

DESIGN OF N-WAY POWER DIVIDER SIMILAR TO THE BAGLEY POLYGON DIVIDER WITH AN EVEN NUMBER OF OUTPUT PORTS

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Abstract—In this paper, a general design of an equal-split N-way power divider, similar to Bagley polygon power divider, but with an even number of output ports is proposed. A circular-shaped 4-way divider is designed and simulated using two different full-wave simulators. Very good matching at the input port is achieved, and good transmission parameters are obtained. After that, the same circular-shaped divider is redrawn in a rectangular form to save more circuit area, and to align the four output ports together. For verification purposes, the 4-way rectangular-shaped Bagley power divider is simulated, fabricated and measured. Both simulation and measurement results prove the validity of the design.

1. INTRODUCTION

Recently, much attention has been devoted on the design of power dividers/combiners which are widely used in RF circuits and wireless communication systems, such as antenna diversity. One of the power dividers, which has been a new area of research, is the Bagley polygon power divider [1–8]. Compared to other power dividers, such as the Wilkinson power divider, Bagley polygon power divider does not use lumped elements, such as resistors, and can be easily extended to any number of output ports. However, the output ports for such dividers are not matched, and the isolation between them is not as good as that of the Wilkinson power divider. In [1], reduced size

3-way and 5-way Bagley power dividers (BPDs), using open stubs, were presented. In [2], an optimum design of a modified 3-way Bagley rectangular power divider was presented. In [3, 4], a general design of compact multi-way dividers (with odd number of output ports) based on BPDs was introduced. In [5], a compact dual-frequency 3-way BPD using composite right/left handed (CRLH) transmission lines was implemented. Recently, based on the generalized 3-way Bagley polygon power divider, dual-passband filter section was presented in [6]. Moreover, compact 5-way BPD for dual-band (or wide-band) operation was presented in [7]. Very recently, multi-band miniaturized 3-way and 5-way BPDs were proposed in [8]. It should be mentioned here that all of the BPDs investigated in [1–8] had an odd number of output ports.

In this paper, a general design of N-way modified BPD with an even number of output ports is proposed. For verification purposes, a 4-way BPD is designed, simulated, and measured. Both full-wave and experimental results verify the design approach.

2. DESIGN OF MODIFIED BPD WITH AN EVEN NUMBER OF OUTPUT PORTS

The method of designing modified BPDs, with an odd number of output ports, proposed in [3, 4] will be adopted here to the design of modified BPDs with an even number of output ports. Fig. 1 shows the schematic of the proposed even N-way BPD along with its equivalent circuit looking from the input port to the right side. The same equivalent circuit can be used to model the divider looking from the input port to the left side, since the structure is symmetric around the center line, except for having a $3\lambda/4$ transformer which effectively acts similar to the $\lambda/4$ one.

From the symmetry of the structure and the use of the $\frac{3\lambda}{4}$ transformer to the left of the input port, while a $\frac{\lambda}{4}$ one is used to the right of the input port, a short circuit exists at point x shown in Fig. 1(a). Now, looking at Fig. 1(b), it can be easily realized that by choosing $l_h = \frac{\lambda}{4}$ and $Z_1 = Z_0$, the input impedance $Z_{in}^{(1)} = Z_0$ independent of the length l_1 and the value of Z_h . Similarly, choosing $Z_2 = \frac{Z_0}{2}$, the input impedance $Z_{in}^{(2)} = \frac{Z_0}{2}$ for any arbitrary length l_2 . In general, choosing $Z_n = \frac{Z_0}{n}$ (where $n = 1, 2, \dots, N/2 - 1$) gives an input impedance $Z_{in}^{(n)} = \frac{Z_0}{n}$ with arbitrarily chosen lengths l_n . Finally, to achieve a perfect match at the input port, the impedances of the $\frac{\lambda}{4}$

