Si/SiGe HBT UWB Impulse Generator Tunable to FCC, ECC and Japanese Spectral Masks

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***Abstract*— In this paper a fully integrated, low power and differential ultra-wide band (UWB) impulse generator is presented. The proposed circuit uses an on-chip generated current spike to shortly switch on an LC oscillator. The configurable current spike width leads to a tunable duration of the generated impulses. The corresponding spectrum has a controllable 10 dB bandwidth thus fitting the spectral allocations in the USA, Europe and Japan. The realized circuit has a low power consumption of 6 mW when targeting the FCC mask and of 10 mW when targeting the ECC and Japanese masks at 100 MHz output impulse repetition rate. This compact design occupies a chip size of 0.32 mm^2 including bounding pads.**

***Index Terms*— Ultra-wide band, Impulse generator, LC oscillator, FCC, ECC, Japanese mask.**

I. Introduction

Carrier-less impulse radio UWB (IR-UWB), using short time-domain impulses, is an interesting candidate for biomedical applications, e.g. communication with medical implants. In contrast to existing techniques, IR-UWB offers the advantage of a low power spectral density (PSD) reducing concerns over interference with existing medical equipment.

The spectrum of the transmitted impulses is intended to fit into regulatory spectrum masks which differ from country to country. Generally, frequency ranges are preferred where no interference mitigation is mandated. The original FCC mask for the US is from 3.1-10.6 GHz. For Europe, ECC mask is from 6-8.5 GHz, for Japan, 7.25-10.25 GHz. Maximum allowable equivalent isotropically radiated power (EIRP) density is -41.3 dBm/MHz in all these cases. Fig.1 shows the allowed power spectral densities (PSD) vs. frequency of the three masks. Previous publications used to target a specified mask. E.g. [1] presents a single-ended impulse generator using a current spike to trigger an under-damped resonant circuit, it generate impulses with a spectrum well fitting the FCC mask. Another concept, shown in [2], uses a finite impulse response filter approach for accurate spectrum control to comply with the FCC spectrum mask. A differential pulse generator, again targeting the FCC mask, based on an on-off LC oscillator with a maximum output data rate of 2 Mbit/s, is shown in [3]. The differential concept is favourable to UWB systems, because differential antennas can avoid radiation from the outer shield of unbalanced feed lines. As to the ECC mask, a multi-cycle impulse generator based on a spike triggered triple-circuit bandpass filter can be found in [4].

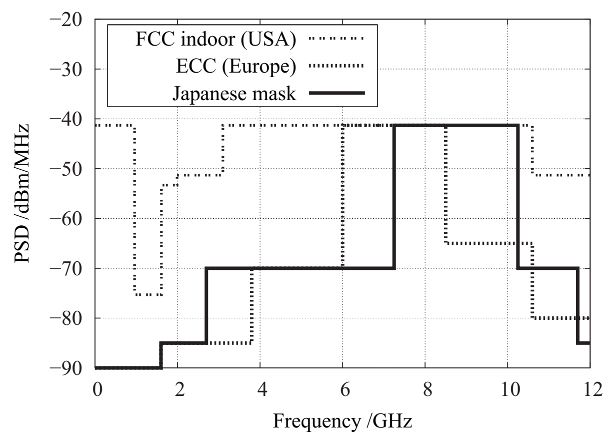

Fig. 1. The FCC, ECC and Japanese spectral masks

In this paper, a low power, low complexity and tunable impulse generator, based on a cross-coupled LC oscillator triggered by a tunable current spike, is presented. The generated impulse shape is adjustable by tuning the center frequency and the impulse envelope, this makes the spectrum meet the FCC, ECC and Japanese spectral masks well without any complex external filters. To the best of the authors' knowledge, this is the the first pulse source with direct pulse generation adaptable to all three bands.

II. Technology

The impulse generator is realized in the Telefunken Semiconductors SiGe2RF 0.8 μm HBT technology [5]. Transistors with f_T = 80 GHz and BV_{CEO} = 2.4 V are used. The technology has 0.8 μm feature size and a minimum effective emitter size for vertical HBT transistors of 0.5 x 1.1 μm^2. The process incorporates three metallization layers, four different types of resistors and dielectric MIM capacitors. All devices were fabricated on a low resistivity 20Ω cm substrate.

III. Circuit Design

The complete tunable impulse generator can be seen in Fig. 2, it can be divided into three function blocks: a Schmitt trigger, a current spike circuit and an LC oscillator. The baseband input signal can be either sinusoidal or rectangular wave in this design.

