

# Substrate Integrated Waveguide Unequal Power Divider with Adjustable Dividing Ratio

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**Abstract:** An unequal power divider with substrate integrated waveguide technology has been designed. This structure is compact in size and has the capacity to develop to the n-port unequal power divider. Its output powers ratio is also adjustable. The output powers can be easily change by varying the width of the output ports. The design procedure has been done analytically. Then a two-way unequal SIW power divider is designed. Simulation results of the proposed structure shows that return loss is below than 10dB from 9GHz to 11 GHz. Transitions show that there is approximately 2 dB difference between output ports from 9.2GHz to 10.4 GHz.

**Key words:** Substrate Integrated Waveguide, Unequal Power Divider, Adjustable Ratio, Small Size, Multilayer, Analytic Solution, Low Cost.

## 1. Introduction.

Power dividers have many applications in millimeter wave and microwave power amplifier, array feeding network and different type of test equipment's. There are some restrictive points on design and production of the unequal power divider. The most common unequal power divider which have been reported [1, 8] is based on microstrip technology. These structures have been realized with high impedance microstrip line that means very thin conductor width. It is almost impractical to take in a high impedance line using the conventional microstrip structure. Also recently Defected Ground Structure (DGS) microstrip line for conquering the characteristic impedance problem has been reported [2], but they have been used for low frequencies. Dual band microstrip power divider in [4] has been focused on its operation center frequency and the performance at the frequencies between these desired two bands is not considered. A multi-way dual band planar power divider with arbitrary power division in [8] is very complicated structure and its operation frequency is low.

All the above structures have the inherent limitation of the microstrip technology like radiation loss. Especially in feeding network of array antenna which have been employed microstrip line as beam forming network (BFN). By increasing the number

of elements BFN becomes larger and complicated. Therefore the radiation loss due to microstrip line becomes considerably large. Substrate Integrated Waveguide (SIW) as a component with easily integration to planar structures can be used for the design of the unequal power divider with low disappeared power.

In general, SIW has a relatively large footprint compared to conventional printed circuit counterparts. Some advantages such as being low cost of design and production, low disappeared power and its potential to easily integration with microwave and millimeter wave components popularized SIW in the past few years. SIW is an interference free component, so it is suitable for BFN applications. An acceptable performance with considerably decreased size can be offered by SIW technology as a potential solution to the compact communication application. Moreover multilayer SIW not only have all the advantages of conventional multilayer Printed Circuit Board (PCB) structure but also resolve the problem of radiation from the microstrip feed lines due to its closed structure. SIW power divider has the advantages of planar structure and conventional rectangular waveguide power divider. Thus it is a promising device for planar microwave circuits. At the SIW unequal power dividers in [9, 10] by increasing the number of ports the size of the structures becomes larger.

The main structure of SIW power divider has been shown in Fig. 1[11- 12, 18-19]. It consists of two SIW layers which are attached to each other. By removing the copper two slots have been created. The slot in lower layer has been surrounded by via in order to guiding the input waves towards the upper slot. The electromagnetic wave is coupled from lower layer to upper layer through the slots.

As it is shown in Fig.1 there is a slot in the top part of first layer and similar slot is at the bottom part of second layer. This idea can be used for increasing the numbers of output ports by increasing the number of layers and slots in each coupling layer

without increasing the width of structure. Therefore the width of the developed structure is constant. Due to symmetry of the structure the output powers of this main structure in Fig.1 are equals. Changing the width of output ports in upper layer leads to different output power from the two outputs ports.

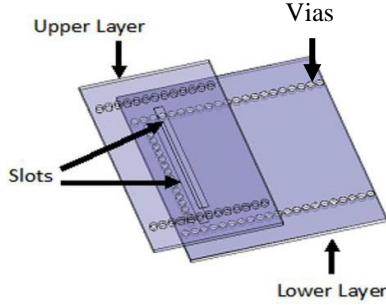


Fig. 1. The main structure of SIW power divider

The design approach for SIW will present in section 2. Similarities between SIW and rectangular waveguide have been used in this section. Width of the first is also elucidated.

