Feedforward Embedding Circulator Enhancement in Transmit/Receive Applications

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Abstract—**In this letter, a feedforward embedding technique is presented to improve the isolation of a circulator. The circuit configuration is particularly suitable for transmit/receive applications where the received signal is extremely weak compared to the transmitted signal and where a mismatch at the antenna may exist. It is demonstrated that the isolation of a circulator can be improved by an additional 30 dB by using a feedforward embedding method. Test performance of a commercial 1-GHz circulator with and without the feedforward network is shown.**

***Index Terms*—Circulator, feedforward, feedback.**

I. INTRODUCTION

CIRCULATORS are widely used in transmit receive applications where a shared antenna is required to be used for both transmission and reception of the signal. Such applications demands excellent isolation properties from the circulator at the receive port as the received signal is often very weak. Conventional ferrite circulators usually offer isolation in the range of 30–35 dB when properly matched. The isolation, however, degrades considerably when such circulators are connected to loads having nonideal VSWR. This is particularly true when antennas are to be used toward their band edge, where there VSWR may degrades from unity.

In this letter a feedforward circuit is presented to enhance the isolation of any circulator, passive [1] or active [2]. The circuit presented here works on the principle of cancellation of the leakage signal by using a sample signal from the input to the third circulator port which has exactly the correct magnitude and phase to nullify any leakage signal. The circuit can improve the isolation between these ports by more than 30 dB. To demonstrate the concept the circuit is implemented using commercially available components at 1 GHz.

II. HIGH ISOLATION FEEDFORWARD CIRCUIT

The feedforward high isolation circuit for the circulator is shown in Fig. 1. Here a sample of the input signal is taken using a coupler C1. This signal is then attenuated and phase shifted such that the amplitude of the sampled signal is the same as that of leakage signal at the receive port, but it is 180° out of phase from the leakage signal. These two signals, when added together using a power combiner, interfere destructively, thus improving the circuit isolation considerably. The addition

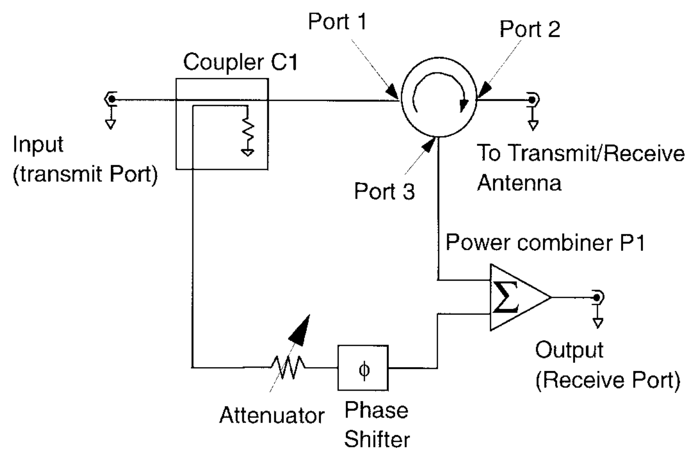

Fig. 1. High isolation circuit for circulator.

of a sample signal with the signal at the received port does not affect the received signal from the antenna since only the leakage signal is cancelled. Power combiner P1 adds loss of 3 dB to the received signal from the antenna; this loss can be minimized using an unequal power combiner or a reactive power combiner.

