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WIDEBAND PLANAR WILKINSON POWER DIVIDER USING DOUBLE-SIDED PARALLEL-STRIP LINE TECHNIQUE

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Abstract—A new design of a wideband Wilkinson power divider using double-sided parallel strip line technique is presented in this paper. To obtain a good isolation value, the proposed design was integrated with three isolation resistors. The proposed power divider is designed for a wide range of frequencies between 2 GHz to 6 GHz with all the ports matched to 50 Ω. The conventional quarter wavelength arms are divided into three different widths to ensure wideband capabilities. Moreover, the novelty of the proposed design is illustrated from the double-sided parallel-strip line technique where proposed design is using similar structure at both the top and bottom layers to ensure balance of transmission. All dimensions for the transmission line section were optimized to achieve wideband operation and were integrated with a lumped element. This design can be used as a double-sided feeder for a microstrip antenna.

1. INTRODUCTION

Wilkinson power divider (WPD) is a type of power divider that has been rapidly developed owing to recent research. This device is among the most common passive circuits used in many microwave systems. The basic design of the WPD is usually integrated with a load resistor to achieve better isolation between output ports [1–4]. The development of wireless technology demands an improved version of a microwave circuit, where they can be operated by a dual- or multi-band. The conventional way to execute a dual-band WPD is by using the stub-lines technique [3–5]. However, this technique

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reduces the operating bandwidth. The problem can be overcome by using the transmission line (TL) technique. In [6], a dual-band WPD using TL extensions with small-frequency separation was proposed. Unfortunately, this design can only operate from 1 GHz to 1.6 GHz. As in [7–10], a novel miniaturized dual-band WPD using an artificial TL was proposed. Even thought the size of the WPD was reduced by about 50%, the separation between the two output ports being small will lead to imperfection in power dividing caused by mutual coupling [11].

In the current research on power divider technology, researchers usually implement a full ground plane on their design, which is not usually suited to the balanced-TL approach that is often used to feed the double-sided patch antenna [12]. The balanced-TL approach uses the same transmission line design at the front- and ground-plane structure, which also can be called as a double-sided parallel-strip line. The details of the double-sided parallel-strip line technique are discussed in [13] wherein they implemented it in their proposed filter design. This technique was also implemented in the circular-ring power-divider design as in [14].

This paper illustrates a new design of WPD using the double-sided parallel-strip line technique. This technique can ensure balance transmission line within the proposed design. The novelty of proposed design is illustrated from the similar structure for front and back design where in normal double-sided parallel-strip transmission line technique, the different width of transmission line for both layers is needed to obtain good power divider performances [12, 13]. The proposed design implements the TL technique with the integration of a lumped element to improve S parameter values. This can be achieved by optimization of the width and length of the electrical transmission lines. Resistors were used to improve the impedance matching and isolation value. A simple WPD was fabricated by using FR-4 board ($\varepsilon_r = 4.7$, thickness = 1.6 mm).

2. WILKINSON POWER DIVIDER DESIGN

Figure 1 shows the equivalent circuit of the conventional power divider. From the figure, it illustrates equal impedance values at the two arms, Z_2 and Z_3. To provide better isolation value, lumped resistor is placed between the port 2 and 3 (output ports). Each port is matched to 50 Ω line impedance.

In the conventional WPD, researchers have used a symmetric design, where the basic dimension of the transmission line for each

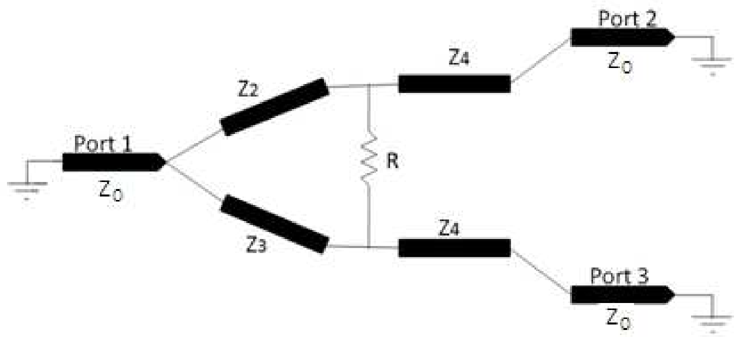


Figure 1. Transmission line model of the normal WPD.

