Ultra-Low Power Reflection Amplifier using Tunnel Diode for RFID applications

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***Abstract*—To increase backscatter efficiency and communication range in RFID systems, we propose an ultra-low power reflection amplifier using a tunnel diode. We measured the input impedance of a tunnel diode and used a compact matching circuit to provide the desired input impedance at 890 MHz for the RFID UHF band. The proposed circuit is designed to be free from oscillations to avoid Signal to Noise Ratio (SNR) degradation.**

This reflection amplifier consumes 0.2 mW DC power at bias voltage of 200 mV, making it an ideal candidate to amplify backscattered electromagnetic field in RFID transceivers. The gain of the proposed reflection amplifier is 17 dB for the incident power of -30 dBm. The fabricated circuit size is 20×25 mm^2 ($0.06\lambda_0\times$ $0.075\lambda_0$) on a substrate with $\epsilon_r = 3$ and $h = 0.762$ mm. The measurement and simulation are in a good agreement.

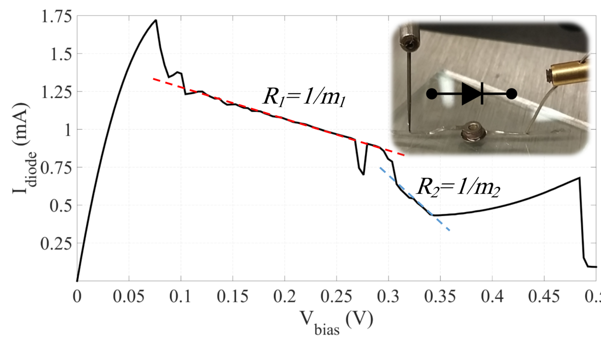


Fig. 1: The IV curve of the AI301A tunnel diode.

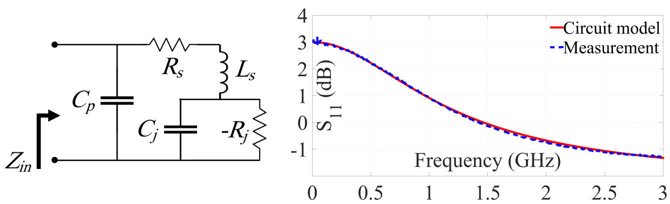
I. Introduction

The significant importance of RFIDs may be better understood by observing that the total RFID market will be worth 18.68 billion by 2026 [1]. RFID systems rely on Back-Scatter Communication (BSC) where the tag uses the received carrier energy to respond to the reader [2]. The tag simply consists of an antenna that is connected to an integrated circuit (IC). This IC can use an external source such as a battery (semi-passive tag) or harvest energy from the reader signal (passive tag) to power itself up. The IC modulates the antenna terminated load and thus changes the antenna Radar Cross Section (RCS). This variation in RCS means data modulation in the scattered wave that can be demodulated in the reader [3]. One major challenge in passive RFID systems is their short-range. Indeed, some portion of the received power is used to power up the IC and the backscattered signal experiences two times the path-loss. Many solutions have been proposed to increase the coverage area of BSC systems including using a Retro-Directive Antenna (RDA) [4] or reflection amplifiers [5]–[7]. The RDAs need an array of antennas, which is not desirable in low profile RFID systems. Thus using a reflection amplifier is a prominent way to increase the level of the backscattered wave in RFID applications. Reflection amplifiers are active one-port networks with negative values of the the real part of their input impedance. This results in a reflection coefficient with magnitude larger than one, which is equivalent to an amplified backscattered wave. There are several ways to generate a negative input resistance by properly terminating a transistor [5] or using devices that have negative input resistance as an intrinsic characteristic like Gunn or tunnel diodes [6]–[9]. A tunnel diode is a very heavily-doped p-n junction diode with an extremely thin junction voltage barrier resulting into a quantum mechanical tunneling effect [8] that leads to a negative input resistance at a specified bias voltage range. Tunnel diodes have low profile and ultra-low power consumption which make them a good candidate for RFID applications. In [7], a reflection amplifier using a tunnel diode at 5.8 GHz was discussed.

Here, we propose a reflection amplifier using a tunnel diode. The contribution of this work is (1) extracting the high frequency model of the tunnel diode and (2) designing the matching circuit to have reflection gain for UHF band RFID at 890 MHz. In addition, the reflection amplifier is designed also free from oscillations to remove undesired harmonics from the reflected signal. This behavior is confirmed by measurements of the output frequency spectrum of the fabricated device. The simulations performed with ADS show a very good agreement with measurements.