III. MEASUREMENTS

The circuit was fabricated at 1 GHz using commercially available components. Fig. 2(a) shows the isolation between transmit and receive ports when the antenna port is terminated in a matched load. Fig. 2(b) shows the isolation when a microstrip patch antenna with VSWR of 1.6 is connected to the antenna port of the circulator. It can be seen from Fig. 2(a) that the isolation of the circulator is >20 dB from 950 MHz to 1.2 GHz when matched terminated. The isolation, however, degrades considerably when connected to the microstrip patch antenna, and is >10 dB only in the band between 990–1020 MHz, as shown in Fig. 2(b). At the design frequency of 1 GHz the raw isolation, which was −32 dB with matched loads, degrades to approximately −13 dB when connected to the patch antenna. Fig. 3(a) and (b) shows that the isolation between transmit and receive ports when incorporated with the high-isolation feedforward circuit improves each case considerably. It can be seen from these figures that in matched condition the isolation of the circulator is >20 dB throughout the measurement range 0.8–1.2 GHz, improving to a minimum value −71 dB, i.e., improvement of >35 dB at 1 GHz relative to the matched response in Fig. 2(a). With a microstrip patch antenna connected, the isolation obtained is >10 dB throughout the measurement range improving to −43 dB at 1 GHz, an improvement of >30 dB relative to the response

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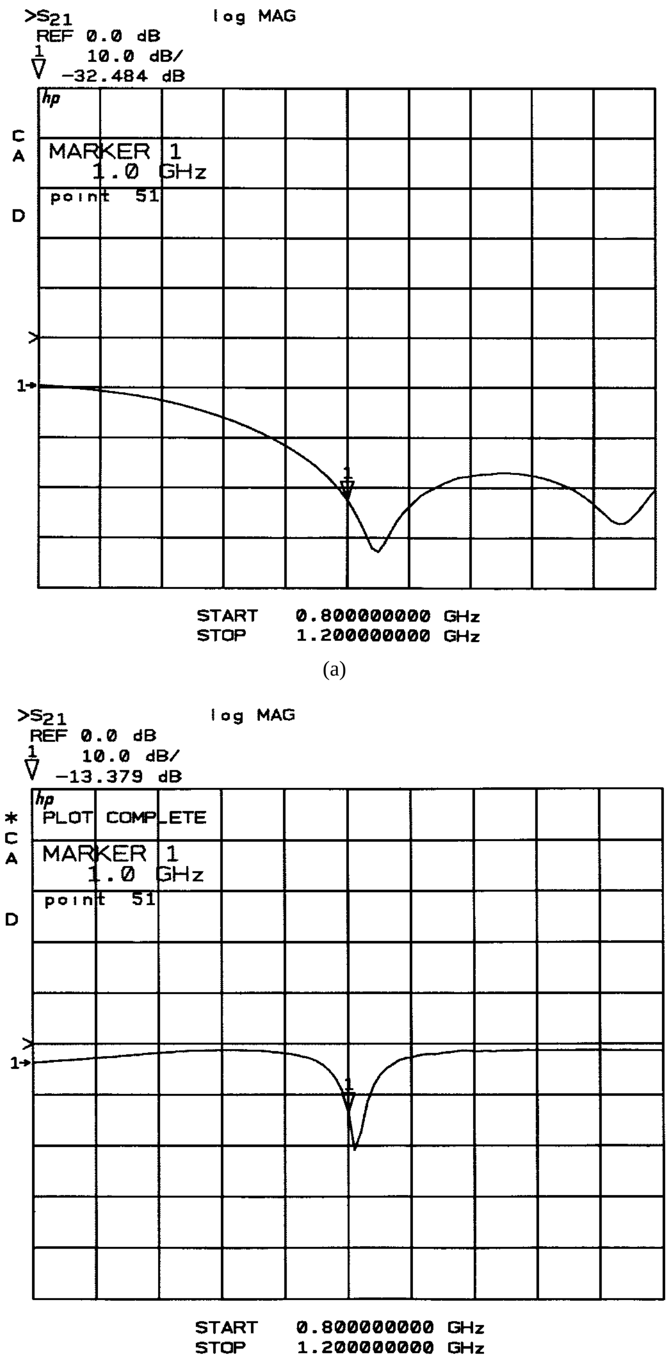

Fig. 2. (a) Isolation between transmit and receive ports of circulator with a matched antenna port and (b) with an unmatched microstrip patch antenna connected at the antenna port.

