THE DESIGN OF A 6-PORT ACTIVE CIRCULATOR

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ABSTRACT

Design of a fully monolithically integrable active circulator without any externally added circuit components is described in this paper. The circuit is capable of providing 0 dB loss, and return loss and isolation better than 16 dB and 23 dB, respectively over an octave or higher bandwidth.

INTRODUCTION

In many microwave systems, nonreciprocal components such as isolators and circulators are needed for avoiding interaction between various ports of a system. In conventional microwave circuits and hybrid microwave integrated circuits, the ferrite material is used to realize these components. Similar to hybrid MICs, these components can also be realized in MMIC form on GaAs substrate by adding ferrite disks and permanent magnets. However, this technique results in excessively large size and weight and is not compatible with monolithic microwave integrated circuit technology.

A novel approach is presented in this paper to realize circulators in the form of GaAs MMICs without using any ferrite material and external magnets. The configuration is known as an active circulator and is very suitable for system applications where a fully integrable lightweight, and small size subsystem is required. This paper describes the design of such devices.

OPERATION OF ACTIVE CIRCULATOR

An active circulator consists of three active isolators and three directional couplers as shown in Fig. 1 [1]. The active isolators must have enough gain to compensate for the dissipated and coupling loss in the couplers. For loosely coupled directional couplers, high gain isolators are required. Both these components must have sufficient bandwidths to cover the design bandwidth of the circulator.

An active isolator is a two-port nonreciprocal network. In the forward direction, the signal is

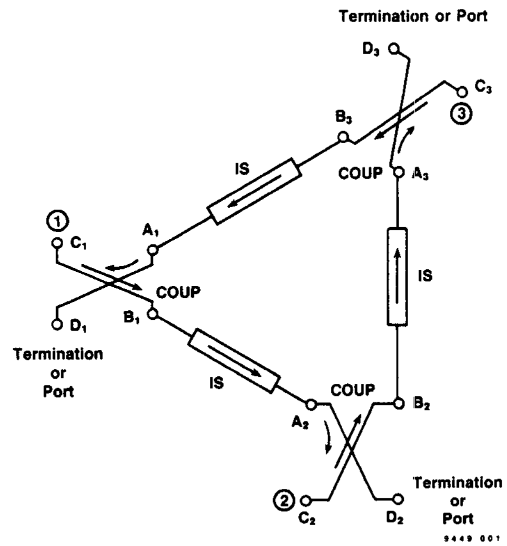

Fig. 1 3 to 6 port active circulator.

transmitted with insertion gain, while in the reverse direction there is no transmission. Any power entering from the output side is absorbed in the circuit. A microwave amplifier using three terminal devices such as MESFETs can be used as an active isolator. These amplifiers have inherent isolation (greater than 15 dB up to X-band) between the output and input of the device. The active isolator should have sufficient gain, and good return loss and isolation. Any coupler, or 90° or 180° hybrid can be used as a directional coupler. The desirable features are tight coupling, and good return loss and directivity (greater than 25 dB). The operation of the active circulator is described in the following.

A directional coupler (COUP) is a four-port network commonly used for sampling a known fraction of power flowing in a particular direction. When a wave travels from port A to port D, a fixed fraction of this power appears at port C, and there is no power at port B. The coupler shown here is a 3 dB Lange coupler with 30 dB minimum isolation. When port C_1 is excited with signal of unit

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amplitude, -3 dB signal appears at port A, and another -3 dB signal appears at port B_1 (the coupler has been assumed lossless). The port D_1 may be terminated or used as another port. Due to excellent isolation of the active isolator (IS), which is better than 20 dB over the operating frequency band, the signal level at port B_3 is less than -23 dB and at port C_3 less than -26 dB due to the signal flowing in the reverse direction. The signal between the ports B_1 and A_2 is amplified by 6 dB when it passes through the active isolator (6 dB gain) and the signal at port A_2 appears to be 3 dB more than the signal entering at port C_1. Thus, signal levels reaching ports C_2, D_2 and B_2 are 0 dB, 0 dB and -27 dB, respectively. Simultaneously signals appear at ports B_3 and C_3 have magnitudes of -51 dB and -24 dB, respectively due to the signal flowing in the forward direction. The total signal at ports B_3 and C_3 have magnitudes of -23 dB and -22 dB in the worst case. Thus, the whole configuration works as a circulator with 0 dB insertion loss and -23 dB isolation between ports C_2 and C_1.

The noise figure of the device is about 3 dB higher than the noise figure of the active isolator used in the circuit. However, the nonlinear characteristics and power handling capability of the device are the same as that for the active isolator.

The active circulators are also capable of providing three pairs of ports instead of 3 ports as in conventional circulators. Both the ports in each pair have the same amplitude but quadrature phase.