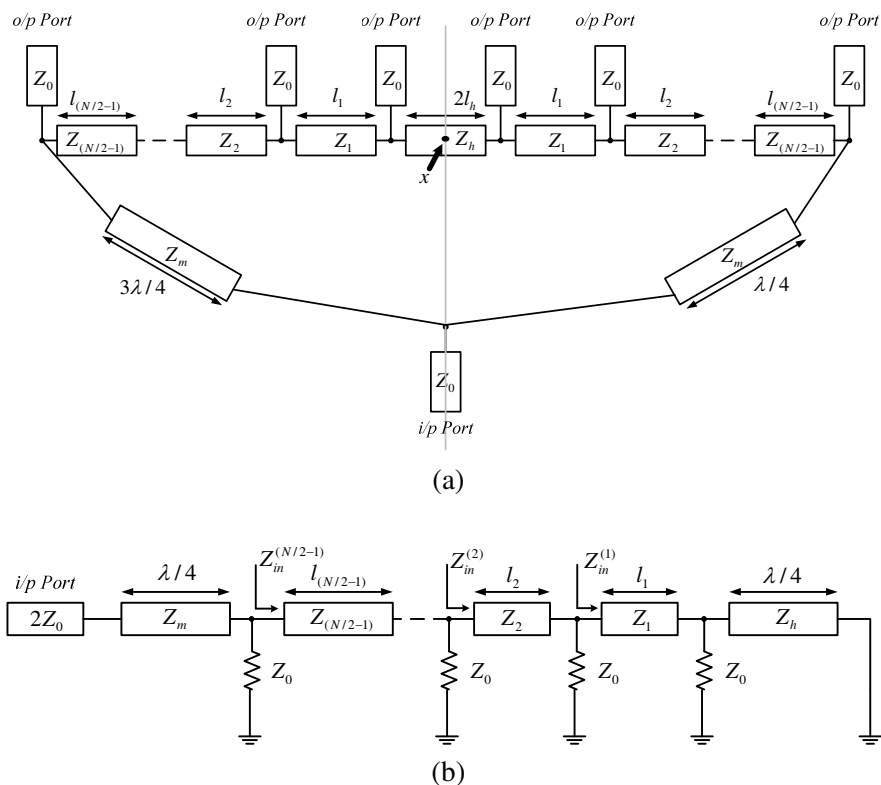


Figure 1. (a) The proposed structure of the even N-way modified BPD, and (b) The circuit model of the proposed divider.

and the $\frac{3\lambda}{4}$ transformers are chosen as follows:

$$Z_m = \sqrt{2Z_0 \left(Z_{in}^{(N/2-1)} // Z_0 \right)} = \sqrt{2Z_0 \frac{2Z_0}{N}} = \frac{2Z_0}{\sqrt{N}} \quad (1)$$

3. A 4-WAY MODIFIED BPD DESIGN EXAMPLE

Figure 2 shows a schematic diagram of the proposed 4-way BPD (that is $N = 4$). For a design frequency of 1 GHz and considering an FR-4 substrate with a relative permittivity of 4.6 and a substrate height of 1.6 mm; and ports impedances of 50Ω , the length of the $\lambda/4$ transformer section and the length l_h are equal to 40.36 mm, while the $3\lambda/4$ section is 121 mm long, and l_1 is arbitrarily chosen to be around 8 mm. It should be emphasized here that choosing a different

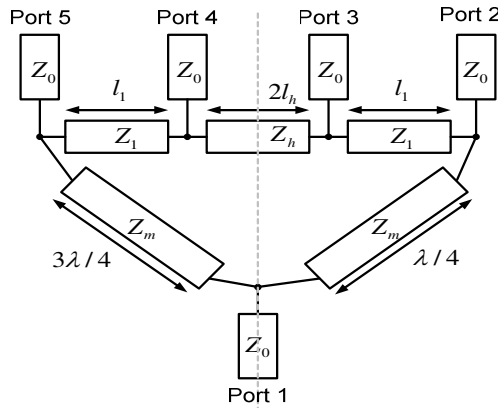


Figure 2. The proposed structure of the 4-way modified BPD.

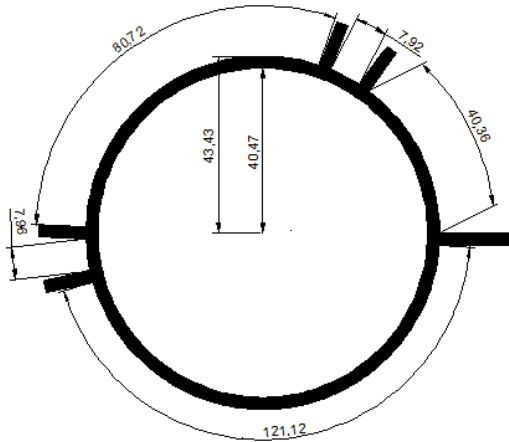


Figure 3. The layout of the proposed 4-way circular-shaped BPD. (Dimensions are in mm).

value for l_1 will not affect the matching at the input port and the equal split property of this divider (as will be shown below). However, it was set to 8 mm in this design to leave an appropriate distance between the output ports so that the BNC connectors can be placed (in the fabricated divider) without being overlapped with each other. Moreover, choosing l_1 to be large will increase the BPD area.

