5.6 A New TX Leakage-Suppression Technique for an RFID Receiver Using a Dead-Zone Amplifier

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RFID systems use backscattering communication in which the TX transmits a continuous wave (CW) to provide energy to the tag while the RX receives data from it. Due to the simultaneous operation of the RX and TX, large TX leakage is the main issue in securing RX sensitivity. Although external isolation components such as a circulator or directional coupler are widely used in RFID systems, TX leakage is still a dominant source of sensitivity degradation due to its finite isolation and environmentally dependent antenna reflection ratio, as shown in Fig. 5.6.1(a). In a single-antenna-based RFID system, the TX carrier leakage is typically above 0dBm at the RX input despite off-chip isolation components [1]. As can be seen in Fig. 5.6.1(b), when the close-in phase noise of the TX carrier is -85dBc/Hz, the phase noise level of 0dBm TX leakage in the receive channel reaches 89dB higher than the thermal noise level, thus directly degrading the SNR. In efforts to solve the leakage problem, leakage cancellation [2,3] and self-correlated RX [4] techniques have been reported. However, high power consumption for leakage replica generation and long calibration time, as in [2,3], and hardware complexity for a 45 degree phase shift [4] are issues that need to be resolved.

This work introduces a simple and low-power TX leakage suppression technique using a proposed dead-zone amplifier and a power detector, as shown in Fig. 5.6.2. In Fig. 5.6.2, the dead-zone amplifier offers gain only where $|V_{in}| > V_{DZ}$ (V_{DZ}, the dead-zone voltage); otherwise the gain becomes zero. Since the RFID system uses Miller or FM0-based amplitude modulation, the signal at the input of the RX, which is the sum of the tag and leakage signals, contains information only in the envelope part, as shown in Fig. 5.6.2. Therefore, by adopting the dead-zone amplifier, and by choosing $V_{DZ} \le V_{LKG}$, only the envelope part of the signal can be amplified while suppressing the leakage.

A dead-zone amplifier can be realized by Class-B operation of a simple common-source (CS) amplifier as shown in Fig. 5.6.3, by the proper selection of $V_{G,CTRL}$; that is, $V_{DZ} = V_t - V_{G,CTRL}$. However, with a simple CS amplifier, the amount of TX leakage suppression is limited by two reasons; non-zero drain current for $V_{GS} < V_t$ and leakage feedthrough via gate-drain parasitic capacitance. Figure 5.6.4(a) shows the schematic of a differential dead-zone amplifier that can overcome these two problems. In Fig. 5.6.4(a), M_1 and M_2 constitute the main transistors, as in the CS amplifier shown in Fig. 5.6.3, and M_3-M_6 constitute auxiliary transistors that are used for cancelling the non-zero dead-zone current of M_1 and M_2. For $V_{GS} < V_t$, the auxiliary transistors M_3 and M_4 generate the same current as that of the main transistors, M_1 and M_2. As V_{GS} increases beyond V_t, M_1 and M_2 remain in saturation region operation and the drain voltages drop by the increase in drain currents. This drain voltage drop drives M_3 and M_4 into the triode region operation and ultimately turns off M_3-M_6, reducing the auxiliary current to zero. Therefore, by the subtraction of this auxiliary current from the main transistor current, the overall output current of the dead-zone amplifier becomes more ideal, as shown in Fig. 5.6.4(b). M_5-M_8 help to suppress the leakage feedthrough to the output by forming a cascode configuration.

In an RFID system, the antenna reflection coefficient varies with environmental influences; therefore, it is also important that the RX guarantees sensitivity over the TX leakage power variation. Contrary to the previous leakage cancellation techniques [2,3] which require extra controls and a complex cancellation algorithm, the proposed technique can achieve a constant RX sensitivity by only adopting the power detector to control V_{DZ} as a function of leakage power. Figure 5.6.4(c) shows the schematic of a negative–polarity full-wave rectifier that is adopted as the power detector shown in Fig. 5.6.2. In Fig. 5.6.4, in order to minimize the effect of V_t variation on V_{DZ} ($V_{DZ} = V_t - V_{GS,CTRL}$), the size of M_{13} is chosen to be the same as that of M_1-M_4. From Fig. 5.6.4(c), the power detector output is given by

$$V_{GS,CTRL} = V_{GS,13} - \left(\frac{2}{\pi}\right)V_{LKG} \text{ , where } V_{GS,13} = V_{t,13} + \sqrt{\frac{2I_B}{k_n'(W/L)_{13}}} \text{ .}$$

