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A CANCELLATION NETWORK FOR FULL-DUPLEX FRONT END CIRCUIT

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Abstract—A circulator is needed in a C-band airborne synthetic aperture radar system which employs single antenna configuration. The circulator provides full-duplex capability to transmit high-power RF signal and receive the echo signal via the same antenna simultaneously. Commercially available circulators with moderate isolation are inadequate for this application. An innovative Cancellation Network (CN) has been designed to enhance the performance of the conventional circulator. This paper highlights the conceptual design and measurement results of the CN. An improvement of more than 27 dB has been achieved.

1. INTRODUCTION

A circulator is a three-port non-reciprocal device that passes microwave energy in a forward direction but provides isolation in reverse direction. Circulator has been widely used in transmit and receive (T/R) modules of communication and radar system as a duplexer [1, 2]. Other applications include time delay switching application [3] and phase shifter [4]. Conventional ferrite circulators are constructed with permanent magnets and ferrite materials on microstrip circuit. The non-reciprocal action is brought by gyromagnetic action [1]. A new approach for realization of microwave circulator makes use of the non-reciprocal properties of microwave field effect transistor [5–7]. This

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active circulator can be implemented by Indium Gallium Arsenide (InGaAs)/Indium Aluminum Arsenide (InAlAs)/Indium Phosphide (InP) based microwave monolithic integrated circuit (MMIC) which offers small size and weight, and lower cost [7–11]. Recent development includes integrated active circulator antenna which combines hybrid active circulator with a passive microstrip antenna [12–14]. They are lightweight and low cost solutions for high-volume milimeter-wave system.

A number of articles on theory and design of three-port circulator can be found in the literature. The emphasis is on performance improvement in terms of insertion loss [15–17], wide band operation [20, 22, 28, 29], temperature stabilization [29, 30], isolation bandwidth [15, 16, 23], miniaturization [28, 30–32], isolation [17, 24] and high power operation [19, 21, 26, 30]. Isolation performance is critical in some radar systems. Insufficient isolation may result in the transmitter power leaking into the receiver input and causes saturation and intermodulation distortion to the receiver front-end circuit. In this paper a novel technique to improve isolation of a circulator is described. The circuit has been used on a C-band airborne synthetic aperture radar (SAR).

2. DESIGN THEORY AND IMPLEMENTATION

The basic block diagram of a radar system is shown in Fig. 1. Its major function is to isolate different part of an electronic system from one another. Poor isolation of the circulator may give rise to significantly large leakage signal from the transmitter to the sensitive receiver and interfere the reception of return echo.

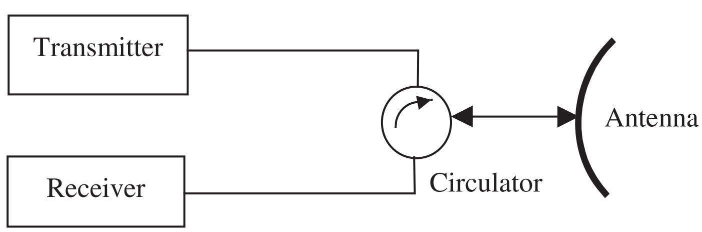

Figure 1. Radar system block diagram.

The block diagram of a circulator is shown in Fig. 2. With an input signal at port P1, most of the energy will appear at port P2, with small energy lost due to the insertion loss from P1 to P2. The coupling from P1 to P3 is undesirable and is characterized by the isolation of the circulator. On the other hand, a signal connected to

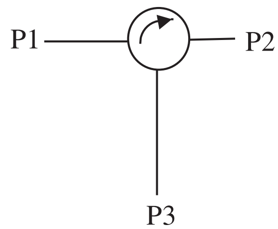

Figure 2. Component level diagram of a single circulator.

P2 will be routed to P3. For radar application, the transmitter is connected to P1, antenna to P2 and receiver to P3. This configuration allows simultaneous transmission and reception.