section uses the following equations [15]:

$$l = \frac{n\pi}{\beta_1 + \beta_2} \tag{1}$$

Electrical length of Z_2 and Z_3,

$$Z_4 = Z_0\sqrt{\frac{1}{2\alpha} + \sqrt{\frac{1}{4\alpha^2} + 2}} \tag{2}$$

$$Z_{2,3} = \frac{2Z_0^2}{Z_4} \tag{3}$$

where,

$$\alpha = (\tan(\beta_1 + l_1))^2, \quad \beta = 2\pi/\lambda$$

In the initial step of designing the WPD, the authors have used 5.8 GHz and 2.45 GHz as the reference frequencies. By using Equations (1)–(3), all the impedance values for Z_2, Z_3 and Z_4 can be determined. In Ref. [15], the value of n must be positive arbitrary integer where in this paper, authors has choose the value of $n = 1$ since a small value of n can occupied the small size of WPD. These values can be used to compute the width and length of the TL within the proposed WPD design. However, the calculated dimension from the above equation will results to a dual band WPD only. The authors have made some adjustment to the calculated values so that the WPD can operate at wideband frequencies. Thus, authors made some parametric studies in width of Z_4 where the value of Z_4 was divided into three different widths such as Z_A, Z_B, and Z_C in order to obtain wideband WPD and the length of Z_4 remain constant. The equivalent circuit for modified WPD is shown in Figure 2.

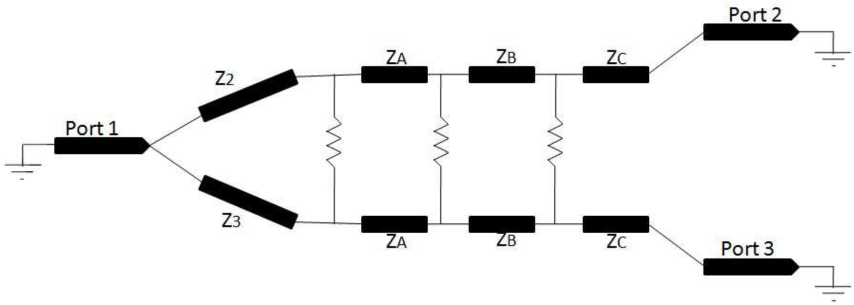


Figure 2. Transmission line model of the modified/proposed WPD.

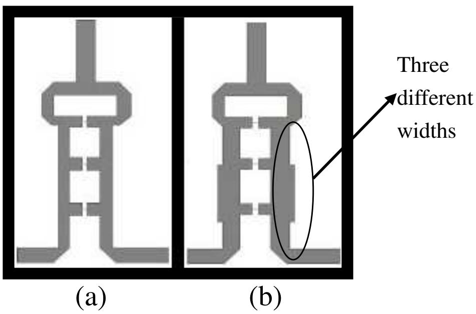


Figure 3. (a) Initial design of proposed WPD; (b) Final design of proposed WPD.

In order to get wideband capabilities, the authors have introduced three different widths within this WPD design while the length of Z_4 is maintained at modified design. Figure 2 illustrates the proposed wide-band WPD architecture. For proposed design, authors had used the basic TL theory as given more wide to TL can shifted the return loss value to lower frequencies. Modification in width of the TL can affect the overall performance of the WPD [3] because changing the width can disturb matching value of overall design. The relationship between operating frequency and the width of transmission line can be seen in basic equation of transmission line as shown in equation [4].

$$w = \frac{c}{2f_r\sqrt{\frac{\varepsilon_r+1}{2}}} \tag{4}$$

As shown in this equation, the width of transmission line, w is inversely proportional to the resonance frequency, f_r. this means, by varying the width of transmission line, the resonance frequency

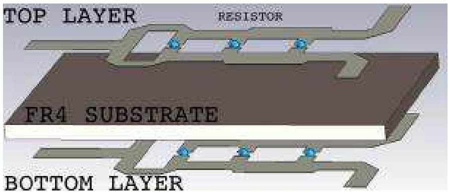


Figure 4. Wideband WPD architecture (the metal strips have been detached from the substrate in order to enhance the visibility of the structure, the lumped resistors are drawn in blue).

