BROADBAND LUMPED-DISTRIBUTED HYBRID RING COUPLER

Jihad Basuni, Prof. Adnan Affandi

Department of Electrical and Computer Engineering
King Abdulaziz University, Jeddah, Saudi Arabia

DOI: 10.29322/IJSRP.13.09.2023.p14130
https://dx.doi.org/10.29322/IJSRP.13.09.2023.p14130

Abstract— three different versions of hybrid ring couplers are proposed in this paper. The first one is an improved version of an old distributed coupler. The other two couplers are broadband lumped-distributed hybrid ring couplers. Theoretical analyses, simulations, and practical measurements are covered in this paper. Moreover, the theoretical results are almost matching with the practical results, so these couplers are almost fully corresponded with the theoretical results. All designs and simulations are implemented by the Advance Design System (ADS) software.

Keywords— coupler, distributed, hybrid ring, lumped, broadband, lumped-distributed, microstrip, transmission line

I. INTRODUCTION

Having wide bandwidth in the high frequency is a serious case for the future. This is attributed to the fact that quantity of data sent and transferred through the wireless network increases day after day. Therefore, finding new techniques to increase the bandwidth has to be considered. One equipment in the telecom filed is a coupler which is used to divide or combine signals. The most common types of couplers are three types: a coupled line coupler, branch line coupler, and hybrid ring coupler. The challenging part is improving couplers' performances by increasing the bandwidth range and reducing losses. Therefore, there are several techniques used to do that task such as editing the thickness of microstrip lines, editing the dimensions of designs, and editing the shape of designs. However, there is one successful and powerful technique that can guarantee to enhance the performance of any distributed coupler. This is called lumped-distributed technique in which lumped components such as resistors, capacitors, and inductors are added to distributed designs.

II. PROPOSED DESIGN

An example of the distributed coupler is shown in the figure (1). This proposed design is an improved version of an old design presented in the figure (5). The figure (2) is showing the lumped-distributed coupler, and it is clear to notice that there are four lumped resistors connected to the distributed design.

