Design and Implementation of a Novel Directional Coupler for UHF RFID Reader

Jianxiong Li, Shanlin Song, Xiaoyu Chen, Hua Nian and Weiguang Shi

Abstract—**The directional coupler is applied to isolating RX from TX because of low cost and simplicity compared to the circulator in the radio-frequency identification (RFID) reader. Because of unequal phase velocity between odd and even mode, the drawback of the traditional microstrip directional coupler is poor isolation. In this paper, to obtain a good isolation between RX and TX, a novel directional coupler is proposed to be applied to the UHF RFID system with a single antenna. Measurement result shows that the proposed directional coupler possesses a good isolation of -35dB in operating frequency band.**

***Index Terms*—Isolation, Directional Coupler, Radio-frequency identification (RFID)**

Original Research Paper
DOI: 10.7251/ELS1620022L

I. Introduction

Radio-frequency identification (RFID) technology is becoming more and more popular from the 1990s [1], its applications are extending rapidly and the commercial potential is getting huger and huger [2]. It uses radio-frequency signal to realize automatic identification of object through space coupling. The biggest advantage of the UHF RFID is that it can complete identification without physical contact [3]. A set of the UHF RFID system is composed of the reader, the electronic tag and the application software. In the common passive UHF RFID system, the reader transmits continuous waves to the tag, part of the continuous waves will be converted into energy by the tag, and the tag sends its back-scattered data to the reader. Because continuous wave from the reader and back-scattered wave from the tags simultaneously occupy the same frequency band, TX leakage to RX leads to many technical difficulties. For example, the strong TX leakage makes the low noise amplifier (LNA) of the receiver saturated and the dynamic range of the LNA decreased [1]. In order to improve the performance of the RFID reader, a novel directional coupler is proposed to obtain high isolation between RX and TX. An attenuator, a phase shifter and a power synthesizer are added at the coupling port of the transmit chain at the same time. The signal of the anti-phase and equal magnitude of the TX leakage is designed by using the attenuator and the phase shifter at the coupling port, and combined with the TX leakage at the isolation port. Consequently, these two signals are offset by using the power synthesizer. Accordingly, RX is isolated from the TX leakage effectively and thus the proposed directional coupler can be applied to the UHF RFID reader.

Manuscript received 4 September 2015. Accepted for publication 25 December 2015.

Jianxiong Li is with the School of Electronics and Information Engineering, Tianjin Polytechnic University, Tianjin, China (e-mail: lijianxiong@tjpu.edu.cn).
Shanlin Song is with the School of Electronics and Information Engineering, Tianjin Polytechnic University, Tianjin, China.
Xiaoyu Chen is with the School of Electronics and Information Engineering, Tianjin Polytechnic University, Tianjin, China.
Hua Nian is with the School of Electronics and Information Engineering, Tianjin Polytechnic University, Tianjin, China.
Weiguang Shi is with the School of Electronics and Information Engineering, Tianjin Polytechnic University, Tianjin, China.

II. Introduction of the Principle

A. Introduction of the directional coupler

The directional coupler is a kind of passive microwave component and power distribution component, which is widely used in power distribution and synthesis [4]. The four ports of directional coupler are the input port, the output port, the coupling port and the isolation port, respectively. The transmitted signals from the input port are moved to the output port and the coupling port according to certain proportion, no signals to the isolation port ideally.

As reciprocal network, the function of each port is interchangeable. Each port can be the input port, the function of other ports changes in turn.

Because of its port reciprocity, the proposed directional coupler is applied to the RFID reader which shares a single antenna, as shown in Fig. 1. In TX, transmitter connects port 1 of the directional coupler. At this point, port 1 serves as the input port, port 2 as the isolation port, port 3 as the coupling port, port 4 as the output port. The transmitted signals transferred to the output port are radiated through the antenna. In RX, the antenna connects port 4 of the directional coupler. At this point, port 4 serves as the input port, port 1 as the output port, port 2 as the coupling port, port 3 as the isolation port. The received signals are transferred through the coupling port. In this way, the directional coupler provides the maximum isolation between RX and TX.

The isolation between the transmitter and the receiver is provided by the directional coupler completely. Nevertheless, the isolation of the directional coupler is limited, and the transmitted signal will leak to RX inevitably, which makes the performance of the receiver worse.

