Comparision Of Optimal S-Band Power Divider Design For Imaging Radar Application

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***Abstract*: The performance parameters of two competitive feeding networks is compared by means of Return Loss and Insertion Loss. The Design of 1:2 Wilkinson Power Divider and 1:2 Gysel Power Divider are analysed and the results are compared to choose proper category power divider suitable for Imaging Radar application. Gysel Power Divider (GPD) is shown to be effective for low frequency (S-band) application. Hence 1:N GPD can be designed for 1xN linear array antenna. The result shows that 37% improvement of Return Loss in 1:2 GPD. The design is evaluated and results are analysed using ANSOFT DESIGNER v7.0 software.**

Keywords: *Wilkinson Power Divider WPD, Gysel Power Divider GPD, Insertion Loss, Return Loss.*

I. INTRODUCTION

Power Dividers/Combiners are key components in many applications as modulator, balanced mixer, antenna array feeds that are used to partition signal into two or more identical output signals or for fusing two or multiple signals into one output. For standard Power Dividers the condition for this fusing or partitioning function is to maintain a constant impedance of Zo at all ports over operating frequency to avoid impedance mismatch and high system loss. Although Power Dividers are built for different applications and the most applications require isolation among output ports. The advantage of an isolated Divider is that the output at one port is not affected by an impedance mismatch at another output port also the isolation would limit the power leakage from one output to another output port.

For any multi port network, there are some conditions to be satisfied. These are sometime the properties of such devices. Such properties used to validate the Multiport network are ahown below[1].

A. Lossless Condition

A network is called as lossless network only when sum of all the powers at output is equal to the incident power at the input port. No power should be dissipated as heat or radiation internally or externally[2]. But, in practical case an active devices are not able to be a lossless network while adding bias through the bias junction.

If the network satisfies " the sum of the squares of magnitude of any row or any column of the Scattering Matrix is equal to one"[2], then the network is called lossless network. If not, then it is called lossy network.

Total input power = Total output power

$$\sum_{i=1}^{n} a_i a_i^* = \sum_{i=1}^{n} b_i b_i^* \quad (1)$$

Where a and b are the amplitude of the signal

$$S^t S^* = I \qquad \text{It is called unitary matrix} \quad (2)$$

$$\sum_{k=1}^{n} S_{ki} S_{kj}^* = \left.\begin{matrix} 1 & for\, i = j \\ 0 & for\, i \neq j \end{matrix}\right\} \quad (3)$$

B. Matching Condition

Matching condition is plays a vital role in multiport network. The maximum power is delivered to the load only when the impedance of all ports are matched. All the network should satisfy this condition to minimize the loss at ports. There found any mismatch in impedance then the loss shall be maximum.

The network is a matching network, only if it satisfy $\mathbf{S_{ii}=0}$ [1] (i.e all diagonal Scattering elements of output port should be zero in ideal case and equal for practical case).

C. Reciprocity

The are two categories of the N-port network are Reciprocal Network and Non-Reciprocal Network. If the change in the terminal conditions at one port affects the conditions at the other ports that network is called as Non-reciprocal[1]. There is no effect while changing terminal conditions of two ports that network is called as Reciprocal Network. The reciprocity is charecterized by Symmetric property.

Some examples of Reciprocal networks are Coupler, Power divider/combiner,etc.. and Non-Reciprocal networks are Isolator, Circulator and so on.

The network is said to be Reciprocal when it's S-matrix is in the form $\mathbf{S_{ij}=S_{ji}}$ **or** $\mathbf{[S]_t = [S]}$. Otherwise the network is Non-Reciprocal. For any reciprocal network with assumed normalization, the impedance matrix equation is

$$[V]= [Z][I]=[Z]([a] - [b]) = [a] + [b] \quad (4)$$

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(or) $([Z] + [U])\,[b] = ([Z] - [U])\,[a]$ (5)

(or) $[b] = ([Z] + [U])^{-1}\,([Z] - [U])\,[a]$ (6)

Where [U] is the unit matrix

The S-matrix equation for the network is

$[b] = [S]\,[a]$ (7)

$[S] = ([Z] + [U])^{-1}\,([Z] - [U])$ (8)

Let $[R] = ([Z] - [U])$ and $[Q] = ([Z] + [U])^{-1}$ (9)

