



## **Multi Opening Broadband Active Circulator**

**Iman Ahanian<sup>1\*</sup>, Fatemeh Jabbari<sup>1</sup>, Hossein Heidari<sup>1</sup>**

<sup>1</sup> Department of Electrical Engineering, South Tehran Branch, Islamic Azad University, Tehran, Iran.

### **Abstract**

In this paper, details of designing a four-opening broadband active circulator are investigated. The proposed model works in the 2-26GHz frequency band and also amplifies the output wave to  $11.35 \pm 0.018$ , which is one of the advantages of the designed model. Common circulators are passive ones with disadvantages of the limited bandwidth, frequency dependency and large dimensions in the case of large number of openings. Also, either increasing or decreasing the number of openings requires redesigning of the circulator. However, for the proposed model in this paper, the bandwidth is increased, the dimensions are reduced and the number of craters can easily be changed.

**Keywords:** Broadband, circulator, active, multi-opening.

### **1. INTRODUCTION**

A circulator is an invertible multi-opening device that a microwave-frequency signal or a radio frequency which has entered from each opening extends from the next spindle in the direction of rotation while the reached power to the other openings are negligible. In a passive circulator, the wave move within a rotating structure from a port to another port respectively [1]. There are several methods in the passive circulators to avoid of reaching the wave in the unwanted crater, for example one can introduce a method which is the summation waves with 180-degree phases in unwanted crater [2, 3]. Another model for the passive circulator is a ferrite piece usage to eliminate the wave that goes into the unwanted opening. For this method, the ferrite property is replaced with an appropriate active circuit [4].

One of the most important usages of a circulator is when transmitter and receiver use a single antenna. That means, the transmitter

power is transmitted only to the antenna, and the antenna power is only transmitted to the receiver and degradation of receiver is prevented by the high power of the transmitter [5]. As an example, radars, which work by sending and receiving radio waves, initially distribute waves by means of the antenna and receive the reflective waves by the same antenna.

In general, active circulators have many advantages over the passive types. High bandwidth with Ripple lower than 0.3dB is one of the most important features of these devices [6]. Unlike active models, passive types have some disadvantages. First of all, their bandwidth is limited. They are also designed for a specific mode or frequency with a specified number of ports. The dependence of dimensions on the frequency and big dimensions in case of large number of openings are their other disadvantages that distinguish them from the active typed [6]. Also, the circulator if required is to be redesigned in case of increasing or decreasing the number of openings.

---

\*Corresponding Author's Email: iman\_ahanian@aut.ac.ir

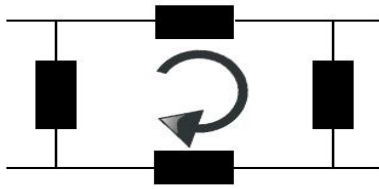


Fig. 1. General Circulator Model.

Considering both the benefits of the active circulators versus the passive ones and disadvantages of passive circulators, it seems that the uses of active circulators are economic and logical.

In this paper, creating an active circulator structure is explained at first and then, the working frequency range of this circulator will be discussed by using a broadband amplifier and shifter.

## 2. MODELING

In a circulator, the wave moves in a rotating structure from a crater to another one, so the proposed model is based on the mentioned behavior. In the circular active circuit, due to the

one-way amplifier, the wave moves only in the direct direction. Here, the one-way amplification means that the  $S_{12}$  is very small. Fig. 1 shows the input waves rotate in one direction only because of the one-sidedness of the amplifiers. Now, in order to achieve the structure of the circulator, the structure should be changed so that if the opening 1 is assumed to be an input, the wave only reaches the opening 1 and opening 2, not the openings 3 and 4.

Due to the one-way amplifiers, the wave will not be reached from opening 1 to opening 4. So just make sure that the wave from opening 1 does not reach opening 3. If the wave does not reach the 3th opening, the second path will not reach the 4th opening. It should be noted that this structure is symmetric and the above trend is repeated by considering each opening as input.

The model presented in Fig. 2 is used to satisfy the desired structure.