B. Analysis of the carrier leakage

The passive UHF RFID system communicates by back-scattered communication. Although the reader and the tag send information in half-duplex communication which agreement stipulated, back-scattered communication requires that the tag sends signal when energy signal is transmitted by the reader, so it also can be regarded as full-duplex communication. Other full-duplex communication devices cannot be interfered with each other by using different frequency band. However, continuous wave from the reader and back-scattered wave from the tags simultaneously occupy the same frequency band. Therefore, they cannot be filtered by the filter if they enter into RX at the same time. At present, the directional couplers are extensively applied to insulate RX from TX in the UHF RFID reader, as shown in Fig. 2.The transmitted signal of the transmitter will leak into RX inevitably due to the fact that the directional coupler has limited isolation. And the leakage signal is stronger than the back-scattered signal of tags, which makes the LNA of the receiver saturation easily. As a result, the received signal cannot be amplified effectively. Since the leakage signal will lower the signal to noise ratio, it has an adverse effect on the detection rang of the tag [5].

If the transmitted power of the transmitter is 30dBm, according to the formula of Friss:

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi R)^2} \tag{1}$$

where G_t is the gain of the reader antenna, G_r the gain of the tag antenna, P_t the transmitted power by the reader, P_r the received power by the reader, λ the wavelength.

When the tag is 10 meters away from the reader, $G_t = 8\text{dBi}$ and $G_r = 1.2\text{dBi}$, the back-scattered power of the tag is above -60dBm for proper communication. If the isolation of the directional coupler is -20dB, there will be 10dBm transmitted signal leaks into RX. In this way, the 10dBm noise added to the -60dBm effective signal, which will lead to the signal to noise ratio very poor inevitably. In addition, the linearity of the LNA will not very high, if the 1dB compression point of the LNA less than 10dBm, the 10dBm noise will cause the LNA saturation which is unable to enlarge effective signal. Therefore, we must try to increase the isolation of the directional coupler.

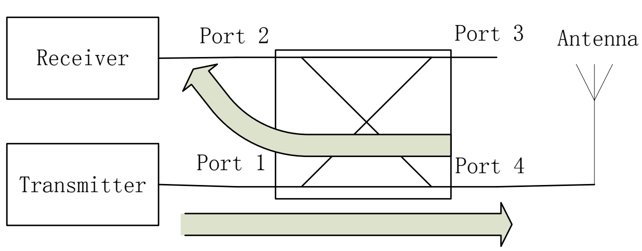

Fig.1 Structure of single antenna transceiver

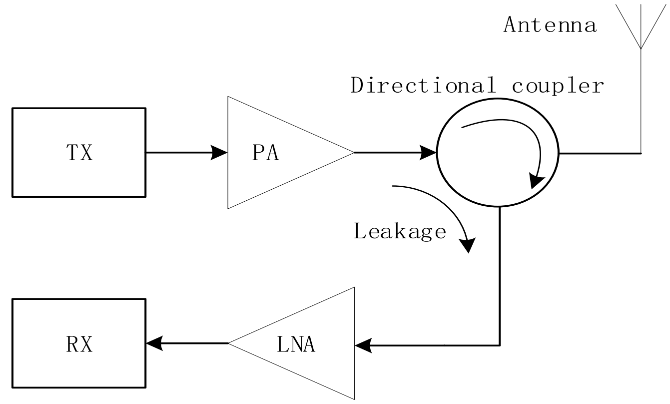

Fig.2 Circuit diagram of the transceiver isolation

C. Improving method of the directional coupler

This paper uses directional coupler chip RCP890A05 as the isolation component of the transceiver. The proposed technique to increase the isolation is that the canceling loop is designed and offsets TX leakage. The canceling loop includes the attenuator, the phase shifter and the power synthesizer and the principle circuit is created in Agilent ADS 2009 as shown in Fig. 3. The model of the directional coupler is set by the parameters of the RCP890A05 chip in the simulation. Port 1 connects the transmitter as the input port, port 2 connects the antenna as the output port, port 3 is the coupling port, port 4 is the isolation port. The coupling signal travels through the attenuator and the phase shifter, and combines with the leakage of the isolation port by the power synthesizer which connects to the receiver. The phase difference between the coupling signal and the leakage changes from 90° to 180° through the phase shifter. Then the coupling signal becomes the same magnitude with the leakage through the attenuator. At last, two signals are cancelled out in the power synthesizer. Consequently, the proposed directional coupler increases the isolation.