DESIGN AND PERFORMANCE OF ACTIVE CIRCULATOR

A monolithic distributed amplifier having 4 cells designed for 1 to 10 GHz with 7 dB gain, and return loss and isolation better than 12 dB and 20 dB, respectively has been used as an active isolator. The amplifier uses four 0.5 x 150 µm FETs and dissipate about 60 mW of dc power. The design of distributed (also commonly known as traveling-wave) amplifiers can be found in Reference 2.

The hybrids used are 3-dB Lange couplers which have capacitive compensation [3] to improve their directivity. The physical and electrical parameters for such couplers are summarized in Table 1. The capacitive compensation is also an integral part of monolithic IC fabrication.

The calculated values for $|S_{11}|$ and $|S_{21}|$ of an active circulator when the isolators are replaced with lossless through lines (Fig. 1) are shown in Fig. 2. It may be noted that the total coupling and dissipated loss between the ports 1 and 2 is about 7 dB which will be compensated by a distributed amplifier. Figure 3 shows a calculated performance of an active circulator when used as a six port device. The prime sign denotes complementary port which has almost the same amplitude but quadrature phase as compared to unprimed port. The active circulator has insertion loss within ± 0.2 dB, and return loss and isolation better than 16 dB and 23 dB, respectively over the 3 to 8 GHz frequency range. The performance may be improved further by optimizing the amplifier and the coupler simultaneously.

Table 1

Physical and Electrical Parameters of a Capacitively Compensated Lange Coupler

Substrate: ε_r = 12.9, h = 125 µm, t = 5 µm and tanδ = 0.001

W = 6 µm, S = 9 µm and l = 4300 µm

C = 0.08 pF (each side)

Frequency = 3.5 to 7.5 GHz

P_{out} = -3.1 ± 0.4 dB

P_{coup} = -3.4 ± 0.4 dB

Ret. Loss > 24 dB

Isolation > 31 dB

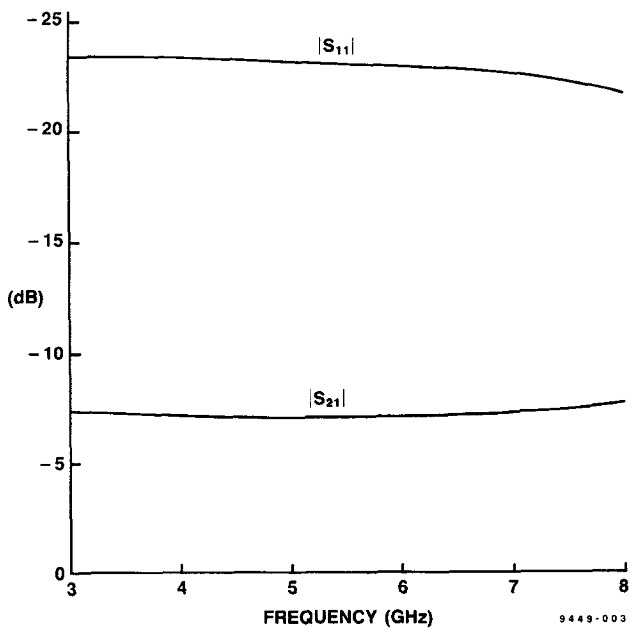

Fig. 2 Performance of 3 Lange couplers connected in closed loop configuration.

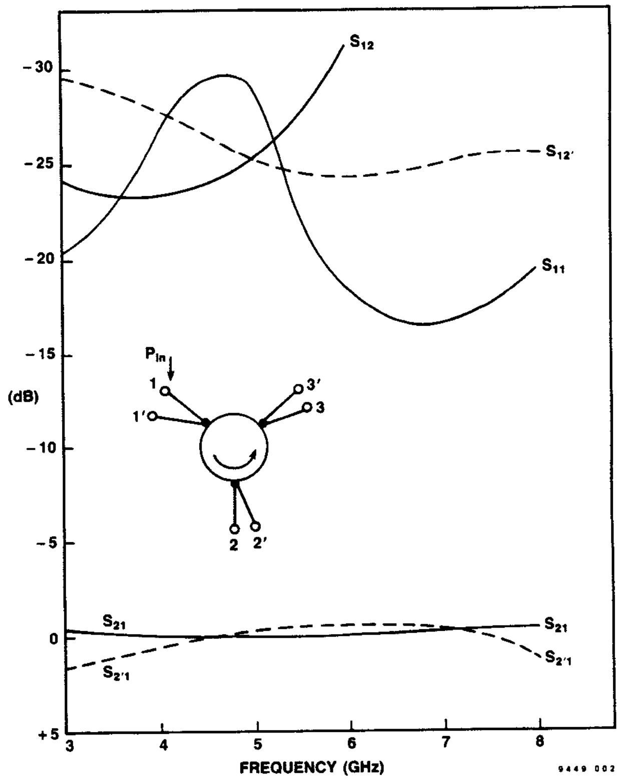

Fig. 3 Performance of a 6-port active circulator.