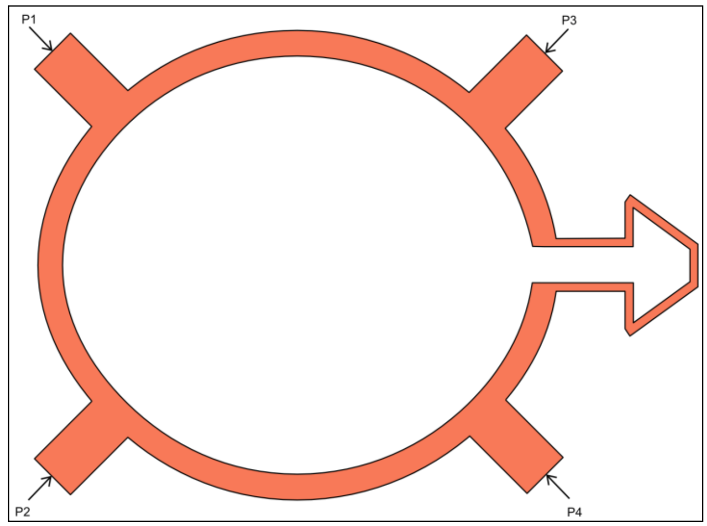

Fig (1): Proposed distributed hybrid ring coupler

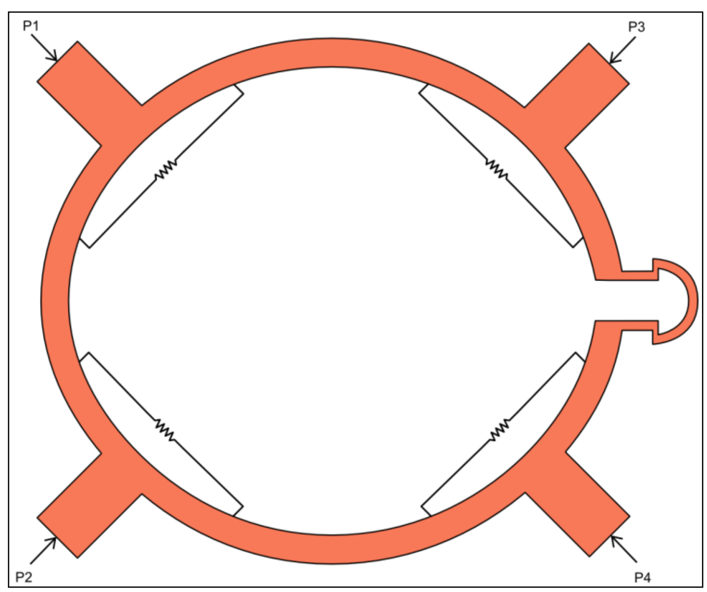

Fig (2): Proposed lumped-distributed hybrid ring coupler v2

III. Theoretical Analyses

A. Even mode analysis of the HRC:

$$\begin{pmatrix} A & B \\ C & D \end{pmatrix}_e = \begin{pmatrix} 1 & 0 \\ j & 1 \end{pmatrix} \begin{pmatrix} 0 & j\sqrt{2} \\ j/\sqrt{2} & 0 \end{pmatrix} \begin{pmatrix} 1 & 0 \\ -j & 1 \end{pmatrix}$$

$$= \begin{pmatrix} 1 & j\sqrt{2} \\ j\sqrt{2} & -1 \end{pmatrix}$$

$$\Gamma_e = \frac{A+B-C-D}{A+B+C+D} = \frac{(1+j\sqrt{2}-j\sqrt{2}+1)}{(1+j\sqrt{2}+j\sqrt{2}-1)} = \frac{-j}{\sqrt{2}}$$

$$T_e = \frac{2}{A+B+C+D} = \frac{2}{(1+j\sqrt{2}+j\sqrt{2}-1)} = \frac{-j}{\sqrt{2}}$$

B. Odd mode analysis of the BLC:

$$\begin{pmatrix} A & B \\ C & D \end{pmatrix}_o = \begin{pmatrix} 1 & 0 \\ -j & 1 \end{pmatrix} \begin{pmatrix} 0 & j\sqrt{2} \\ j/\sqrt{2} & 0 \end{pmatrix} \begin{pmatrix} 1 & 0 \\ j & 1 \end{pmatrix}$$

$$= \begin{pmatrix} -1 & j\sqrt{2} \\ j\sqrt{2} & 1 \end{pmatrix}$$

$$\Gamma_o = \frac{A+B-C-D}{A+B+C+D} = \frac{(-1+j\sqrt{2}-j\sqrt{2}-1)}{(-1+j\sqrt{2}+j\sqrt{2}+1)} = \frac{j}{\sqrt{2}}$$

$$T_o = \frac{2}{A+B+C+D} = \frac{2}{(-1+j\sqrt{2}+j\sqrt{2}+1)} = \frac{-j}{\sqrt{2}}$$

Combining the both modes to get the S matrix:

$B_1 = 1/2(\Gamma_e + \Gamma_o) = 0$ P1 is matched

$B_2 = 1/2(T_e + T_o) = -j/\sqrt{2}$ Half of the power passes from P1 to P2

$B_3 = 1/2(\Gamma_e - \Gamma_o) = -j/\sqrt{2}$ Half of the power passes from P1 to P3

$B_4 = 1/2(T_e - T_o) = 0$ P4 is isolated

Note: these B_1, B_2, B_3, B_4 values are for the first row in the following S matrix:

$$[S] = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 & -j & -j & 0 \\ -j & 0 & 0 & j \\ -j & 0 & 0 & -j \\ 0 & j & -j & 0 \end{pmatrix}$$

The signal flow of the hybrid branch line coupler (HBLC):

