A 0.18-μm CMOS Fully Integrated Antenna Pulse Transceiver with Leakage-Cancellation Technique for Wide-band Microwave Range Sensing Radar

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***Abstract*— This paper presents a leakage cancellation technique for on-chip transceiver for range sensing radar. A 180-nm CMOS transceiver with on-chip antennas is implemented with a 9 – 11-GHz damping-pulse transmitter (Tx) and a receiver (Rx) including a mixer and a 3-stage low-noise amplifier (LNA). By adding a polarity-reversal switch to the receiver mixer, leakage, reflected signals, and traveling time of transmitted pulses can be measured. Another improvement is the design of the Rx's mixer and the 3-stage wide-band LNA to reduce on-chip DC blocking capacitors. Experimental results with/without reflector placed at several distances from the transceiver are performed to demonstrate the technique. Pulse traveling times are measured with 0.8 ns, 1 ns, and 1.25 ns for the distance of 10 cm, 14 cm, and 18 cm, respectively. Furthermore, reflected signals are measured separately from leakage in cases of different distances.**

***Index Terms*— leakage cancellation, transceiver, on-chip antenna, CMOS, switch, range sensing, radar.**

I. INTRODUCTION

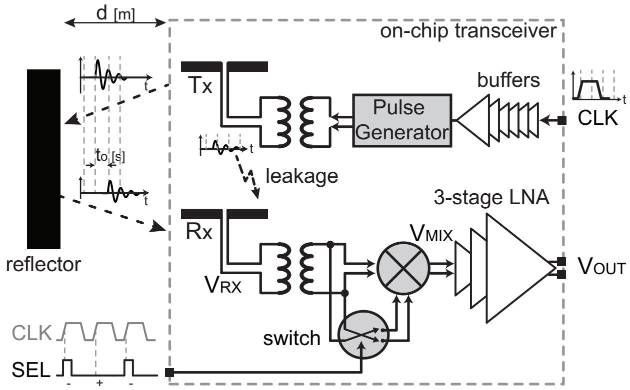
Recent radio frequency integrated circuits (RFICs) with all the blocks including transmitter (Tx) and receiver (Rx) fabricated on the same chip often confront with leakage or cross-talk problems. Especially monolithic antenna integration for transceivers has the risk of leakage or cross-talk between the Rx's and Tx's radiators both in communication links and radar applications. Leakage can cause several problems for the receiver to detect reflected signals and hence degrades radar's performance. Methods so-called "balanced topology radar" and "quadrature radar topology" have been proposed to reduce Tx leakage [1], [2]. However, a coupler or a quadrature coupler is needed but still dissipates transmitting signals. A reflected power canceller (RPC) method has proposed but requires digital signal processing [3]. Moreover, these approaches are applied for continuous wave radars and single antenna systems which suffer inherent problems and large leakage due to low isolation of circulator and low Tx-to-Rx isolation especially for integrated antenna transceiver.

In this paper, we present a leakage cancellation technique in on-chip transceiver for wide-band microwave sensing radar applications. A polarity-reversal switch is placed between the Rx's mixer input and transformer's secondary terminal to invert the polarity of received signals for each of two transmitting pulses. Leakage between antennas of Tx and Rx is canceled by controlling not only the polarity the Rx's mixer input through the polarity-reversal switch but also the timing scanning of the switch. Then, an accumulation of an even number of output voltage values is performed to eliminate leakage components. Furthermore, reflected signals and traveling time of transmitted pulses can be measured. Another improvement is the design of the Rx's mixer and the 3-stage wide-band LNA to reduce on-chip DC blocking capacitors between the mixer and LNA. For the last stage of the LNA, we proposed a self-bias cascode structure and LNA's 2^{nd} stage so that these two stage can be connected directly without DC-blocking capacitors. Measurements are performed with a copper reflector from distances of 10, 14, and 18 cm to the transceiver to demonstrate the leakage cancellation.