Then, $V_{DZ} = \frac{2}{\pi}V_{LKG} - \sqrt{\frac{2I_B}{k_n'(W/L)_{13}}}$, and thus V_{DZ} becomes only a function of I_B, $(W/L)_{13}$, and V_{LKG}, but is not dependent on V_t.

From Fig. 5.6.2, the SNR at the output of the dead-zone amplifier would be maximized when $V_{DZ}=V_{LKG}$. However, in a real circuit, the gain in the amp-zone (in Fig. 5.6.2-(b)) decreases gradually as V_{GS} approaches V_t, such that the SNR degrades by the decrease in the tag signal at the output while the thermal noise remains the same. Therefore, by choosing V_{DZ} to be slightly smaller than V_{LKG}, a higher value of SNR can be obtained. In this design, $V_{DZ} = 0.78\ V_{LKG}$ is chosen for the best SNR.

Figure 5.6.5 shows the RFID receiver front-end that adopts the proposed leakage suppression technique. The front-end consists of a preamplifier, a hysteresis comparator to turn on/off the preamplifier, a dead-zone amplifier in combination with a power detector, and a mixer. The dead-zone amplifier is designed to suppress the leakage power higher than -8dBm by control of the power detector output. The leakage suppression characteristic of the dead-zone amplifier can be controlled by changing the output slope or $V_{GS,13}$ in the power detector. In this work, the dead-zone amplifier is designed to suppress the leakage in proportion to the leakage power at the input, such that the leakage power at the output stays constant. This secures constant system sensitivity and stable operation of the following stages. The preamplifier is located in front of the dead-zone amplifier to extend the leakage suppression range down to -20dBm by the additional amplification of the received signal. The hysteresis comparator determines turn on/off or the bypass condition of the preamplifier in accordance with the received leakage power. The mixer consists of a passive current switch and a transimpedance amplifier (TIA) with a DC offset cancellation feedback loop.

The proposed receiver front-end is implemented in a standard 0.18µm CMOS process, drawing 19mA from a 3.3V supply, while the dead-zone amplifier with the power detector consumes only 2.5mA, which is less than 25% that of other leakage cancellation techniques [2,3]. The packaged chip is evaluated by applying the AM tag signal with TX leakage over the leakage power range of -20 to +10dBm. The measurement results are shown in Fig. 5.6.6. Figure 5.6.6(a) is the measured output spectrum of the dead-zone amplifier, showing SNR improvement of 15.77dB. The SNR improvement remains as high as 14.93dB at the output of the down-conversion mixer, as shown in Figure 5.6.6(b). Figure 5.6.6(c) shows the input leakage power vs. the mixer output noise power spectral density caused by the phase noise of the TX leakage, with and without the dead-zone amplifier. It can be seen that the dead-zone amplifier keeps the output noise power constant. The measured SNR improvement vs. TX leakage power at the RX input is shown in Fig. 5.6.6(d), showing SNR improvement proportional to the incoming TX leakage power. Figure 5.6.7 shows a performance summary table and a chip micrograph of the fabricated RFID front-end with size of 1600 × 800μm^2.

This new approach provides a straight forward means of TX leakage suppression with a simple and low-power structure while offering auto-calibration of the leakage suppression against TX leakage power. Note that the SNR of the proposed RFID front-end can be further improved by additional adoption of the proposed dead-zone amplifier.