Following the design procedure presented in the previous section, the impedances can be easily calculated to be $Z_m = Z_h = Z_1 = Z_0 = 50 \Omega$, keeping in mind that Z_h can be arbitrarily chosen. Fig. 3 shows

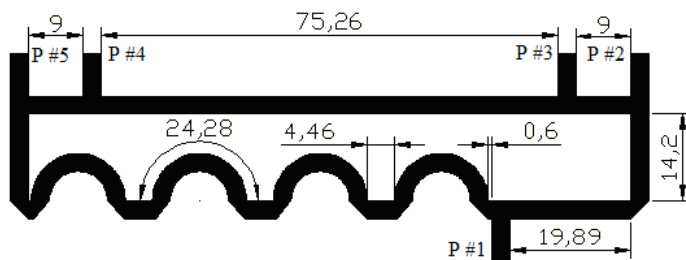


Figure 4. The layout of the proposed 4-way rectangular-shaped BPD. (Dimensions are in mm).

the layout of the proposed 4-way BPD (using a circular shape similar to the rat-race). For the sake of reducing the overall area, the same power divider can be redrawn in a rectangular form as shown in Fig. 4. It should be stressed here that the two Figures (Fig. 3 and Fig. 4) represent the same 4-way BPD, but in two different shapes. It is clear from Fig. 4 that the overall area of the proposed rectangular-shaped 4-way divider is 18 cm^2 , due to the meandering of the $3\lambda/4$ transformer. On the other hand, the circular-shaped divider occupies an area of 60 cm^2 . Another advantage of using the rectangular-shaped divider is that all the output ports are aligned together. It should be emphasized here that all transmission lines have the same characteristic impedance (similar to the input and output ports impedances) of 50Ω . Thus, they all share the same microstrip width of 2.95 mm.

4. SIMULATIONS AND MEASUREMENTS

In this section, the 4-way rectangular-shaped and circular-shaped modified BPD structures are simulated using the full-wave simulators IE3D [9] and HFSS [10]. Moreover, experimental results for the rectangular-shaped BPD are given. Fig. 5 shows the simulation results for the circular-shaped 4-way BPD. Very good input port matching is achieved with S_{11} below -30 dB at the design frequency (1 GHz) as shown in Fig. 5(a), and the agreement between both full-wave simulators can be clearly seen. Figs. 5(b) and 5(c) show that the transmission parameters (S_{12} , S_{13} , S_{14} , and S_{15}) are very close to their theoretical values of -6 dB at the design frequency, which verifies the equal-split behavior of this divider. The small discrepancies could be due to losses and discontinuities.

Figure 6 shows the isolation between the circular-shaped 4-way BPD output ports. As mentioned before, the isolation between the

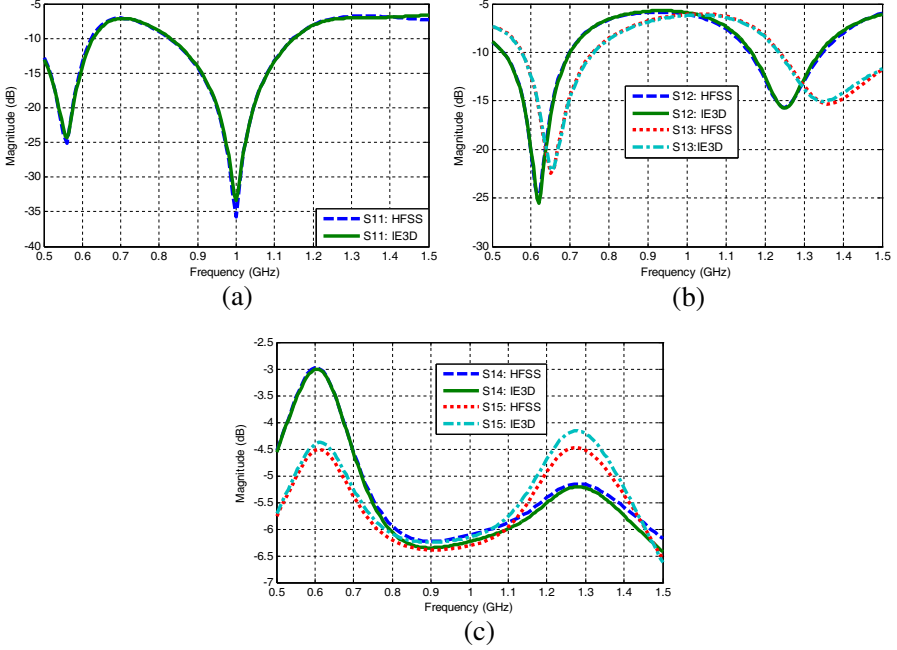


Figure 5. Full-wave simulation results for the circular-shaped 4-way BPD.

