Novel Lumped-Distributed Variable Coupler

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DOI: 10.29322/IJSRP.13.09.2023.p14132
https://dx.doi.org/10.29322/IJSRP.13.09.2023.p14132

Abstract— a variable lumped-distributed branch line coupler with three selected coupling levels is designed and proposed in this paper. This variable coupler combines three separate couplers. Each coupler has its own coupling level and bandwidth. The first coupler is a distributed, and the second and third couplers are lumped-distributed. A comparison between simulated and practical results is covered in this study. Minor and ignorable differences between the simulated and practical results are found, so this coupler closely aligns with the theoretical results. Moreover, 3D designs and fabrications are executed and included in this paper. Circuit designs and their simulations are implemented using the Advance Design System (ADS) software.

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

I. INTRODUCTION

Briefly, a coupler is a device that has ability to divide an incoming signal to two signals or more according to the number of its ports. Therefore, if it has four ports, it divides an incoming signal to two signals, and also it can combine two incoming signals to become one signal. Since the invention of the coupler, most of couplers have been built of distributed elements such as transmission lines and microstrips lines. Furthermore, since that time, the coupler has been known as a fixed value device that can work only in a determined bandwidth range and at specific coupling level. However, a novel unique technique has been found by which a huge jump in the telecom field can be achieved. This technique is called lumped-distributed in which couplers can be built of microstrip lines and lumped components such as resistors, capacitors, and inductors in the same circuit. Adding lumped components to distributed couplers play an effective role in impedance matching. Additionally, coupling levels of distributed couplers can be controlled by adding lumped components. Moreover, using lumped-distributed technique is able to convert ordinary couplers to broadband or ultra-broadband couplers that have very wide bandwidths. Apart from that, by using lumped-distributed technique, it is possible to have variable couplers that can be set and adjusted to desired coupling levels and bandwidths.

II. PROPOSED DESIGN

The proposed designs of the variable coupler are presented in the figures (1) and (2). The first figure shows the proposed 3D module of this variable coupler while the coupler circuit diagram can be seen in the second figure.

