Design and Simulation of N-Way In-phase Equal power Wilkinson Power Divider

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Abstract

In this paper, three designs of Wilkinson Power Divider (WPD) at 9.0 GHz center frequency are proposed. The first design is 2-way in-phase equal power outputs implemented on the Roger RT-duroid 6006, PTFE ceramic, relative permittivity $e_r = 10.2$ and thickness of substrate material $h = 0.365mm$. The second design is 4-way and the third design is 8-way in-phase equal power dividers are implemented on the same substrate. The third design is a new shape of 8-way WPD consists of feeder connected with four WPD via cut cortex rhombus to achieve matching with inputs. All designs are simulated by using CAD (Microwave Office 2000). The simulation results demonstrate that the power divider works well at assigned operating frequency with compact size. Low insertion and high isolation are achieved.

Keywords: Wilkinson, Power divider

تصميم ومحاكاة مقسمات قدرة ويلكنسون ذو عدد (N) من المخارج بنفس الطور وقدرة خرج متساوية

الخلاصة

في هذا البحث ، تم التطرق الى ثلاثة تصاميم لمقسم قدرة ويلكنسون عند التردد المركزي 9 كيكاهرتز. التصميم الاول عبارة عن مقسم قدرة متساوي بنفس الطور تم تنفيذه على المادة نوع سيراميك (RT-duroid 6006) بسماحية 10.2 وسمك 0.365 ملم . التصميم الثاني ذو اربعة مخارج والتصميم الثالث ذو ثمان مخارج وهي مقسمات قدرة متساوية بنفس الطورتم تنفيذهما على نفس المادة . التصميم الثالث عبارة عن شكل جديد ذو ثمان مخارج ويتكون من مغذي يرتبط باربع مقسمات قدرة ويلكنسون من خلال معين مقطوع الرؤوس للحصول على اقتران مع المداخل. تم اجراء المحاكاة لكافة التصاميم باستخدام الحقيبة البرمجية Microwave Office 2000. النتائج المستحصلة تبين ان مقسم القدرة بهذا الحجم المدمج يعمل بشكل جيد عند تردد العمل المحدد . تم الحصول على خسارة ادخال واطئة وعزل عالي.

Introduction

Broadband microwave power dividers are a very important category of passive microwave circuits. Indeed, these components are often used in microwave systems to combine or divide RF signals, and they are commonly used in many applications, such as antennas feeds, power amplifiers, mixers and so on. The Wilkinson divider is most widely used in microwave communication systems. Recently, parallel striplines have been used with a modified configuration of the Wilkinson Power Divider (WPD) [1].

The lossless T-junction divider suffers from the problem of not being matched at all ports and, in addition, does not have any isolation between

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output ports. The resistive divider can be matched at all ports, but even though it is not lossless and isolation is still not achieved. Wilkinson power divider is such a network, with the useful property of being lossless when the output ports are matched; that is, only reflected power is dissipated [2].

The in-phase power combiners and dividers are important components of the RF and microwave transmitters where it is necessary to deliver a high level of the output power to antenna, especially in phased-array systems. In this case, it is also required to provide a high degree of isolation between output ports over some frequency range for identical in-phase signals with equal amplitudes [3].

A Wilkinson coupler is a two-way power divider or combiner. It offers broadband and in-phase characteristics at each of its output ports. For a 3dB coupler, the input at port (1) is split equally into two signals at ports(2) and (3). Ports (2) and (3) are isolated by resistor of $2Z_o$ connected between the two output ports to ensure the isolation [4]. The Wilkinson power divider can be made with arbitrary power division, but we will first consider the equal-split (3dB) case. This divider is often made in microstrip or stripline form, as depicted in figure (1a); the corresponding transmission line circuit is given in figure (1b).