Section 3 includes power divider design with SIW technology. In this section E-plane power divider and its equivalent circuits are illustrated. The analytic solution is also included. Width of the second layer and transition parts dimensions are determined by considering the power ratio between the output ports and also matching the input port.

According to the procedure in section 3 a two-way unequal power divider has been designed and simulated in section 4. Finally conclusion and suggestion for future work will be offered in section 5.

## 2. SIW Design

SIW is an artificial rectangular waveguide. It has been realized by metallic vias as side walls and metals of PCB as bottom and top walls. With the knowledge of pitch between consecutive vias and via diameters, SIW can be replaced by an equivalent rectangular waveguide. The equivalent width ( $a_e$ ) is computed using the method presented in [13, 14]. The cut-off frequency for dominant mode of rectangular waveguide is given as follows:

$$f_{cmn} = \frac{1}{2\pi\sqrt{\mu\epsilon}} \sqrt{\left(\frac{m\pi}{a_e}\right)^2 + \left(\frac{n\pi}{b}\right)^2} \quad (1)$$

$$f_{c10} = \frac{1}{2a_e\sqrt{\mu\epsilon}} \quad (2)$$

where  $b$  is the substrate thickness,  $a_e$  is the equivalent width of SIW,  $\epsilon$  and  $\mu$  are the

permittivity and permeability of the free space, respectively. By using the above formula width of the first layer corresponding to cut-off frequency will be calculated. Width of different parts on second layer will be determined by considering the power ratio between output ports and also matching the input port.

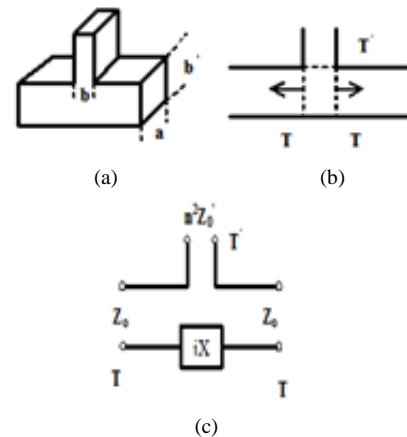
## 3. Power Divider Design.

The SIW power divider in Fig. 1 is resemble to E-plane power divider. Therefore the E-plane power divider design procedure could be use for designing the SIW counterpart.

The equivalent circuit model for E-plane power divider is shown in Fig.2 [15]. The reactive effect associated with the localized higher-mode can be account in equivalent circuit. The data in [15] indicate that for  $b \leq b'$ ,  $X$  is quite small and negligible. For SIW structure  $b = b'$  is the substrate thickness,  $Z_0$  is the characteristic impedance of the rectangular waveguide and  $n$  can be calculated from [15]. For SIW power divider in Fig.1  $Z_0$  is the characteristic impedance of the input line (first layer) and  $Z_0$  is the characteristic impedance of the two output lines (second layer). For the SIW equivalent circuit in Fig.2(c)  $b = b'$  is the substrate thickness, so the width of the SIW,  $a$ , is the only variable to achieve the desired response.

In order to accomplish different power at the output ports the two different characteristic impedances must be acquired. So the equivalent E-plane power divider must be changed so that the output ports have different characteristic impedances as shown in Fig.2 (d).

The characteristic impedance of rectangular waveguide linked to its width and height. The only variable for SIW is width of the structure. So by changing the width of two output ports, the unequal SIW power divider has been designed. It is easily possible in the light of via positions in second layer of unequal SIW power divider.



