonstrate that the generated pulse repetition rate reaches the GHz range, the circuit is tested at 1.5 GHz input frequency. The measured pulse waveforms with 200 MHz and 1.5 GHz pulse repetition rates can be seen in Fig. 4. It shows that the realised circuit generates uniform pulses up to 1.5 GHz in terms of pulse shape and amplitude. The circuit can also work in excess of 1.5 GHz but with a degraded performance. This is mainly because either transistor T_1 or transistor T_2 is in saturation, and saturated bipolar transistors need some time to recover. Supplying 1.5 V, the complete pulse generator consumes 4.6 mW at 200 MHz and 6 mW at 1.5 GHz pulse repetition rates, and the energy consumption per pulse is 23 pJ and 4 pJ respectively. The higher energy consumption at lower output pulse repetition rate is due to the on-chip spike generation circuit, which on the other hand adds freedom in terms of the input signal. This property makes this pulse generator especially suitable for high-speed UWB systems.

Fig. 4. Measured generated output pulse waveforms at 200 MHz, and 1.5 GHz pulse repetition rates.

B. Frequency domain measurements

Measurements in the frequency domain were carried out using a spectrum analyzer. The measured power spectral density (PSD) with 1 MHz resolution bandwidth of pulse train with 200 MHz repetition rate is shown in Fig. 5. The maximum measured PSD is -41.3 dBm/MHz, with a 10-dB bandwidth of 5.6 GHz from 3.1 - 8.7 GHz. It can be seen that the output spectrum complies well with the FCC spectral mask for indoor UWB systems. It shows that the spectral components in the GPS band are highly suppressed, because the RC network in the pulse shaper circuit performs a high pass filter. Some spectral components appearing below 1 GHz are owed to the leakage from input to output. This pulse generator can be operated with on-off keying (OOK) and pulse-position modulation (PPM) schemes. Further implementation can be done to realise biphase modulation when this pulse generator is directly combined with the UWB modulator circuit in [6].

A comparison between the proposed circuit and published pulse generators with high repetition rate targeting the FCC mask is contained in Table I. It shows that the presented circuit occupies very small die area and achieves extremely large 10-dB bandwidth, while only drawing very low power consumption. However, its large freedom regarding the input signal power level and frequency range, which is also a big advantage of this circuit, is not mentioned in this table.

V. CONCLUSION

This paper presents a highly compact monolithic ultra-wide band (UWB) pulse generator using SiGe HBT technology. This circuit is based on a novel, low power consumption spike generation and pulse shaper circuit. The generated time domain waveform has a peak-peak amplitude of 120 mV, a shape similar to the fifth order derivative of Gaussian pulse, with a short duration around 600 ps. The generated pulse repetition rate can be up to 1.5 GHz depending on the input signal

TABLE I
COMPARISONS WITH PREVIOUSLY PUBLISHED WORKS

Reference	Technology	Pulse width (ns)	BW (-10 dB) (GHz)	V_{pp} (V)	Power Cons. (mW)	chip area (mm^2)
[3]-2009 *	65 nm CMOS	2.1	1.2	0.6	7.3 @ 200 MHz	0.04(core)
[4]-2007	0.8 μm SiGe HBT	0.5	5.3	0.51	38 @ 200 MHz	0.31 (die)
[7]-2008	0.18 μm CMOS	3.5	0.52	0.16	1.68 @ 100 MHz	0.3(core)
[8]-2009 **	0.13 μm CMOS	0.42	5.3	2	26.8 @ 200 MHz	0.02 (core)
this work	0.8 μm SiGe HBT	0.6	5.6	0.13	4.6 @ 200 MHz 6 @ 1.5 GHz	0.18 (die)

*:LC resonator generator,

**:simulation results.

Fig. 5. Comparison of the measured power spectral density with FCC mask for indoor UWB systems.

frequency. The measured spectrum of the generated pulse train with 200 MHz repetition rate is centered around 6 GHz with a 10-dB bandwidth of 5.6 GHz, which well complies with the FCC spectral mask for indoor UWB systems. The circuit has a very low power consumption: 4.6 mW at 200 MHz and 6 mW at 1.5 GHz pulse repetition rates, and the energy consumption per pulse is 23 pJ and 4 pJ respectively. This compact design occupies a quite small chip area of 0.18 mm^2 including all pads.

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REFERENCES

- [1] H. Sheng, P. Orlik, A. M. Haimovich, L. J. Cimini and J. Zhang, "On the spectral and power requirements for ultra-wideband transmission", *IEEE Conf. on Communications*, Anchorage, USA, 11-15 May, 2003, pp. 738-742.
- [2] Y. Zheng et al., "A 0.18 μm CMOS Dual-Band UWB Transceiver", *Solid-State Circuits, IEEE International Conference Digest of Technical Papers*, San Francisco, USA, 11-15 February 2007, pp. 114-590.
- [3] O. Novak, C. Charles, "Low-power UWB pulse generators for biomedical implants", *IEEE International Conference on Ultra-Wideband*, Vancouver, BC, Canada, 9-11 September, 2009, pp. 778 - 782.
- [4] J. Dederer, B. Schleicher, F. Tabarani Santos, A. Trasser and H. Schumacher, "FCC compliant 3.1-10.6 GHz UWB Pulse Radar System using Correlation Detection", *IEEE International Microwave Symposium*, Honolulu, HI, USA, 3-8 June, 2007, pp. 391-394.
- [5] A. Schüppen et al., "An 80 GHz SiGe production technology", *III-V Review*, vol. 14, pp. 42-46, August 2001.
- [6] B. Schleicher; C.A. Ulusoy; H. Schumacher; "A Biphase Modulator Circuit for Impulse Radio-UWB Applications", *IEEE Microwave and Wireless Components Letters*, Volume 20, Issue 2, pp.115 - 117, Feb. 2010.
- [7] A. T. Phan, L. Jeongseon, V. Krizhanovskii, Q. Le, S. Han, S. Lee, "Energy-Efficient Low-Complexity CMOS Pulse Generator for Multiband UWB Impulse Radio", *IEEE Transactions on Circuits and Systems I: Regular Papers*, Volume 55, Issue 11, pp. 3552-3563, Dec. 2008.
- [8] R. Vauche, S. Bourdel, N. Dehaese, O. Fourquin, J. Gaubert, "Fully tunable UWB pulse generator with zero DC power consumption", *IEEE International Conference on Ultra-Wideband*, Vancouver, BC, Canada, 9-11 September, 2009, pp. 418 - 422.