Hence $[S] = [R]\,[Q]^{-1}$ (10)

Now transpose of [S] is $[S]_t = ([Z] + [U])_t^{-1}\,([Z] - [U])_t$ (11)

Now the proof should be made from S-parameters as

$$[S] = [S]_t \quad (12)$$

II. DESIGN OF 2-WAY WILKINSON POWER DIVIDER

A. Wilkinson Power Divider

The Wilkinson power divider can achieve the ideal Multiple port network conditions- Lossless, Reciprocal and Matched. Hence Wilkinson power divider is made as best choice when compare with T-junction and Resistive power dividers in corporate-fed network for an antenna array.

The Two-way Wilkinson power divider / Wilkinson combiner Fig. 1 uses quarter wave transformers to divide the input signal into two output signals with in-phase and equal magnitude[7].

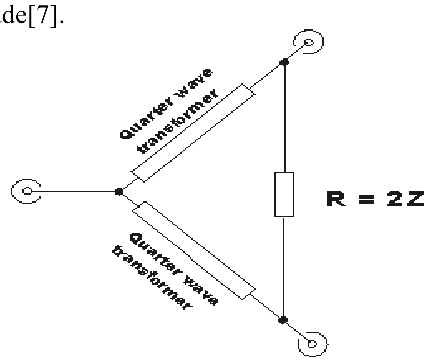

Fig. 1 Two-way Wilkinson Power Divider

The values used in the two-way Wilkinson divider / combiner can be calculated:

R = 2 x Zo
Z_{match} = √2 x Zo
= 1.414 x Zo

Where: R = the value of the resistor connecting two ports
Zo= the characteristic impedance of the system
Z_{match} = transformer impedance

A signal falling at port1 shown in Fig. 1 reaches the divider junction and passes to two output ports- port 2 and port 3 of the Power divider. If Divider/combiner's transformers are identical then it produces the same phase output signal.Same potential is produced with zero current flow at the terminals.

B. Design

The optimal design of Wilkinson Power Divider is constructed using transmission lines with electrical length, 50ohm impedance,3.2GHz frequency and terminating resistor[7]. It's function is to divide the input power into equal output power at N-ports. The input power is given at input line impedance Zo and is taken out as equally divided power at N-ports.

If the 2-way Wilkinson power divider is considered, and it's power 'P' input port1 then power at two output ports- port2 and port3 should be 'P/2' each for an equally split divider/Combiner. The same design can be used as Power Combiner by interchanging Input and output ports. It means the power is given at port2 and port3 and output is taken at port1[3]. Now, this design act as combiner by providing sum powers at port1. Isolating resistor plays major role in power divider, as it separates output ports that two ports are operating independently. Using this isolating resistor limits the power handling capability of a device[4].

The circuit Fig. 2 is optimized to operate at S-band. Hence it can be used in array of Imaging Aperture Radars.

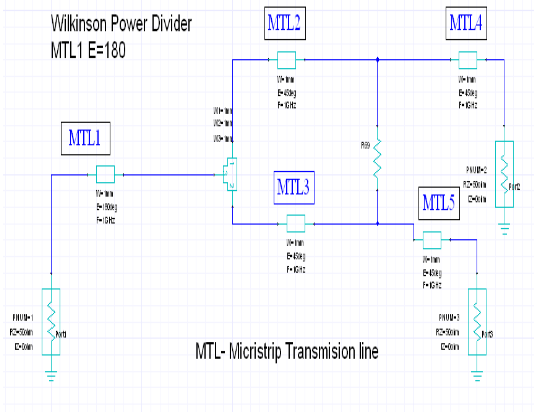

Fig. 2 Two way Wilkinson Power Divider at 3.2GHz

There are many techniques raised to overcome the above limitation. Among that, Gysel has found the new way to improve power handling capacity[8]. With that, loss can also be reduced. Later in Chapter III Gysel Power Divider is designed for same S-frequency of 3.2GHz and performance of 2-way Wilkinson and Gysel Power Dividers are compared to choose better technology for Radar application. Chapter IV

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shows optimal design and analysis of 4-way Gysel Power Divider.