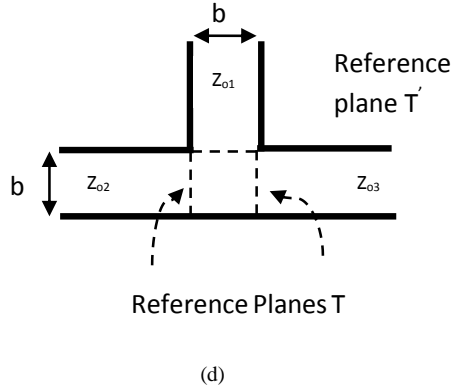


Fig. 2. E-plane power divider (a) General view (b) Side view (c) Equivalent circuit (d) Equivalent circuit for unequal SIW power divider

With ignoring the reactive component in Fig.2d, the power ratio equation can be writing as follows [16].

$$P_2 = Z_{02} I^2 ; \quad P_3 = Z_{03} I^2 \quad (3)$$

$$Z_0 = \frac{b \sqrt{\mu_r} \lambda_g}{a \sqrt{\epsilon_r} \lambda} ; \quad \lambda_g = \frac{\lambda}{\sqrt{1 - \left(\frac{\lambda}{2a}\right)^2}} \quad (4)$$

$$\frac{P_2}{P_3} = \frac{1}{k} \rightarrow a_3 = \sqrt{(ka_2)^2 + \left(\frac{\lambda}{2}\right)^2 (1 - k^2)} \quad (5)$$

Where  $P_2$  and  $P_3$  are the power coupled to the output ports and  $k$  is the power ratio.  $Z_0$  is the characteristic impedance of waveguide. Equation (5) show the relation between width of port 2 ( $a_2$ ) and width of port 3 ( $a_3$ ) in term of power ratio  $k$ . So it is possible to achieve desired power ratio for SIW unequal power divider. Also after finding the first and second layer dimensions with the mentioned procedure it must be optimized by software. It is because of some effects like slot in layers that can change a little bit on the component behavior. An SIW unequal two-way power divider design and simulation based on above procedure will be illustrated at the following.

#### 4. Two-Way Unequal Power Divider Design.

According to the above procedure an unequal SIW power divider has been designed for 10GHz operation frequency. As it is exhibited in Fig.3 SIW component connected to the 50Ω microstrip line by tapered section. The quasi-TEM mode of the microstrip line has been converted to the  $TE_{10}$  mode in the waveguide by this section. Design of this circuit is straightforward [17]. According to the Fig.3

there are three tapered sections which are all the same. This is not only simplified the calculation and simulation of the structure but also it causes that TRL calibration method can be applied to the structure. Therefore by TRL approach S-parameters of the whole structure without tapered sections can be measured. Increasing the number of output ports will be lead to increase the number of the layers, so it is needed to design a system so that it's electrical performances is in depend on the transition parts.

For this SIW power divider  $k=0.6$  is selected and R04003 substrate with  $h=0.508\text{mm}$ ,  $\epsilon_r=3.38$  and  $\tan\delta=0.0027$  has been used.

The vias diameter is 0.8mm and the distance between adjacent via is 1mm. Based on authors experience in fabrication [11] narrow slot leads to good results. The slot width is selected 1mm. The position of slot also effects on the return loss. The length of the tapered section is multiple of quarter wavelength and its width must be optimized.

The dimensions of the structure are shown in Table 1.

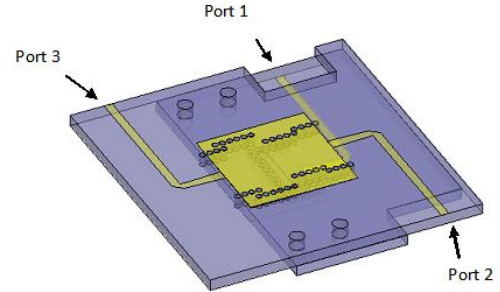


Fig. 3. Two-way SIW unequal power divider

Table. 1 Unequal SIW power divider dimensions (mm)

	Length	Width
First Layer	8.2	9
Second port	4	11.5
Third port	4	17.5
Transition Part	4.6	1.5

According to Fig.3 the width of two output of the unequal power divider are different from each other. Also the widths at connecting to tapered parts are equal in order to have the same with for tapered parts.