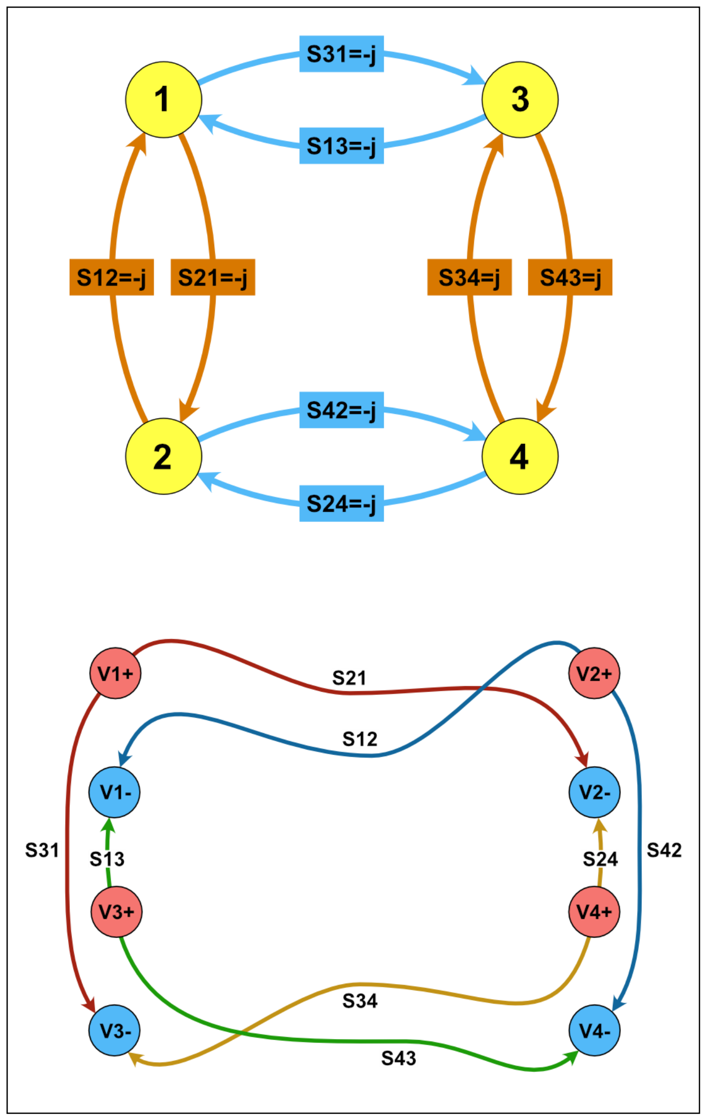

Fig (3) The signal flow of the HBLC:

IV. Design and Implementation

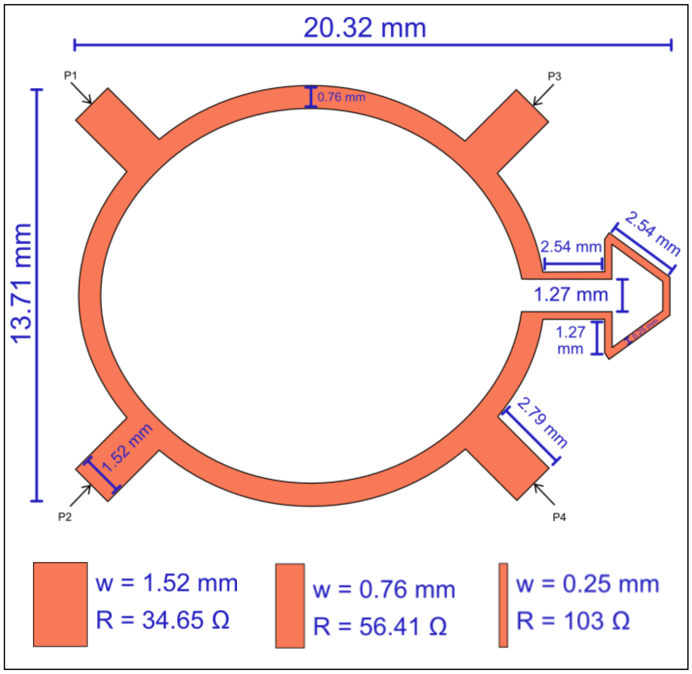

Fig (4): Dimensions of the SMA female connector

This coupler shown in the figure 8 seems like a male gender symbol, the idea of this design came from an old published paper "*Size-reduction and band-broadening design technique of uniplanar hybrid ring coupler using phase inverter for M(H)MIC's*" written by (Wang and Ke, 1999). This old design can be seen in the following:

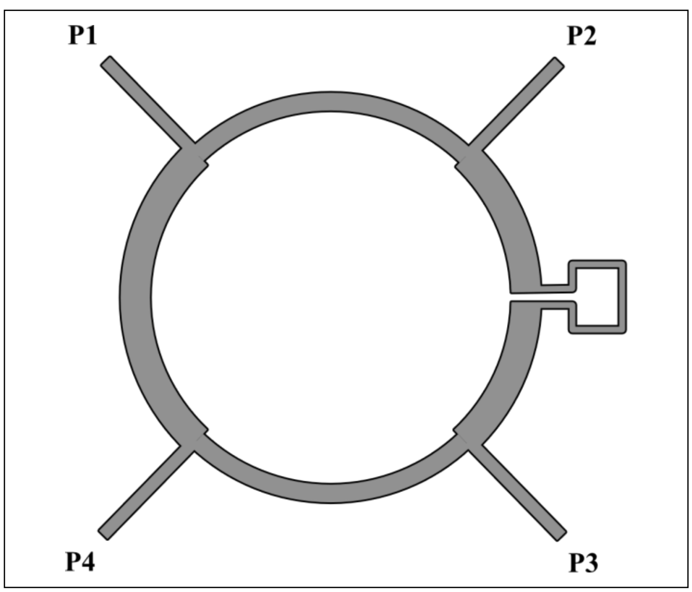

Fig (5): Old distributed coupler

This proposed coupler shown in the figure (4) has four ports, each has a length equals 2.79 mm and width equals 1.52 mm. This coupler is not a complete circle but it is a semi-circle with a radius equal to 7.62 mm. On the right side, there is a branch that looks like an arrow. Its length is around 5.35 mm, and its width is around 3.80 mm. The total length of the design is 20.32 mm, and the width is 13.71 mm. This design has a thickness H equals to 0.276 mm and, it has a dielectric constant Er that equals 2. Both results of the proposed design and old design will be presented and discussed in the following:

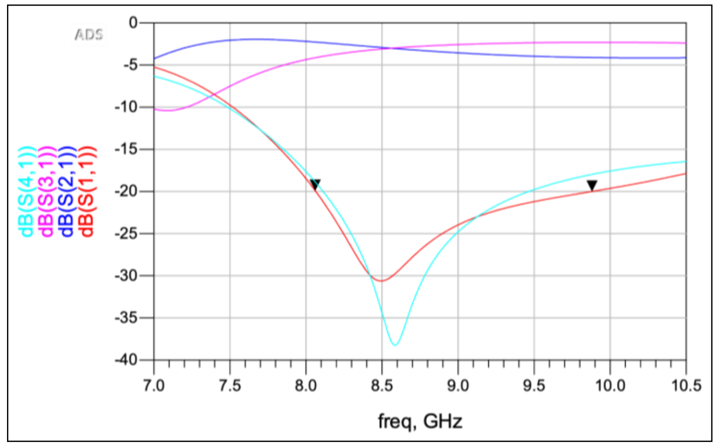

Fig (6): Simulated reflection coefficients of the proposed distributed design

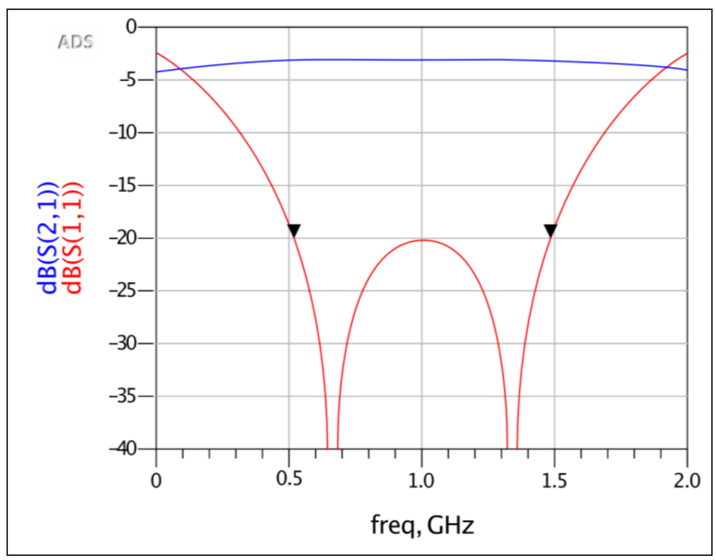

Fig (7): Simulated reflection coefficients of the old design

The comparing here is about two parameters: the return loss represented by the S(1,1), and the coupling level represented by the S(2,1).

For the proposed design results shown in the figure (6), and by looking at the return loss parameter the S(1,1), this coupler can provide a good and an acceptable bandwidth which is about 1.8 GHz under -20 dB. This bandwidth starts at 8.06 GHz and ends at 9.87 GHz. In terms of the coupling level, for the entire range of the bandwidth, the coupling level is around -3.5 dB.

On the other hand, the figure (7) shows the bandwidth of the old design. This bandwidth ranges around 0.97 GHz under -20 dB from 0.52 GHz to 1.49 GHz. Moreover, the coupling level is almost -3 dB for the whole range.

Regardless the period of the bandwidth, the bandwidth of the proposed design is wider than the bandwidth of the old design by around two times. The wider bandwidth range the coupler has, the better performance can be achieved. Regarding the coupling level, it is around -3 dB for both designs. Therefore, the both of them are equal in that point.