output ports at the design frequency (1 GHz) is not as good as that in the Wilkinson power divider. From Fig. 6, it can be seen that S_{23} , S_{24} , S_{35} , and S_{45} are all equal to -12 dB, while S_{25} and S_{34} are equal to -8 dB at the design frequency. It is worth mentioning here that, in BPDs, increasing the number of the output ports will improve the isolation between them.

Figure 7 shows the output ports matching parameters S_{22} , S_{33} , S_{44} , and S_{55} for the circular-shaped 4-way BPD. As mentioned in the introduction, the output ports in the BPD are not matched at the design frequency, and according to Fig. 7, the output ports return losses are all around 3 dB at the design frequency (1 GHz). Nevertheless, BPDs can be applied into many RF communication systems that require power splitting rather than power combining, such as antenna arrays, in which the power applied to the feeding line (the input port) is divided equally between all output ports. In this case, the output port matching condition is not important. Another advantage when using BPDs in antenna arrays or applications demanding antenna diversity, is that the number of output ports, and hence the number of fed antennas,

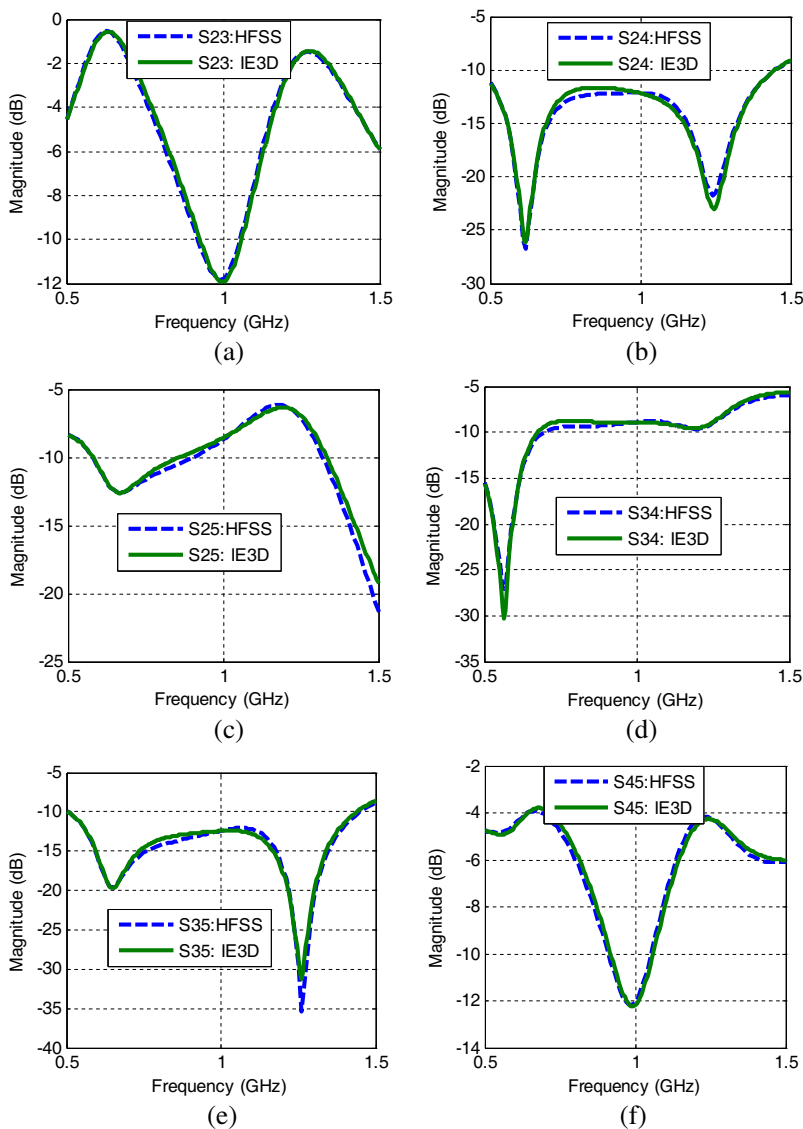


Figure 6. The isolation parameters for the circular-shaped 4-way BPD.

