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A Reconfigurable Directional Coupler Using a Variable Impedance Mismatch Reflector for High Isolation

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Abstract

This letter proposes a reconfigurable directional coupler that uses a variable impedance mismatch reflector to achieve high isolation characteristics in the antenna front end. The reconfigurable coupler consists of a directional coupler and a single-pole four-throw (SP4T) switch with different load impedances as a variable load mismatch reflector. Selection of the load impedance by the reflector allows cancellation of the reflected signal due to antenna load mismatch and the leakage from the input to isolation port of the directional coupler, resulting in high isolation characteristics. The performance of the proposed architecture in separating the received (Rx) signal from the transmitted (Tx) signal in the antenna front end was verified by implementing and testing the reconfigurable coupler at 917 MHz for UHF radio-frequency identification (RFID) applications. The proposed reconfigurable directional coupler showed an improvement in the isolation characteristics of more than 20 dB at the operation frequency band.

Key Words: Antenna Front-End, High Tx/Rx Isolation, Reconfigurable Coupler, Reconfigurable Duplexer, Variable Reflector.

I. INTRODUCTION

Radio-frequency identification (RFID) readers rely on the isolation characteristics of the Tx and Rx paths in the antenna front end, since the Tx leakage directly affects the Rx sensitivity. The bi-static architecture where Tx and Rx antennas are used separately can achieve high isolation characteristics, but this increases the system size and cost. Thus, a mono-static architecture is preferable in an RFID reader system, since it only requires a single antenna, thereby giving a smaller size and lower cost. The correct application of the mono-static architecture to an RFID reader requires resolution of the degradation in Rx sensitivity due to Tx.

Many studies have adopted the use of Tx leakage cancellers that are configured by a range of different structures, including multiple hybrid couplers [1], quadrature feedback circuits [2], variable attenuators, phase shifters controlled by micro-controller units (MCUs) [3], and single impedance mismatch reflectors [4]. However, these previously proposed structures impose a large size and design complexity to achieve the required leakage suppression. The architecture with a single impedance mismatch reflector also undergoes a limited range of Tx leakage cancellation due to the fixed impedance in the reflector. These limitations emphasize the need for a new type of reconfigurable coupler that can be used to suppress Tx leakage in a mono-static RFID reader front end with a simple implementation, as is proposed in this letter.

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II. Circuit Design and Analysis

Fig. 1 shows the proposed reconfigurable directional coupler in the RFID front end. Referring to Fig. 1, Tx leakage generally consists of the coupled signal from the Tx port to the isolation port due to the intrinsic isolation characteristic of the directional coupler (L_1) and the reflected signal due to the antenna impedance mismatch (L_2). These unwanted leakages are canceled by having the proposed structure adopt a variable impedance mismatch reflector to generate the leakage-cancelling signal from port 3 of the directional coupler. The leakage-cancelling signal is determined by the impedance loaded at port 3 of the directional coupler. If the transmission coefficient (T), coupling factor (C), the isolation characteristic (I) of the directional coupler, and the reflection coefficient (Γ_A) of an arbitrary antenna are known, then the required reflection coefficient of the variable mismatch reflector (Γ) at port 3 of the directional coupler is determined by:

$$\Gamma = \frac{I + T \cdot \Gamma_A \cdot C}{C \cdot T + C^2 \cdot I \cdot \Gamma_A + T \cdot \Gamma_A}. \quad (1)$$

The values of Γ determine the cancellation of the Tx leakage flows to the Rx (port 4 of the directional coupler). That is, if multiple values for Γ can be generated according to the antenna impedance variations, then the Tx leakage can be cancelled regardless of the antenna load conditions.

Since determination of Γ depends on varying the antenna matching conditions by the circumstances of system usage, Γ must also be controllable according to the values of Γ_A. As shown in Fig. 1, a SP4T switch is connected with different loads R_1, R_2, C_1, and C_2. The combination of these impedances can generate a total of 16 ($=2^4$) different Γs. Fig. 2 shows the simulated results for different Γ generations obtained by adopting different R_1, R_2, C_1, and C_2 values to cover the range for an antenna return loss of less than 12 dB. When all switches are off, the default impedance is set by the parallel connection of R and L, as shown in Fig. 2, instead of the high impedance due to the open state. Thus, manipulation of the different Γs produced by different combinations of loads connected through SP4T cancels the Tx leakage under variable circumstances.

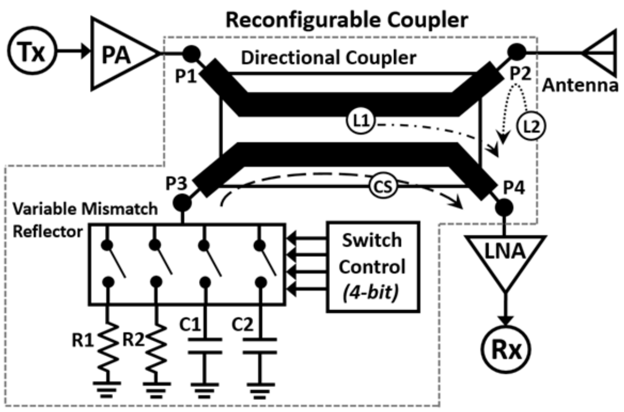

Fig. 1. Block diagram of the proposed reconfigurable coupler in the RFID front end.

