ULTRA-BROADBAND LUMPED-DISTRIBUTED BRANCH LINE COUPLER IN NON-UNIFORMITY

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Abstract— a distributed broadband branch line coupler and a lumped-distributed ultra-broadband branch line coupler are designed and fabricated. Both couplers are designed in non-uniformity. Theoretical analyses, simulations, and practical measurements are conducted in this paper. Moreover, the ability of the proposed lumped-distributed coupler shows ultra-broadband operation. The theoretical simulation is not far of the practical measurement, and it is showing slight differences. This indicates that this coupler almost fully agreed with the theoretical result. The design and the simulation are done using the Advance Design System (ADS) software.

Keywords— branch line, broadband, coupler, distributed, lumped, lumped-distributed, microstrip line, transmission line, ultra-broadband

I. INTRODUCTION

In brief, a coupler is a device that can split and divide an incoming signal to two signals or more, so the signal can be used in more than one circuit. There are different types of couplers such as coupled line couplers, branch line couplers, and ring couplers. Designing a branch line coupler to match specific features and characteristics is not that easy. There are a number of methods to edit these characteristics till they match the requirements. For instance, changing a size of a design can make huge difference in the results, also changing the width or the length of a strip line can improve the performance. Furthermore, another method has been founded in this paper which is the non-uniformity. It is obvious that most of the branch line couplers have uniform shape with straight lines and same widths as shown in the figure (1). However, changing this uniformity by adding curves and making the lengths or widths variant like what is shown in the figure (2) can make a big difference and enhance the results. Moreover, another effective way to improve a branch line performance is adding lumped components to the distributed design like what is shown in the figure (3).

II. PROPOSED DESIGN

The conventional branch line coupler is shown in the figure (1), the proposed couplers are shown in the figures (2), (3). The uniformity can be seen from the figure (1), but the non-uniformity can be noted from the figures (2), (3). In addition, the figure (3) presents the lumped-distributed branch line coupler.