In Fig. 2, one-way amplifiers are shown using the '→' symbol. All amplifiers are ideal and identical. The wave after entering the first opening, only passes through the first path due to the one-way amplifiers. Now, to prevent the

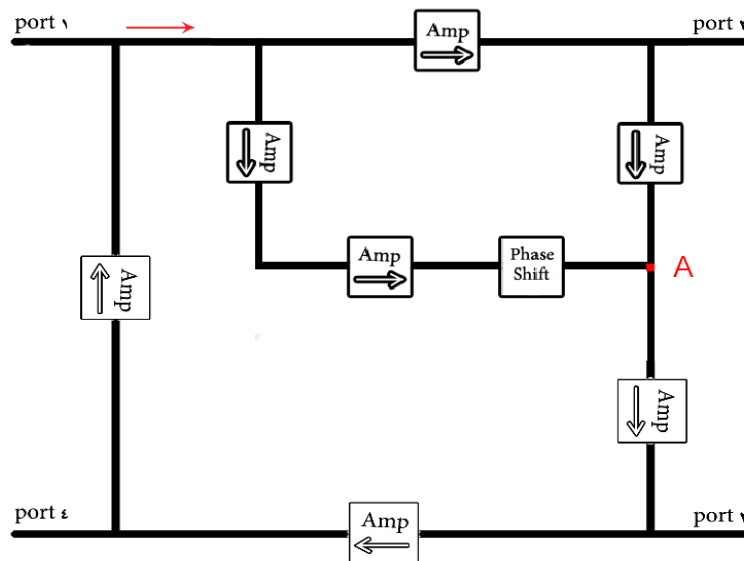


Fig. 2. Structure of a circulator for isolating opening 1 with 3 and 4.

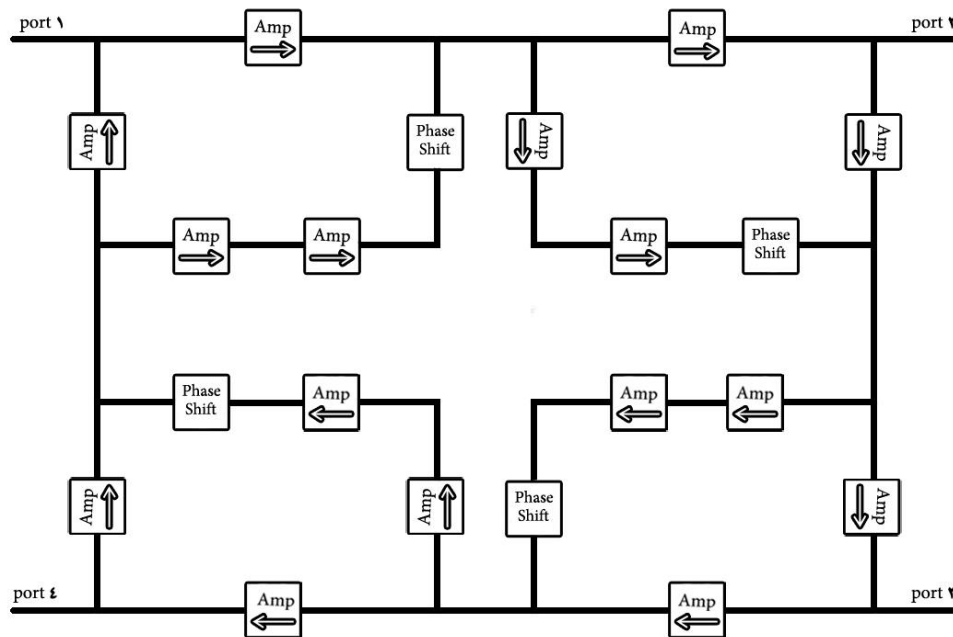


Fig. 3. Active circulator structure.

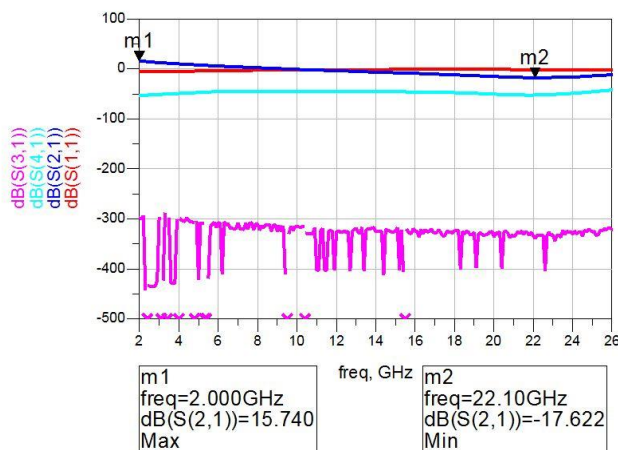


Fig. 4. Results of the active single transistor circulator.

wave from reaching point 1, a new branch is created in the circuit where the wave is divided equally across the paths due to the identical two paths. By creating a phase difference of 180 degrees in one of the directions, the wave seen at the point A will be zero. Phase separator has been used to create this phase shift.

