# Two-Way Backscatter Communication Tag Using Reflection Amplifier

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***Abstract*—We propose a two-way backscatter tag that uses a reflection amplifier. The reflection gain $S_{11}$ is used to modulate the backscatter signal while the forward gain $S_{21}$ is fixed. The circuit is analyzed and designed to operate at 2.45 GHz with bandwidth of 120 MHz. Measurements show that we can have $S_{11}$ ≈20 dB and -20 dB to implement on/off keying (OOK) backscatter modulation scheme, while $S_{21}$ ≈15 dB.**

***Index Terms*—Backscatter modulation, full-duplex, negative resistance, reflection amplifier, two-way RFID.**

## I. Introduction

ALTHOUGH, the history of backscatter communication (BSC) traces back to 1948 [1], only recently has it found many applications in communication systems. Radio frequency identifications (RFIDs) are the most well-known applications of BSC [2]. The main characteristics of conventional passive BSC tags can be highlighted as follows: i) instead of having a separate transmitter, they use backscattered signal to send their data, ii) they are used in one-way (read-only) applications rather than two-way (read/write) communication, iii) the amount of reflected power is limited, which restricts their applications to only short-range communication. By overcoming ii) and iii), we can leverage BSC in two-way communication systems, such as wireless network sensors, internet of things (IoT) or in-band full-duplex (IBFD) communication systems [3], [4].

Recently, several prototypes of one-way BSC systems succeed to increase the communication range by using reflection amplifiers. Reflection amplifiers show reflection coefficient larger than one ($|\Gamma| > 1$) and amplify the reflected signal. They can be built using non-linear components with negative input differential resistance, such as tunnel diodes [5] or using RF transistors [6], [7]. Reflection amplifiers also can be used in two-way BSC systems, where two of them are added in one branch line coupler structure to build bidirectional amplifier [5], [7]. However, to the best of the authors' knowledge, the first and only two-way reflection amplifier which provides reflection and forward gain simultaneously, is reported in [8]. By changing the dc voltage bias of the transistor, the authors could change the reflection gain and modulate the backscatter signal. In this case, the forward gain also varies by the bias voltage. Thus, the main drawback is that in high/low voltage regime both reflection and forward gains are high/low. It makes it difficult to maximize the distance between backscatter constellation points and maintain a fixed/high forward gain, at the same time.

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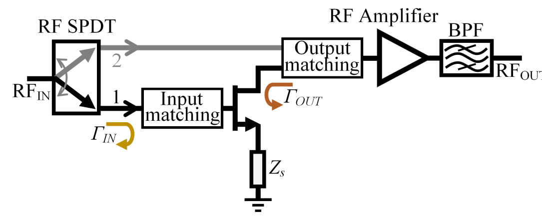



Fig. 1: Proposed two-way backscatter communication tag block diagram.

In this paper, we propose a two-way BSC tag with fixed forward gain and adjustable reflection gain. The proposed circuit includes an RF single-port dual-terminal (SPDT) switch, a designed two-way reflection amplifier, an unilateral RF amplifier as a block gain and a band-pass filter (BPF). One switch is used to modulate the amplified backscattered signals in On/Off Key (OOK) while the fixed/high forward gain is always present. Compared to [8], we increased the communication range and decreased the bit error rate (BER) at the reader by maximizing the difference between reflection gain and maintaining a fixed/high forward gain.

## II. Two-way BSC system

The block diagram of the proposed two-way BSC circuit is shown in Fig. 1. There are two modes of operation according to the path of the input signal ($\mathrm{RF_{IN}}$), which is selected by an RF SPDT switch. In path 1, we have both reflection and forward gain, simultaneously. A portion of $\mathrm{RF_{IN}}$ is amplified and reflected back toward the antenna, due to the reflection amplifier and the is amplified in forward direction and delivered to the RF amplifier, BPF and the receiver ($\mathrm{RF_{OUT}}$). A band-pass filter is used to filter the output spectrum from the spurs and harmonics. This amplified signal can be received and demodulated at the receiver.