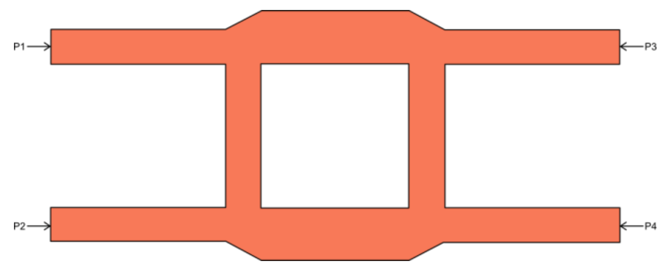

Fig (1): conventional branch line coupler

Fig (2): Proposed distributed branch line coupler

Fig (3): Proposed lumped-distributed branch line coupler

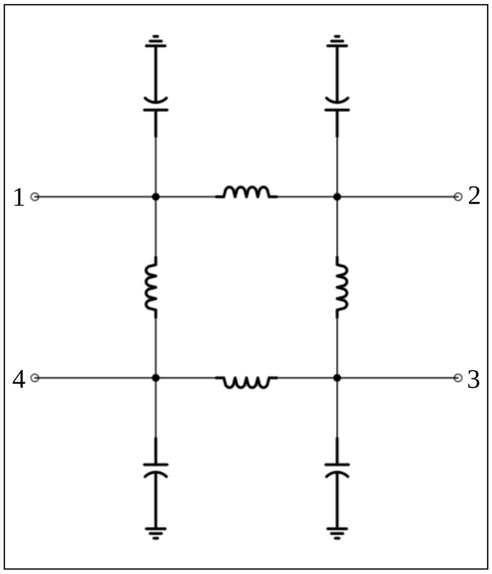

Fig (4): Equivalent circuit of the branch line

III. Theoretical Analyses

A. Even mode analysis of the branch line coupler:

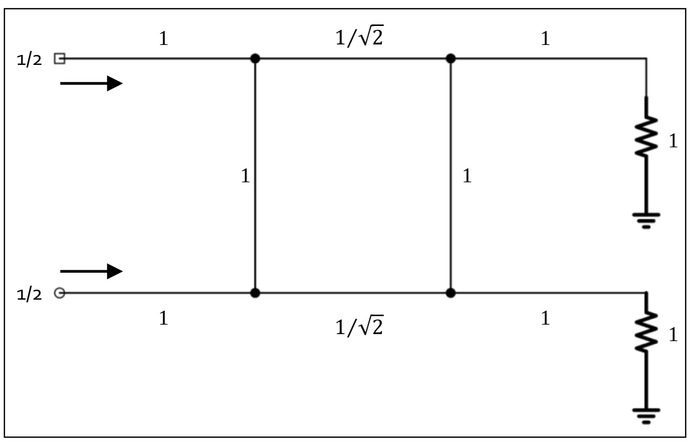

Fig (5): Even mode normalized impedance circuit

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

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

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

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

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

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

B. Odd mode analysis of the branch line coupler:

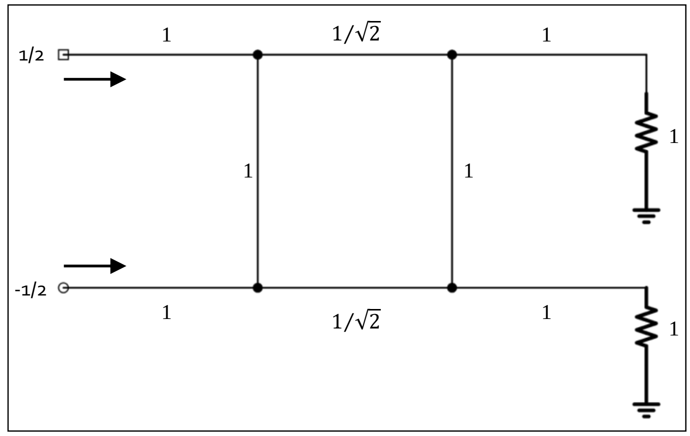

Fig (6): Odd mode normalized impedance circuit

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

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

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

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

$$\Gamma_o = \frac{A+B-C-D}{A+B+C+D} = \frac{(1+j-j-1)/\sqrt{2}}{(1+j+j+1)/\sqrt{2}} = 0 \quad \{3\}$$

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

Using {1},{2},{3},{4} to combine both modes, and hence 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

$B_3 = 1/2(T_e - T_o) = -1/\sqrt{2}$ 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:

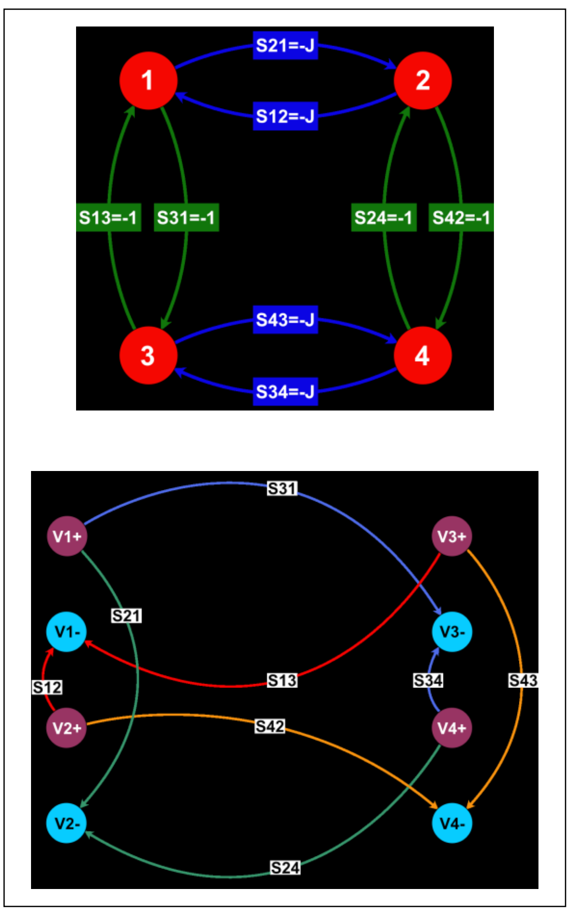

Fig (7): The signal flow of the branch line coupler

IV. Design and Implementation

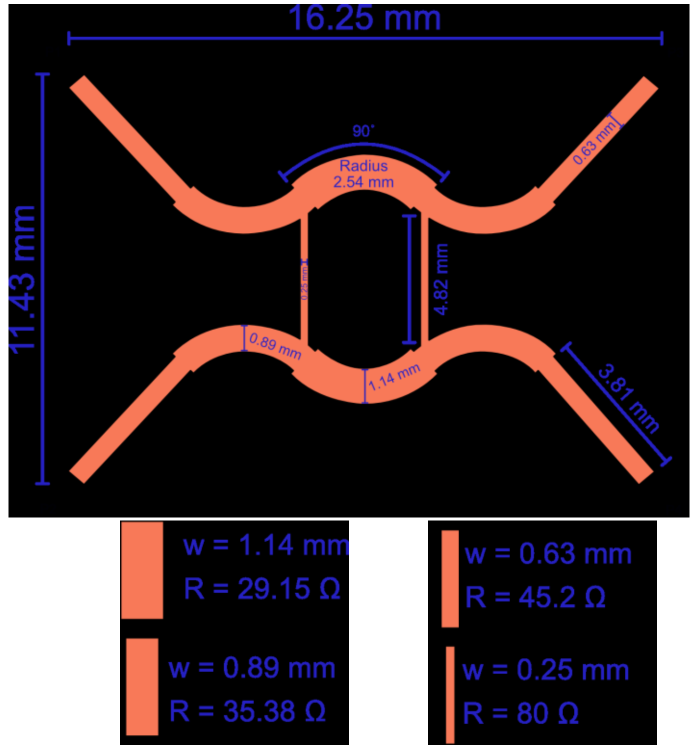

Fig (8): Impedance and dimensions of the proposed distributed branch line coupler

This branch line is non-uniform, but it is symmetrical. As shown in the figure (8), the port 1 and port 3 on the up side, but the port 2 and the port 4 on the bottom side. The up side and the bottom side are connected by two lines with the length equals 4.82 mm and the width equals 0.25 mm. Each side, the bottom and the upper, has five microstrip lines. Two straight lines with the length equals 3.81 mm, and the width equals 0.63 mm. In addition, three curves with a radius that equals 2.54 mm and an angle that equals 90 degrees. The total length of the design is 16.25 mm, and the width is 11.43 mm. The thickness of the design is H = 0.381 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. Therefore, the transmission line with 1.14 mm width has impedance that equals 29.15 Ω, and what it has 0.89 mm width has 35.38 Ω. The other two widths are 0.63 mm and 0.25 mm, and their impedance values equal 45.20 Ω and 80 Ω respectively. After running the simulation, the following result was presented:

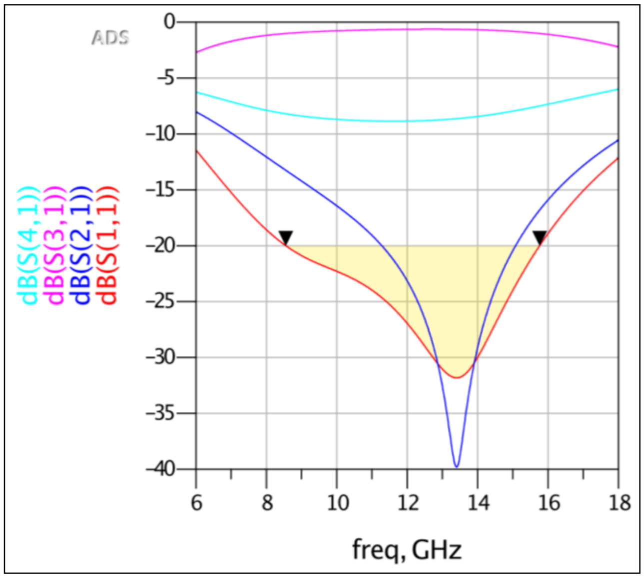

Fig (9): Simulated reflection coefficients of the distributed branch line coupler

From the figure (9) the S(1,1) is the return loss, the S(2,1) is the isolation, the S(3,1) is the transmission, and the S(4,1) is the coupling. Therefore, it can be seen that the proposed design can provide a very wide bandwidth which is equal to 7.21 GHz. This starts from 8.55 GHz to 15.76 GHz, and this bandwidth range is always taken under -20 dB. The central frequency is 13 GHz, and the coupling level of this design is at around -9 dB. This result is a theoretical, so it is needed to be compared with a practical result. Thus, building and composing the module is the first step as shown in the following figure:

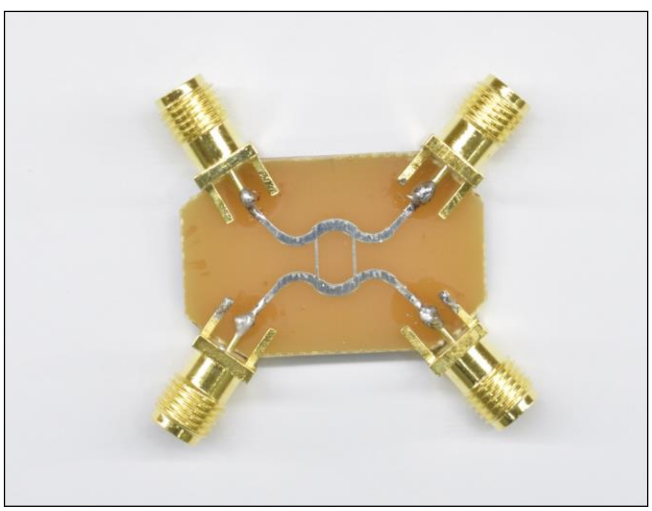

Fig (10): Front side of the module of the proposed distributed branch line coupler

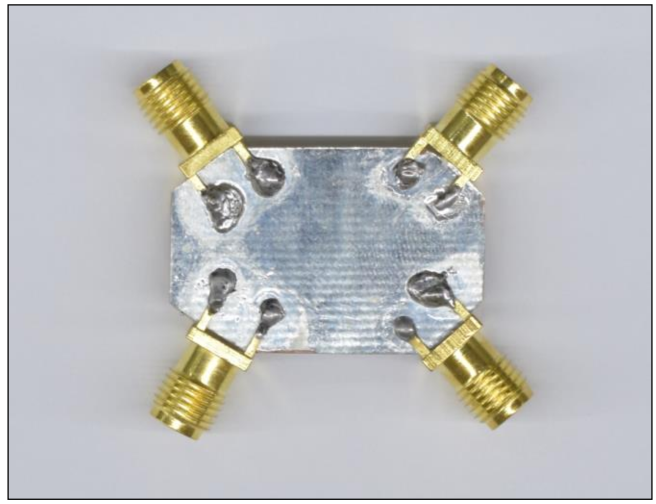

Fig (11): Back side of the module of the proposed distributed branch line coupler

The dimension of the transmission line area has already been presented in the figure (8), and the dimensions of the SMA female connector are shown in the following:

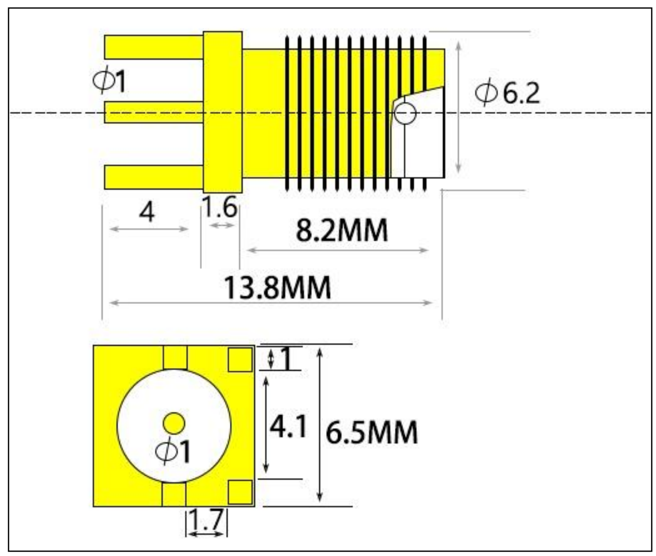

Fig (12): Dimensions of the SMA female connector

After connecting the coupler to the analyzer, the practical result has been presented in the next figure in which both results are drawn. The solid track refers to the simulated (theoretical) results, and the dashed track refers to the measured (practical) results.