Nihad Dib, Majid Khodier[5] are introduced a general and easy procedure for designing the symmetrical Wilkinson power divider that achieves equal-power split at N arbitrary frequencies. . Stephen Horst, et al[6] is presented a modification of the Wilkinson power divider that eases planar implementation while maintaining performance. Two frequency bands are demonstrated. At V-band, the circuit gives 0.3dB excess insertion loss, 19dB isolation, and 50% bandwidth. At the W-band, the circuit gives 0.75dB excess insertion loss, 24dB isolation, and 39%bandwidth. Hualiang Zhang, Hao Xin[7] presents new designs of Wilkinson power dividers for dual-band operations. Two types of dual-band quarter-wavelength ($l/4$) transmission lines are proposed first, where both open- and short-ended stubs are applied. Haiwen Liu, et al [8] are presented a newly asymmetrical spurline structure by using two LCR-resonators and the circuit parameters extracted from EM simulation. S. Shamsinejad, et al[9] describe the miniaturization of a microstrip WPD by substituting the quarter wave transmission lines employed in conventional WPDs with its equal circuit consisting of two stubs and an inductor.

In this research, three designs of WPD are presented. The first design is a 2-way in-phase equal power output implemented on the Roger RT-duroid 6006, PTFE ceramic substrate, $e_r = 10.2, h = 0.365mm$. The second design is a 4-way WPD is implemented on the same substrate. The third design is a new shape 8-way WPD consists of feeder as input connected to four 2-way WPD via cut cortex rhombus, this design is implemented on the same substrate.
All designs are simulated by using CAD (Microwave Office 2000).

Theory

For any propagating wave the velocity (c) is given by the appropriate frequency (f)-wavelength product. In free space we have [10]:

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$$c = fl_o \quad \ldots\ldots\ldots (1)$$

In microstrip, the velocity (v_p) is:

$$v_p = fl_g \quad \ldots\ldots\ldots\ldots (2)$$

where

l_o is wavelength in free space

l_g is the guide wavelength

The effective microstrip permittivity e_{eff} is given by [10]:

$$e_{eff} = \left(\frac{c}{v_p} \right)^2 \quad \ldots\ldots\ldots\ldots (3)$$

l_g can be obtained by substituting equations(1 & 2) in equation (3) as following:

$$l_g = \frac{l_o}{\sqrt{e_{eff}}} \quad \ldots\ldots\ldots (4)$$

The effective permittivity for $t/h << 0.005$ are summarized as [11]:

$$e_{eff} = \frac{e_r + 1}{2} + \frac{e_r - 1}{2}(1 + \frac{12}{w/h})^{-1/2}$$

for $w/h \geq 1$ ….. (5)

where

e_r is the relative dielectric constant

h is the height of dielectric substrate

w is the width of the strip conductor

t is the thickness of the strip conductor

and the wavelength of the dielectric medium (l) is given by:

$$l = \frac{l_o}{\left[1 + 0.63(e_r - 1).(w/h)^{0.1255}\right]^{1/2}}$$

for $w/h \geq 0.6$ ….. (6)

The hybrid planar microstrip realization of the simplest two-way Wilkinson divider is shown in figure (1). It consists of two quarter-wave microstrip lines connected in parallel at the input end and the resistor connected between the output ports of the microstrip lines. Figure (2) shows that resistor is changing by planar ballast resistor. Despite its small dimension and simple construction, such a divider provides a sufficient isolation between output ports over sufficiently wide frequency bandwidth when equal power division is provided due to a symmetrical configuration with:

$$R = 2Z_o \quad \ldots\ldots\ldots \quad (7)$$

and $Z_1 = \sqrt{R.Z_o}$ …….. (8)

where

R is the input and output characteristic impedance

Z_o is the shunt resistanc between two output ports

Z_1 is the matching impedance between R and Z_o

No power is lost, either due to reflection at the input port or absorption by the WPD. This device can be referred to 3dB power divider, as:

$$10\log\left[\frac{P_{out}}{P_{in}}\right] = 10\log\left[\frac{1}{2}\right] = -3dB$$

The termination resistor in WPD creates balance between the output ports. The termination resistor also determines the power rating of the device. To determine the size or needed power rating of the termination resistor for a given input power (P_{in}) the following formulas are used [12]:

$$\Gamma_v = \frac{VSWR - 1}{VSWR + 1} \quad \ldots\ldots\ldots\ldots (9)$$

where

Γ_v is the voltage reflection coefficient

$VSWR$ is the Voltage Standing Wave Ratio.