can be easily extended in contrast to other dividers, such as T-splitters, that provide only two output ports. Thus, increasing the number of output ports will demand increasing the number of splitters, leading to more complex and larger circuit area. Finally, it should be mentioned

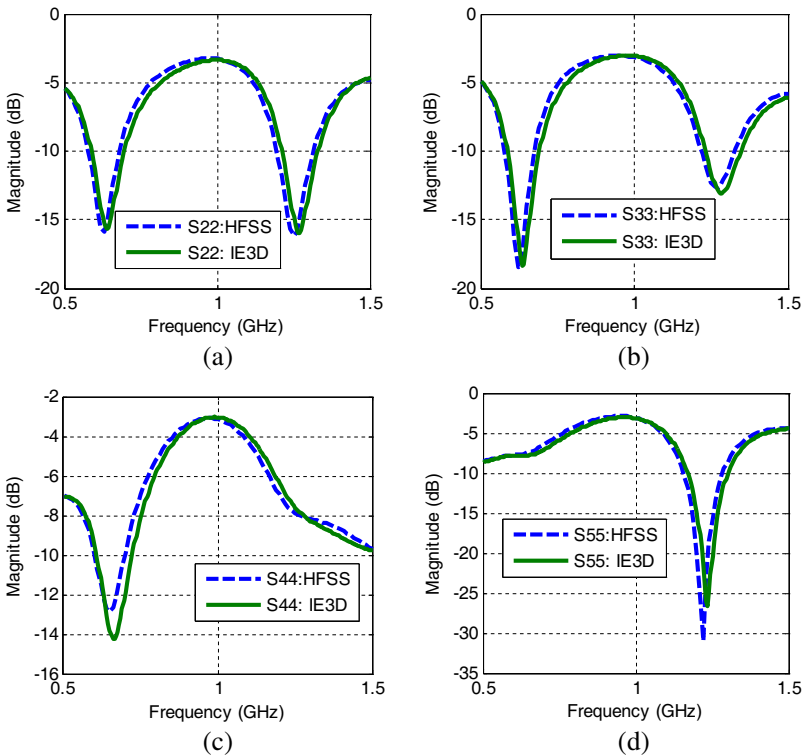


Figure 7. The output ports matching parameters of the circular-shaped 4-way BPD.

that if the matching condition at the output ports is necessary, simple matching networks (e.g., shunt stub) that aim to match the BPD's output ports at a certain design frequency can be easily designed and incorporated in the circuit.

Having said that the length l_1 can be arbitrarily chosen, a different value from 8 mm, specifically a 100 mm, was taken to see the effect of increasing the length of these sections. As expected, it was noted that increasing the length l_1 had no effect on the input port matching parameter (S_{11}), while the transmission coefficients were slightly affected due to losses. Specifically, when $l_1 = 8$ mm, S_{12} , S_{13} , S_{14} , and S_{15} were about -6 dB at the design frequency (1 GHz), while they became -6.15 dB when $l_1 = 100$ mm. Moreover, with $l_1 = 100$ mm, the value of the isolation parameters S_{23} , S_{24} , S_{35} , and S_{45} at the design frequency was not affected (remained -12 dB), while S_{25} and S_{34} changed to -5 dB. Finally, with $l_1 = 100$ mm, the output

ports return losses have changed to -5 dB at the design frequency, compared to -3 dB when l_1 was 8 mm.

Figure 8 shows the simulation and measurement results for the rectangular-shaped 4-way BPD. The input port matching (S_{11}) is below -20 dB at the design frequency (1 GHz) as shown in Fig. 8(a). Moreover, Figs. 8(b)–8(e) show that the transmission parameters (S_{12} , S_{13} , S_{14} , and S_{15}) are again close to their theoretical values of -6 dB at the design frequency. It is worth mentioning here that