We simulate the proposed model, see Fig. 3., by using a single transistor NEC710 in ADS software, which results for opening 1 are as follows:

As can be seen in Fig. 4, depending on the values of  $S_{31}$  and  $S_{41}$ , if the wave enters from opening of 1, it does not reach the openings 3 and 4, which it is desirable.

It is also preferred in the circulator that the entire wave reaches the opening 2 when it enters from the opening 1 and the reciprocating wave to the opening 1 is low. As shown in Fig. 4, only at low frequencies (2-4 GHz) this has been achieved which is the main bottleneck of the proposed structure shown in Fig. 3.

Due to the symmetry of the structure, the above results are repeated by setting each opening as entrance.

In order to broaden the bandwidth of the proposed structure, instead of a single transistor, we use a broadband amplifier shown in Fig. 5 which increases both the bandwidth of the circulator and the gain of the input waveform amplification.

This structure consist of  $4 \times 3$  amplifier, which is represented by 4 continuous rows including 3 transcoders in each row, which has the S- parameters shown in Fig. 6.

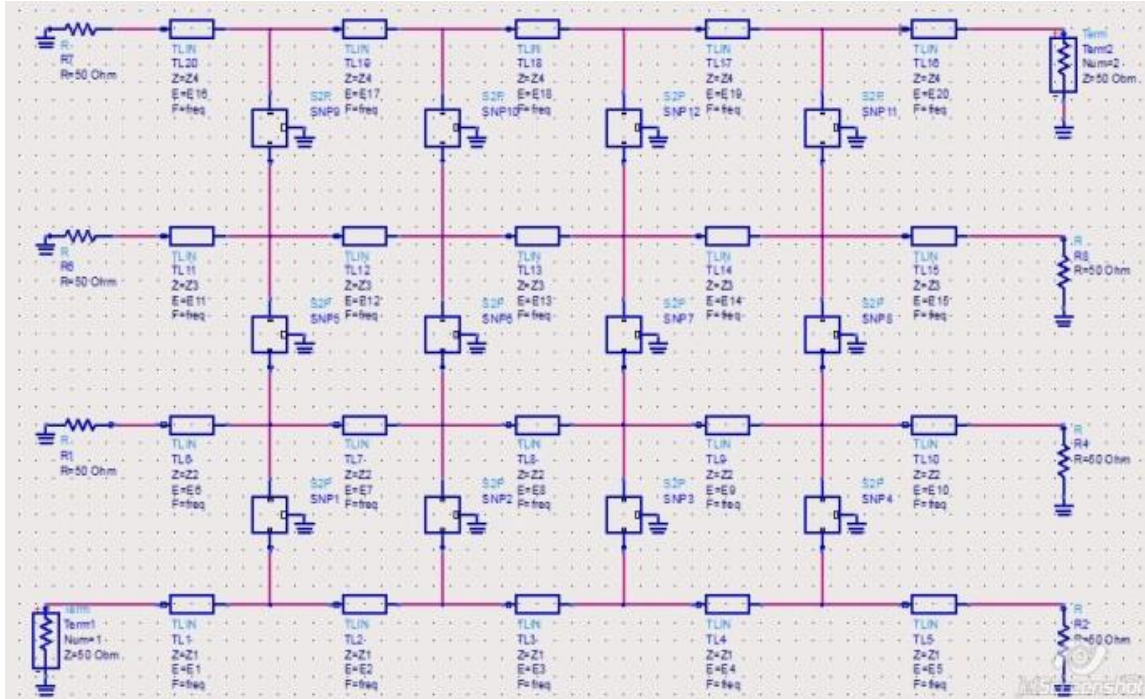


Fig. 5. Broadband amplifier 4 × 3.