In the second mode, when path 2 is selected, we only have forward gain from the input to the output. In this mode, $\mathrm{RF_{IN}}$ directly goes to the RF amplifier and the BPF. Therefore, the forward gain is always present in both operation modes. However, the reflection gain can be modulated between the maximum or minimum value (path 1/2), independently. The input matching circuit is designed to guarantee a stable output reflection coefficient ($|\Gamma_{OUT}| < 1$) to avoid oscillation and extra spurs and harmonic in the system. It also matches

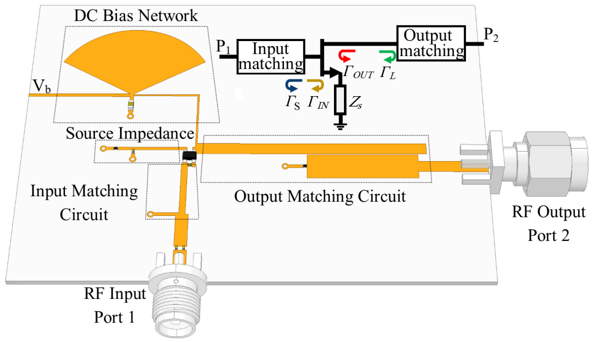



Fig. 2: Layout of the proposed two-way reflection amplifier.

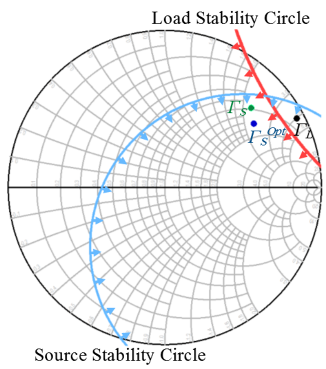



Fig. 3: Load and source stability circles at 2.45 GHz.

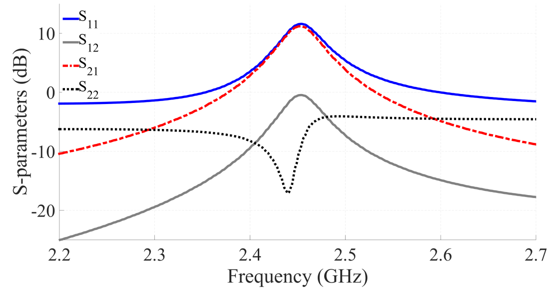



Fig. 4: S-parameters of the two-way reflection amplifier, $V_b = 1.5\ V$.

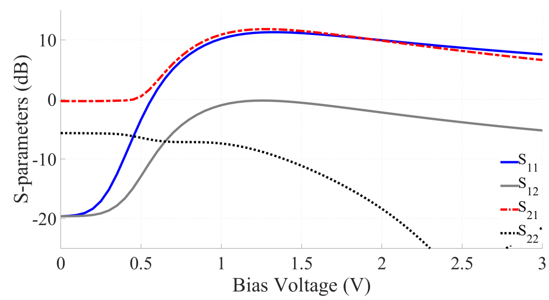



Fig. 5: S-parameters of the two-way reflection amplifier at 2.45 GHz vs. bias voltage of the transistor.

$\Gamma_{IN}$ to desired value in desired frequency bandwidth. The output matching circuit is designed to enable forward gain in both modes. We investigate each part of the proposed circuit analytically and through simulations. We also built the circuit to validate the implementation.