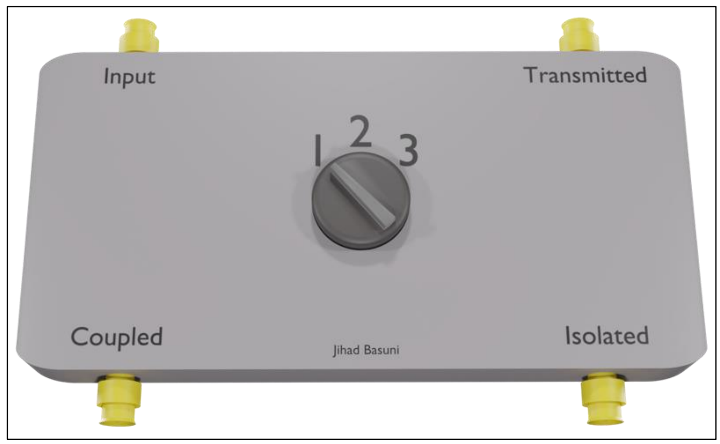

Fig (1): Proposed 3D module of the variable coupler

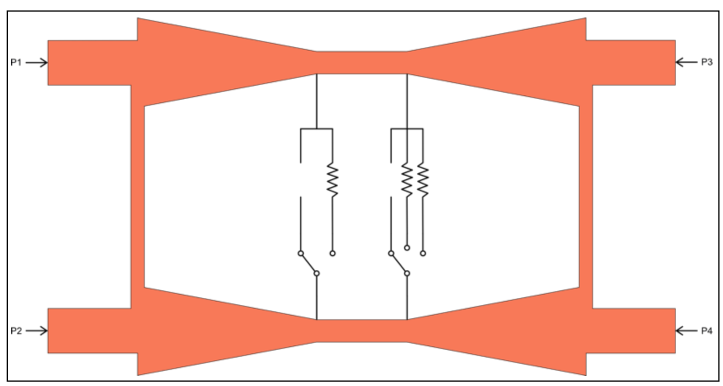

Fig (2): Proposed circuit diagram of the variable coupler

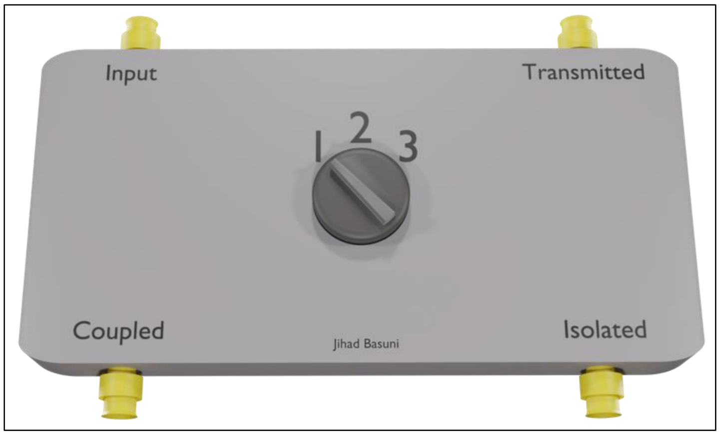

Fig (3): The front side of the 3D module of the variable coupler

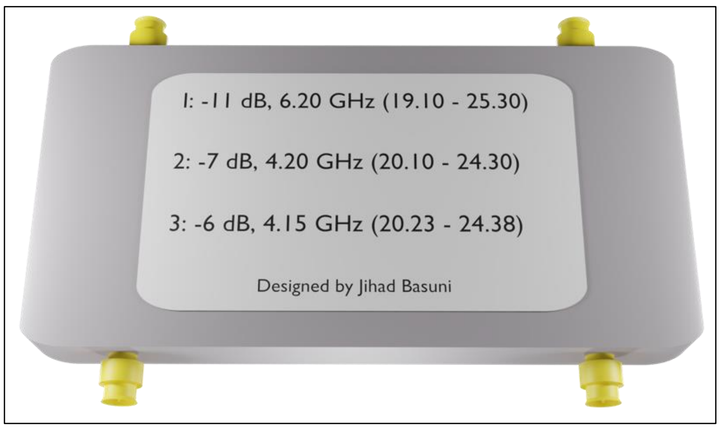

Fig (4): The back side of the 3D module of the variable coupler

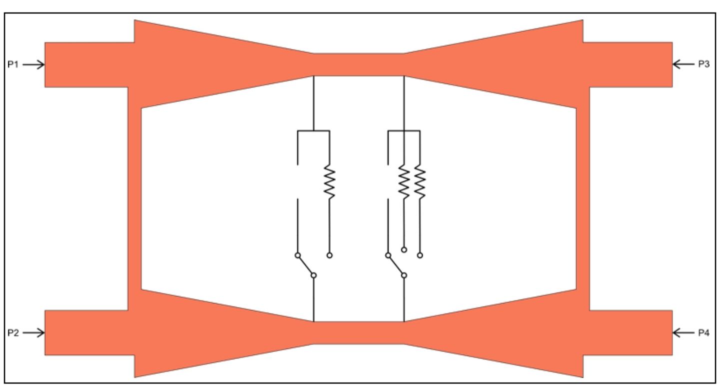

Fig (5): Internal design of the variable coupler

The figure (3) shows the front side of the variable coupler in which there are four ports and one manual rotary switch. The first port is the input port used to get a signal inside the coupler. Then, the signal gets divided to two signals. One part goes toward the transmitted port as a main output signal while the other part passes to the coupled port as a coupled signal. The splitting of the input signal is not happened equally in most of cases. In fact, this depends on the coupling level of the coupler. The only case in which the input signal can be divided equally is if the coupling level equals -3 dB. On the other hand, if the coupling level equals -6 dB, three quarters of the input signal goes to the transmitted port, and only one quarter of the input signal goes to the coupled port. The fourth port is the isolated port, and it is used to prevent any amount of signal from going out of the coupler.