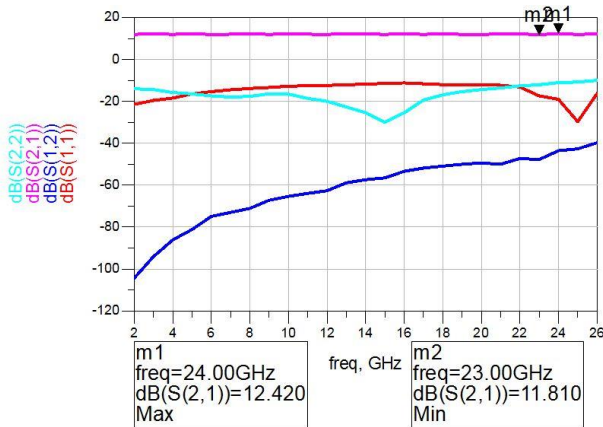


Fig. 6. Broadband amplifier dispersion parameters.

This amplifier with a bandwidth of 2-26 GHz has a  $S_{21}$  gain of 12 dB and a maximum waveform amplification of 0.6 dB at various frequencies. We also need a broadband phase shifter to fulfill this structure, which uses a fuzzy shifter with a non-frequency characteristic with 180 degrees of phase change [7]. This phase shifter consists of a 3-dB hybrid coupler

and a pair of reciprocally terminated circuits. The latent circuit of the reflector switches the two modes of the LC series and parallel circuitry. Where the condition of circuit elements is obtained irrespective of the used frequency as an ideal circuit model without parasitic elements. This 180-degree reflective circuit has built like a microwave integrated circuit (MMIC) at a frequency of 0.5 to 30 GHz with phase difference of  $183 \pm 3$ .

The circulator uses the above amplifier is shown in Fig. 6.

In the structure shown in Fig. 7, ADS software uses a hierarchy structure, meaning that each block of broadband in the high-compressed amplifier presented in Fig. 5.

Also, to achieve the intended purpose of the circulator, the optimization of this structure through defining the width of the lines parameters as variable in the amplifier is utilized to obtain an impedance matching.

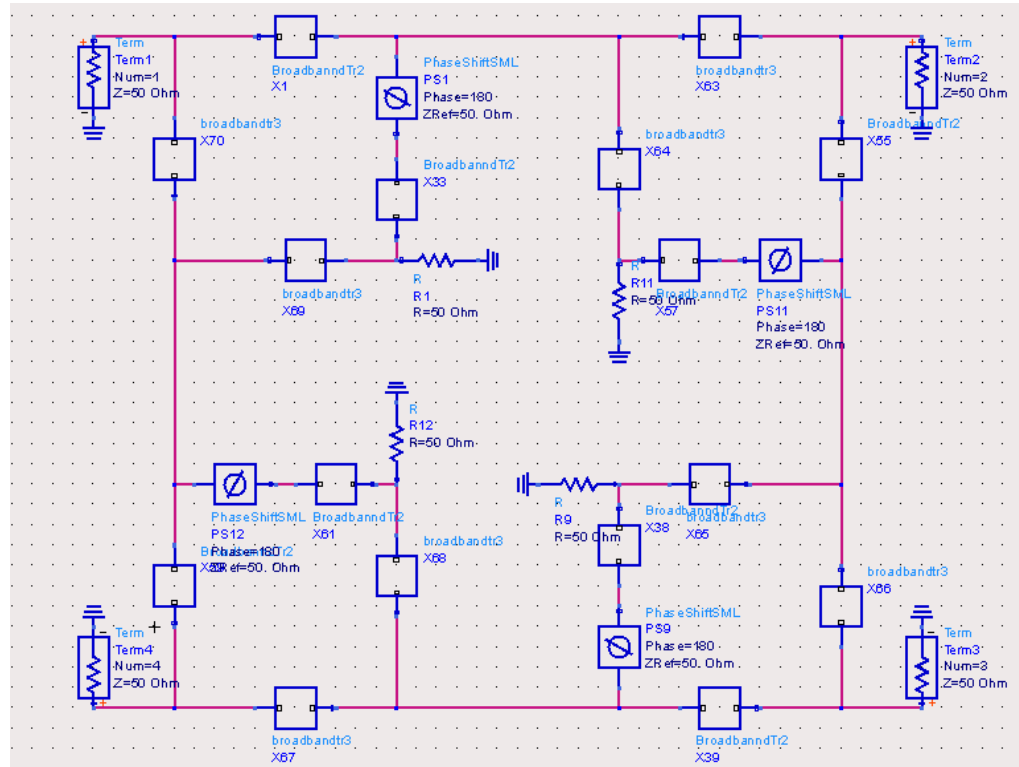


Fig. 7. Optimized active circulator block.