However, this proposed coupler can be improved and perform better by adding lumped components as it is shown in the following:

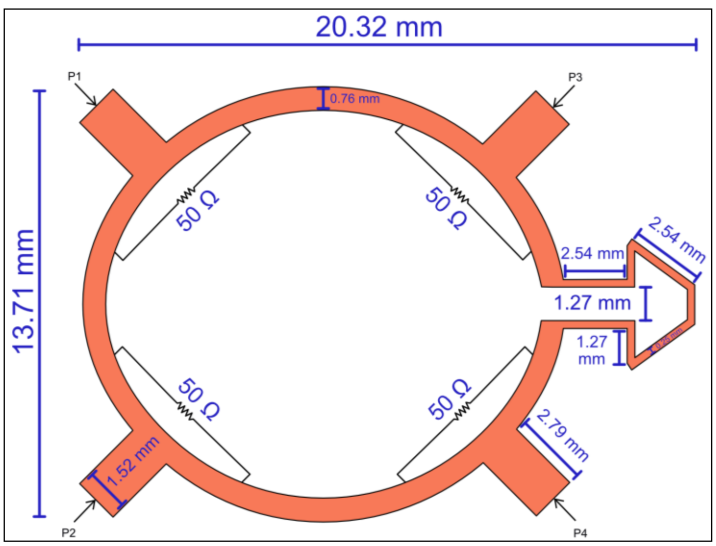

Fig (8): Proposed lumped-distributed hybrid ring coupler v1

This design is called a lumped-distributed coupler because lumped components were added to the distributed design. It can be observed that there are four lumped resisters have been added, and all of the have same value 50 Ω. Each resistor is parallel with a port. After running the simulation, the following results have been presented:

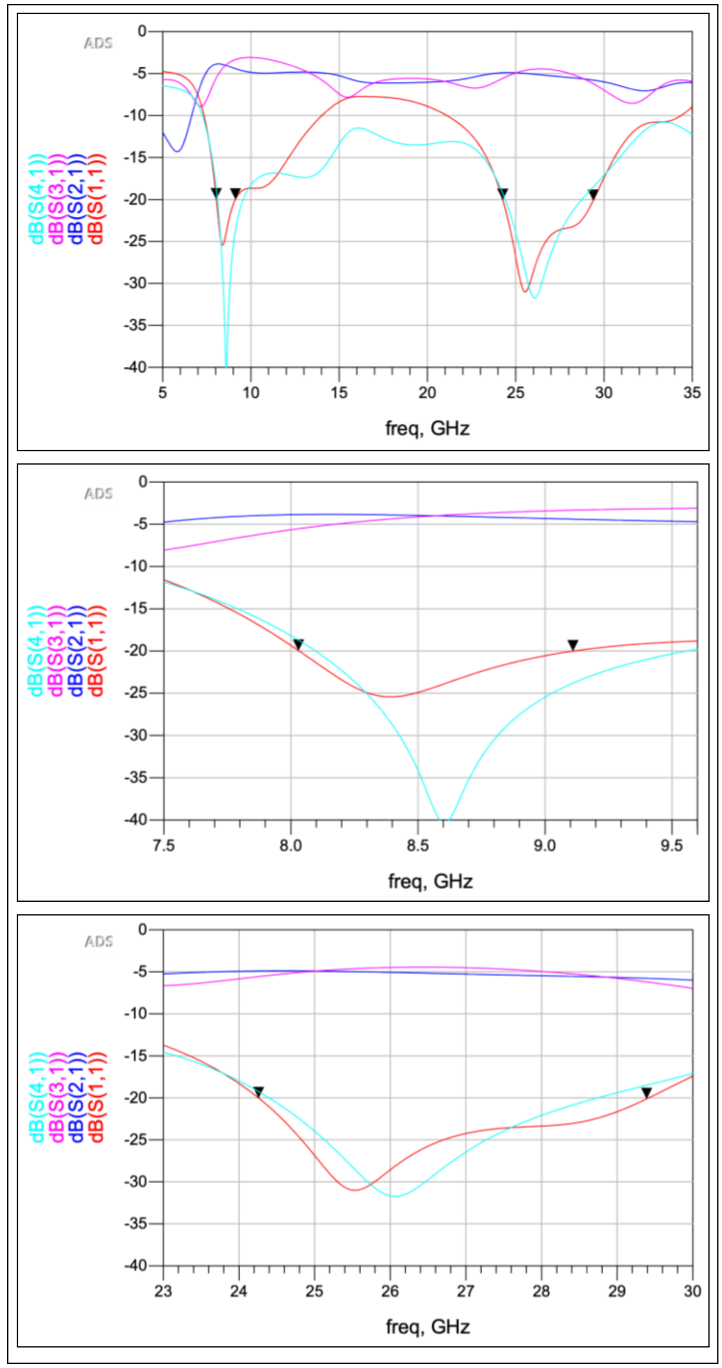

Fig (9): Simulated reflection coefficients of the proposed lumped-distributed design v1