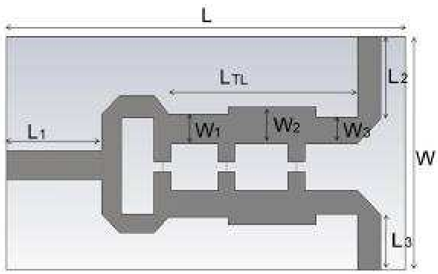


Figure 5. Wideband WPD parameters notation (top view).

will affected hence will change the scattering parameter of proposed design. In simple word, the changes in width of Z_A, Z_B, and Z_C can modified the impedance match at each output ports. Thus, it will give a different value of the S-Parameters at each frequency band thereby changing the proposed design performance. Figure 3 shows the normal WPD design with dual band capabilities and the proposed design of WPD with enhanced wideband capabilities. This figure had shown a comparison between initial design and the proposed design of authors' WPD. While in Figure 4, the picture shows screen capture of proposed WPD in Computer Simulation Technology (CST) 2010 simulation software where the top layer is representing the conducting layer while the bottom layers is represent grounding layer of proposed WPD. It is clearly seen from the figure that both the conducting and grounding layers uses the same design.

All the parameters used in the proposed design are shown in Figure 5. As shown in the middle of the figure, 1 mm slots were introduced to accommodate the three 100 Ω resistors. The chamfering produced at the edge (mitered bend) of the top PEC layer of proposed WPD was used to reduce the signal reflection effect where this can cause degradation in term of WPD performances. All the proposed dimensions are tabulate in Section 3.

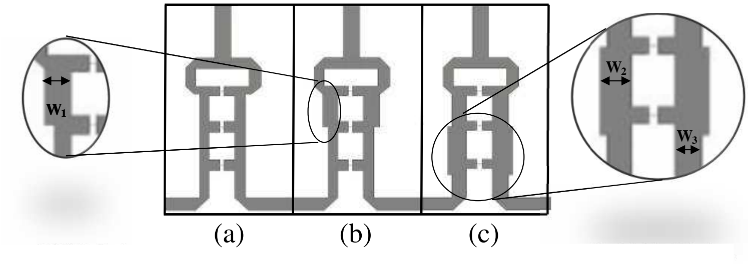


Figure 6. WPD design evolution: (a) First design; (b) Second design with the change on W_1; (c) Final design.

3. RESULT AND DISCUSSION

In the proposed WPD design, the main parameters that affect the WPD performance are the length and width of the center TL (L_{TL}, W_1, W_2, and W_3). At the initial phase of designing the proposed WPD, the author used the basic Wilkinson power divider dimensions as illustrated in Section 2. Figure 6 shows the proposed WPD evolution in order to achieve wideband properties. Figure 6(a) shows the initial version of the proposed WPD where the calculated Z_4 value has been used to construct the center TL. In Figure 6(b), the parasitic elements are introduced to increase some width in the center TL which indicates as W_1. The changes made in centre TL can modify the S-parameter of proposed design. The final structure of the proposed WPD is shown in Figure 6(c) with changes made the width of W_2 and W_3. All result regarding on optimization process from first design to final design are carefully discuss in next paragraph.

Figure 7(a) shows S-parameters for the first design of proposed WPD. In this figure, author try to picture where initial proposed design can only give good performance at upper resonance frequency. In order to develop the initial proposed design from dual-band WPD to wideband WPD, the initial proposed structure will undergo optimization process on their width of centre TL. The author have introduced the second design of the WPD by making changes in width within the center TL (W_1) as shown in Figure 6(b) as the changes of width can vary the scattering parameter values for proposed WPD. At initial design, the width of W_1 was initially set as same value as $50\,\Omega$ TL with electrical length of 90° that is 2.987 mm where this value is the calculated width value of transmission line at 2.45 GHz band for FR4 material. Changes of W_1 can affect $|S_{22}|$ and $|S_{33}|$ performance (second WPD design) where it can give better performance. This is shown in Figure 7(b) where the output return loss at 4 GHz to 5 GHz increases

