An Integrated Active Circulator Antenna

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***Abstract*— An active circulator is integrated with a quarter-wave short-circuited microstrip patch antenna to produce a fully duplexed transceiver with transmit and receive operation at the same frequency and with the same polarization. The active circulator antenna is shown to have 14-dBi transmit gain and 7.4-dBi receive gain with a transmit-receive isolation of 26.9 dB at 3.745 GHz. This active antenna has potential uses in both short-range communication and radar systems.**

I. Introduction

An ACTIVE antenna combines active devices with a passive antenna in order to improve its performance or introduce multifunctionality directly into the antenna. New high-volume millimetric applications such as wireless LAN [1] and collision avoidance radars require very low-cost and low-weight solutions, and the high level of integration achievable with active antennas inherently fulfill these requirements. In this letter we will present the integration of an active circulator with a microstrip antenna in order to combine both transmit and receive functions into a single integrated antenna.

Active circulators have been of interest for many years with their inherent advantages of size and weight over conventional ferrite devices [2], [3]. They are also highly compatible with monolithic technology and are being used as part of complete microwave transmit receive front-ends [4]. This work presents a novel hybrid active circulator based on a phase cancellation technique integrated with a microstrip antenna, forming a fully duplexed transceiver module. Arrays of these elements could overcome the power-handling problems that limit the performance of current active circulators. A circulator is in general a three-port device in which signals pass from one port to another in one direction only. They are used to separate transmit and receive paths in communication systems or radars. In this work, three gain blocks (HP MGA-86 576) are connected in a ring such that signals can pass from the transmitter to the antenna, from the antenna to the receiver, and from the transmitter to the receiver. Thus, there are two signal paths from the transmitter to the receiver, one via the antenna and a direct path. The phase lengths of these paths can then be adjusted so that phase cancellation occurs at the receiver. Ayasli [2] uses nonreciprocal phase shifters to obtain a similar cancellation effect, however, insertion loss is present in all the signal paths, whereas here measurements of a nonintegrated circulator have shown gains in both transmit and receive paths.

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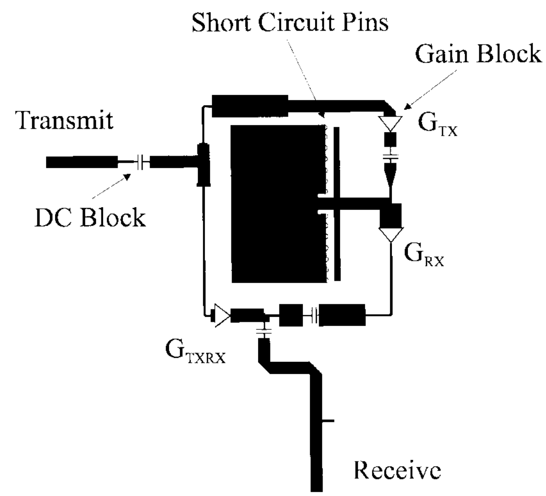

Fig. 1. Schematic layout of an active circulator antenna.

II. Results

Fig. 1 shows a schematic of the transceiver circuit. The circuit was designed using the Hewlett Packard Microwave Design System (MDS). The S-parameters of the one of the gain blocks were measured at ten different gain levels and were imported into MDS, which allowed for optimization of the amplifier gains and the widths and lengths of the transmission lines in order to obtain simultaneous matching and isolation. The transceiver is linearly polarized with same polarization for transmit and receive. Transmit power is amplified by gain block G_{TX} and coupled to the antenna by a length of 50-Ω microstrip line. Receive power is coupled into the circulator via the same line and passes through G_{RX} since the reverse isolation of G_{TX} prevents power coupling back into the transmitter. The gain of G_{TXRX} is set to the modeled value given by MDS and then adjusted until minimum transmit power is observed at the receive port. A short-circuit inset-matched microstrip antenna is placed in the center of the ring, which optimizes circuit area and would allow arrays of these elements to be formed. Two open circuit stubs have been used to match the antenna to the circulator, however, an optimized inset geometry would allow matching without the use of stubs. The receive port is matched using a small short circuited stub. The antenna measures 20 mm $\times$ 12 mm and the whole circuit occupies less than 50 mm $\times$ 40 mm. The circuit is fully planar, with only dc bias coils placed on the underside of the board.

Fig. 2 shows measured S-parameters. The transmit port return loss is seen to be reasonable, however the receive port is less good; with further modifications to the matching circuits this could be improved. Fig. 3 shows the transmit and receive parameters. The isolation is seen to be quite narrow band,

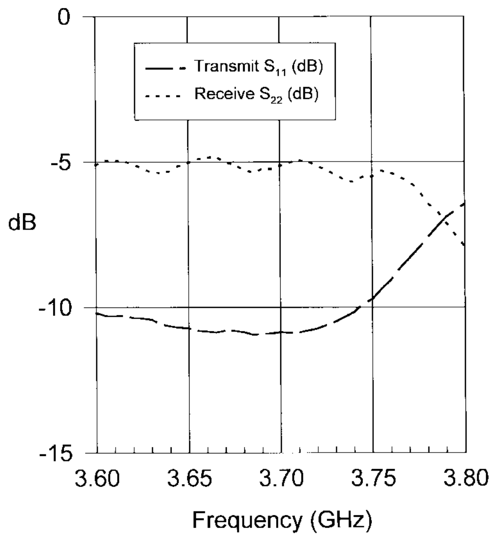

Fig. 2. Measured input and output S-parameters for an active circulator antenna.