From the figure (9), this design provides dual bandwidths: a narrow bandwidth and a wide bandwidth. According to the S(1,1), the first bandwidth is equal to 1.08 GHz below -20 dB and from 8.03 GHz to 9.11 GHz. The second bandwidth ranges 5.13 GHz under -20 dB, and from 24.26 GHz to 29.39 GHz. For the both bandwidths, the isolation level, which is represented by the S(4,1), is excellent. Therefore, the amount of losses in this coupler is ignorable. Furthermore, the coupling level, represented by the S(2,1), of the narrow bandwidth is around -4 dB, and the coupling level of the wide bandwidth is around - 5 dB. It is obvious now, adding lumped components to a distributed design is so effective, and can make a huge improvement.

In addition to that, a better performance can be accomplished by editing the design as following:

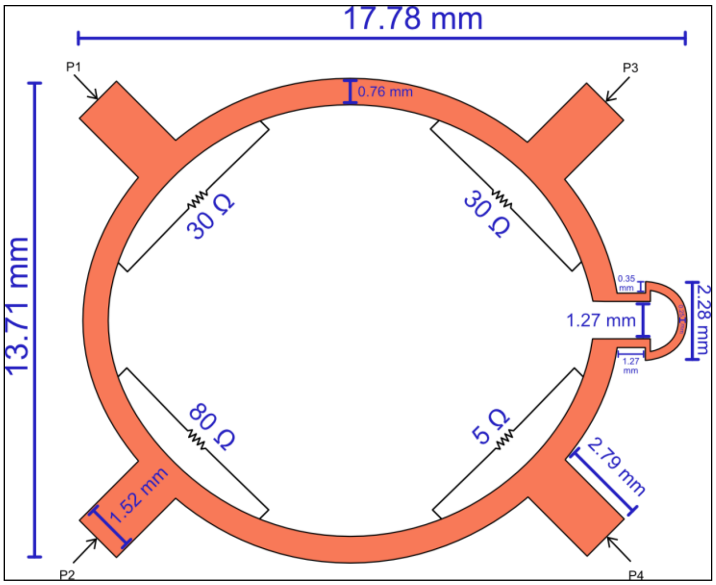

Fig (10): Proposed lumped-distributed hybrid ring coupler v2

This design in the figure (10) is smaller than the previous one by around 1.33 mm, so its total length is equal to 17.78 mm. This is because the right side polygonal branch got replaced by a curve. Apart from that, the resistors' values have been changed. Instead of having the same value of all resistors, the port1 resistor is 30 Ω, the port 2 resistor is 80 Ω, the port 3 resistor is 30 Ω, and the port 4 resistor is 5 Ω. After reusing the simulation, the impact of these changes can be noticed from the following:

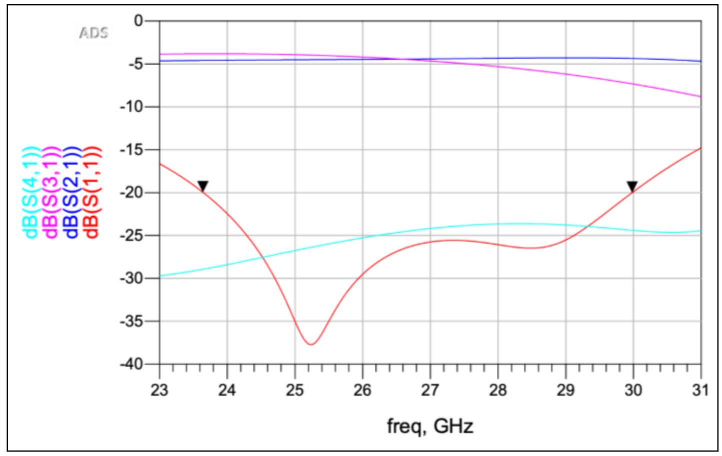

Fig (11): Simulated reflection coefficients of the proposed lumped-distributed design v2

Even though this design can only provide one bandwidth, the bandwidth is broadband. It ranges 6.25 GHz that starts at 23.64 and ends at 29.89 GHz. Moreover, all other parameters are showing very pleasant results. The isolation level is under -20 dB for the entire range of the bandwidth. The coupling level is at -5 dB level for the whole bandwidth.