Assuming the leakage of the isolation port is

$$S_{leak}(t) = A_{leak} \cdot \cos(\omega t) \tag{2}$$

The back-scattered signal which the antenna receives is

$$S_V(t) = A_V(t) \cdot \cos(\omega t + \varphi) \tag{3}$$

The coupling signal of the transmitter is

$$S_{C0}(t) = A_C \cdot \cos\left(\omega t + 90^{\circ}\right) \tag{4}$$

The coupling signal through the attenuator and the phase shifter is

$$S_C(t) = kA_C \cdot \cos\left(\omega t + 90^{\circ} + \varphi_C\right) \tag{5}$$

where k is the coefficient of the attenuation and φ_C is the amount of the phase-shift.

Three signals are combined in the power synthesizer, that is

$$S_R(t) = S_{leak}(t) + S_C(t) + S_V(t) \tag{6}$$

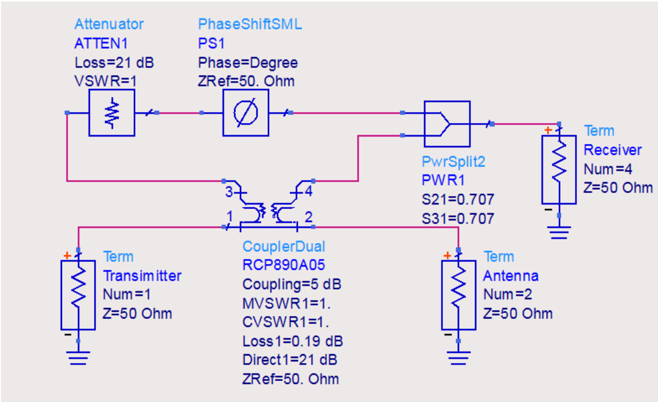

Fig.3 Principle circuit of the proposed directional coupler

If one wants to increase the isolation, the leakage S_{leak} should be reduced as much as possible. Ideally, $S_{leak} + S_C = 0$. As a result, two signals will be cancelled out for the same magnitude and the contrary phase, as shown in (7) and (8):

$$A_{leak} = kA_C \tag{7}$$

$$90^{\circ} + \varphi_C = 180^{\circ} \tag{8}$$

In practice, however, it is difficult to obtain absolutely equal value, and the frequency change will cause phase change. So it can only minimize the leakage, but cannot cancell out the leakage completely.

The simulation results using Agilent ADS 2009 in Table I show that the proposed directional coupler improves the isolation of the chip from -26dB to -342dB, which all the components are ideal. Therefore, in theory, the proposed method is feasible.

III. DESIGN OF THE DIRECTIONAL COUPLER

Actual model is added in Agilent ADS 2009, as shown in Fig. 4. The attenuator uses the π attenuation network instead, the phase shifter uses the microstrip line instead, and the power synthesizer is the Wilkinson power synthesizer which is made up of microstrip line. Adjusting the attenuation of the attenuation network makes the leakage of the isolation port and the coupling signal the same magnitude, then only adjusting the size of the microstrip line of the phase shifter makes the phase difference between the leakage and the phase-shifted signal equal to 180°. Layout is made to do electromagnetic simulation and frequency band of the simulation is from 860MHz to 960MHz. The simulation results of the physical layout at frequency of 915MHz are shown in Fig. 5. The insertion loss (m4) is about -1.7dB in TX, the isolation (m6) between RX and TX is -53dB which shows that the proposed directional coupler has higher isolation, and the coupling (m5) between the antenna and the receiver is -8dB in RX.

Because the actual board and the layout are not ideal, we also need to adjust the size of the phase shifter and the attenuator according to measured results finally.