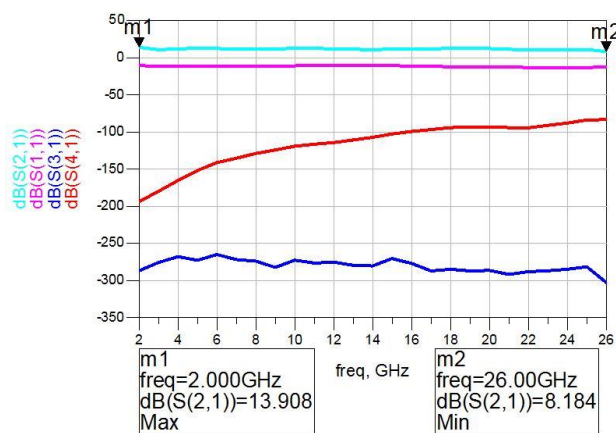


Fig. 8. Results of an active circulator with optimized block.

The desired targets in the circulator include low return loss from each opening and a better amplification of the wave from the input to the output to flatten the output as much as possible. The following results are obtained:

As shown in the Fig.8, the  $S_{21}$  is 13 dB in a broad range of frequency (2 – 26 GHz). Also the return loss from opening 1 is less than 0.1 input way which is desirable. In addition, the

reached way to the opening 3, 4 is less than -80 dB.

Ripple of ways in the frequency range is more than 5.8 dB. By using two different amplifier block as shown in Fig. 9 with different matching impedance, the ripples is also improved (see Fig.10). actually, by using the mentioned method, the ripple in the frequency range is decreased to 0.37 dB, also the amplification is decreased to 1 dB, see Figs. 10-11.

As mentioned, typical circulators are passive ones that bandwidth constraints, dependence of dimension on frequencies, large dimensions in the case of large numbers of seeds are their disadvantages. Also, increase or decrease the number of openings needs redesigning the circulator. However, in the proposed model the bandwidth has increased, the dimensions are reduced and the number of openings can be easily changed. Fig. 12 shows a 6 opening circulator and its results.

As shown in Fig. 13, changing number of openings is very simple, S-parameters are desirable and the Ripple is also low.



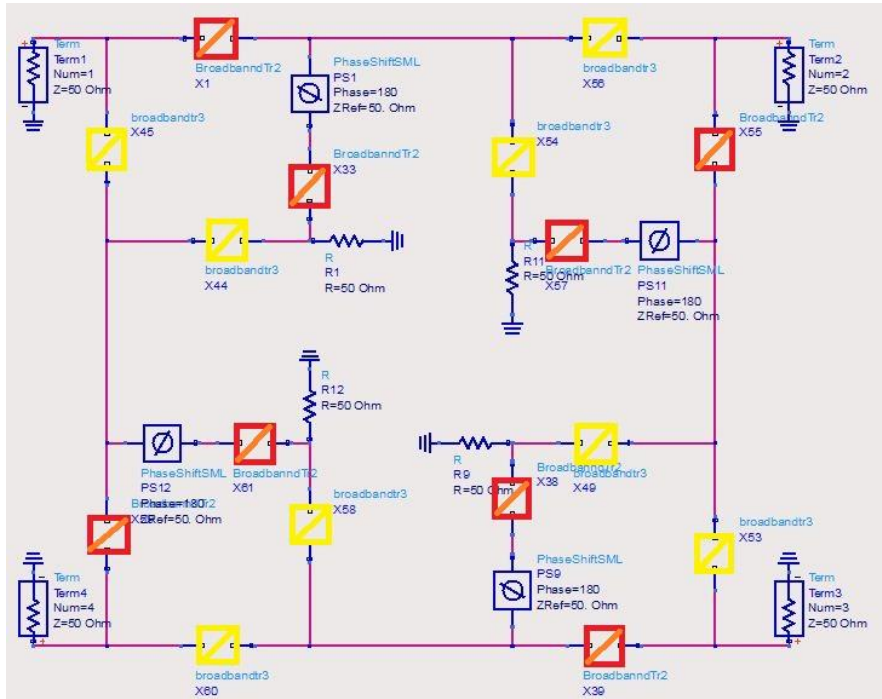


Fig. 9. Active circulator with two optimized blocks.