### A. *Two-way reflection amplifier design*

A reflection amplifier can be designed using a proper terminated RF transistor [7]. At high microwave frequencies, the impedance and admittance parameters of the transistor cannot be directly measured. Thus, we used the scattering parameters to design the transistor-based amplifier [9].
Here, we are going to design an unstable (but not oscillating) two-way reflection amplifier which shows reflection gain at its input port (port 1) $S_{11} >> 0$ dB ($|\Gamma_{IN}| >> 1$) along with forward gain from input to output port (port 1 to port 2) $S_{21} >> 0$ dB. The output is connected to the receiver so it should be stable and matched at port 2, $S_{22} << 0$ dB ($|\Gamma_{OUT}| << 1$). It also shows maximum output to input isolation $S_{12} << 0$ dB to avoid unwanted feedback, see Fig. 2. We used a super low noise figure and high associated gain GaAs FET transistor from Renesase with part number NE3509M04. The circuit substrate is Rogers 4003C with $\varepsilon_r = 3.55$ and $h = 0.8$ mm. The input and output matching circuits are designed to achieved the reflection and forward gain. The input matching consists of a microstrip line with length 8.5 mm and width 0.9 mm and a short-ended stub with length 4 mm and width 0.5 mm, with 0.2 mm gap. The output matching is an edge-coupled line which is open-ended at the narrower arm and terminated with a 50 Ω load at the wider arm. The length of the edge-coupled line is 16 mm. The narrow and wide arms width are 1.8 mm and 4 mm, respectively. The output matching provides the necessary $\Gamma_L$ and desired forward gain. Load and source stability circles of the transistor at 2.4 GHz including the effect of the source impedance and dc bias networks are shown in Fig. 3. The load and source stability circles are shown with red and blue lines, respectively. Small arrows show the region of stability which are outside and inside of the load and source stability circles, respectively. To have $|\Gamma_{IN}| > 1$, $\Gamma_L$ seen at the output matching circuit, should be inside the load stability circle, $\Gamma_L = 0.95e^{j27.5}$. The source reflection coefficient $\Gamma_S$ should be inside the source stability circle to have $|\Gamma_{OUT}| < 1$. $\Gamma_S$ is selected close to the optimum source reflection coefficient $\Gamma_S^{Opt}$ , to have the noise figure (NF) close to $\mathrm{NF}_{\min}$. The NF≈0.3 dB for the selected $\Gamma_S$. The S-parameter results of the proposed two-way reflection amplifier is shown in Fig. 4. The reflection and forward gain $S_{11} = S_{21} = 11.5$ dB at 2.45 GHz. $S_{11}$ and $S_{21}$, show the same trend as we increase the transistor voltage bias, Fig. 5. At the low voltage regime ($0\ V < V_b < 0.5\ V$), there is no reflection and forward gain, while at high voltage regime ($V_b > 1V$), both reflection and forward gain reach to 11.5 dB. Thus, backscatter modulation via changing the bias voltage jeopardizes the forward gain. In order to implement BSC with fixed forward gain, we use an RF switch, as explained in the following section.

### B. *Two-way BSC circuit*

We propose a two-way BSC circuit with on/off reflection gain (OOK backscatter modulation), and a constant forward gain, Fig. 6. In this circuit, an RF SPDT switch with part number VSWA2-63DR+ is controlled by voltage $V_c$ to select the reflection gain on (path 1, $V_c = 3$ V) or reflection gain off

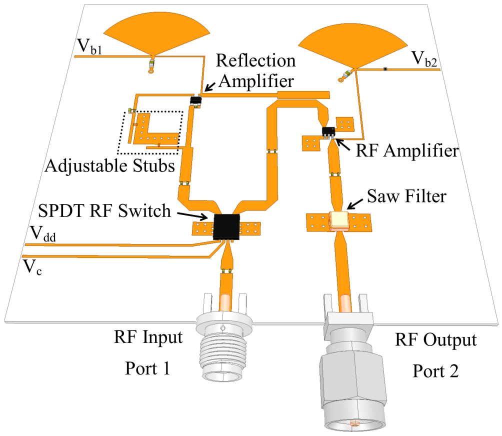
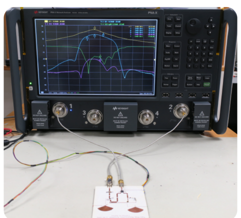
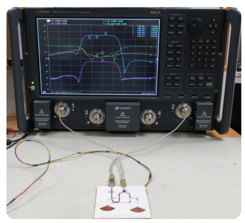



Fig. 6: Layout of the proposed two-way BSC circuit.



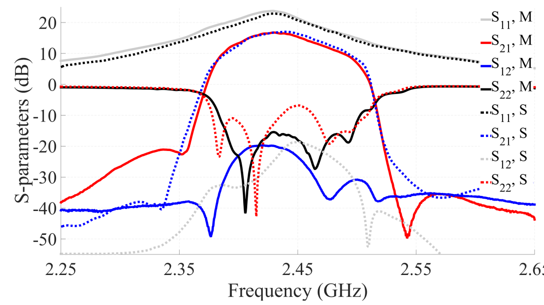
(a)



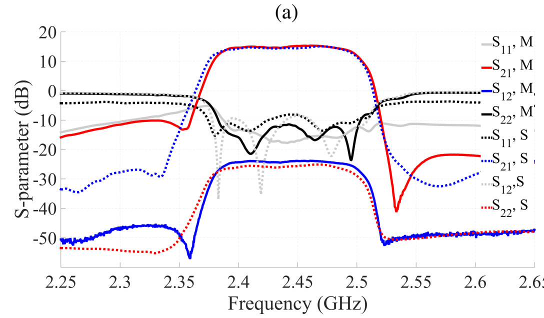
(b)

Fig. 7: (a) and (b) are the setup measurements for reflection gain on/off mode. The network analyzer is Keysight PNA-X N5242B.