II. TRANSCEIVER DESCRIPTION AND THE LEAKAGE CANCELLATION CONCEPT

Figure 1(a) shows the proposed transceiver including a 9–11-GHz damping-pulse Tx as [4]. The capacitor C, the inductor L_{t1}, and the PMOS Q_P, operating as a resistor, form a RLC damping-pulse generator while the NMOS Q_N operates as an on/off switch as in Fig. 1(b). Damping pulses are transmitted at the rising-edge of Tx's CLK. An on-chip transformer transfers damping-pulses to the top-metal meandering dipole antenna. A pattern-ground-mesh by poly-layer and metal-1-layer is put underneath the transformer to eliminate image-current and minimize cross-talk between the transformer and the antenna. Measured bandwidth of the on-chip antenna is 4.4 GHz with the frequency range of 7.4 – 11.8-GHz.

Transmitted pulse is forwarded to the reflector at a distance d from the Tx's antenna, reflected and then arrives at the Rx's antenna in a travelling time of t_0=2d/c where c is the speed of light in the air. Although Tx and Rx antennas are integrated in an orthogonal polarization direction to minimize cross talk, they are close together and in the same die leakage occurs during the transmission and is added to the Rx's output before the reflected signal



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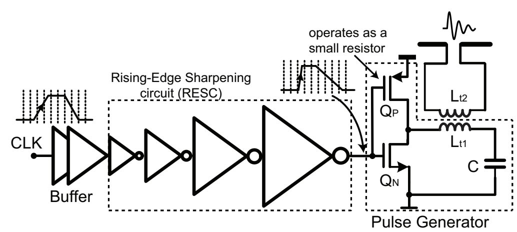


(b)

Fig. 1. Block diagrams of: (a) the proposed on-chip transceiver and (b) the transmitter using damping-pulse generator circuit.

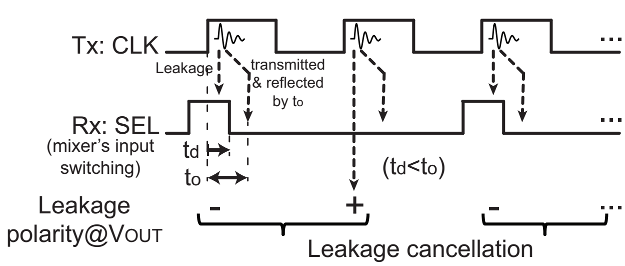


Fig. 2. The proposed leakage cancellation technique.

arrives at Rx's antenna in t_o. Therefore, Rx's output signal consists of both leakage and reflected signals. By inverting the polarity of mixer's local oscillator (LO) input earlier than the arrival of the reflected signal, the corresponding Rx's output includes inverted (-) leakage signal and the reflected one as illustrated in Fig. 2. In the next rising-edge of CLK or the next transmitted pulse, by keeping the same polarity of the mixer's LO input, Rx's output contains non-inverted leakage signal and the same reflected one. Therefore, the accumulation of a couple of these adjacent Rx's outputs removes the leakage signal. If the timing of CLK's rising-edge to falling-edge of SEL is t_d, the condition for leakage cancellation is $t_o > t_d$.

The Rx is composed of a transformer, an on-chip antenna, and a Gilbert mixer followed by a 3-stage LNA. Rx's antenna terminal is connected to the primary of a transformer whose secondary terminal is connected to

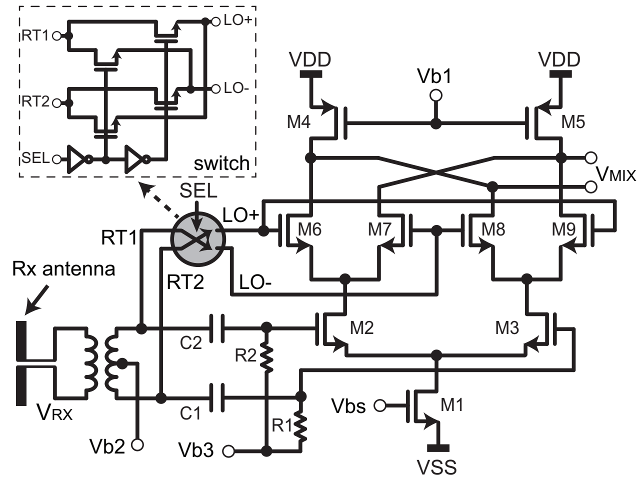


Fig. 3. Simplified receiver Gilbert mixer with the polarity-reversal switch. Switch's NMOS drain diffusion parasitic capacitors are determined to resonant with the secondary inductor of the transformer to enhance the switch performance. Bias details are omitted.