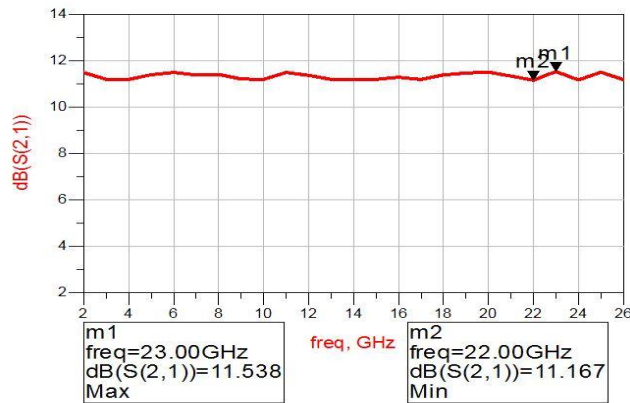


Fig. 10. S11 parameter of active circulator with two optimized blocks.

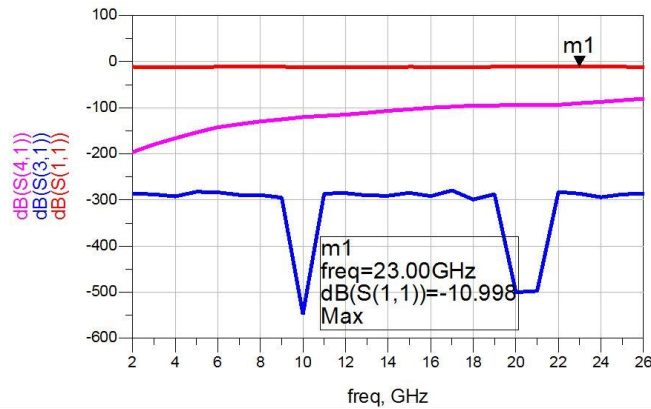


Fig. 11. The results of an active circulator with two optimized blocks.