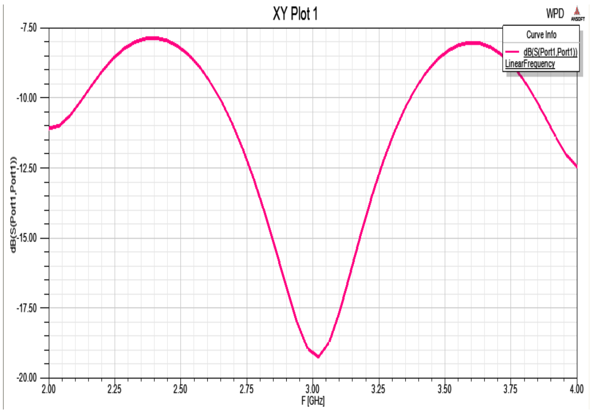

Fig. 3 Simulation Result of S-band WPD

From the Fig. 3 graph, we observe that the proposed Wilkinson Power Divider provides the return loss of -24.18dB at 3.2GHz.

III. DESIGN OF 2-WAY GYSEL POWER DIVIDER

A. Gysel Power Divider

The Gysel Power Divider differs from Wilkinson Power Divider by replacing the Resistor contact between output ports by transmission line[9]. This makes Gysel power divider more beneficial than above one. Its benefits are (1) External Isolation TL let it to handle high power, (2) Simple realization of circuit and (3) Auditing of imbalanced ports.

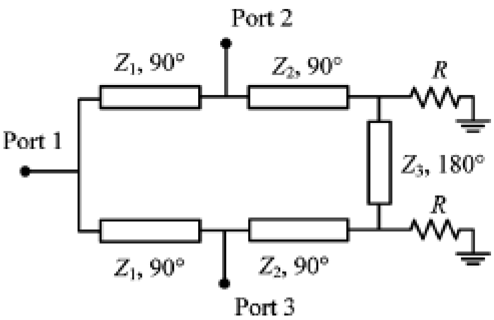

Fig. 4 Conventional Gysel Power Divider

B. Design

The Isolation resistor used between two terminals of Wilkinson Power divider is to control the power handling capability[9] of the device at power less than 100W due to its inadequate heat sink of terminal resistor. Thus for applications in high power WPD is not selected. Hence Gysel proposed the power divider by replacing terminating resistance shown in Fig. 1 using transmission line. A new power divider[5] after replacement looks like Fig. 4.

The circuit Fig. 5 is optimized to operate at S-band. Hence it can be used in array of Imaging Aperture Radars.

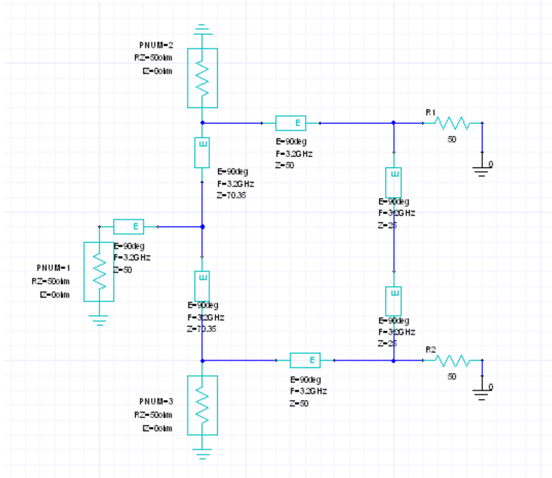
Fig. 5 Two way Gysel Power Divider at 3.2GHz

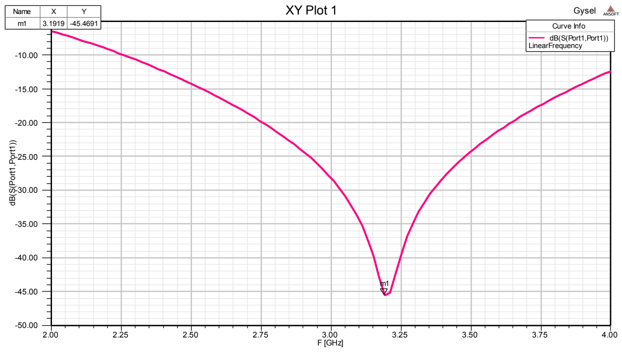

Fig. 6 Simulation Result of S-band GPD

From the Fig. 6 graph, we observe that the proposed Gysel Power Divider produces the return loss of -33.15dB at 3.2GHz.