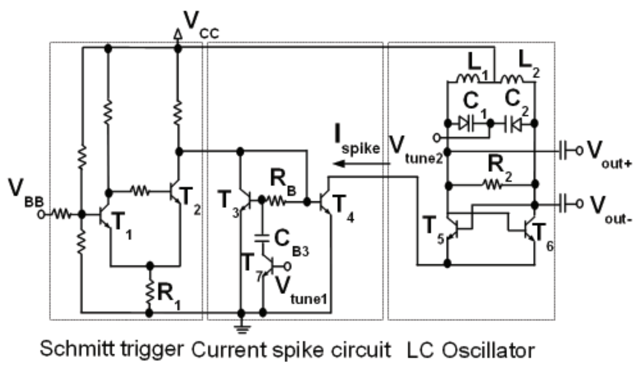

Fig. 2. Complete circuit of the tunable impulse generator.

A. Schmitt Trigger

The Schmitt trigger stage provides a square wave signal with a fast risetime not depending on the risetime of the incoming signal, this allows the circuit to operate with sinusoidal input signals. The transistor T_1 is biased in off state, while the output voltage of the Schmitt trigger is in low state. As soon as a positive input signal triggers T_1 to be on, the output voltage switches to be high, with T_2 off. Careful selection of the biasing can make the circuit operate at a very low input power level. The output voltage becomes low again when the positive input signal disappears. Due to the positive feedback R_1, a square wave signal with very a short transition time (picosecond range) is generated.

B. Current Spike Circuit

A current spike can be generated at every rising edge of the square wave, as the Schmitt trigger output is connected to the current spike circuit. When the Schmitt trigger provides a high voltage potential, the diode-configurated transistor T_3 will bring that potential down to the built-in potential of the diode with a time constant determined by the charging circuit consisting of R_B and the base-emitter capacitor C_{BE3} of T_3 together with C_{B3} of 2 pF. So, the collector voltage of transistor T_3 has a spike performance before it becomes stable, and this responds to a collector current spike of T_4. During the rest of a period, the collector current of T_4 is negligible. Tuning of the current spike width is achieved through V_{tune1}. When V_{tune1} = 0, the transistor T_7 is off and the charging circuit includes only R_B and C_{BE3}. The time constant τ_1 of the charging circuit can be written as

$$\tau_1 = R_B C_{BE3}. \tag{1}$$

When V_{tune1} = 1 V, T_7 is on. The transistor T_7 can be treated as an ideal switch here and the charging circuit includes R_B and C_{BE3} in parallel with C_{B3}. In this case, the time constant τ_2 can be written as

$$\tau_2 = R_B(C_{BE3} + C_{B3}). \tag{2}$$

In the latter case, the current spike width will be much larger because C_{B3} is much larger than C_{BE3}. By suitable selection of transistor size of T_7 and resistance of R_B, the current spike has a full width at half maximum (FWHM) of either 0.4 ns or 2 ns. The amplitude of the current spike can be easily adjusted through changing the size of T_4. The repetition rate of the current spikes is equal to the input signal frequency.

C. LC oscillator

The generated current spikes switch the LC oscillator on by generating a negative impedance through the cross-coupled pair (T_5 and T_6). The resonator of this oscillator includes two inductors in series (L_1 and L_2), two varactors (C_1 and C_2) and a parallel resistor (R_2). In general, the total oscillation time of a shortly switched on LC oscillator consists of start-up time, oscillation duration and quenching time. A fast start-up is necessary to make the needed current spike width for certain duration impulses short, which in turn decreases power consumption. Therefore, in this design a deliberate asymmetry of the resonator through the different sizes of T_5 and T_6 is introduced to shorten the start-up time. This asymmetry simultaneously makes the oscillation start up with always the same phase condition, which makes the generated impulses suitable for both correlation and energy detections. The resistor R_2 is inserted into the resonator for a quick quenching, which is required for short time domain impulses. However, it reduces the output impulse amplitude. Two big capacitors are used instead of a buffer stage to block the impact of the load on resonator. The center frequency ω_0 of the oscillator is determined by L_1, L_2, C_1, C_2 and the parasitic capacitance from the cross-coupled pair C_{para}. It can be expressed as:

$$\omega_0 = \frac{1}{\sqrt{(\frac{C_1 C_2}{C_1 + C_2} + C_{para})(L_1 + L_2)}}. \tag{3}$$

When the shorter spike current with V_{tune1} = 0 triggers the oscillator, the generated impulse will be very short. In this case, there is almost no oscillation duration. The corresponding spectrum has a large 10 dB bandwidth and complies with the FCC mask. Under the condition of V_{tune1} = 1 V, multi-cycle impulse with a reduced 10 dB bandwidth is generated. The oscillation in this mode is quenched off after a certain duration. By adjusting the center frequency ω_0 through changing the varactor capacitances C_1 and C_2 with V_{tune2}, it suits either the ECC or the Japanese spectral mask.

The microphotograph of the realized tunable impulse generator is shown in Fig. 3. It is a quite compact design with an area of 0.53 x 0.61 mm^2 due to a simple circuit topology.