(path 2, $V_c = 0$ V). Thus, by changing switch voltage, we can implement OOK backscatter modulation. This is an absorptive switch, thus the edge-coupled line is always terminated even when the input RF is directed to reflection amplifier. The switch bias voltage is $V_{dd} = 3$ V. The short-ended stub of the input matching circuit and the length of the source impedance have distributed ground to provide adjustable length stubs for tuning after fabrication. The RF amplifier is a gain block with part number ECG001F-G from QORVO. The amplifier output spectrum is filtered by a SAW filter with part number SF2124E from Murata with 2.5 dB insertion loss. This filter can be replaced with lower insertion loss microstrip filters if there is enough space in the circuit layout. The measurement setup of the circuit in both modes are shown in Fig. 7a and 7b. The measurement and simulation results of the BSC circuit in both modes are shown in Fig. 8. Fig. 8a shows a reflection gain $S_{11} = 20$ dB and a forward gain $S_{21} = 15$ dB, at the frequency bandwidth of 120 MHz, when path 1 is selected (mode on). The output return loss $S_{22}$ and port 2 to port 1 gain $S_{12}$ are below -15 dB and -20 dB, respectively. This avoids oscillation, harmonics and extra spurs, due to any potential impedance mismatch at receiver port. Fig. 8b shows that when path 2 is selected (mode off), there is no reflection gain as $S_{11} < -15$ dB and the forward gain is $S_{21} = 15$ dB. Similar to Fig. 8a, $S_{22}$ and $S_{21}$ are below -12 dB and -23 dB respectively. As can be seen, the forward gain is present regardless of the operation mode and the reflection gain can be modulated with OOK modulation scheme. The input and output ports of the circuit is monitored with a spectrum analyzer. The output spectrum frequency at the ports in both operating modes is clear from




(a)




(b)

Fig. 8: Measurement (M) and simulation (S) results of the proposed two-way BSC circuit in (a) reflection gain on, and (b) reflection gain off.

spurs and oscillation.

## III. Conclusion

We proposed a new two-way (read/write) BSC tag that operates in two modes. There is a forward gain from the input port to the output port in both modes, but the reflection gain can be turned on or off by changing the mode. As a result, the proposed BSC tag is both writable (amplifies and delivers a portion of received signal to the tag receiver), and readable (implements OOK backscatter modulation by changing the reflection gain mode).

## References


[1] H. Stockman, "Communication by means of reflected power," *Proceedings of the IRE*, vol. 36, no. 10, pp. 1196–1204, Oct. 1948.

[2] K. Finkenzeller and D. Muller, *RFID handbook: Fundamentals and applications in contactless smart cards, radio frequency identification and near-field communication*. John Wiley & Son Ltd, 1999.

[3] G. Vannucci, A. Bletsas, and D. Leigh, "Implementing backscatter radio for wireless sensor networks," Athens, Greece, Sep. 2007.

[4] B. Smida and S. Khaledian, "ReflectFX: In-Band Full-Duplex Wireless Communication by Means of Reflected Power," *IEEE Transactions on Communications*, vol. 65, no. 5, pp. 2207–2219, May 2017.

[5] S. Khaledian, F. Farzami, D. Erricolo, and B. Smida, "A full-duplex bidirectional amplifier with low dc power consumption using tunnel diodes," *IEEE Microwave and Wireless Components Letters*, vol. 27, no. 12, pp. 1125–1127, Dec 2017.

[6] H. I. Cantu, V. F. Fusco, and S. Simms, "Microwave reflection amplifier for detection and tagging applications," *IET Microwaves, Antennas and Propagation*, vol. 2, no. 2, pp. 115–119, Mar. 2008.

[7] F. Farzami, S. Khaledian, B. Smida, and D. Erricolo, "Reconfigurable dual-band bidirectional reflection amplifier with applications in van atta array," *IEEE Transactions on Microwave Theory and Techniques*, vol. 65, no. 11, pp. 4198–4207, Nov 2017.

[8] P. Chan and V. Fusco, "Full duplex reflection amplifier tag," *IET Microwaves, Antennas and Propagation*, vol. 7, no. 6, pp. 415–420, Apr. 2013.

[9] R. E. Collin, *Foundations for Microwave Engineering, 2nd Edition*. Wiley-IEEE Press, 2001.