C. Performance Analysis

Table 3.1 gives the performance analysis of GPD versus WPD with respect to return loss at the center frequency of 3.2GHz. The Return loss measured for WPD and GPD are –24.18dB and -33.15dB respectively. Hence the comparative result shows that return loss of GPD is found to be 37% lesser when it is related to WPD.

TABLE I
PERFORMANCE ANALYSIS OF GPD AND WPD

1:2 Power Divider Type	Frequency in GHz	S_{11}	Return loss in dB
WPD	3.2	-16.18	-24.18
GPD	3.2	-45.46	-33.15

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From the above **TABLE II,** it is clear that using GPD will provide better results than WPD. Hence we can design 1:N Gysel Power Divider[6] by using 1:2 power dividers as required.

IV. FOUR-WAY GYSEL POWER DIVIDER

A. Design

The proposed Four-way Gysel power divider for S-band is shown in Fig. 7 splits the input power into four equal output power. Here isolation is done by microstrip transmission line connected between output ports.

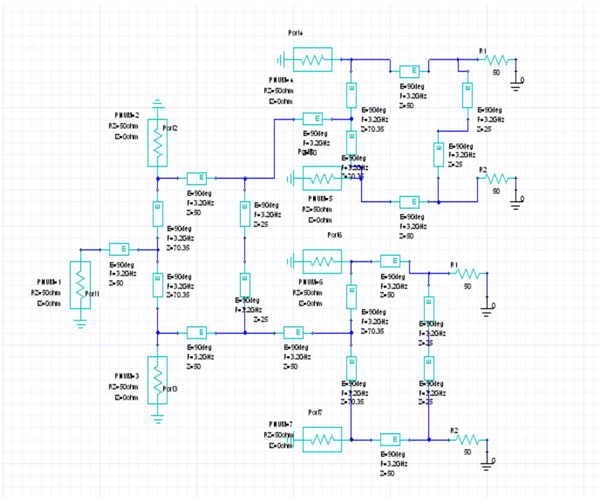

Fig. 7 Four way Gysel Power Divider at 3.2GHz

B. Simulation Result

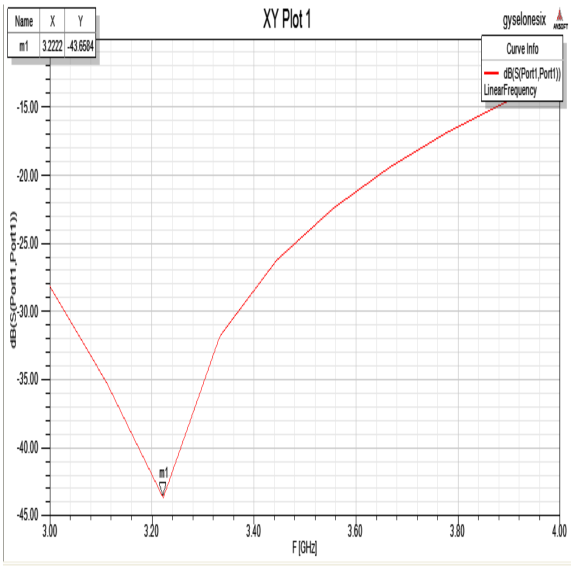

Fig. 8 Return loss

Fig. 8 expose that the proposed 1:4 Gysel Power Divider produces Return loss of about -45.63dB

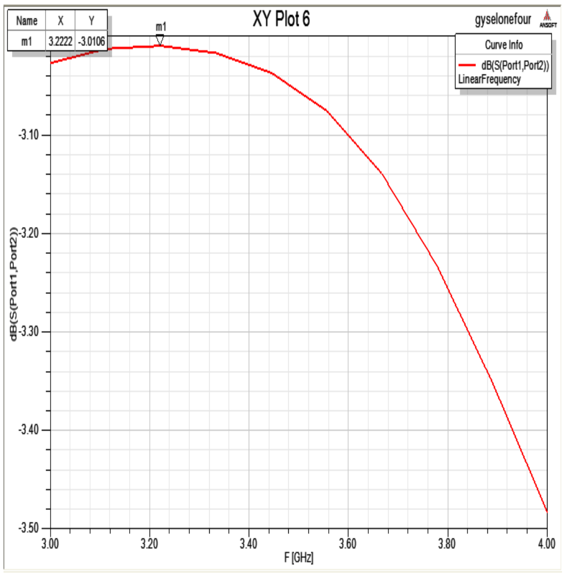

Fig. 9 Insertion loss

Fig. 9 Expose that the suggested 4-way power divider provides Insertion loss of about -3dB.

