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Effects of Injecting Lumped Components into Distributed Branch Line Coupler

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Abstract**—** *This paper presents the design and fabrication of two types of branch line couplers: a distributed branch line coupler and a lumped-distributed branch line coupler. Both couplers are designed out of uniformity. This study includes theoretical analyses, simulations, and practical measurements. Theoretical simulations closely align with the practical measurements, indicating a high degree of agreement between the coupler's performance and the theoretical predictions. The design and simulations were implemented using the Advance Design System (ADS) software.*

Keywords**—***branch line, coupler, distributed, lumped, lumped-distributed, microstrip line, transmission line*

I. INTRODUCTION

A coupler is a device that can split an incoming signal into two or more signals, allowing it to be used in multiple circuits. There are various types of couplers, including coupled line couplers, branch line couplers, and ring couplers. Designing a branch line coupler to meet specific requirements and characteristics can be challenging. However, there are several methods available to adjust these characteristics until they align with the desired specifications. One approach involves modifying the physical dimensions of the design. Altering the size can have a significant impact on the coupler's performance. Additionally, adjusting the width or length of the microstrip line can enhance its capabilities. Furthermore, most of branch line couplers have uniform shapes with straight lines and consistent widths as presented in the figure (1). However, thinking out of uniformity and introducing variations in this uniformity by incorporating curves and making the lengths or widths variable, as illustrated in the figure (2), can yield substantial improvements, and significantly enhance results. Ideas of non-uniform shapes can be found in outer environments such as the nature, arts, or any other field. Moreover, another effective method for enhancing the performance of branch line couplers involves injection lumped components into a distributed design, as shown in the figure (3). This approach can further optimize the coupler's functionality and overall performance.

II. PROPOSED DESIGN

By thinking out of uniformity, the idea of the proposed coupler design came from the nature, and precisely from clouds. Therefore, it is called the cloudy branch line coupler presented in the figure (2). Apart from uniformity, classical couplers are made of distributed elements only while the proposed coupler is made of distributed and lumped elements as it is illustrated in the figure (3).