TEST RESULTS

To demonstrate the concept of active circulator we assembled two active circulator circuits using MMIC distributed amplifiers and hybrid Lange couplers on alumina substrate. A schematic of the assembly is shown in Fig. 4. The test results for the amplifier, Lange coupler, and an active circulator are summarized below.

MMIC Distributed Amplifier

Frequency = 2-8 GHz

Gain = 9 ± 0.5

Isolation ≥ 22 dB

Ret. Loss ≥ 10 dB

Lange Coupler

Frequency = 4-6 GHz

P_{out} = -3 ± 0.5 dB

P_{coup} = -4 ± 0.5 dB

Isolation > 15 dB

Ret. Loss > 14 dB

Active Circulator

Frequency = 4-6 GHz

Insertion Loss = ± 0.3 dB

Isolation > 17 dB

Ret. Loss > 12 dB

CONCLUSIONS

The concept of a fully integrable 6-port active circulator without any externally added circuit components is demonstrated in this paper. The device is small in size and is light-weight, and is capable of providing conversion gain with wider bandwidths.

REFERENCES

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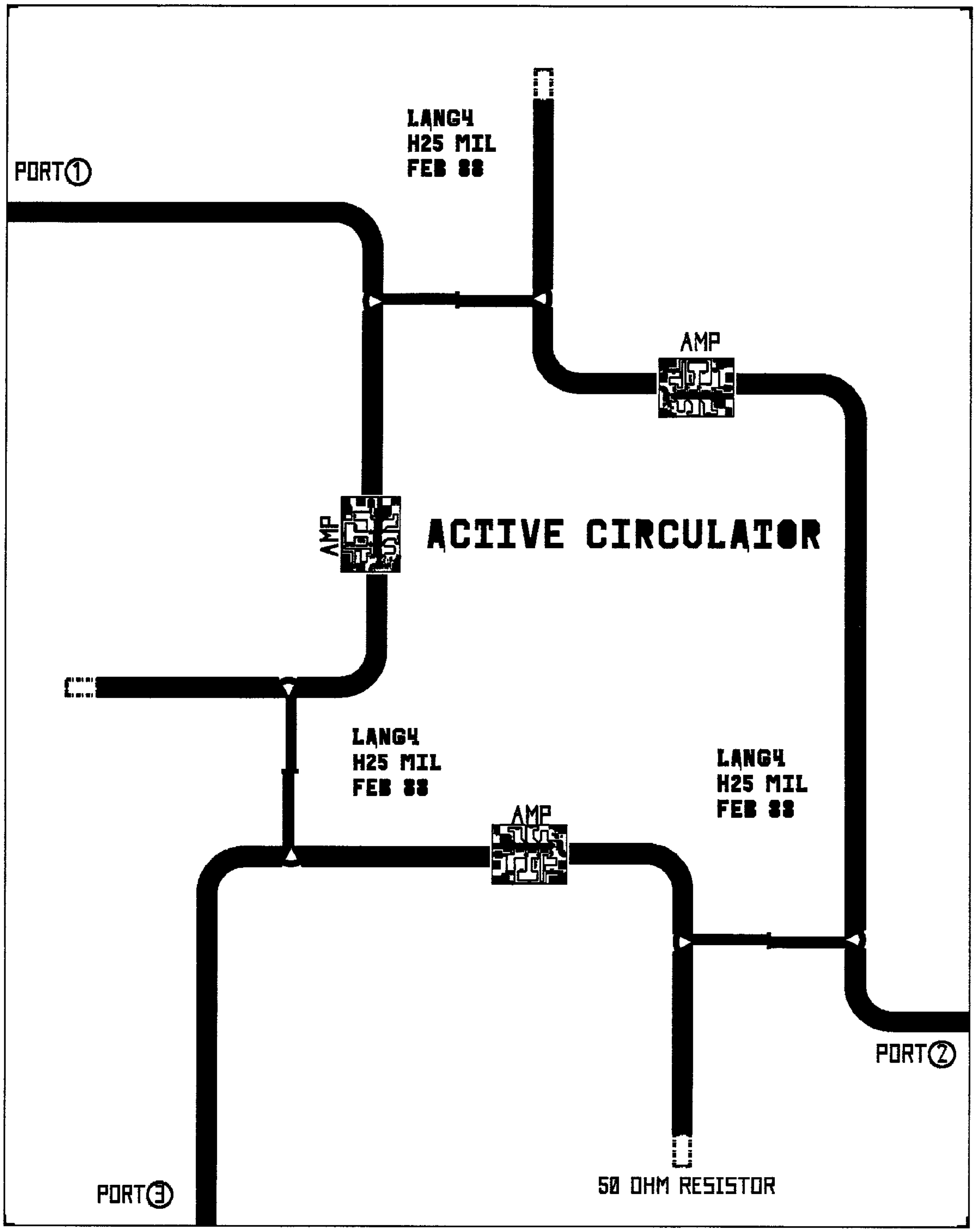

Fig. 4 Schematic of an active circulator.