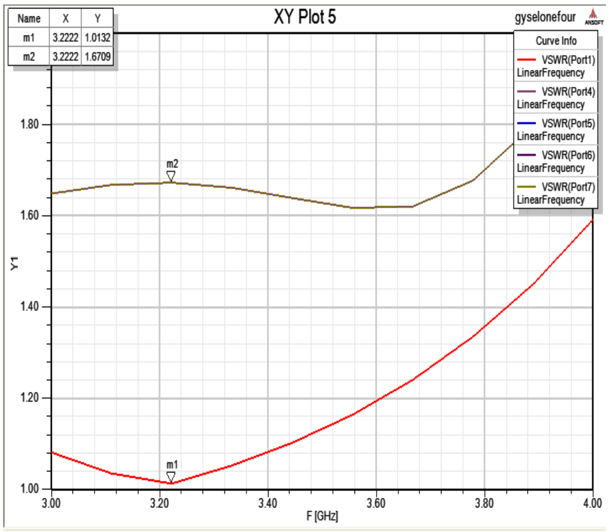

Fig. 10 VSWR

The Voltage Standing Wave ration of proposed 4-way power divider produced is within the suggested range. It is shown in graph Fig. 10.

TABLE II
PERFORMANCE ANALYSIS OF 1:4 GPD

Frequency in GHz	**Return loss in dB**	**Insertion loss in dB**	**VSWR**	
			Port1	**Port2,3,45**
3.2	-45.63	-3	1.032	1.567

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Scattering Matrix

The S-matrix for 5 port network is given that

$$[S] = \begin{pmatrix} S_{11} & S_{12} & S_{13} & S_{14} & S_{15} \\ S_{21} & S_{22} & S_{23} & S_{24} & S_{25} \\ S_{31} & S_{32} & S_{33} & S_{34} & S_{35} \\ S_{41} & S_{42} & S_{43} & S_{44} & S_{45} \\ S_{51} & S_{52} & S_{53} & S_{54} & S_{55} \end{pmatrix}$$

The S-parameter is a mathematical construction which defines how the RF energy travel through each port of the multiport network. It is also used to describe electrical behaviour of network. It is represented by notation S_{ij}. In which i denotes responding port and j denotes incident port. S_{11} is called reflection loss (i.e) If a signal incident on port1, the same port responds. This response is called reflection at port1 or loss due to reflection.

The S-matrix of 5port power divider

$$[S] = \begin{pmatrix} -43.66 & -51.33 & -51.33 & -51.33 & -51.33 \\ -51.33 & -12.00 & -12.00 & -12.08 & -12.08 \\ -51.33 & -12.00 & -12.00 & -12.08 & -12.08 \\ -51.33 & -12.08 & -12.08 & -12.00 & -12.00 \\ -51.33 & -12.00 & -12.08 & -12.00 & -12.00 \end{pmatrix}$$

C. *Validation of five port network*

The results are compared with the conditions given in Chapter I. These results indicate that the proposed network is the perfectly matched, lossy and reciprocal network.This conclusion is made by comparing the results with conditions for N-port network given in Chapter I.

V. CONCLUSION

The results documented in this paper indicate that 1:2 Gysel Power Divider can provide a significant amount of improvement in return loss comparable with conventional Wilkinson Power Divider. The conventional structures of power dividers were described and optimization was done using ANSOFT Designer to operate at 3.2GHz.The Return loss versus frequency was presented for two competitive power divider/combiner. From this plot, we observed the return loss of 1:2 WPD and 1:2 GPD are -24.18dB and -33.15dB respectively. This result shows return loss of GPD is 37% less compared to WPD. The 1:4 GPD is designed with Return loss of -45.63dB at 3.2GHz. The Scattering matrix of multiport network are considered and the properties of S-parameter for perfectly matched, reciprocal and lossless network were proven.

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