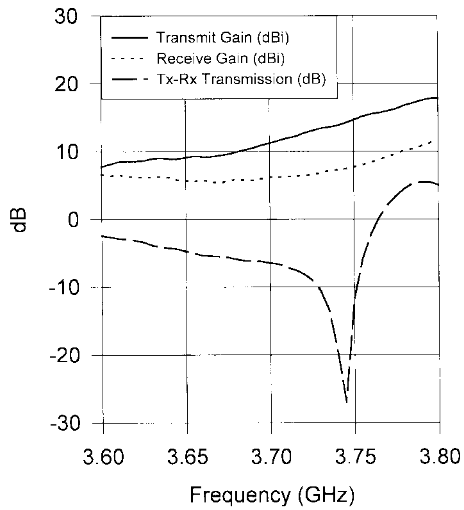

Fig. 3. Measured transmit and receive parameters for an active circulator antenna.

as expected for a cancellation technique, giving better than 20 dB over a 7-MHz band, with a maximum of 26.9 dB at 3.745 GHz. The gains are seen to have larger bandwidths, as have the return losses. The gain of the short-circuit antenna has been measured separately as approximately 3 dBi, thus the circulator is adding approximately 4-dB gain on receive and 10 dB on transmit. It is felt that with the use of constant phase shift networks such as Schiffman phase shifters broader band isolation could be obtained. The transmit and receive antenna patterns have been measured and are shown in Figs. 4 and 5. The patterns are seen to be reasonable considering the proximity of the patch to the surrounding circuitry. It is seen that the transmit and receive patterns are not identical, which is caused by differences in the current distributions in the feed lines and active devices when operating in transmit and receive modes. The cross-polar level was typically better than -10 dB at boresight, being degraded at wider angles due to the radiation from the microstrip lines and components, and also in the H-plane by the inherent poor cross-polar of a short-circuit patch.

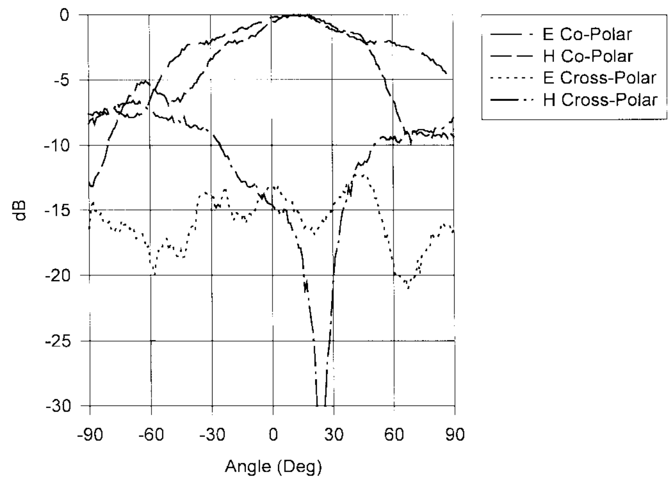

Fig. 4. Measured transmit radiation patterns for an active circulator antenna.

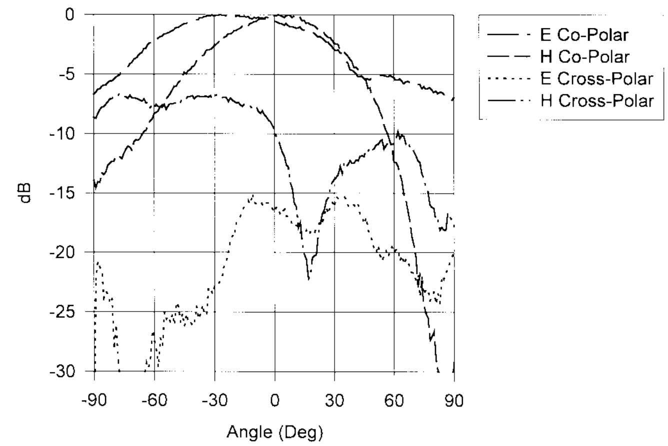

Fig. 5. Measured receive radiation patterns for an active circulator antenna.

III. Conclusion

An active circulator antenna has been presented that gives 26.9 dB of transmit-receive isolation with transmit and receive gains of 14 and 7.4 dBi, respectively, at 3.745 GHz and is implemented in less than 50 mm $\times$ 40 mm of substrate area. These results show the possibility of using larger arrays of this type in the millimetric bands for short-range communication or radar systems. Furthermore, the use of millimeter-wave monolithic integrated circuits would enable this technique to be implemented with high repeatability, at very low cost, and in large volumes.

References

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