Commercial on-the-shelf circulators have moderate isolation over its operation bandwidth. It is possible to cancel the leakage signal by injecting a sample of the transmitter signal in equal amplitude but opposite phase into the receiver input. Fig. 3 shows the component level diagram of the cancellation network (CN) together with a circulator. The CN consists of 2 directional couplers, C1 and C2, a variable attenuator, R1, and two fixed-length coaxial cables. The sample of transmitter signal is coupled from main line by C1 and injected into the receiver by C2. The lengths of the cables are trimmed to provide the desired 180° phase shift and the variable attenuator controls the amplitude.

The CN has been implemented in an experimental airborne SAR sensor designed and developed at Multimedia University [33, 34], Malaysia. The airborne system is an inexpensive C-band, single polarization, linear-FM airborne radar sensor. The block diagram of the airborne SAR sensor is shown in Fig. 4.

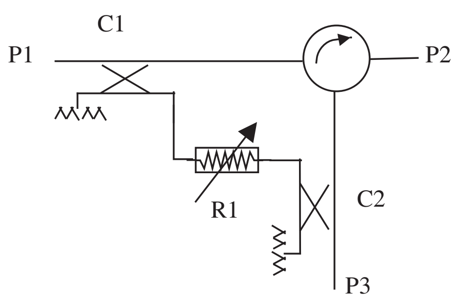

Figure 3. Component level diagram of a cancellation network.

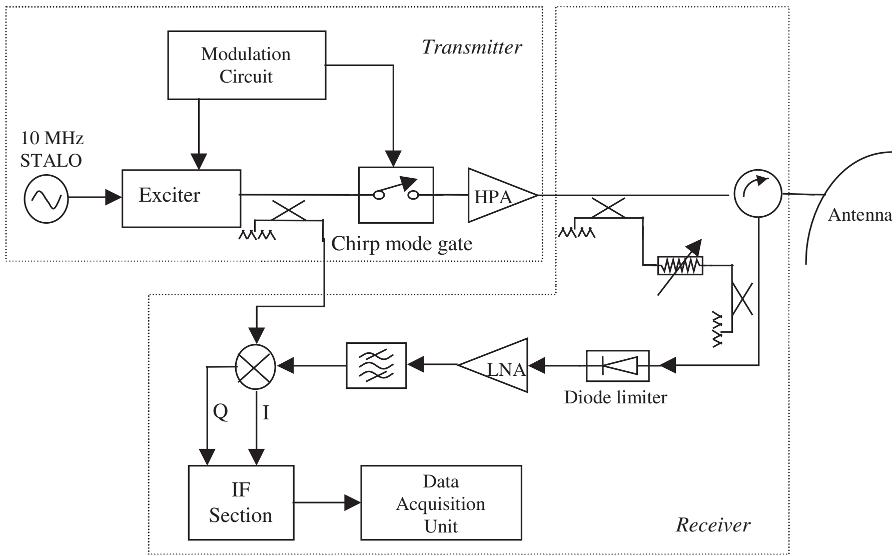

Figure 4. Component level diagram of the C-band SAR transmitter and receiver.

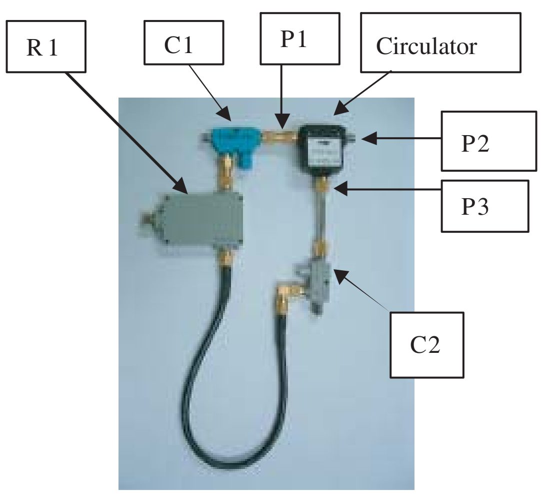

Figure 5. CN based on C-band circulator.