In terms of the rotary switch, it is used to change the coupling level of the coupler by changing the value of the lumped components. This rotary switch has three positions, and each position has a certain coupling level and a certain bandwidth range. As it is shown in the figure (4), the first position has -11 dB coupling level, and it has 6.20 GHz bandwidth range. This coupling level means that only one part of twelve parts of the input signal is coupled, and the remaining eleven is transmitted as main output. The second position has a coupling level at -7 dB, and its bandwidth ranges 4.20 GHz from 20.10 GHz to 24.30 GHz. -7 dB coupling level indicates that only a fifth of the input signal is coupled, and four fifths of the input signal are transmitted. The third position has a bandwidth that ranges 4.15 GHz, and it has a coupling level at -6 dB. Thus, only one variable coupler is equivalent to three different couplers.

In addition to that, from the both figures (3) and (4), it can be noticed that there are four SMA connectors. These connectors are used to connect couplers to a signal analyzer. It comes in two types: male and female.

The figure (5) illustrates that there are two sets of lumped components. The first set is formed of an open circuit and a lumped resistor. By a mechanical switch, a desired option can be chosen. The second set is formed of an open circuit and two lumped resistors with different values. Similar to the first set, the second set is also connected to a mechanical switch used to choose the right lumped component to be connected to the coupler.

III. Design and Implementation

For this variable coupler there are three cases. Choosing the required case is by setting the rotary switch position. Each case is simulated, studied, and discussed individually:

A. First case: the rotary switch at 1

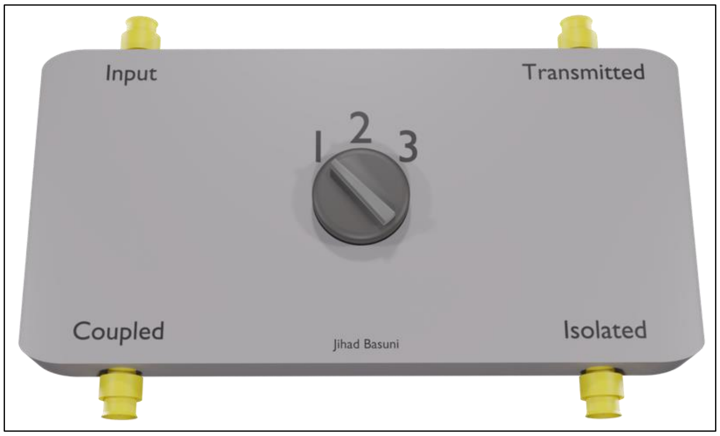

Fig (6): First case with rotary switch at 1

Having the rotary switch at 1 makes the two mechanical switches in internal circuit connected to the open circuits as shown in the following:

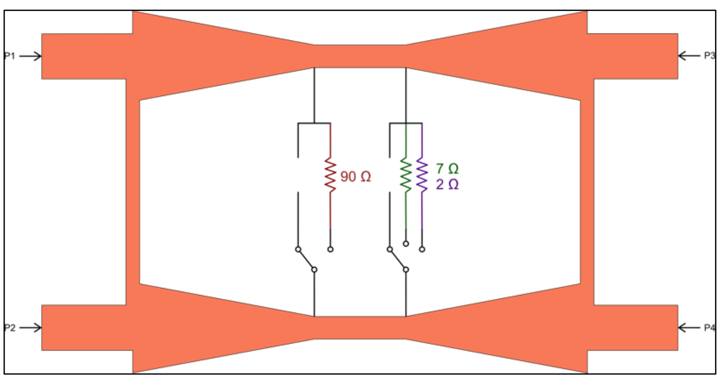

Fig (7): First case of the internal circuit

This circuit in the figure (7) represents the distributed version of this coupler, and the equivalent circuit for this case is showing in the figure (8).