mixer's (LO+, LO-) inputs through a polarity-reversal switch as presented in Fig. 3. In the switch circuit, the connection of NMOS's drains and the secondary inductor of the transformer improves the switch performance due to the resonant of the switch's NMOS drain diffusion parasitic capacitors and the inductor. SEL signal is used to control the polarity of the switch. The proposed mixer output DC bias can be used to bias LNA's input so that no bias-circuit and no on-chip DC blocking capacitor is needed for the first LNA's stage. Also, the 2^{nd} and 3^{rd} LNA stage are proposed so that outputs of the 2^{nd} stage are connected directly to inputs of the 3^{rd} LNA stage. No DC-blocking on-chip capacitor is required for the connection between the 2^{nd} and the 3^{rd} LNA stage. Post-layout simulation gain and noise figure of the 3-stage LNA in the frequency range of 1GHz – 5MHz are 33.4dB – 60dB and 2.25dB – 2.68dB, respectively.

Figure 5 presents simulation results of mixer output and the 3-stage LNA output. A 30-μV_{pp} receiving pulse is fed to Rx's antenna terminals and the mixer's output is achieved with 1.4 uV_{pp}. Losses in the switch circuit and passive components such as the transformer, capacitors and resistors degrade the mixer's output by -13.3 dB but due to the active self-mixing operation V_{MIX} is converted to lower frequency range. The 3-stage LNA does not only enhance the peak-peak voltage by a gain around 34.3 dB but also enlarge the pulse width by output transistor capacitors. Due to output transistor capacitors of the 3-stage LNA, during the switching of SEL output pulses are accumulated to be in saw-tooth voltage shapes which can be used to detect reflected objects in pulse radar applications. Moreover, by controlling t_d of SEL's falling-edge in the condition of $t_d < t_o$ leakages between Tx's and Rx's

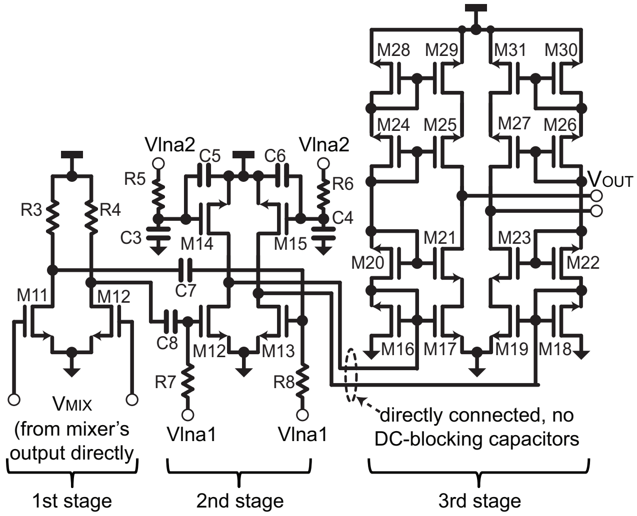


Fig. 4. Simplified schematic of the 3-stage LNA

antennas can be canceled as the following experimental results.

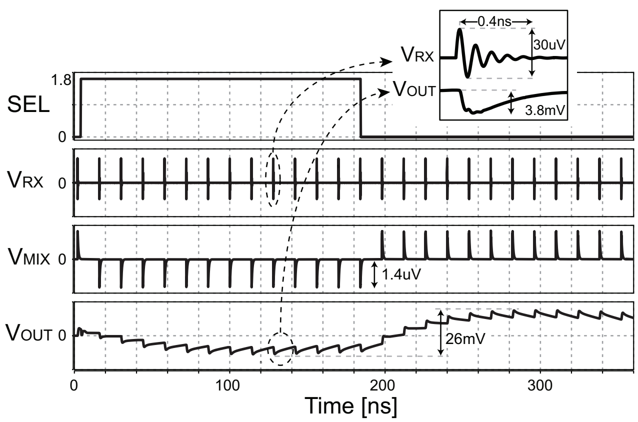


Fig. 5. Simulated results of the receiver: switching the polarity of mixer's input by SEL without leakage cancellation.