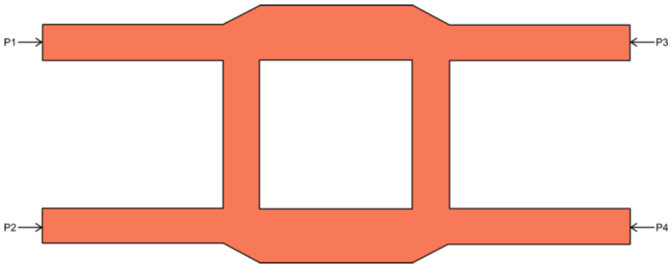

Fig (1): Conventional branch line coupler

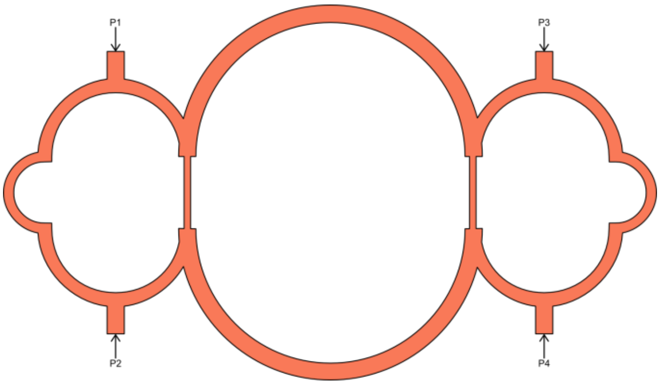

Fig (2): Cloudy distributed branch line coupler

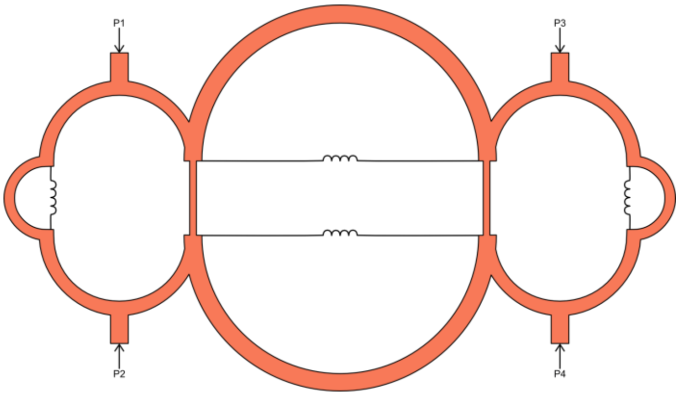

Fig (3): Cloudy distributed branch line coupler

III. THEORETICAL ANALYSES

A. *Even mode analysis of the branch line coupler:*

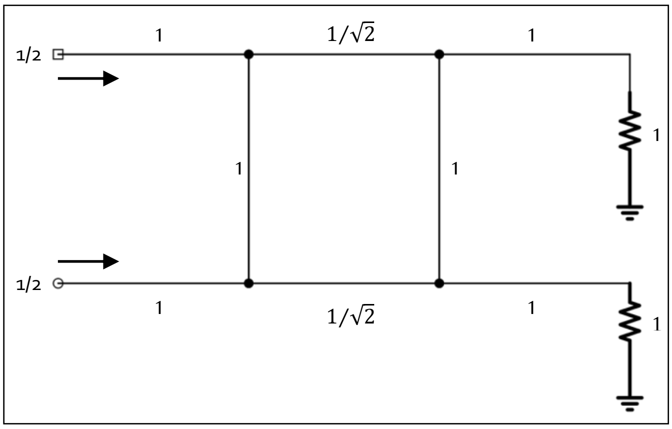

Fig (4): Even mode normalized impedance circuit

$$\begin{pmatrix}A & B\\ C & D\end{pmatrix}_e = [\lambda/8Stub][\lambda/4TL][\lambda/8Stub]$$

$$= \begin{pmatrix}1 & 0\\ Y & 1\end{pmatrix}\begin{pmatrix}cos\beta\ell & jZ_o sin\beta\ell\\ j/Z_o sin\beta\ell & cos\beta\ell\end{pmatrix}\begin{pmatrix}1 & 0\\ Y & 1\end{pmatrix}$$

$$= \begin{pmatrix}1 & 0\\ j & 1\end{pmatrix}\begin{pmatrix}0 & j/\sqrt{2}\\ j\sqrt{2} & 0\end{pmatrix}\begin{pmatrix}1 & 0\\ j & 1\end{pmatrix}$$

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

$$\Gamma_e = \frac{A+B-C-D}{A+B+C+D} = \frac{(-1+j-j+1)/\sqrt{2}}{(-1+j+j-1)/\sqrt{2}} = 0 \qquad \{1\}$$

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

B. *Odd mode analysis of the branch line coupler:*

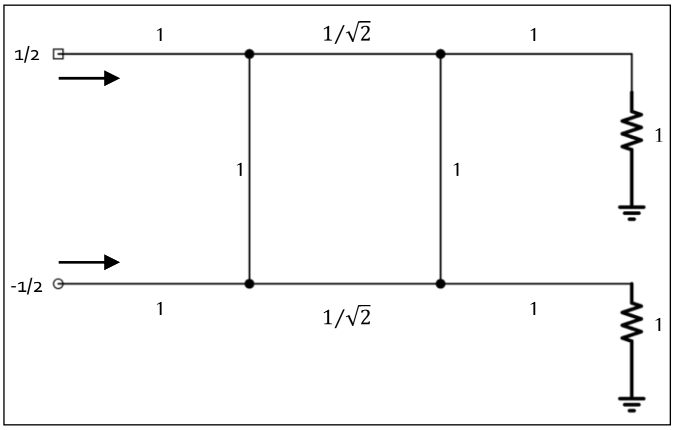

Fig (5): Odd mode normalized impedance circuit

$$\begin{pmatrix}A & B\\ C & D\end{pmatrix}_o = [\lambda/8Stub][\lambda/4TL][\lambda$$