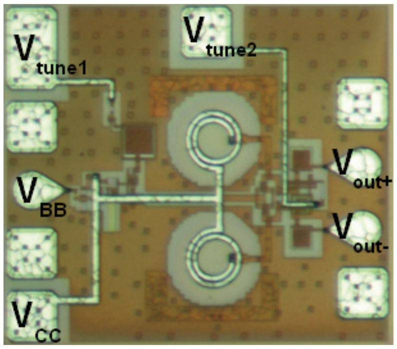

Fig. 3. Microphotogragh of the realized impulse generator IC. It has a chip size of 0.53 x 0.61 mm^2.

IV. Measurement Results

The impulse generator was measured on-wafer connecting the differential output to two channels of a real time oscilloscope with a bandwidth of 13 GHz. The differential output can be extracted by subtraction of the two oscilloscope channels. Ground-signal-ground and ground-signal-signal-ground microwave probes were used to connect the input and output ports of the circuit. The circuit is tested with a 100 MHz sinusoidal input signal.

A. Targeting the FCC mask

By setting V_{tune1} = 0 and V_{tune2} = 2.0 V, the generated impulses are targeted at the FCC mask. Now the oscillator is triggered with a shorter current spike. In Fig. 4, the

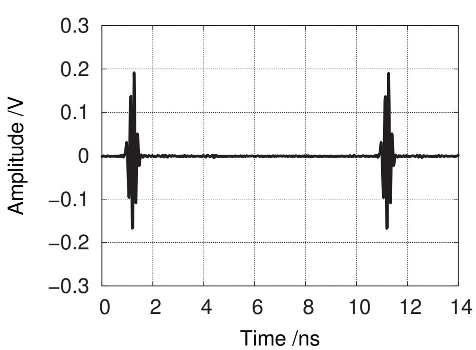

Fig. 4. Measured output waveform at 100 MHz pulse repetition rate suitable for the FCC mask.

recorded output impulse train can be seen. The measured sub-nanosecond impulses have a peak-peak amplitude of 0.36 V. The FWHM of the envelope is a more precisely measurable figure, which for these impulses is around 400 ps. The circuit draws a total power consumption of 6 mW. The input signal can have a power level smaller than -16 dBm because of the Schmitt trigger. The output impulse repetition rate under this mode can be up to GHz range. Fig. 5 presents the normalised PSD of this impulse

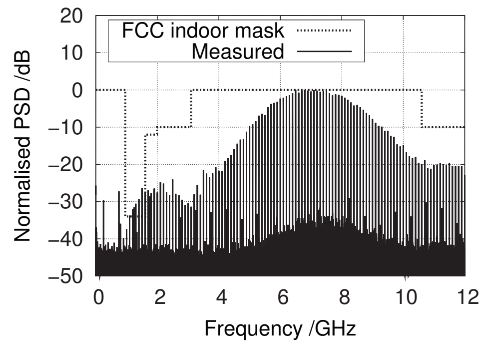

Fig. 5. Normalised PSD with the FCC mask.

train complying with the normalised FCC mask for indoor systems. In general, the maximum EIRP also depends on the gain of the transmission antenna, the impulse repetition rate and the modulation type. A normalised PSD can well show the fitness for the spectral masks. This impulse train has a 10 dB bandwidth of 4.2 GHz from 5-9.2 GHz with the center frequency around 7 GHz. It can be seen that the output spectrum complies well with the FCC indoor mask.

B. Targeting the ECC mask

The impulse generator is suitable for the ECC mask when V_{tune1} = 1 V and V_{tune2} = 2.3 V. Under these con-

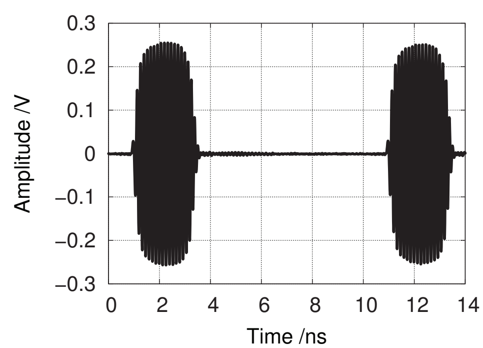

Fig. 6. Measured output waveform at 100MHz impulse repetition rate tageting the ECC mask

ditions, the LC oscillator is triggered with a longer current spike with a FWHM of 2 ns. The measured output impulse train can be seen in Fig. 6. The impulses have a peak-peak amplitude of 0.5 V and the FWHM of the envelope is around 2 ns. The circuit has a total power consumption of 10 mW and a maximum output impulse repetition rate exceeding 300 MHz in this case. The normalized PSD of this impulse train has a center frequency around 7 GHz with a 10 dB bandwidth of 600 MHz, as shown in Fig. 7. It fits well into the ECC mask.