TABLE I
COMPARISON OF THE PRINCIPLE SIMULATION RESULTS

	RCP890A05	directional coupler
Isolation.	-26dB	-342.769dB

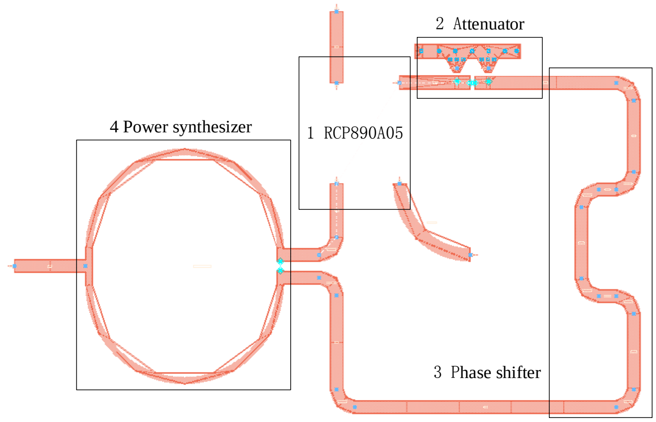

Fig.4 Layout of the proposed directional coupler

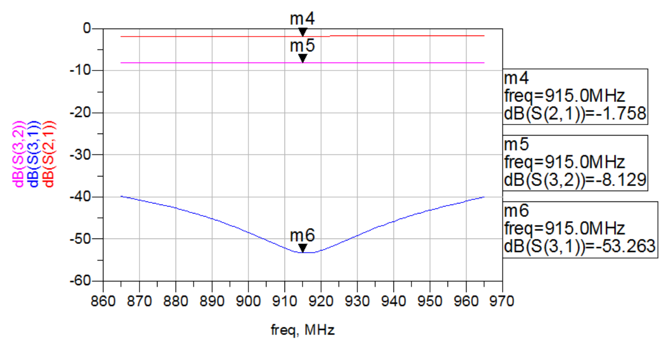

Fig.5 Simulation results of the layout

IV. TEST AND ANALYSIS OF THE PROPOSED DIRECTIONAL COUPLER

The main function of the directional coupler is to isolate RX from TX, so the important index of testing is the isolation. There will be energy loss when the signal is transmitted from the transmitter to the antenna through the directional coupler, so one needs to test the insertion loss between the input and the output. One also needs to test the coupling of RX due to the fact that the received wave is transferred through the coupling port [6]. Fig. 6 shows the physical picture of the proposed directional coupler. To demonstrate the correctness of the proposed directional coupler, the experimental set-up uses a network analyzer for measuring the S-parameters of the directional coupler.

The proposed directional coupler has the isolation of -35dB at 915MHz as shown in Fig. 7 which is higher isolation than the directional coupler chip as expected. The actual circuit has many unideal factors so that the measured result is not -53dB obtained by the simulation. As shown in Fig. 8, the insertion loss is almost similar with that of the directional coupler chip.

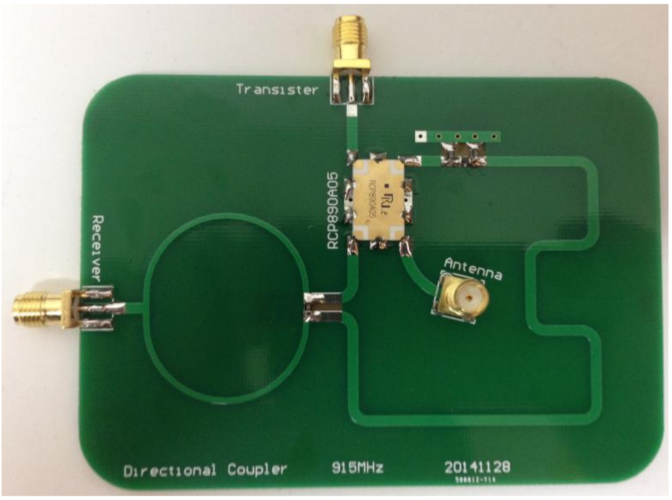

Fig.6 Physical picture of the proposed directional coupler

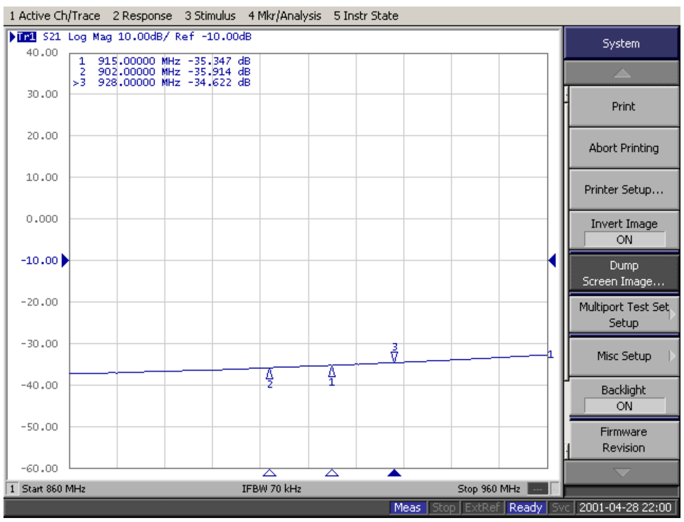

Fig.7 Isolation of the proposed directional coupler

In Fig. 9, the coupling of the proposed directional coupler exhibits -9.1dB. The return loss of each port is less than -10dB which is a good match to the 50Ω load.

TABLE II is the performance contrast of the chip RCP890A05 and the proposed directional coupler. The proposed directional coupler improves the isolation of about 10dB compared with the chip, which decreases the design difficulty of the LNA to a great extent, achieving the purpose of improvement. However, the coupling lowers a little and it is still in the acceptable range. In general, the proposed directional coupler has reached the purpose.