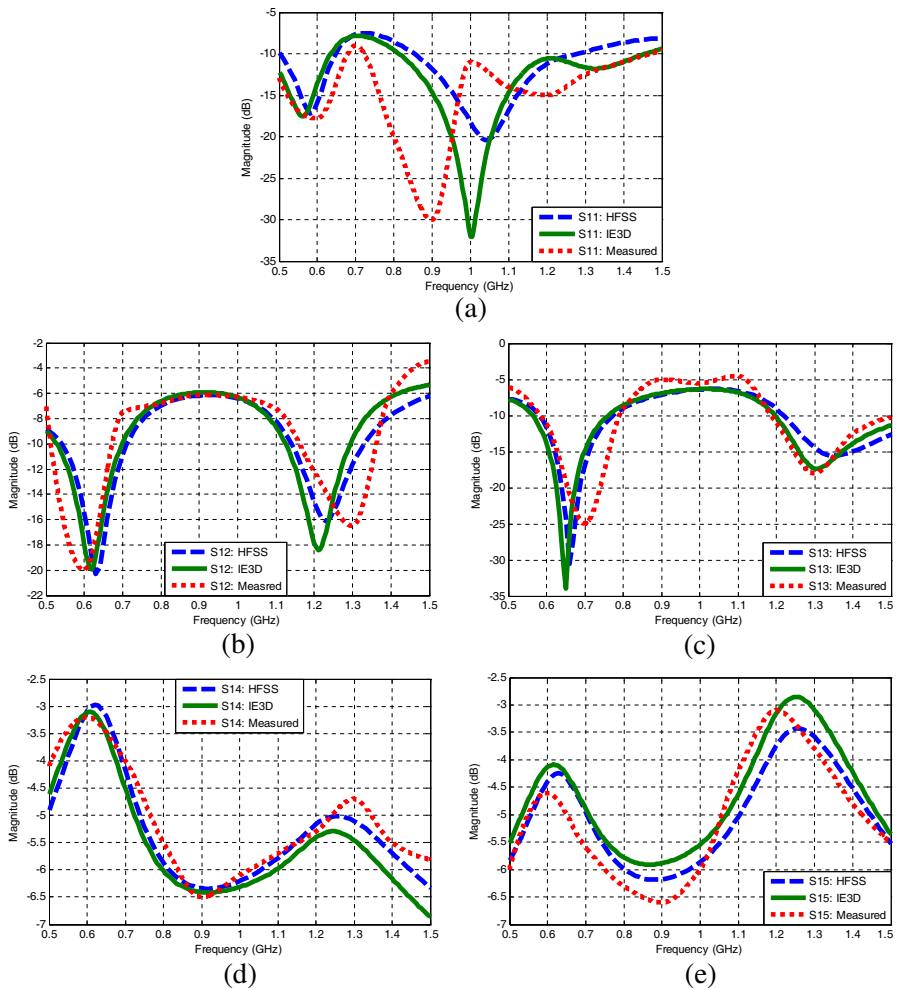


Figure 8. The rectangular-shaped 4-way BPD simulation and experimental results.

the measurement results were obtained using an Agilent Spectrum Analyzer (with a built in tracking generator extending from 0–1.5 GHz). Acceptable measurement results for the modified 4-way BPD are obtained. The differences between simulation and measurement results could be due to the fabrication process, measurement errors, the BNC connectors, and the fact that a spectrum analyzer (not a network analyzer) was used to perform the measurements. The same discussion mentioned in the circular-shaped 4-way BPD concerning the isolation between the output ports and the output ports matching holds in the case of the 4-way rectangular BPD. So, such results were omitted for the sake of brevity.

A picture of the fabricated 4-way BPD is shown in Fig. 9. An extra 15 mm feeding lines were used at each port of the 4-way BPD to make it possible to attach the BNC connectors that adapt to the coaxial cables connecting to the spectrum analyzer, when measurements were performed.

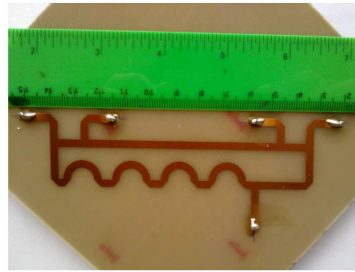


Figure 9. A photograph of the fabricated 4-way BPD.

5. CONCLUSION

In this paper, a general method of designing an N-way power divider similar to the BPD with an even number of output ports was presented. Simple design equations were given. For verification purposes, a 4-way modified BPD has been presented in two different shapes: circular and rectangular. The first structure occupies an area of 60 cm^2 , while the second one occupies an area of 18 cm^2 . Full-wave simulation results for both structures prove the validity of the two designs. Moreover, experimental results for the second structure are acceptable keeping in mind the presence of different kinds of errors in the measurements.

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