3. EXPERIMENTAL SETUP

In order to reduce the leakage signal from port P1 to port P3, the amplitude and phase of the signal coupled from CN to the receiver must be properly adjusted. A commercial on-the-shelf C-band circulator was used. Fig. 5 shows the C-band circulator and the CN. The specification of the commercial circulator used in this experiment setup is list in the table below.

Table 1. Technical specification of circulator.

Model	H175FFF-S (Microwave Technology Corporation)
Frequency range	5.5–6.5 GHz
Isolation	35 dB
Insertion Loss	0.3 dB
VSWR	1.15:1 (max)
Power	10 W average, 100 W peak

3.1. Measurement of Leakage Signal from P1 to P3

The leakage signal can be measured by terminating both directional couplers with matched loads. The measurement setup is shown in Fig. 6. Both the phase and amplitude of S_{21} is measured over the operating bandwidth of our SAR system, i.e., 6 GHz center frequency with 20 MHz bandwidth. An Agilent Vector Network Analyzer (VNA) is used to perform the measurement.

Figure 7 shows the S_{21} of single circulator obtained from the measurement. It shows an average 35 dB isolation. Such isolation is not sufficient for the radar system which uses high power transmitter.

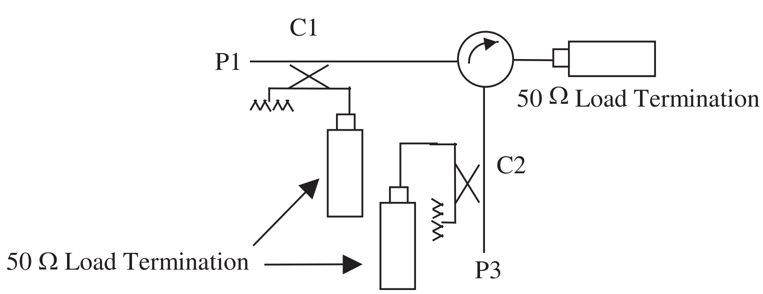

Figure 6. S_{21} measurement setup of leakage signal.

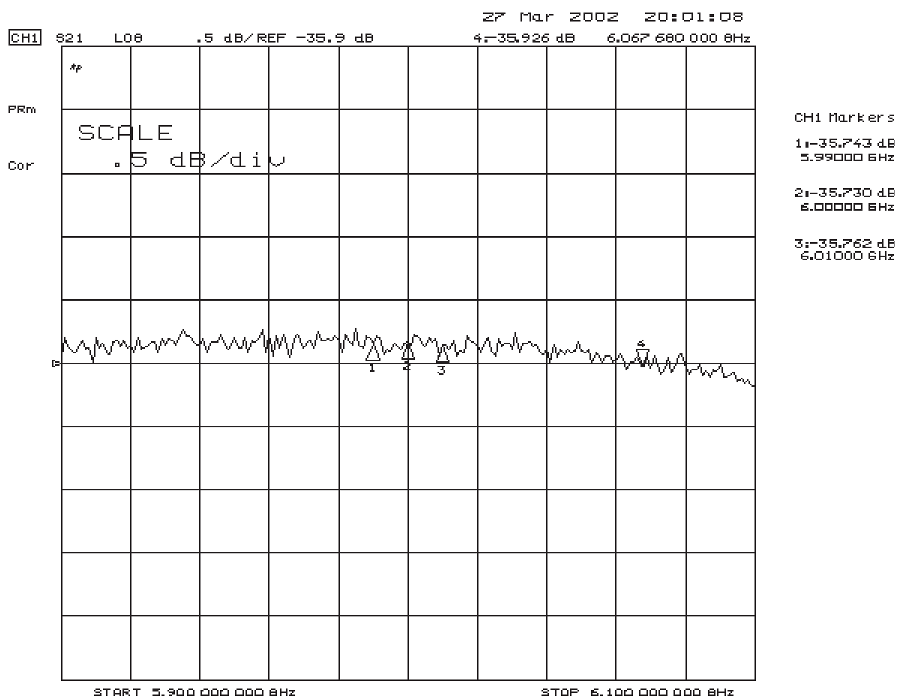

Figure 7. S_{21} of single circulator measured by VNA.