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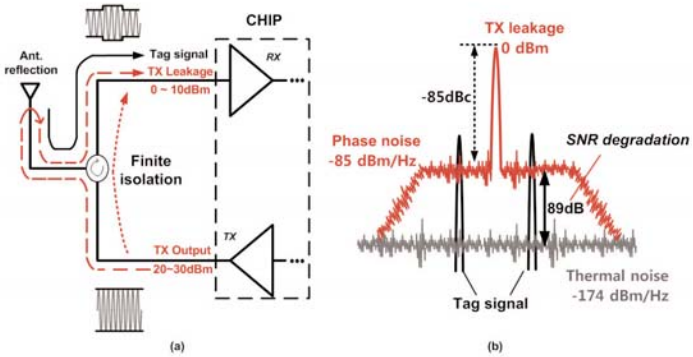

Figure 5.6.1: (a) Leakages and signal in RFID system and (b) sensitivity degradation by leakage.

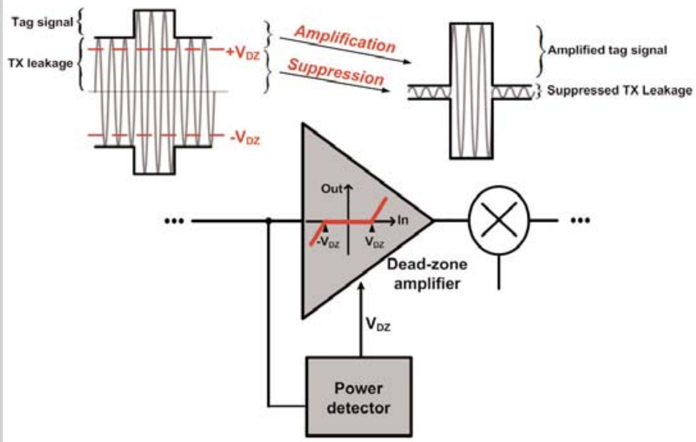

Figure 5.6.2: Leakage suppression technique using a dead-zone amplifier.

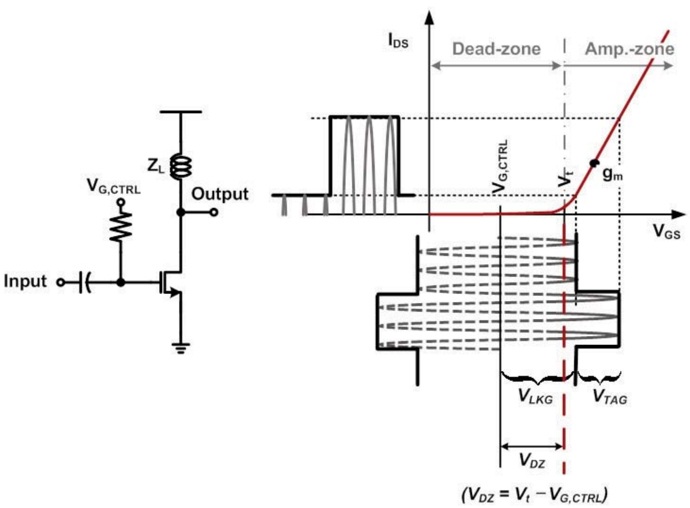

Figure 5.6.3: A common-source-amplifier-based dead-zone amplifier.

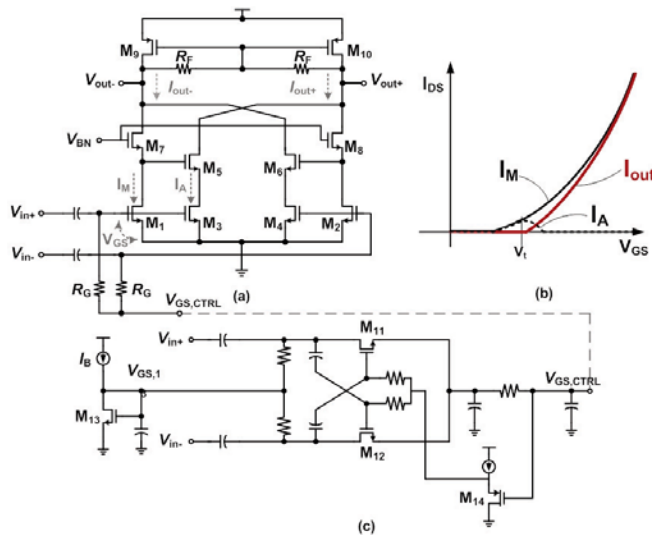

Figure 5.6.4: (a) Schematic of the proposed dead-zone amplifier, (b) the corresponding transfer curve, and (c) schematic of power detector.