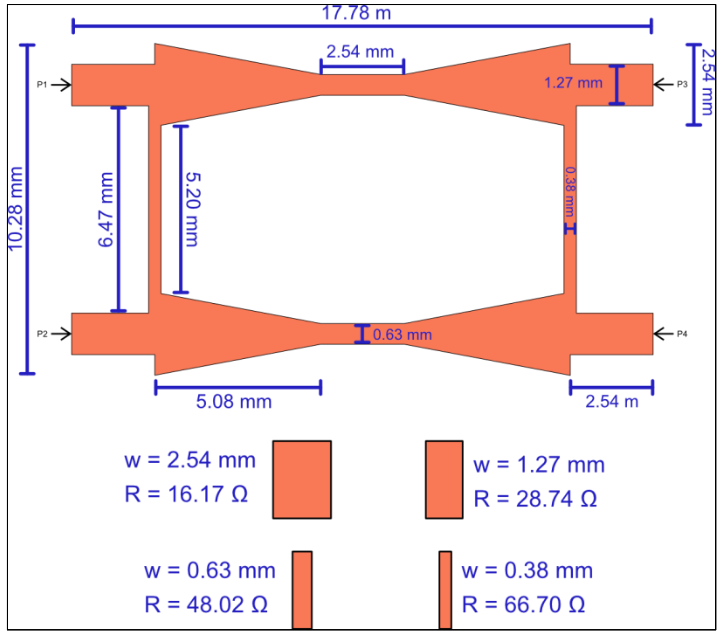

Fig (8): Dimensions of the proposed distributed branch line coupler

This figure (8) represents the equivalent circuit of the first case. Because the two mechanical switches, presented in the figure (7), are connected to open circuit, the coupler in this case is considered as a distributed coupler. This branch line coupler is symmetrical, and it has four ports. Each port has 2.54 mm length and 1.27 mm width. The total length of the design is 17.78 mm, and the total width is 10.28 mm. This coupler has a thickness H = 0.183 mm, and its dielectric constant Er = 2. In terms of impedance, the impedance of each microstrip line varies with its width. The wider width the line gets, the smaller resistance the line has and vice versa. For example, there are four variant widths in this design, and their impedances are 16.17 Ω for 2.54 mm width, 28.74 Ω for 1.27 mm width, 48.02 Ω for 0.63 mm width, and 66.70 Ω for 0.38 mm width. After running the simulation, the following results was presented:

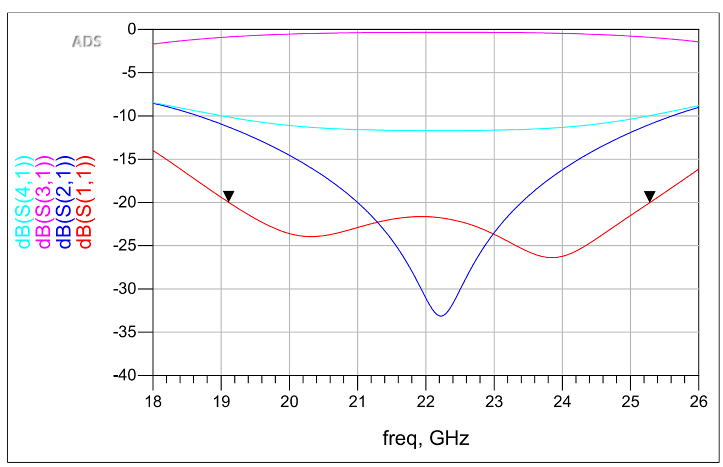

Fig (9): Simulated reflection coefficients of the proposed distributed branch line coupler

From the figure (9), the parameter S(1,1) indicates that the bandwidth below -20 dB is very sufficient. It ranges 6.20 GHz that starts at 19.10 GHz and ends at 25.30 GHz. Therefore, for the whole bandwidth, there is no any reflection that will get back to the port 1. Nevertheless, the isolation level represented by the S(2,1) has an acceptable performance, but it is not a perfect because it is not under -20 dB for the all area of the bandwidth range. In terms of the S(3,1) the transmission parameter, it is showing a very good performance and there is no issue about it. However, as it has been discussed before, the focusing in this design is on the coupling level that is represented by the S(4,1). According to the graph, the coupling level is at around -11 dB. The goal here is controlling the coupling level, and this can be done by several ways such as editing the thickness of the design, changing the constant dielectric, or adding lumped components. However, using the first two options is not recommended because it will deteriorate the performance of the coupler. Consequently, the only option remaining is adding lumped components to the distributed design. This can be done by rotating the switch of the proposed variable coupler as shown in the following in the second case:

B. Second case: the rotary switch at 2

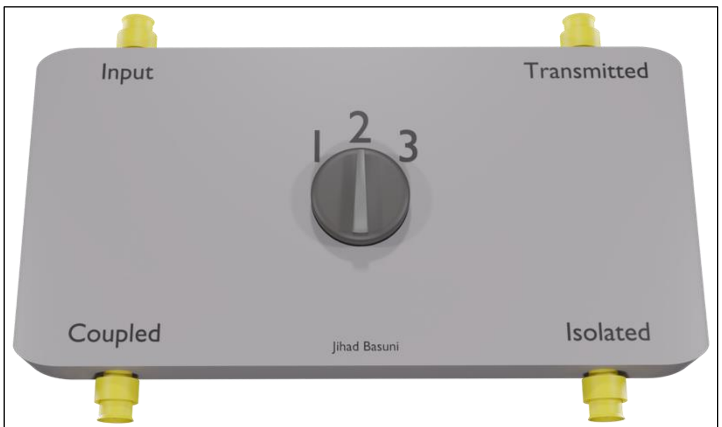

Fig (10): Second case with rotary switch at 2

Having the rotary switch at 2 makes the left side mechanical switch connected to the 90 Ω lumped resistor as it is illustrated in the figure (10). Similarly, it makes the right side mechanical switch connected to the 7 Ω lumped resistor. Therefore, the coupler is converted from a distributed coupler to a lumped-distributed coupler as it is shown in the figure (11). The equivalent circuit of this lumped-distributed coupler is presented in the figure (12):

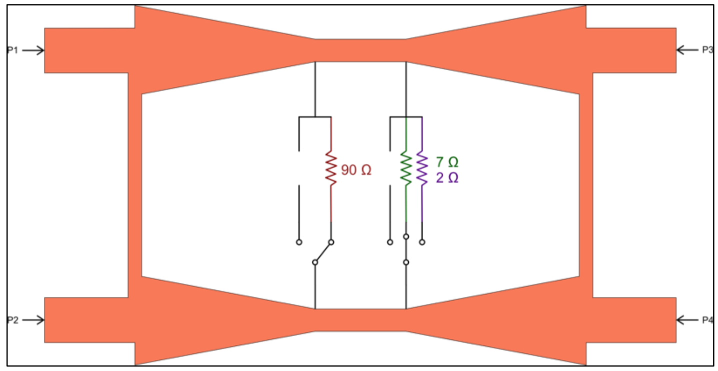

Fig (11): Second case of the internal circuit

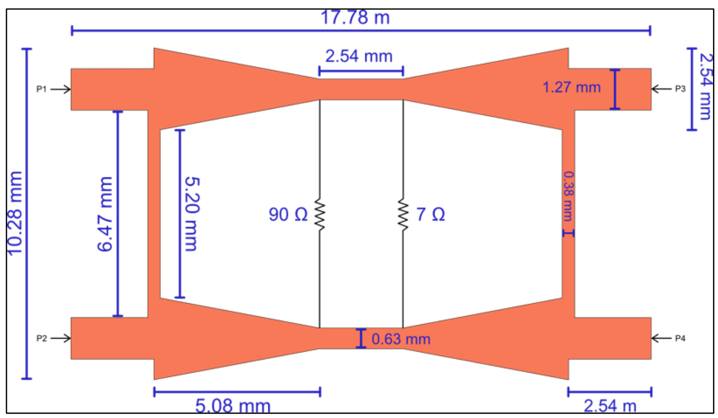

Fig (12): Dimensions of the proposed lumped-distributed branch line coupler v1

All dimensions and impedance values are as same as what is mentioned in the figure (8). The only difference in this case is having two lumped resistors. After running the simulation, the following results were achieved:

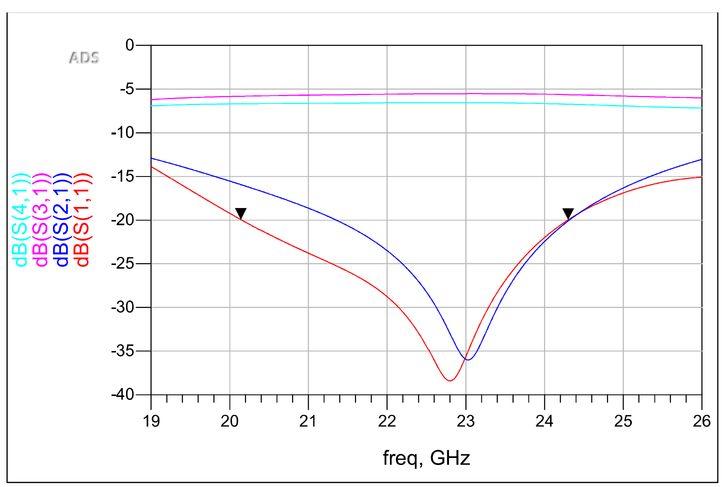

Fig (13): Simulated reflection coefficients of the proposed lumped-distributed branch line coupler v1