The dimensions in Table.1 is calculated for having 2dB ( $k=0.6$ ) difference at the output ports and 10GHz operation frequency. Different width of the output ports leads to different output power ratio.

Simulation results for two port unequal power divider with above dimensions are shown in Fig.4.

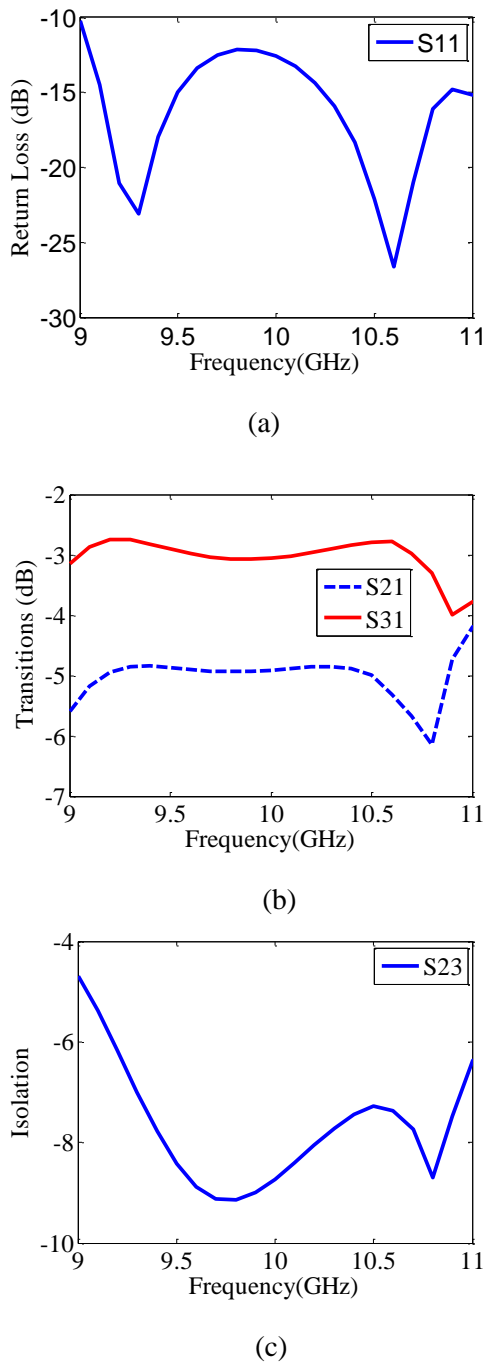


Fig. 4. Simulation results of SIW unequal power divider (a) Return Loss (b) Transitions (c) Isolation

Simulation results shows that return loss is below than 10dB from 9GHz to 11 GHz. Transitions show that there are approximately 2 dB differences between output ports from 9.2GHz to 10.4 GHz. According to Fig.4(c) there is not good isolation between output ports as expected. Good isolation can be achieved with a resistance between output ports. These results are very good when it compare with available unequal power dividers. The available unequal power dividers have been designed for a

single frequency or at the dual mode structure they have been focused on center frequency of dual band.

## 5. Conclusion

SIW technology has been used for designing the unequal power divider. The similarity between this structure and E-plane power divider has been used for controlling the amount of output power from each output ports. Adjusting the output power in each output port carried out easily by changing the width of the SIW in second layer. Therefore it is possible to achieve arbitrary proportion between output powers. This two-way structure can be modified to n-way with only increasing the number of SIW layers. So the length of the structure becomes larger when its output ports increases and its width remains constant.

Compact size, low cost, easily fabrication process makes this structure suitable candidate for microwave designer. For the future work this structure can be used as feed network for microstrip array antenna. Feeding network and radiation parts are integrated at the same PCB.

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