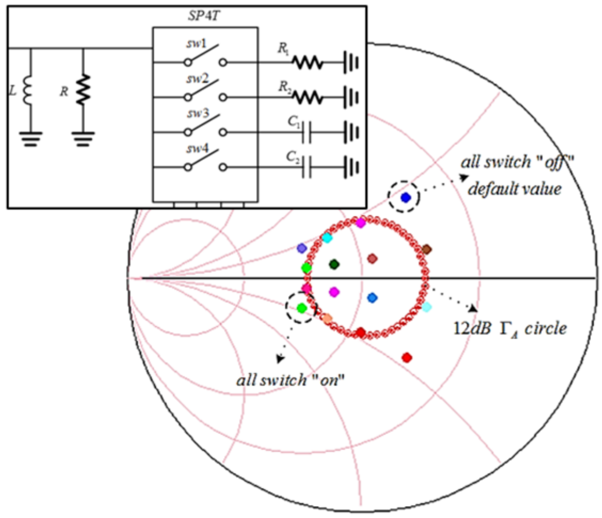

Fig. 2. Variable Γ generations by a variable mismatch reflector consisting of an SP4T switch and different impedances.

III. Measurement

The proposed reconfigurable directional coupler was implemented with a LTCC 10-dB directional coupler from RN2 Technology and a SP4T (MASW-007813) from MA-COM. The discrete load impedances were implemented using $R = 90\ \Omega$, $L = 19$ nH, $R_1 = 140\ \Omega$, $R_2 = 70\ \Omega$, $C_1 = 1$ pF, and $C_2 = 2$ pF. Fig. 3 shows the implemented reconfigurable directional coupler with a variable impedance mismatch reflector. The isolation characteristics of the reconfigurable

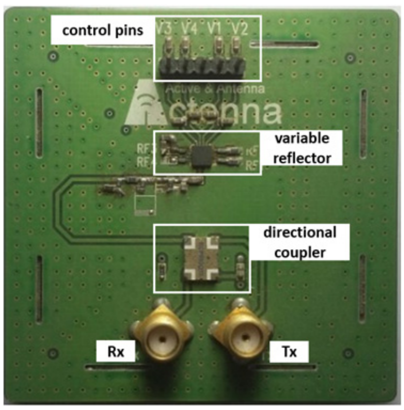

Fig. 3. Implemented reconfigurable directional coupler with a variable impedance mismatch reflector.

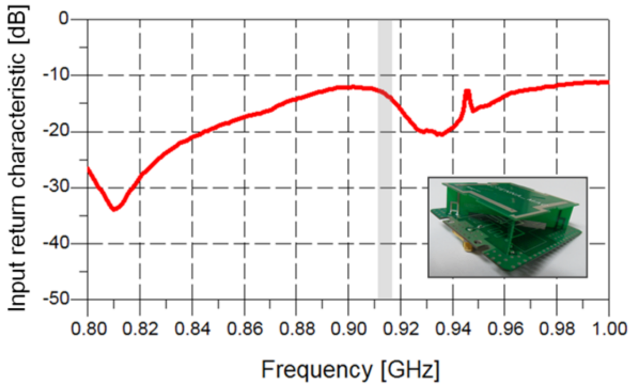

Fig. 4. Measured antenna input return characteristic.

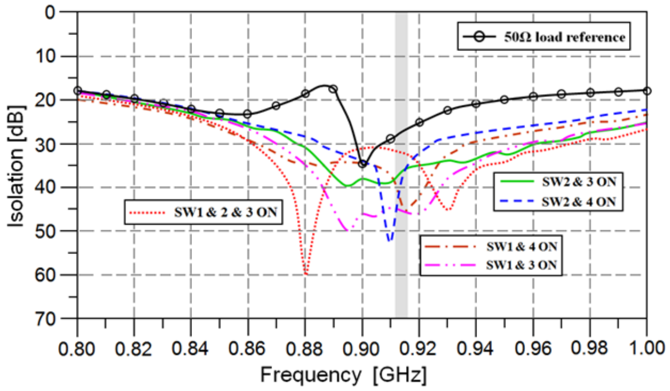

Fig. 5. Measured isolation characteristic of the reconfigurable directional coupler according to different reflector values.

coupler in the RFID front end were found using a commercially available quadrifilar spiral antenna (QSA) with 12 dB return loss at 917 MHz, as shown in Fig. 4. Referring to Fig. 1, the Tx/Rx isolation characteristics of the antenna were measured by the *S*-parameters from port 1 to port 4. Fig. 5 shows the selective measured isolation characteristics using the proposed variable mismatch reflector. Termination of port 3 of the 10-dB directional coupler with 50 Ω gave an isolation of about 25 dB at 917 MHz. Instead of using the 50 Ω load, the proposed variable mismatch reflector was connected to port 3 of the directional coupler and the maximum isolation of 45 dB was measured at 917 MHz when the switches 1 and 3 were turned on as shown in Fig. 5. Therefore, the proposed reconfigurable coupler showed an improvement of more than 20 dB in the isolation characteristics when compared to the conventional directional coupler architecture in the RFID front end.

IV. CONCLUSION

This letter describes a reconfigurable directional coupler that uses a variable impedance mismatch reflector to enhance the isolation characteristics. The variable impedance mismatch reflector could generate multiple reflection coefficients to cancel the Tx leakage, which varied according to the antenna load impedances. Setting the proper load impedance through the proposed reflector resulted in an improvement of more than 20 dB in the isolation characteristics at the RFID operation band.

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