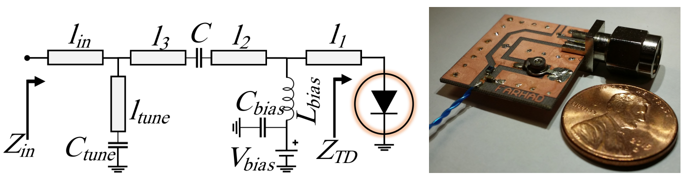
II. Tunnel diode characteristics

We used the Ga-As AI301A tunnel diode whose IV curve was measured with an Agilent HP 4145A Semiconductor Parameter Analyzer, see Fig. 1. As can be seen in this figure, the diode current decreases when the forward bias voltage increases from 0.1 V to 0.35 V. This behavior indicates that the equivalent resistance is negative. With a simple linear approximation, the input resistance of the tunnel diode can be approximated around -400 Ω for 0.125 V<V_{bias}<0.3 V



(a) (b)

Fig. 2: (a), Equivalent circuit model of a tunnel diode, (b) measured S parameters of the diode for V_{bias}=200 mV.



(a) (b)

Fig. 3: (a) Matching circuit block diagram,(b) layout of the proposed reflection amplifire. Dimensions in mm are: $l_1 = 5.5$, $l_2 = 5.5$, $3_1 = 11.5$, $l_{tune} = 1.3$. $C_{bias} = 0.01$ pF, $L_{bias} = 220$ nH, $C = 33$ pF and $C_{tune} = 10$ μF.

and -161 Ω for 0.31 V<V$_{bias}$<0.34 V. To evaluate the frequency response of the diode, the parasitic elements and their values must be considered [9]. The equivalent circuit model of a tunnel diode is shown in Fig. 2a, where R_s, L_s and C_p model the ohmic losses, leads inductance and package equivalent capacitance, respectively. C_j and R_j are the inherent capacitance of the p-n junction and the negative resistance of the tunnel diode, respectively.

We measured the tunnel diode S-parameter and used ADS to fit the equivalent circuit by tuning the elements values, see Fig. 2b. These values for $V_{bias} = 0.2$ V are: C_p=0.4 pF, R_s=7.6 Ω, L_s=0.15 nH,C_j=2.25 pF and R_j=300 Ω.

III. Reflection amplifier design

By extracting the S-parameter of the tunnel diode, we can design a reflection amplifier to have reflection gain at the desired frequency band. The maximum reflection gain is designed at 890 MHz for RFID systems in UHF band. The measured input impedance of the tunnel diode in this frequency is $Z_{TD} = -4.2 - j23.1$ Ω. In order to achieve high gain at this frequency, the input impedance is mapped to a desired value by an impedance matching circuit. By considering the real part of the input impedance, the reflection gain Γ with 10 dB< $\Gamma = 20 \log |S_{11}|$ <20 dB is achieved if -25 Ω $<$ $Re\{Z_{TD}\}$ <-40 Ω. The matching circuit block diagram is shown in Fig. 3a. By tuning the length of the transmission lines, the tunnel diode input impedance is matched to $Z_{in} = -42 - j12$ Ω. The fabricated circuit is shown in Fig. 3b. The size of the circuit on a substrate with $\epsilon_r = 3$ and thickness of 0.762 mm is 20 mm×25 mm. The proposed reflection amplifier has been fabricated and measured in Andrew Lab at UIC. We used an Agilent Vector Network Analyzer PNA N5222A with source power level of -30 dBm to measure the reflection gain. The resulting values of S_{11} for simulation

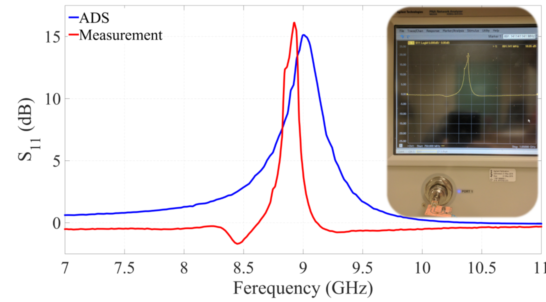


Fig. 4: Reflection gain of the proposed amplifier.

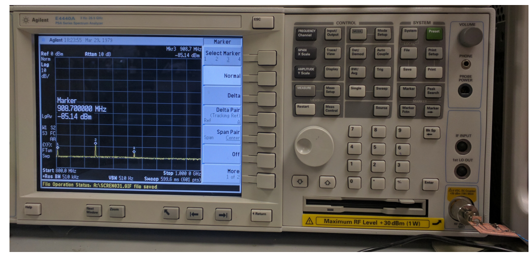


Fig. 5: Reflection amplifier output spectrum. The spurious harmonics power are around -85 dBm.

and measurement are shown in Fig. 4. As can be seen, the reflection gain at 890 MHz is 17 dB. The reflection amplifier is connected to an Agilent E4440A spectrum analyzer to check for the presence of oscillations in the output frequency spectrum. As can be seen in Fig. 5, the proposed reflection amplifier is free from oscillations.

IV. Acknowledgment

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