It can be noticed from the figure (13) that the coupling level, represented by the S(4,1) is shifted up from -11 dB in the first case to -7 dB in this case. Moreover, the bandwidth in this case is smaller than what it was in the first case. According to the parameter S(1,1), the bandwidth below -20 dB ranges 4.20 GHz from 20.10 GHz and ends at 24.30 GHz. Therefore, the reflection on the port 1 is ignorable. The isolation of this case is better than the isolation of the previous case. In the first case the perfect isolation was only for around 2 GHz, but in this case the perfect isolation ranges is around 3 GHz according to the S(2,1). In terms of the S(3,1), it can be observed that its level is shifted down, and that is normal because the coupling level is shifted up. In addition, moving to the third position of the variable coupler by rotating the switch to the number 3 as shown in the following case:

C. Third case: the rotary switch at 3

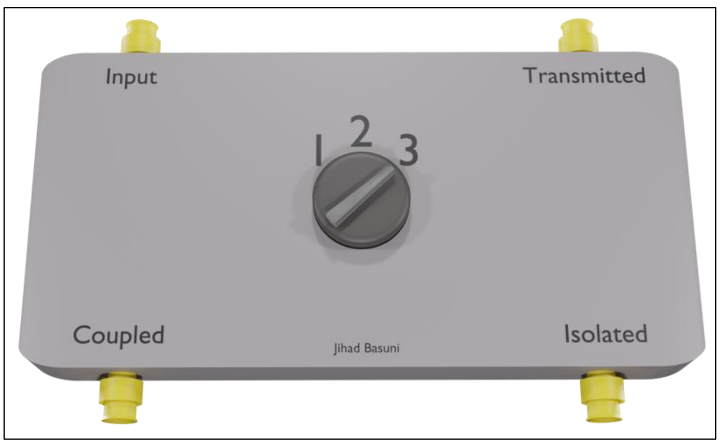

Fig (14): Third case with rotary switch at 3

Setting the rotary switch at 3 changes coupler's coupling level to -6 dB, and also changes coupler's bandwidth to 4.15 GHz. In this case, the left side mechanical switch is still connected to the 90 Ω lumped resistor as it is shown in the figure (15), but the right side mechanical switch is connected to the 2 Ω lumped resistor. From the figures (11) and (15), it can be noticed that the left side switch in the second and third cases is connected to the 90 Ω resistor. The equivalent circuit of this lumped-distributed coupler is presented in the figure (16):