III. Experiment Results

Measurements are set up by mounting the chip on a printed-circuit-board (PCB) and placing a flat copper reflector into a anechoic box and using an *Agilent E8404A* parallel Bit-Error-Ratio-Tester (BERT) to supply for Tx's CLK and Rx's SEL signals. An oscilloscope is used to observe receiver output. The timing t_d of SEL signal is adjusted for the cancellation technique demonstration.

First, a measurement without leakage cancellation with the reflector object at a distance from the chip of d = 18 cm is performed. Rx's SEL frequency is 12 times than the Tx's CLK as shown in Fig. 6. A saw-tooth waveform with 40.2-mV_{pp} achieved at V_{out} output is the accumulation of both reflected signals and leakage ones.

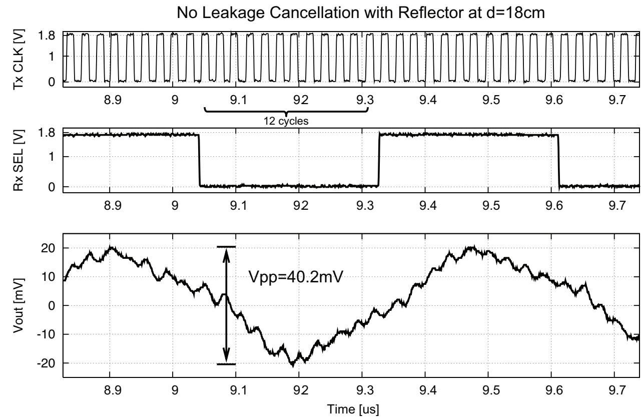


Fig. 6. Measured results in case of no leakage-cancellation with the reflector at d=18cm

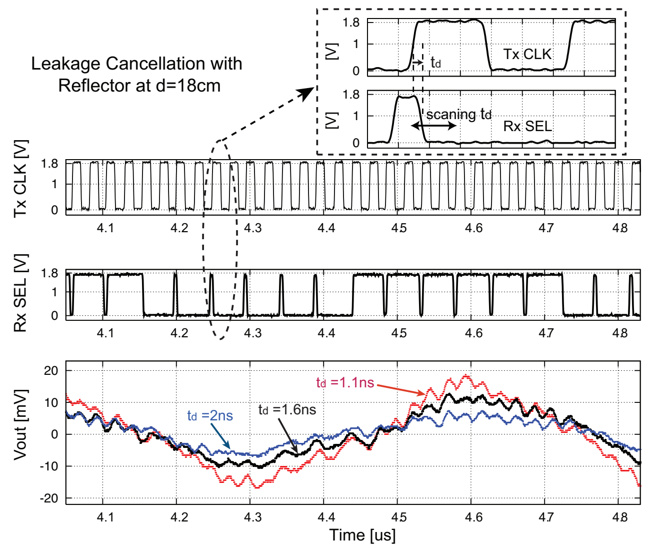
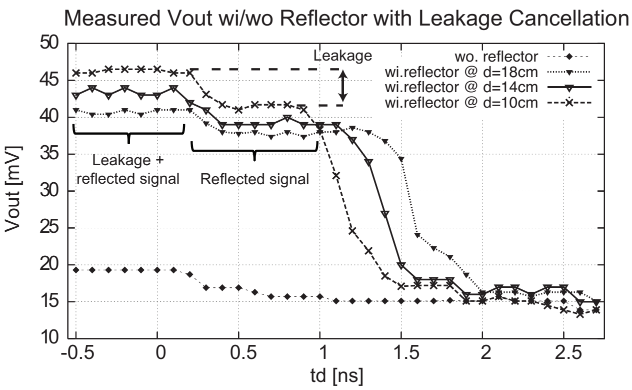


Fig. 7. Measured results using leakage-cancellation with the reflector at d= 18 cm and t_d = 1.1 ns, 1.2 ns, and 2 ns.