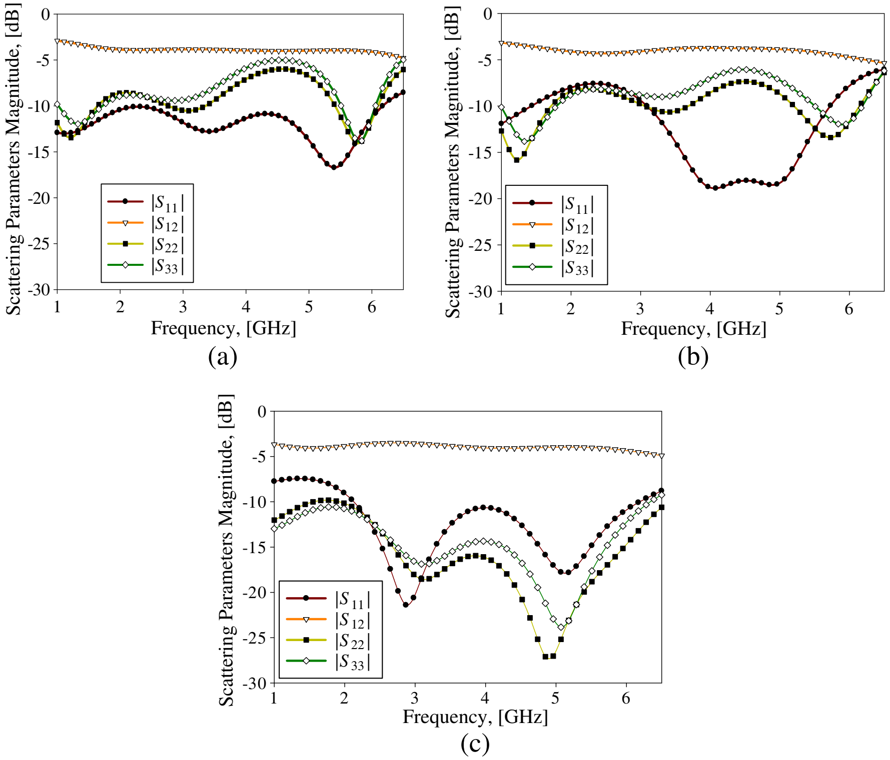


Figure 7. Antenna performance: (a) First design; (b) Second design; with presence of W_1; (c) Final design.

toward the $-10\,\mathrm{dB}$ value. In terms of input return loss, the changes made to W_1 was downgrades the WPD performance when compared with the first WPD design. However, the second WPD performance is still not satisfying the wideband properties. By changing the width of W_2 and W_3, the performance of the proposed WPD can be enhanced from a dual-band WPD into a wideband WPD as shown in Figure 7(c).

In early stage on designing proposed WPD, a ground layer was introduced where this design only satisfied for narrow band operating frequency. The reason for author to used parallel strip line technique in proposed design is to enhance the narrow band capabilities by introducing ground plane layer to wide band WPD capabilities by just implementing the same front-back design into proposed WPD design. Figure 8 shows the coupling parameter result for WPD design with presence of ground layer and WPD with implementation of double sided parallel strip-line technique. The result is taking by using the

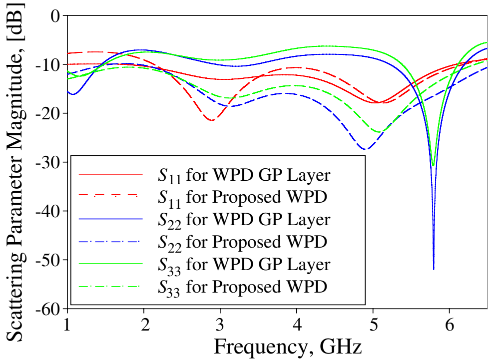


Figure 8. Comparison of coupling parameters between WPD with ground plane layer and proposed WPD.

same front design with ground plane layer and with introduction of double-sided parallel strip technique and the same size of FR4 board is used.

All the solid line represent the simulation coupling data for WPD with ground plane layer while for dotted line, they represent the simulation data for proposed WPD. For $|S_{11}|$ data, both results shows good value for wide band application but for both $|S_{22}|$ and $|S_{33}|$ result, only proposed WPD design shows capabilities in wideband operation. This is because, the present of ground plane layer is compressing the bandwidth of WPD design and it limited to narrow band capabilities.