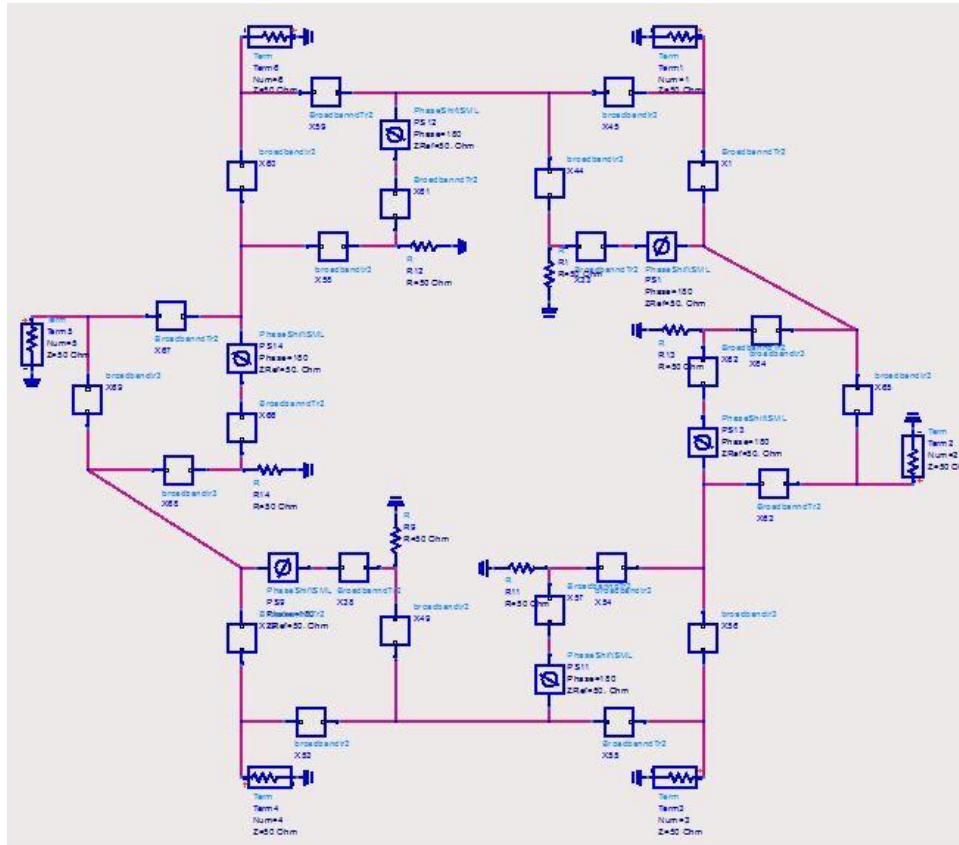


Fig. 12. The 6 opening active circulator is shown.

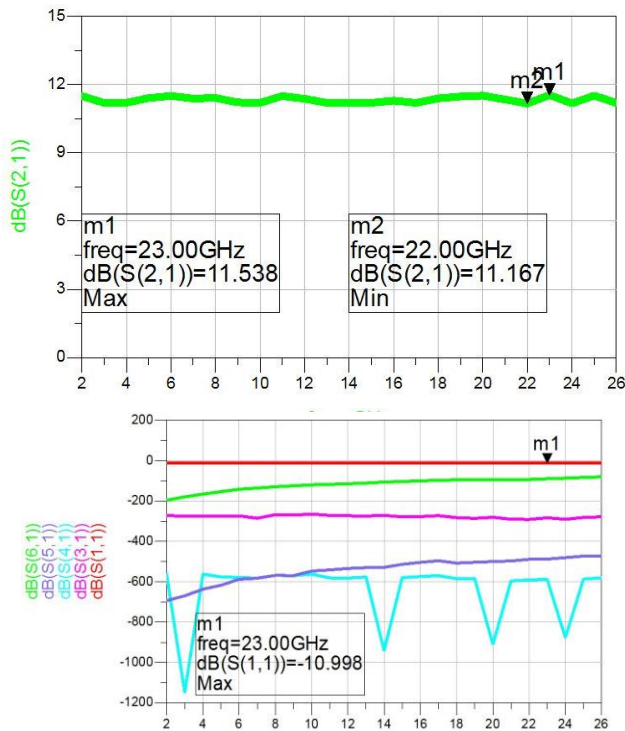


Fig. 13. The 6 opening active circulator dispersion parameters.

### 3. CONCLUSION

In this paper, a model for an active circulator and also widening the bandwidth of this active structure are presented, whereas the circulator has a frequency range of 2-26GHz and is suitable for all microwave devices. It also boosts the output wave to  $11.35 \pm 0.018$ , which is one of the advantages of the designed model.

### REFERENCES

- [1] C. E. Fay and R. L. Comstock, "Operation of the Ferrite Junction Circulator," in IEEE Transactions on Microwave Theory and Techniques, vol. 13, no. 1, pp. 15-27, Jan 1965.
- [2] Pozar, David M. "Microwave engineering," John Wiley & Sons, 2009.
- [3] Tanaka, S., N. Shimomura, and K. htake, "Active circulators The realization of circulators using transistors," Proc.IEEE, Vol. 53, 260{267, Mar. 1965.

- [4] D. M. Zaiden, J. E. Grandfield, T. M. Weller and G. Mumcu, "Compact and Wideband MMIC Phase Shifters Using Tunable Active Inductor-Loaded All-Pass Networks," in *IEEE Transactions on Microwave Theory and Techniques*, vol. 66, no. 2, pp. 1047-1057, Feb. 2018.
- [5] Skolnik, Merrill Ivan. "Radar handbook." (1970).
- [6] Bahri, Reza, Abdolali Abdipour, and Gholamreza Moradi. "Analysis and design of new active quasi circulator and circulators." *Progress In Electromagnetics Research* 96 (2009): 377-395.
- [7] Acikel, Baki, et al. "A new high performance phase shifter using Ba/sub x/Sr/sub 1-x/TiO 3 thin films." *IEEE Microwave and wireless components letters* 12.7 (2002): 237-239.