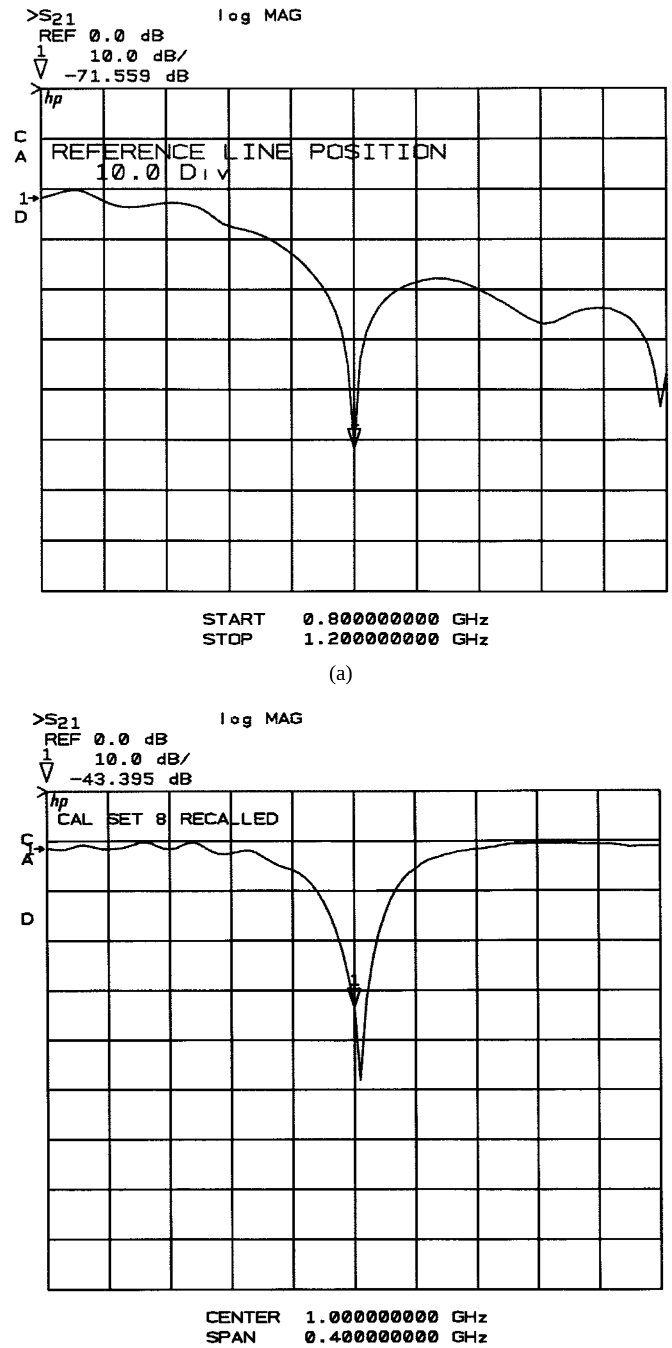

Fig. 3. (a) Isolation between transmit and receive ports of circulator with high isolation feedforward circuit when antenna port is matched and (b) when an unmatched microstrip patch antenna is connected to the antenna port.

in Fig. 2(b). High isolation at any other frequency within the bandwidth of the circulator can be obtain just by changing the attenuation and phase delay of the sampled signal.

IV. Conclusion

A circuit is presented in this letter which improves the intrinsic isolation of a circulator. The circuit improves the isolation of a circulator in transmit/receive antenna setup even when the antennas are poorly matched. A variable phase shifter can be used to make the circuit useful over a broader frequency band. The embedding circuit presented could be implemented in monolithic microwave integrated circuit (MMIC) form allowing for the fabrication of very high-isolation integrated circulators circuits.

References

[1] C. E. Fay and R. L. Comstock, “Operation of the Ferrite junction circulator,” *IEEE Trans. Microwave Theory Tech.*, vol. MTT-13, pp. 15–27, June 1965.

[2] S. Hara, T. Tokumitsu, and M. Aikawa, “Novel unilateral circuits for MMIC circulators,” *IEEE Trans. Microwave Theory Tech.*, vol. 38, pp. 1399–1406, Oct. 1990.