In order to get the optimized value for each parameter in the propose WPD design, several parametric studies need to be done. Through the optimization process of changing width, three different widths (W_1, W_2, and W_3) at the central part of the WPD structure are determined. Figure 9 shows the $|S_{11}|$ value when the value of W_3 parameter was varied. From this figure, the varying W_3 can have an effect on both the $|S_{11}|$ and $|S_{21}|$ values in the 2 GHz to 6 GHz band. The optimized value for W_3 in getting the wideband properties in the proposed WPD is 2.947 mm.

As shown in Figure 9, wideband capabilities can be achieved when the value of W_3 is increased. This step will be repeated at the backside of the WPD in order to get an equal current distribution at both sides. In proposed WPD design, authors also integrated three lump elements, R in between port 2 and 3 where this can give better isolation value between output ports if compared to the used of only one lump resistor in authors' WPD design. For obtaining the value of isolation between output ports, the scattering parameter magnitude for $|S_{23}|$ has to be

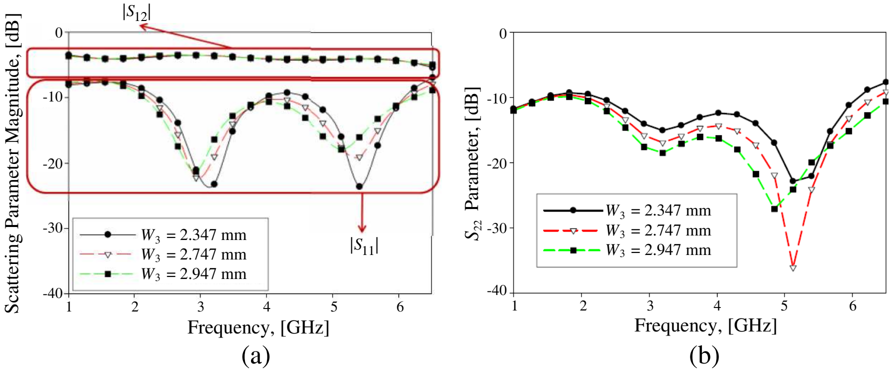


Figure 9. Parametric studies on W_3: (a) $|S_{11}|$ and $|S_{12}|$ parameter, (b) $|S_{22}|$ parameter.

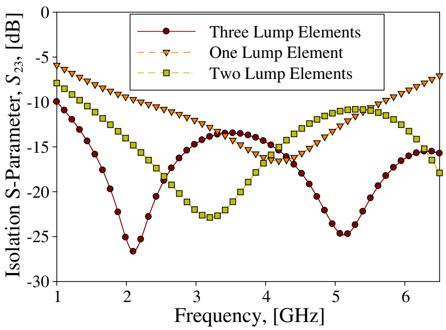


Figure 10. $|S_{23}|$ value when different number of R integrate in proposed WPD.

as high as possible. This is shown in Figure 10. This figure shows the larger the number of lump element used in proposed design, the better isolation value can be obtained.

The optimum value for W_1, W_2 and W_3 were used in the fabrication phase. All the optimized value for proposed WPD dimensions was shown in Table 1.

Figure 11 illustrates the current distribution within the WPD structure at the front- and backsides. As mentioned before, the uniqueness of the proposed WPD is that the authors have designed the same structure at both sides of the board. This design does not use normal full ground plane layer attached in proposed structure. This is useful in designing an antenna structure with an array configuration

Table 1. WPD physical dimension.

Parameter	Dimension, mm
L	40.015
W	23.431
$\mathbf{L_1}$	9.56
$\mathbf{L_2}$	8.215
$\mathbf{L_3}$	5.552
$\mathbf{L_{TL}}$	19
$\mathbf{W_1}$	3.057
$\mathbf{W_2}$	3.830
$\mathbf{W_3}$	2.947