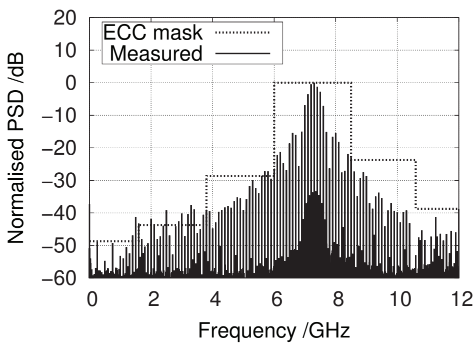

Fig. 7. Normalised PSD with the ECC mask.

C. Targeting the Japanese mask

Through changing the value of V_{tune2}, the center frequency of the impulses will be shifted, this makes the circuit usable for the Japanese mask. Fig. 8 shows the

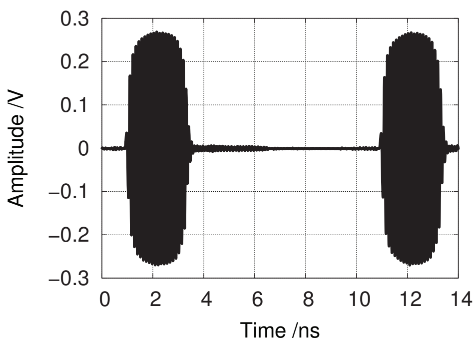

Fig. 8. Measured output waveform at 100MHz impulse repetition rate tageting the Japanese mask

measured output signal at V_{tune2} = 6 V. The measured impulse train has a similar envelope as in the last case because the triggered current spike has the same width. The peak-peak amplitude of the impulses whose envelope has a FWHM of 2 ns is 0.5 V. The complete power consumption in this mode is 10 mW. The spectrum information is presented in Fig. 9. It shows that the center frequency is shifted to 8.7 GHz, leading to a good fitting with the Japanese mask. This impulse generator can be used for on-off keying (OOK) and pulse-position modulation (PPM) schemes in all three modes.

V. Conclusion

In this paper a tunable impulse generator has been shown for the use with the FCC, ECC and Japanese spectral masks. The realized circuit is based on an LC oscillator transiently turned on by a current spike with tunable width.

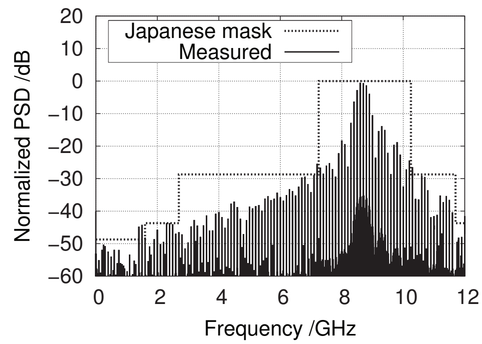

Fig. 9. Normalised PSD with the Japanese mask.

Through two tune voltages, the center frequency and the envelope of the generated impulses can be easily adjusted. The measured sub-nanosecond impulses targeting the FCC mask have a peak-peak amplitude of 0.36 V. This short duration allows the output impulse repetition rate of up to GHz range. The spectrum of the measured 100 MHz impulse train has a 10 dB bandwidth of 4.2 GHz well fitting into the FCC mask. The multi-cycle impulses can be generated with a small 10 dB bandwidth targeting either the ECC or Japanese spectral mask through adjusting the center frequency. The measurement results show a peak-peak amplitude of 0.5 V in both modes. The total power consumption is 6 mW when targeting the FCC mask and 10 mW when targeting the ECC and Japanese masks at 100 MHz output impulse repetition rate. This compact design occupies a small chip area of 0.32 mm^2 including all pads.

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References

[1] 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.

[2] M. Demirkan, R.R. Spencer, "A 1.8Gpulses/s UWB Transmitter in 90nm CMOS", *Solid-State Circuits, IEEE International Conference Digest of Technical Papers*, San Francisco, USA, February 2008, pp. 116-117.

[3] S. Diao, Y. Zheng and C.H. Heng, "A CMOS Ultra Low Power and High Efficiency UWB-IR Transmitter for WPAN Applications", *IEEE Trans. Circuits and Systems - II Express Briefs*, Vol. 56, No. 3, pp. 200-204, March 2009

[4] B. Schleicher, H. Schumacher, "Impulse generator targeting the European UWB mask", *Silicon Monolithic Integrated Circuits in RF Systems (SiRF), 2010 Topical Meeting on*, New Orleans, LA, USA, 11-13 Jan. 2010, pp.21 - 24.

[5] A. Schuppen et al., "An 80 GHz SiGe production technology", *III-V Review*, vol. 14, pp. 42-46, August 2001.