Comparing these simulated results with the practical results can be done by constructing the lumped-distributed module as following:

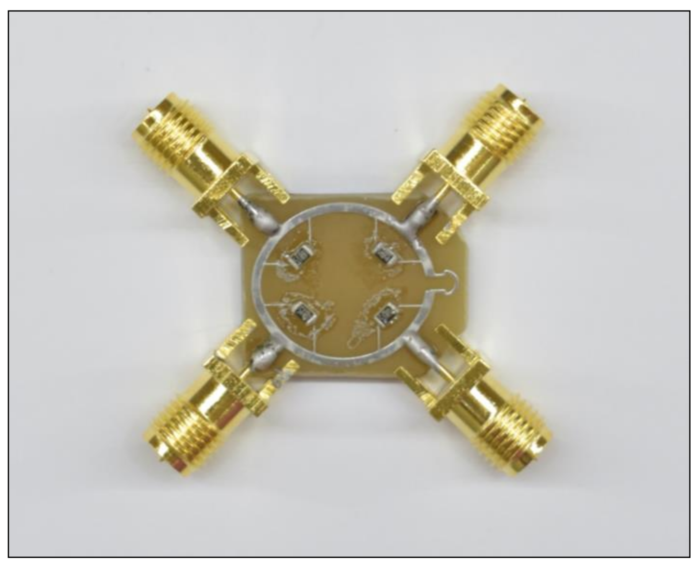

Fig (12): Front side of the module of the lumped-distributed hybrid ring coupler v2

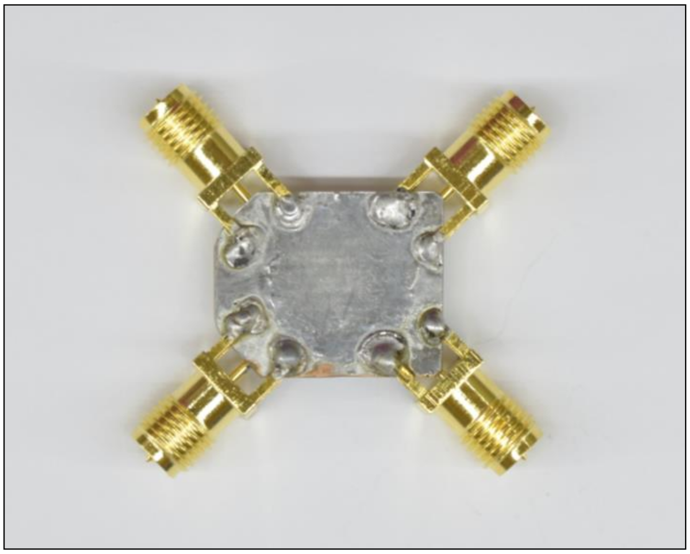

Fig (13): Back side of the module of the lumped-distributed hybrid ring coupler v2

The dimension of the design area has already been illustrated in the figure (10), and the dimensions of the SMA male connector are shown in the following:

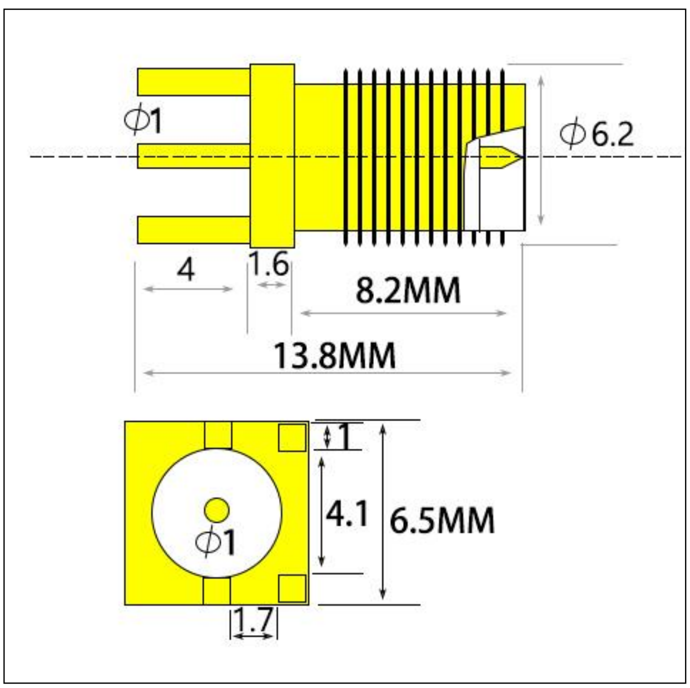

Fig (14): Dimensions of the SMA male connector

After connecting the coupler with the analyzer, the measured (practical) results have been presented in the following figure (15) in which the simulated (theoretical) results are also drawn.