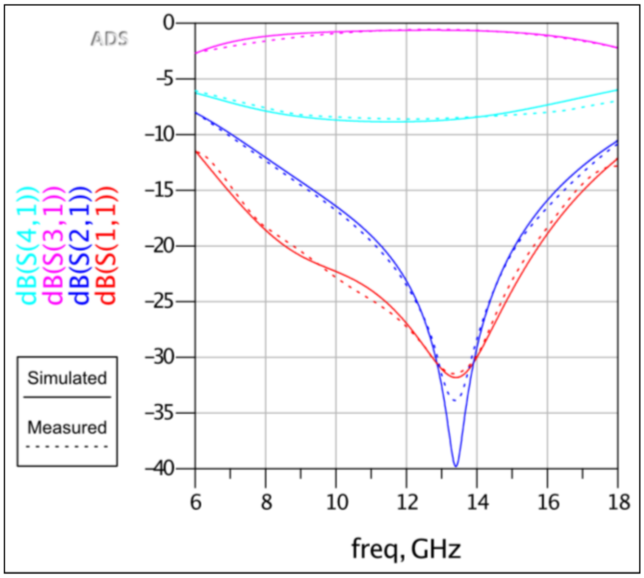

Fig (13): Reflection coefficients of the simulated and fabricated distributed branch line coupler

After seeing both results, it can be said that generally, both results are almost matched with tiny minor differences. For instance, the bandwidth of the simulated S(1,1) is 7.21 GHz while the bandwidth of the measured S(1,1) is 6.96 GHz under -20 dB, which starts from 8.72 GHz to 15.68 GHz. However, these minor differences can be neglected because they do not have serious effects on the performance of the coupler. In order to enhance this result, lumped elements had to be added like what is shown in the figure (14).

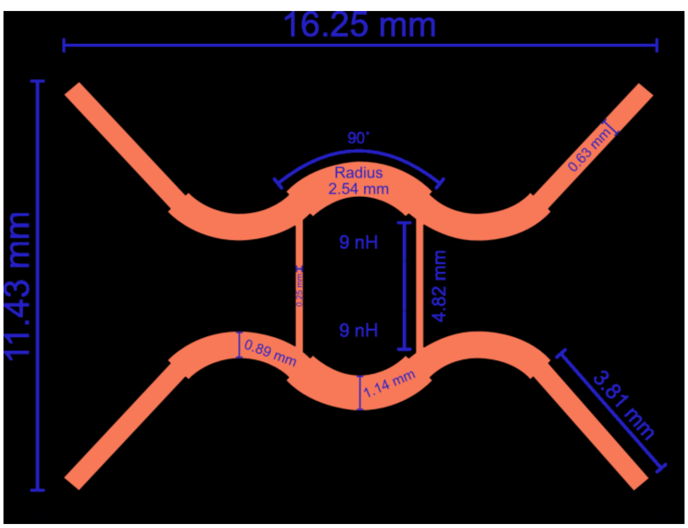

Fig (14): Impedance and dimensions of the Proposed lumped-distributed branch line coupler

It is obvious that there are two lumped inductors have been added to the distributed design, and each one has a value that is equal to 9 nH. It is also clear that there is no any change in the dimensions, but adding these indicators creates a big improvement in the performance of the coupler as shown in the following figure:

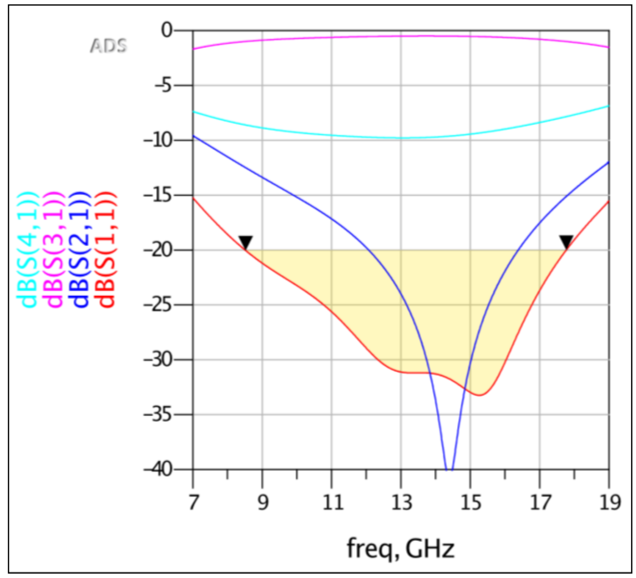

Fig (15): Simulated reflection coefficients of the lumped-distributed branch line coupler