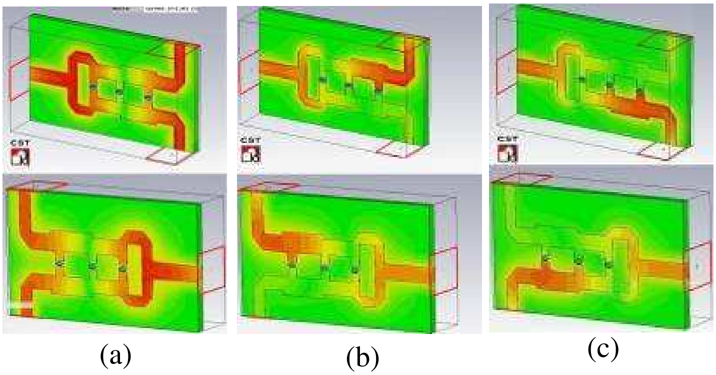
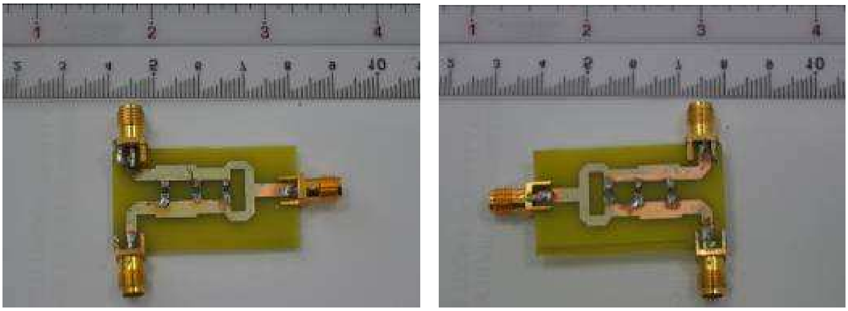


Figure 11. Current distribution at 2.45 GHz: (a) Current distribute equally to port 2 & 3; (b) Isolate port 3; (c) Isolate port 2.

that provides balance in transmission within the proposed design. This structure can give equal current distribution at both sides as can be seen in Figure 11(a). While Figures 11(b) and (c) show that the current is distributed from port 1 to one output port while at the opposite output port, no current is distributed. The fabricated WPD is shown in Figure 12. This fabrication makes use of a 50 Ω SMA connector for all the three ports.

From Figure 13, the return loss value at port 1 is obtained. As can be seen, the proposed WPD is able to operate at a wideband frequency from 2 GHz to 6 GHz. The comparison between the simulation and



(a) (b)

Figure 12. Fabricated proposed WPD: (a) Front view; (b) Back view.

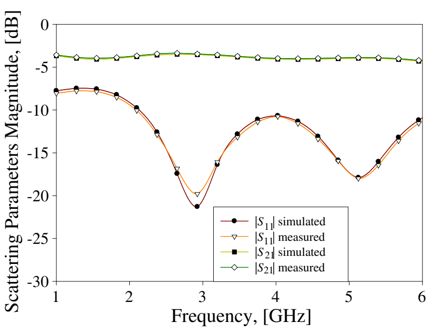


Figure 13. Comparison of simulated and measured $|S_{11}|$, $|S_{21}|$ for proposed WPD.

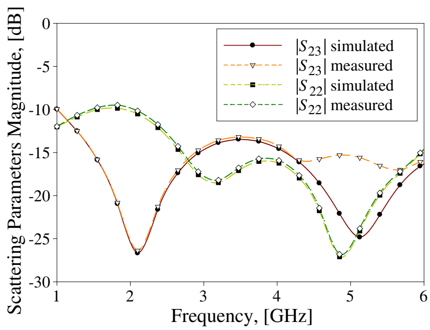


Figure 14. Comparison of simulated and measured $|S_{22}|$, $|S_{23}|$ for the proposed WPD.

measured data is quite similar except for the measurement data of $|S_{23}|$. This directive result shows much difference between the measured and simulated result at an upper frequency response. However, the difference does not affect the performance of the proposed WPD; the measured data at the upper frequency response is still below the -10 dB-threshold. Thus, the WPD enable to operate within this frequency range. Figure 13 also shows the insertion value from Port 2 to Port 1. The most importance challenge in designing wideband WPD is to create equal power dividing between output ports. The simulation and measurement result shows the insertion loss, $|S_{21}|$ is between -3.5 dB to -4.3 dB range at all operating frequency range. It gives an acceptable good performance value since authors only used FR4 board in their proposed design. From Figure 14, the proposed WPD has a good isolation value at the 2 GHz to 6 GHz band.

4. CONCLUSION

A Wilkinson power divider is proposed for a wideband operation in the 2 GHz to 6 GHz frequency band. The novelty of the proposed WPD can be seen in the modification made in their TL. In An equal design at both sides of the board can give an advantage in terms of equally distributed current for both sides. This design helps researchers who want to use double sided feeder in the same array configuration.

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