The solid track refers to the simulated result, and the dashed track refers to the measured result.

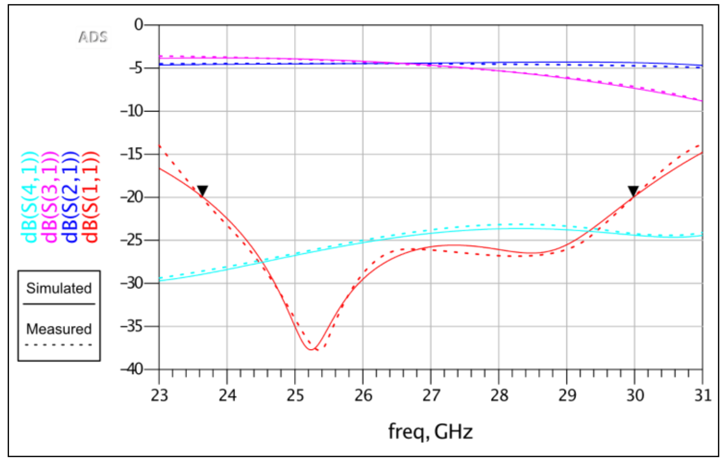

Fig (15): Reflection coefficients of the theoretical and practical lumped-distributed hybrid ring coupler v2

Overall, it can be noticed that the simulated and practical results are matching with each other. Each measured parameter aligns with its corresponding simulated parameter, and all the differences are neglected and have no impacts on the coupler performance.

V. Conclusion

In conclusion, a plenty of techniques can be used to increase the bandwidths of couplers, and to reduce the losses. While the majority of designers choose to make new designs, changing dimensions, or reshape existed designs in order to improve the performances, this paper has proved that using lumped-distributed technique is easier and powerful choice for having better results. This is attributed to the fact that adding external components is easier than editing printed circuits. Moreover, adding lumped components to a distributed design is able to convert a regular or narrow bandwidth to a broadband wide bandwidth.

References

[1] Bahl, I, J. (2003). *Lumped elements for RF and microwave circuits*. London, England: Artech House.

[2] Bharathy, G.T, Bhavanisankari, S., Tamilselvi, T., & Bhargavi, G. (2020). *Analysis and Design of RF Filters with Lumped and Distributed Elements*. International Journal of Recent Technology and Engineering. 8.38-42. 10.35940/ijrte.B1009.0782S519.

[3] Demneh, S., Abnavi, S., Beyragh, D., & Motahari, S. (2012). A lumped-element power divider/combiner suitable for high power applications. 1. 1-4. 10.1109/ICMMT.2012.6229943.

[4] Ojha, S., Bedal, L., Branner, G. R., & Kumar, B. P. (1997). *Analysis of lumped-distributed coupled lines*, Proceedings of 40th Midwest Symposium on Circuits and Systems. Dedicated to the Memory of Professor Mac Van Valkenburg, Sacramento, CA, USA, pp. 603-606 vol.1, doi: 10.1109/MWSCAS

[5] Ricketts, D., *Branchline Coupler Theory*. https://rickettslab.org/bits2waves/design/branchline-coupler/branchline-coupler-theory

[6] Sengul, M. (2007). SYNTHESIS OF MIXED LUMPED AND DISTRIBUTED ELEMENT NETWORKS. https://www.researchgate.net/publication/228764531_SYNTHESIS_OF_MIXED_LUMPED_AND_DISTRIBUTED_ELEMENT_NETWORKS

[7] Wang, T. Ke. W, "Size-reduction and band-broadening design technique of uniplanar hybrid ring coupler using phase inverter for M(H)MIC's," in *IEEE Transactions on Microwave Theory and Techniques*, vol. 47, no. 2, pp. 198-206, Feb. 1999, doi: 10.1109/22.744295.

Authors

First Author – Jihad Basuni, Grad student, Electronic and communication engineering, King Abdulaziz University. Jihad.Basuni@gmail.com

Second Author – Prof. Adnan Affandi, Electronic and communication engineering, King Abdulaziz University. adnanaffandi@yahoo.co.uk