It can be seen that after adding the two inductors, the bandwidth becomes larger by 2.04 GHz. It was 7.21 GHz, but now becomes 9.25 GHz under -20 dB. This starts from 8.52 GHz to 17.77 GHz. The theoretical coupling level of this coupler is around -9 dB and so near to -10 dB. The central frequency is around 15.5 GHz. To compare these results with the practical results, the lumped-distributed module has to be constructed as shown in the following figure:

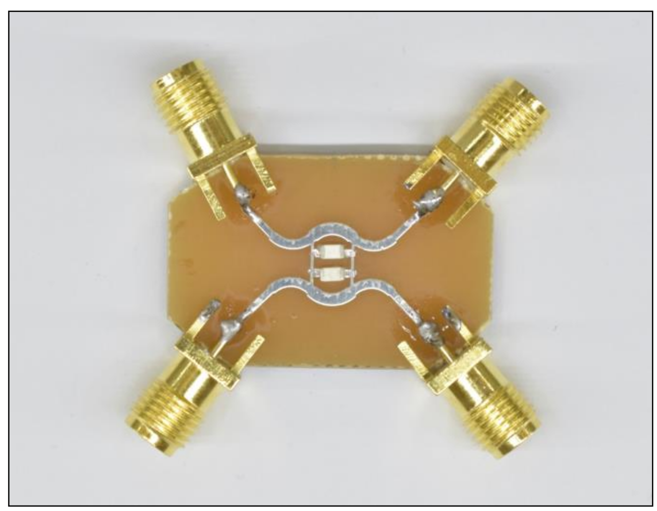

Fig (16): Front side of the module of the proposed lumped-distributed branch line coupler

It is obvious from the figure (16) that there are two lumped inductors have been added to the coupler. After connecting the coupler to the analyzer, the practical result has been presented in the next figure in which both results are drawn.

The solid track refers to the simulated (theoretical) results, and the dashed track refers to the measured (practical) results.

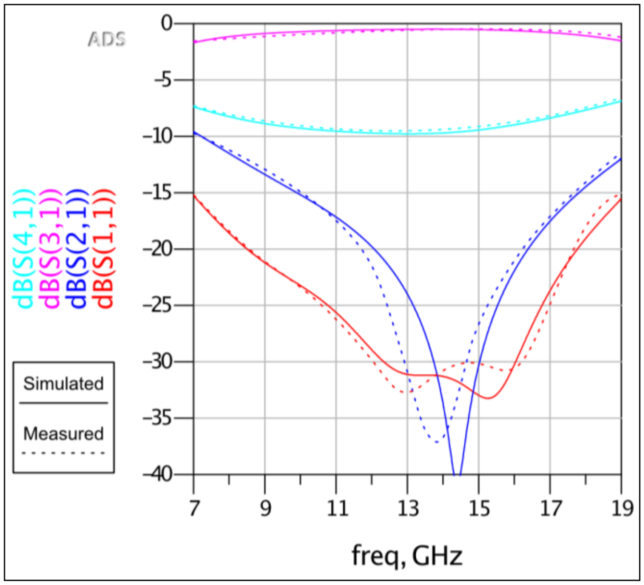

Fig (17): Reflection coefficients of the simulated and fabricated lumped-distributed branch line coupler

Each measured parameter is matching its equivalent simulated parameter, and all the differences are neglected because they have no effects on the performance of the coupler. This coupler can provide a very wide bandwidth that is equal to 9.25 GHz.

V. Conclusion

To conclude, there are a number of ways to design or redesign a branch line. While most of designers go for uniformity, this paper proved that the non-uniformity is able to enhance the results and convert the conventional branch line coupler to the broadband coupler. Moreover, it also has been approved that adding lumped components to a distributed design is able to improve the results and convert the conventional branch line coupler to the ultra-broadband coupler.

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