3.2. Measurement of Injected Signal

In order to cancel the leakage signal, the RF cables must be properly selected so that the electrical length of the cables will produce a total phase shift of 180° compared to the leakage signal. The isolation of CN is measured using the setup shown in Fig. 8. The variable attenuator is adjusted until the S_{21} of the CN has the same magnitude as that of the single circulator. The length of the RF cables is trimmed to obtain the desired 180° phase difference.

The directional couplers are then connected to the circulator. The performance of CN is shown in Fig. 9, which indicates an excellent isolation of more than 62 dB throughout the 20 MHz bandwidth. This result represents an improvement of more than 27 dB. Fine-tuning of the variable attenuator is possible to achieve a better result.

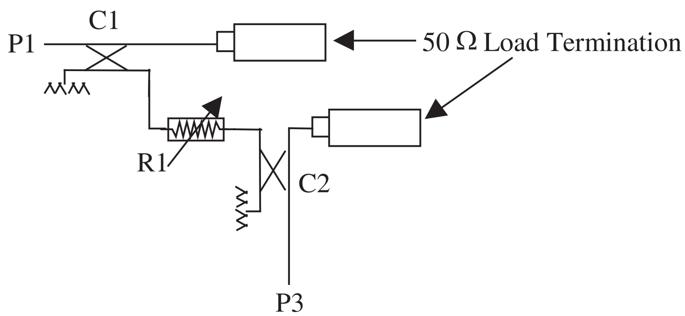

Figure 8. Measurement setup of injected signal by CN.

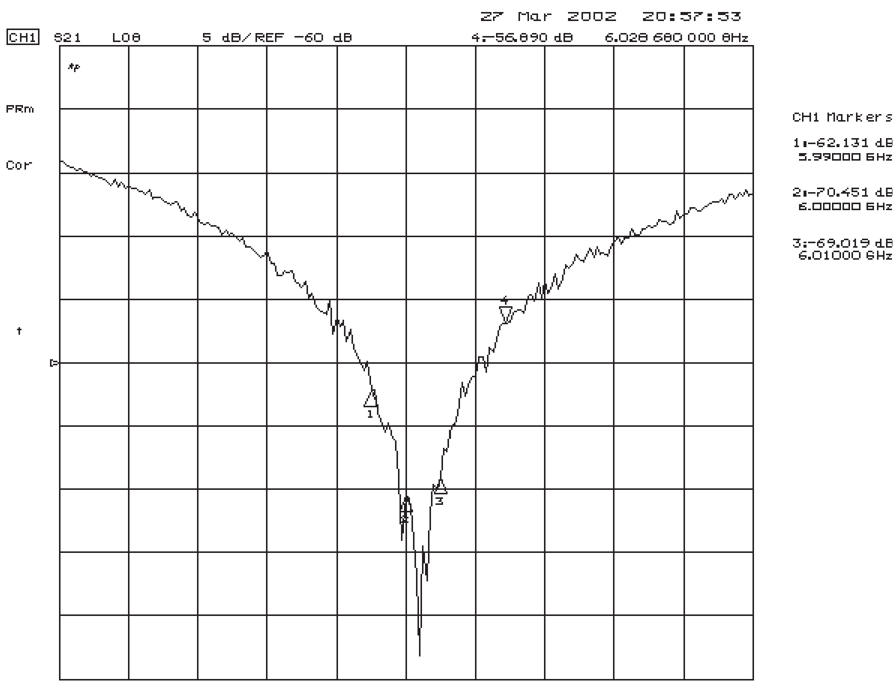

Figure 9. S_{21} of CN measured by VNA across the operation bandwidth of SAR sensor.

4. CONCLUSION

A new approach for improving isolation of circulator has been successfully demonstrated. This CN is incorporated in a prototype airborne SAR sensor developed by Multimedia University. It has been shown that with proper injection of amplitude and phase, the leakage signal can be reduced significantly. An improvement of more than 27 dB can be achieved. The CN technique can be applied to other full-duplex communication systems to improve the isolation performance.

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