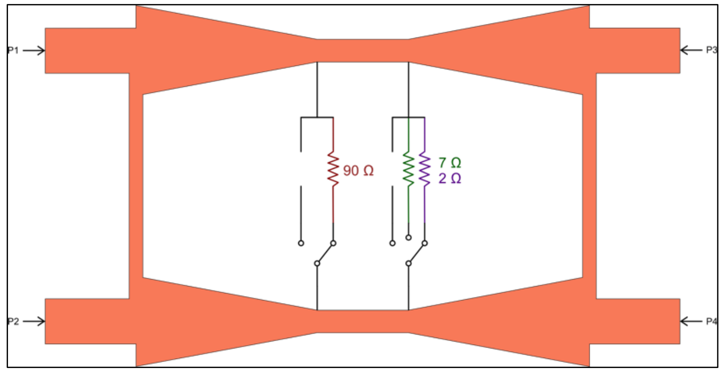

Fig (15): Third case of the internal circuit

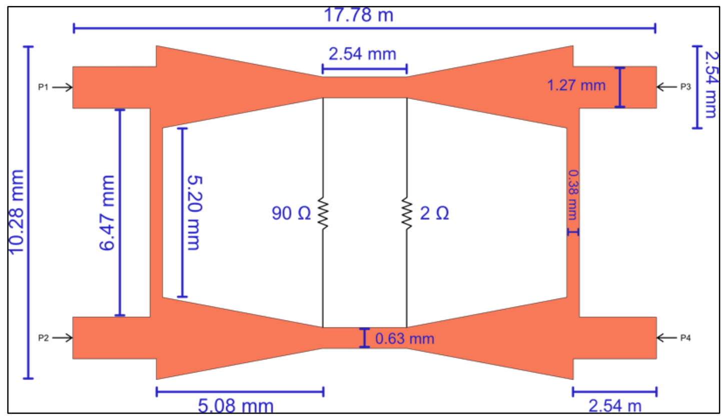

Fig (16): Dimensions of the proposed lumped-distributed branch line coupler v2

From the figure (16), it can be seen that all microstrip lines dimensions are similar to what are mentioned in the previous two versions, and the only difference here is the 2 Ω resistor. After running the simulation, the following graph was accomplished:

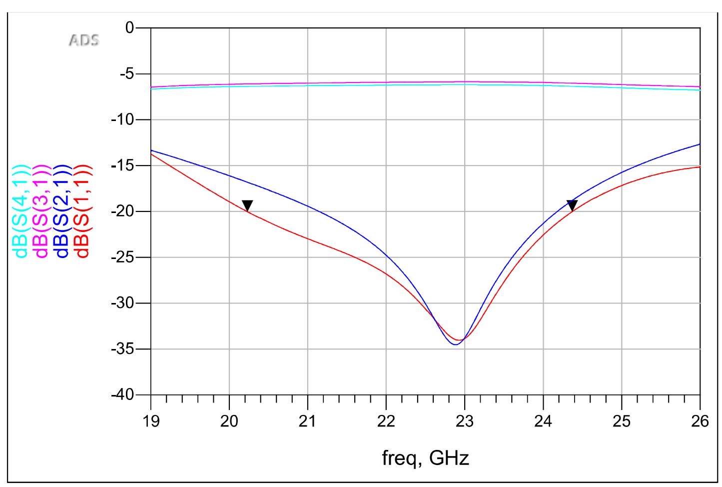

Fig (17): Simulated reflection coefficients of the proposed lumped-distributed branch line coupler v2

Overall, the figure (17) shows excellent results. The coupling level is shifted up to -6 dB one of the most popular coupling levels. The isolation level in this case is better than what it was in the first and second cases. However, the bandwidth range of this case is smaller. In the first case it was 6.20 GHz, and in the second case it was 4.20 GHz, and now it is 4.15 GHz. According to the S(1,1), this range is from 20.23 GHz to 24.38 GHz under -20 dB. The S(2,1), which refers to the isolation level, is now under -20 dB for more than 3 GHz of the bandwidth range. This increases the quality of the coupler because less power can be lost. In terms of the S(4,1) which refers to the coupling level, the -6 dB means that the input signal does not split up equally. Only one part of the power of the signal goes to the coupled port, and the other three parts of the power go toward the transmitted port.

Constructing a lumped-distributed module is required to compare results between simulated and practical results. This module is presented in the following:

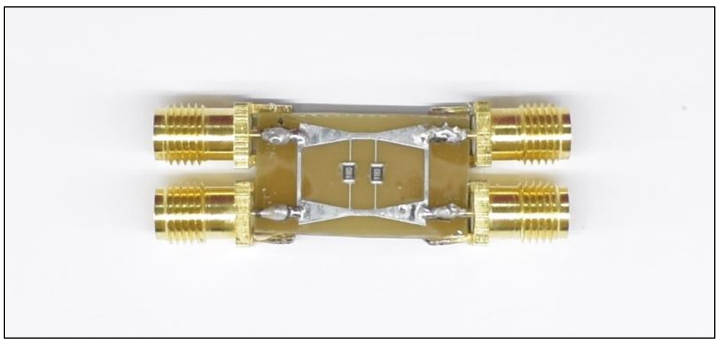

Fig (18): Front side of the module of the lumped-distributed branch line coupler v2

Fig (19): Back side of the module of the lumped-distributed branch line coupler v2

In terms of this module dimensions, they are mentioned in a previous page in the figure (16). However, the dimensions of the SMA female connector are shown in the following:

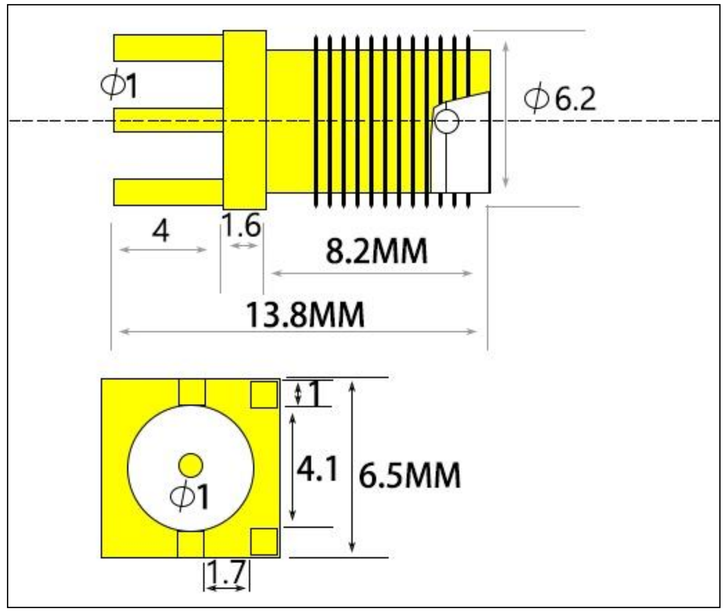

Fig (20): Dimensions of the SMA female connector

Turning the analyzer on and connecting it with the coupler is the way to present measured (practical) results as it is shown in the next figure. In the same figure, the simulated (theoretical) results are drawn for comparison. The solid track refers to the simulated (theoretical) results, and the dashed track refers to the measured (practical) results.

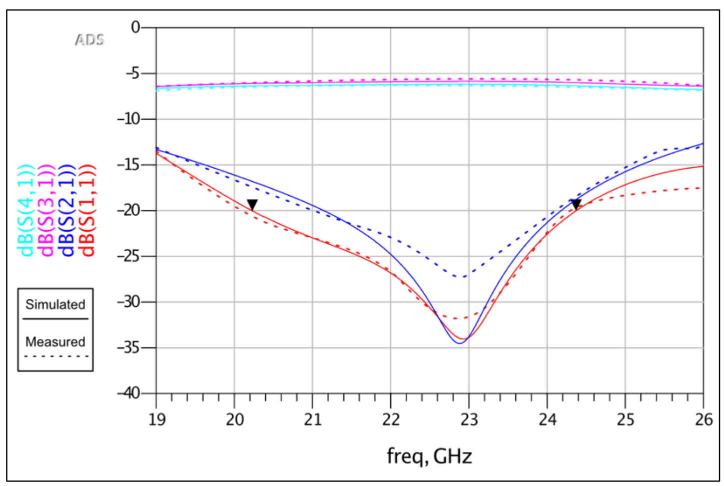

Fig (21): Reflection coefficients of the theoretical and practical lumped-distributed branch line coupler v2

For the whole range of this graph from 19 GHz to 26 GHz, the agreement between the simulated and measured results is obvious and can be observed easily. Regarding the parameters S(3,1) and S(4,1), their practical results are almost 100 % matching with the simulated results. However, for the parameter S(2,1), the measured result aligns with the simulated result for each point on the frequency scale except from 21.6 GHz to 23.8 GHz where neglected differences are detected. There are neglected because they are all under -20 dB, so there is no any negative impact on the coupler performance. Like S(2,1), the measured results of the S(1,1) are corresponding with the simulated results except from 22.6 GHz to 23.2 GHz where negligible differences are founded. Fortunately, these differences have no serious impact on the performance. Overall, it can be said that the simulated and practical results are matching with each other.

IV. Conclusion

To sum up, improving performances of couplers can be done by classical methods such as changing the thickness, dimensions, or dielectric materials. However, in this paper another unique and effective technique has been presented and discussed. This technique is called lumped-distributed. In addition to controlling coupling level and bandwidth range, the lumped-distributed technique can be used to build and design variable couplers like what has been presented and illustrated in this study.

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