V. Conclusion

New method for increasing the isolation of the directional coupler of the UHF RFID reader has been presented. The proposed directional coupler includes the canceling loop to offset TX leakage. The proposed directional coupler possesses a good isolation of -35dB at 915MHz, about 10dB higher than before, and is able to remarkably enhance the sensitivity of the receiver.

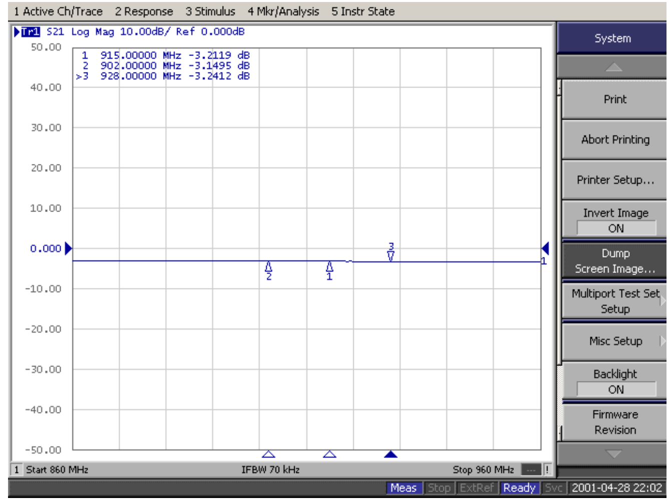

Fig.8 Insertion loss of the proposed directional coupler

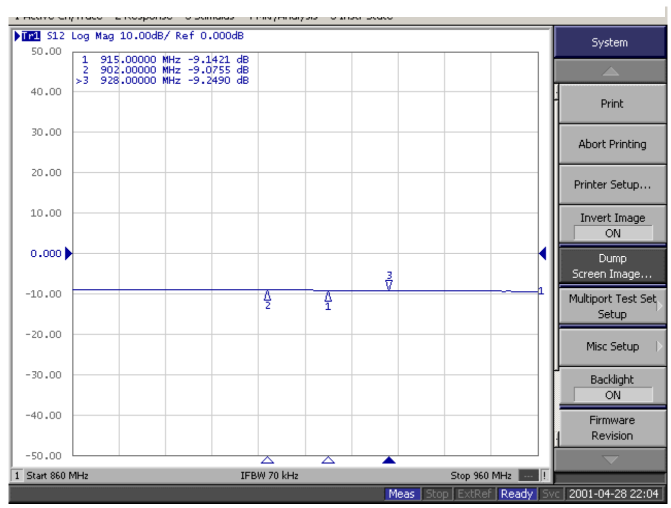

Fig.9 Coupling of the proposed directional coupler

TABLE II
PERFORMANCE CONTRAST OF THE DIRECTIONAL COUPLER

	RCP890A05	*directional coupler*
Isolation	-26*dB*	-35*dB*
Coupling	-6.2*dB*	-9.1*dB*
Insertion loss	-3.2*dB*	-3.2*dB*

References

[1] Kim. Wan-Kyu, Lee. Moon-Que, Kim. Jin-Hyun, Lim. Hyung-Sun, Yu. Jong-Won, Jang. Byung-Jun, Park. Jun-Seok, A passive circulator with high isolation using a directional coupler for RFID, IEEE MTT-S International Microwave Symposium Digest, p 1177-1180, 2006.

[2] Desong Wan, Bin You, Lingling Sun. Radio link analysis and design of directional coupler with high isolation for UHF RFID reader, Communication Technology, 2008. ICCT 2008. 11th IEEE International Conference on.

[3] K. Finkenzeller, RFID Handbook, Radio-Frequency Identification Fundamentals and Applications, New York, Wiley, 2003.

[4] Jin－Wook Jung, Kwan－Kyu Nae, Jay Prakash Thakur, Hong－Gu Cho, Jun－Seok Park. Directional coupler for UHF mobile RFID reader, Microw. Opt. Technol. Lett.,2007,497.

[5] Quan Xu, Kang Xie, Jun Tang, Jiang Ping. Directional coupler design based on coupled cavity waveguides in photonic crystals, Optik - International Journal for Light and Electron Optics,2010,12213.

[6] Zhongbao Wang, Shaojun Fang, Shiqiang Fu, Xiaoming Li. A Broadband 3 dB Coplanar Waveguides Directional Coupler with Conductor-backed Asymmetric Coplanar Waveguides Compensation, IETE Journal of Research,2012,581.