$$= \begin{pmatrix}1 & 0\\ Y & 1\end{pmatrix}\begin{pmatrix}cos\beta\ell & jZ_o sin\beta\ell\\ j/Z_o sin\beta\ell & cos\beta\ell\end{pmatrix}\begin{pmatrix}1 & 0\\ Y & 1\end{pmatrix}$$

$$= \begin{pmatrix}1 & 0\\ -j & 1\end{pmatrix}\begin{pmatrix}0 & j/\sqrt{2}\\ j\sqrt{2} & 0\end{pmatrix}\begin{pmatrix}1 & 0\\ -j & 1\end{pmatrix}$$

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

$$\Gamma_o = \frac{A+B-C-D}{A+B+C+D} = \frac{(1+j-j-1)/\sqrt{2}}{(1+j+j+1)/\sqrt{2}} \qquad \{3\}$$

$$T_o = \frac{2}{A+B+C+D} = \frac{2}{(1+j+j+1)/\sqrt{2}} \qquad \{4\}$$

Using equations {1},{2},{3},{4} in order to combine both modes, and then getting 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

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

$B_4 = 1/2(\Gamma_e - \Gamma_o) = 0$ P4 is isolated

These B1, B2, B3, B4 values are for the first row of the following S matrix:

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

The signal flow of the branch line coupler:

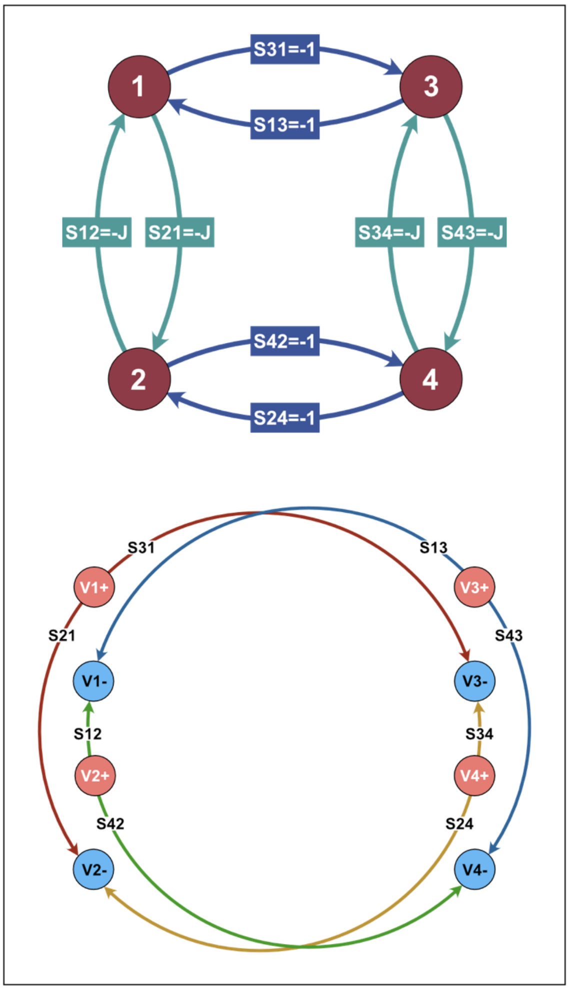

Fig (6): The signal flow of the branch line coupler

IV. DESIGN AND IMPLEMENTATION

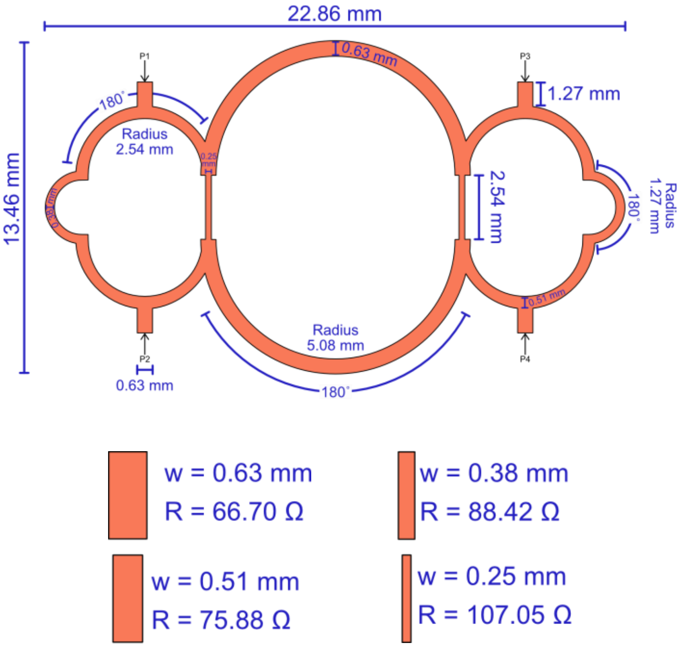

Fig (7): Impedance and dimensions of the cloudy distributed branch line coupler

This branch line coupler is symmetrical, and it has four ports. The port 1 and port 3 are located on the upper side, while ports 2 and 4 are located on the lower side. As shown in the figure (7), the overall length of the design measures 22.86 mm, while the total width is 13.46 mm. All curves are half circles with an angle equals 180˚. All other dimensions are clearly indicated and presented in the same figure. Furthermore, the impedance of each microstrip line varies with its width. The wider width the line has, the smaller resistance it gets and vice versa. The thickness of the design is H = 0.305 mm, and the dielectric constant is Er = 2. The impedance of the transmission lines depends on their widths. A wider transmission line has a smaller impedance and vice versa. For instance, the transmission line with 0.63 mm width has an impedance that equals 66.70 Ω, and what it has 0.51 mm width has 75.88 Ω. The other two widths are 0.38 mm and 0.25 mm, and their impedance values equal 88.42 Ω and 107.05 Ω respectively. After running the simulation, the following result was obtained:

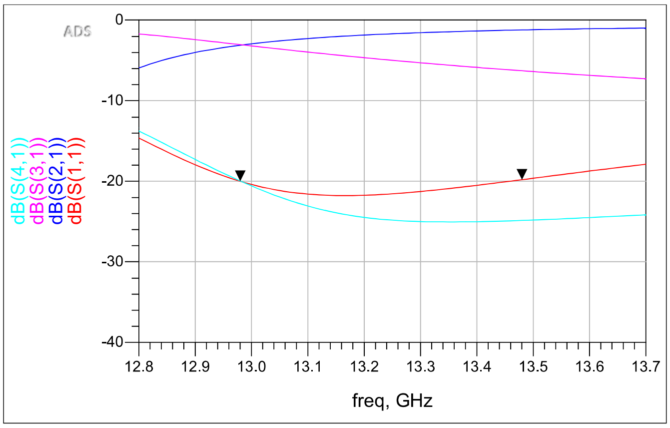

Fig (8): Simulated reflection coefficients of the cloudy distributed branch line coupler

Unfortunately, the results of this distributed coupler is not good enough for real applications as shown in the figure (8). Therefore, the first choice to get pleased results is changing the design: the shape, or dimensions, but there is another option which is adding lumped components with keeping the same shape and dimensions. Before presenting the lumped-distributed design, the result of this distributed design will be discussed.

It is obvious form the graph the S(1,1), which refers to the return loss of the port 1, is not considered as a perfect result. This is because if the S(1,1) above -20 dB, it means that there is a reflection on the same port. Therefore, the bandwidth can be determined with a small range less than 1 GHz under -20 dB. Precisely, the period from 12.98 GHz to 13.48 GHz, which is 0.5 GHz, is the only period for this coupler to have almost zero reflection, so it is not good enough because it is so small. During this range, which is under -20 dB for the S(1,1), the coupling level S(3,1) is dicreasing from -2.5 dB to around -6 dB, and the central frequency is around 13.16 GHz. Better results can be achieved using the lumped-distributed technique as shown in the following:

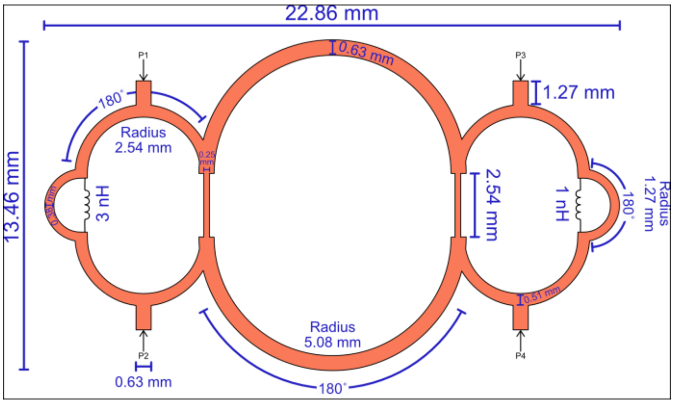

Fig (9): Dimensions of the cloudy lumped-distributed branch line coupler v1

From the figure (9), there are two lumped inductors have been added to the distributed design. Therefore, it becomes lumped-distributed coupler. The first inductor is 1 nH connected in parallel with the 180˚ curve on the right side. The other one is 3 nH connected in parallel with the 180˚ curve as well but on the left side. After running the simulation, the results got improved significantly.

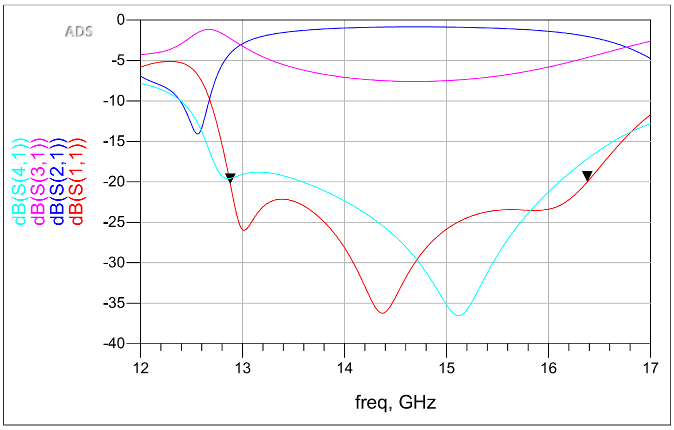

Fig (10): Simulated reflection coefficients of the cloudy lumped-distributed branch line coupler v1

The bandwidth range jumps from 0.5 GHz to 3.5 GHz. This 3.5 GHz starts at 12.88, and it ends at 16.38 GHz. On the graph, the bandwidth is represented by the S(1,1) which is the input port. The S(3,1) represents the coupling port, and the coupling level here is around -7.5 dB. The S(2,1) refers to the transmitted port which is the output port. The isolated port is represented by the S(1,4) which is very good here because for the whole range is almost under -20 dB. This means that the reflection is almost zero, and hence there is no any effective loss. However, adding another two inductors can also improve the performance of the coupler as shown in the following:

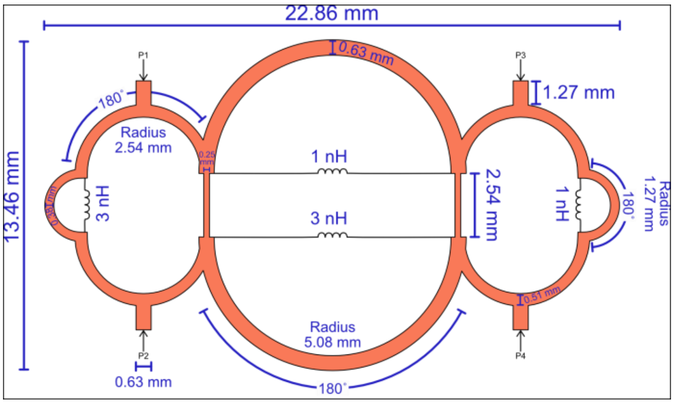

Fig (11): Dimensions of the cloudy lumped-distributed branch line coupler v2

The figure (11) is the second version of the cloudy branch line coupler. Similar to the previous version, it is a lumped-distributed coupler, but instead of having only two inductors, it has four inductors. It has two of 3 nH inductors, and two of 1 nH inductors. The following results were obtained:

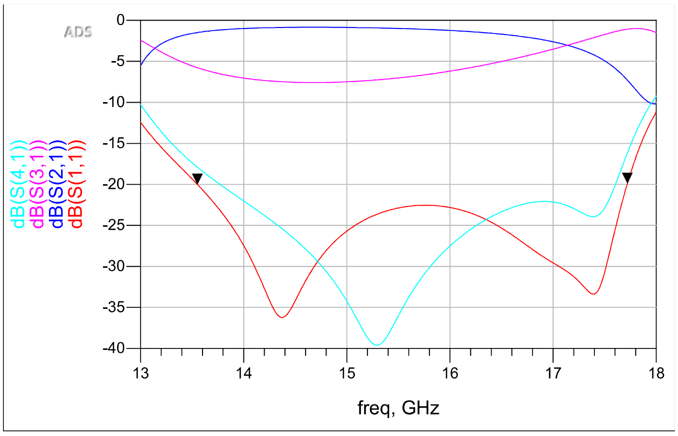

Fig (12): Simulated reflection coefficients of the cloudy lumped-distributed branch line coupler v2

Adding these two inductors is worth it because the bandwidth became wider by more than 0.7 GHz. With only two inductors, the bandwidth was 3.5 GHz, but now after adding two more inductors, the bandwidth becomes 4.17 GHz under - 20 dB. This range starts from 13.55 GHz and ends at 17.72 GHz. The bandwidth is represented by the S(1,1) which is the return loss coefficient. The isolation coefficient is represented by the S(4,1), and from the graph is under - 20 dB for the 4.17 GHz bandwidth. The coupling level is at around - 7.5 dB, and the central frequency is 14.33 GHz. To compare these results with the practical results, the lumped-distributed module has to be constructed as shown in the following figure:

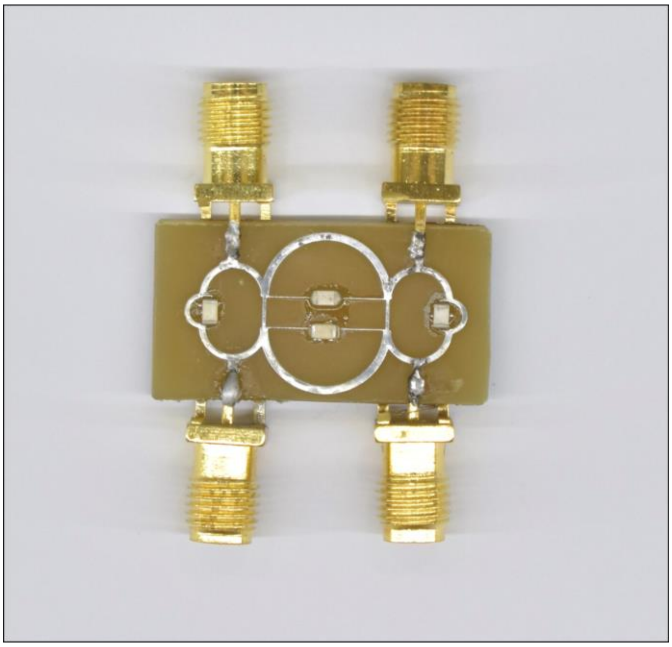

Fig (13): Front side of the module of the cloudy lumped-distributed branch line coupler v2

Fig (14): Back side of the module of the cloudy lumped-distributed branch line coupler v2

The dimensions of the proposed design have already been presented in the figure (7), and the dimensions of the SMA male connector are shown in the following:

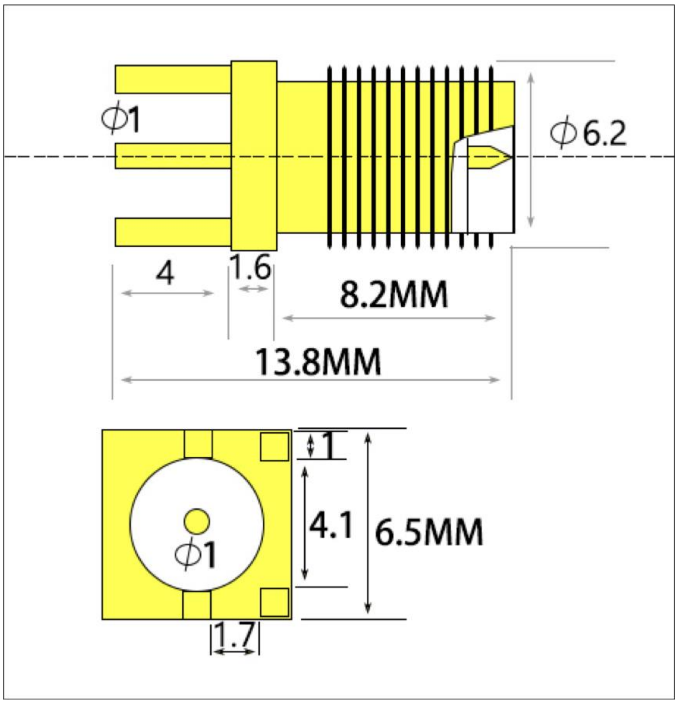

Fig (15): Dimensions of the SMA male connector

Upon connecting the coupler to the analyzer, the practical results were obtained and depicted in the following figure. The figure displays both the simulated (theoretical) results represented by the solid line and the measured (practical) results represented by the dashed line.

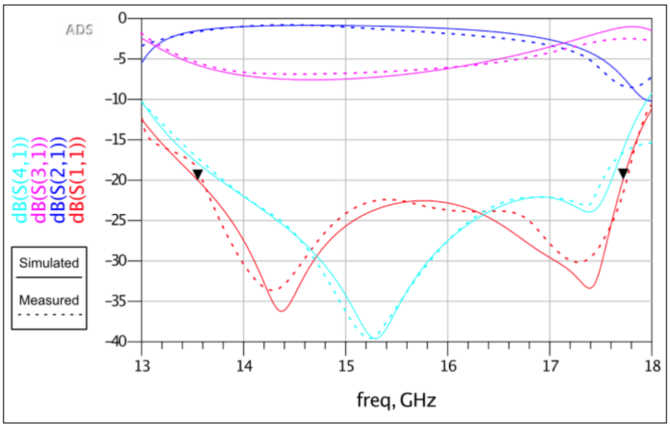

Fig (16): Reflection coefficients of the simulated and fabricated cloudy lumped-distributed branch line coupler v2

It can be noted that each measured parameter aligns with its corresponding simulated parameter, and all the differences are minor and neglected because they have no negative impacts on the performance of the coupler.

V. CONCLUSION

To sum up, while uniformity controls most of coupler designs, thinking out of uniformity is a powerful technique to design or redesign couplers. This study proved that the non-uniformity can effectively enhance the performance and transform a conventional branch line coupler into a broadband coupler. Additionally, it also has been shown and proved that the ability of injecting a distributed coupler with lumped components in order to improve the results. The lumped-distributed approach can convert a regular bandwidth into a broadband bandwidth.

REFERENCES

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

[2] E. Bogatin, (2010) *Signal and Power Integrity – Simplified*, 2^{nd} Ed, Ann Arbor, Michigan, USA : Edwards Brothers.

[3] G. T. Bharathy, S. Bhavanisankari, T. Tamilselvi, G. Bhargavi, (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.

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

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

[6] S. Demneh, S. Abnavi, D. Beyragh, S. Motahari, (2012). A lumped-element power divider/combiner suitable for high power applications. 1. 1-4. 10.1109/ICMMT.2012.6229943.
S. Ojha, L. Bedal, G. R. Branner, B. P. Kumar, (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.