Then, leakage-cancellation measurements are performed with three d values of 10 cm, 14 cm, and 18 cm whose corresponding traveling time t_o = 0.67 ns, 0.93 ns, and 1.2 ns, respectively. SEL waveform is set as shown in Fig. 7 and t_d timing is scanned in a 100-ps step from -0.5 – 2.7 ns to cover the range of t_o and other delays (by cables and paths on the PCB) which cause misalignment between CLK's rising-edge and SEL's falling-edge for t_o = 0 s. Another measurement without reflector is implemented. Figure 8(a) shows all measured V_{out} values wi/wo the reflector. For each case, V_{out} is almost no-change as t_d $<$ 0.25 ns. In case of without reflector, V_{out} also slightly decreases at t_d = 0.25 ns and then comparatively approach to a constant value around 15 mV caused by other substrate leakages because of putting the Tx and Rx on the same die. In the case with reflector, as t_d $>$ 0.25 ns there are two main steps of decrements revealing the leakage value

for the former and the corresponding reflected signal for the latter. Leakages after the 3-stage LNA are measured by around 5-mV for all cases of d = 10 cm, 14 cm, and 18cm. Slopes when $t_d > t_o$ should be steep in theory however the measured falling-edges show offset values because of suffering from SEL signal's slope, phase shift and jitter from signal cables, PCB, and measurement equipment.



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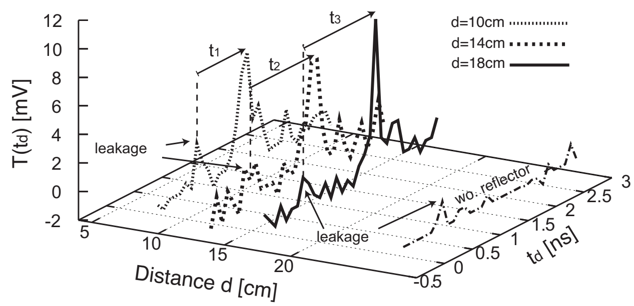

(b)

Fig. 8. Leakage cancellation results wi/wo the reflector: a) measured V_{out} of Tx and b) $T(t_d)$ function to determine timing values of leakage and traveling/reflecting.

To determine the traveling and reflecting time, another calculation is performed with $T(t_d)$ function as $T(t_d)$ = $V_{out}(t_d$-$\Delta t_d)$ - $V_{out}(t_d$+$\Delta t_d)$. Figure 8(b) presents $T(t_d)$ functions for three cases of d values and the case without reflector. From these $T(t_d)$ graphs, the occurrence of leakage is approximately at t_d = 2.5 ns, the same for all cases. Moreover, from the time of leakage, t_d = 2.5 ns, to the peak of $T(t_d)$, we can calculate the traveling and reflecting time of transmitted pulse (neglecting the distance between Tx and Rx) such as t_1 = 0.8 ns, t_2 = 1 ns, t_3 = 1.25 ns for d = 10 cm, 14 cm, and 18 cm, respectively.

IV. Conclusion

A pulse transceiver to demonstrate the proposed leakage measurement and cancellation technique is implemented in the Rohm 0.18-μm CMOS process. On-chip antennas are integrated both in transmitter and receiver circuits. By adding a polarity-reversal switch to the mixer input of

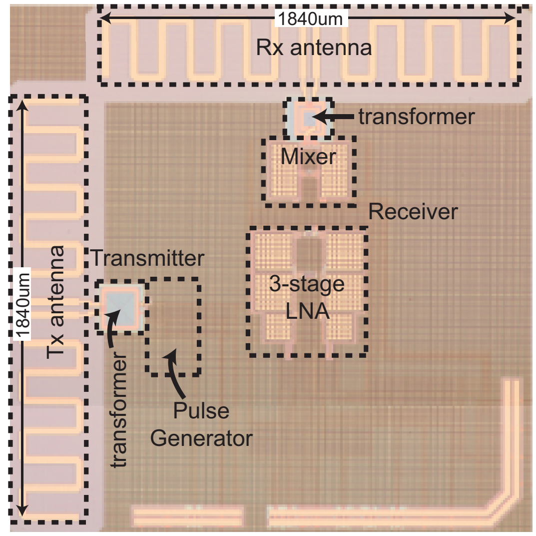

Fig. 9. Micro-photograph of the transceiver. Tx's and Rx's antennas are the same and placed in orthogonal direction to minimize the cross-talk.

the receiver and scanning the falling-edge of the switch, leakage, reflected signals, and traveling both of time and signals of transmitted pulses can be measured. Another improvement is the design of the Rx's mixer and 3-stage wide-band low-noise amplifier to reduce on-chip DC blocking capacitors. Although there are some offsets compared with the theory, measurement results performed with/without reflector from three distances from the chip shows that the leakage cancellation technique can be applied for microwave pulse range sensing applications.

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