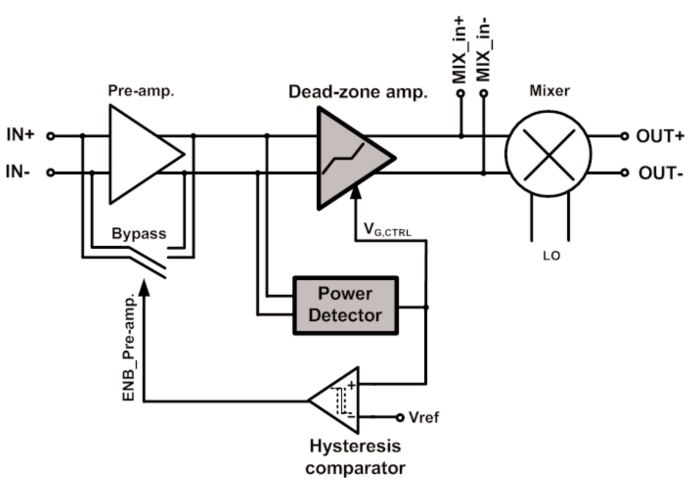

Figure 5.6.5: RFID receiver front-end adopting leakage suppression technique.

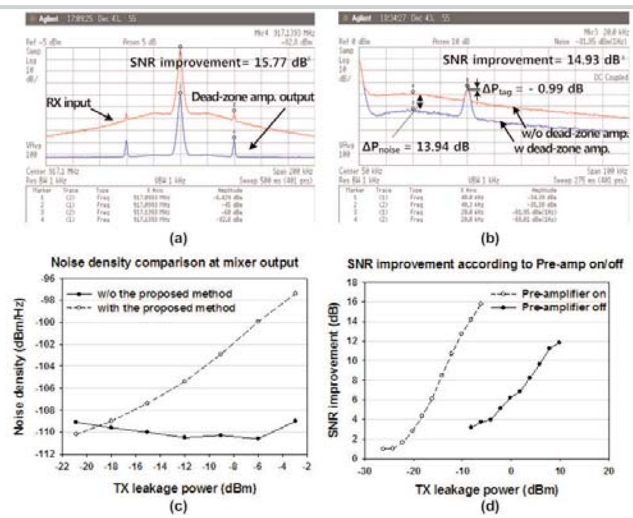

Figure 5.6.6: Measurement results; (a) SNR improvement at dead-zone amp. output, (b) SNR improvement at mixer output, (c) Mixer output noise vs. TX leakage power, and (d) SNR improvement vs. TX leakage power.

Reference	[2]	[3]	This work
TX leakage suppression technique	Active blocker rejection	Replica of TX leakage	Dead-zone amplifier
SNR improvement	50dB	10~12dB	0~15.8dB *
Power consumption	16mA (20dBm leakage)	-	2.5mA **
Complexity	RSSI(2), DSP, 6-bit DAC& ADC, External control path	phase control(13-bit), amplitude control(VGA), External control path	Power detector, Internal auto-control
TX leakage power coverage	-5 to 15dBm	-27 to -6 dBm	-20 to 10 dBm
Supply	3.3 V	1.8 V	3.3 V
Technology	0.18um CMOS	0.18um CMOS	0.18um CMOS

* SNR improvement is proportional to leakage power
** Constant current consumption regardless of TX leakage power

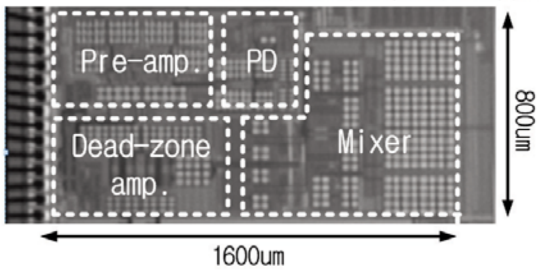

Figure 5.6.7: Performance table and die micrograph (1600 × 800 μm^2).

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