The power reflected from the mismatch (Γ_P) is given by [12]:

$$\Gamma_p = \Gamma_v^{\ 2} \qquad \ldots\ldots.. \ (10)$$

Then, the total power dissipated in the termination resistor is given by [12]:

$$P_{dissipated} = \Gamma_v^{\ 2}.P_{in} \ \ldots\ldots.. (11)$$

Results & Discussions

Figure (2) shows the layout of two way Wilkinson Power Divider, in this figure the input and outputs impedance are equal to 50 ohm. The mutual pure conductor resister between two output ports is equal to 100 ohm. Figure (3) shows the insertion loss ($S_{21} = S_{31}$) dB for two way Wilkinson Power Divider that is equal to -3dB. Figure (4) shows the phase between two output ports is the same value. The input and output power in dBm for 2-way WPD is shown in figure (5), where is, if the input power is 10dBm, the output power is equal to 7dBm on each port. Voltage Standing Wave Ratio (VSWR) in Figure (6) measured at the power divider output ports is enclosed between (1) to (1.5), that represents a good value at which the value of Γ_v is small.

Figure (7) shows the layout of 4-way microstrip Wilkinson divider fabricated on ceramic substrate with three 100Ω planar ballast resistors. Figure (8) shows the schematic diagram for 4-way output port of WPD. Figure (9) shows the insertion loss ($S_{21}, S_{31}, S_{41}, S_{51}$) dB which is equal to -6dB. Figure (10) shows the input and output power in dBm for 4-way WPD, where is, if the input power is 10dBm, the output power is equal to 4dBm on each port. Figure (11) shows the phase between four output ports, that is in the same value. Figure (12) shows the VSWR for 4-way WPD.

Figure(13) shows that the Return Loss of 2-way and 4-way WPD is the same value which is equal to 9GHz. Figure(14) shows the output isolation for 2-way and 4-way WPD.

Figure (15) shows the layout of the third design for 8-way WPD, and the 3-dimensional layout of it, is shown in figure (16). The distance "length" from feeder "port (1)" to any output ports are equal to obtain the same output power and in-phase for each port. The connection between feeder and four WPD via cut cortex rhombus to achieve matching with inputs of four WPD. Figure (17) shows the Insertion Loss of 8-way WPD. Figure (18) shows the input and output power in dBm for 8-way WPD. In this design we get the same phase between output ports as shown in figure (19). VSWR, Return Loss and Output isolation for this design is shown in figures (20, 21, 22) respectively.

Conclusions

In this paper, three designs of a Wilkinson Power Divider are implemented on the Roger RT-duroid 6006, PTFE Ceramic,

$$e_r = 10.2, h = 0.365mm$$

are presented, all designs are simulated by using CAD (Microwave office 2000). The divider response agrees well with simulated results. A good matching and minimum area design are achieved. From the results, the insertion loss between the ports is equal and also the phase between them is same that is very important to work the Wilkinson Power Divider correctly.

A new shape of 8-way WPD is maintaining the ideal performance characteristics of being matched, reciprocal, and isolated between the output ports. The simulation results demonstrate that the power divider works well at assigned operating frequency with compact size.

The measurement results match very well with simulations. Moreover the bandwidth of the designed power divider is examined under the conditions of equal output power, in-phase responses and good isolation.

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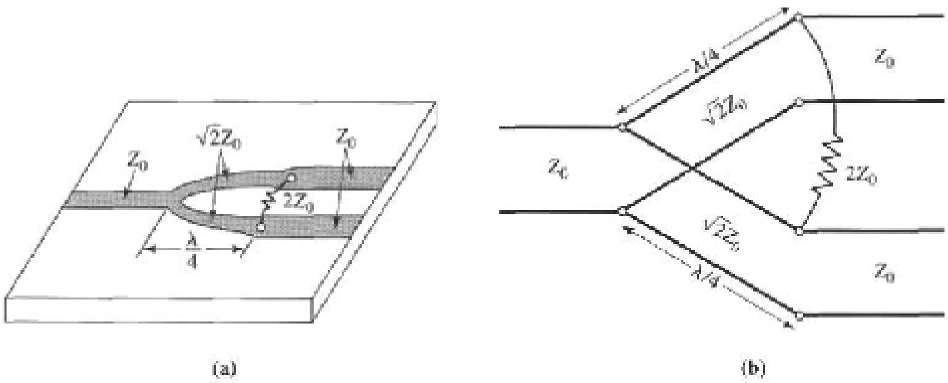

Figure (1): The Wilkinson power divider [2].
(a) An equal-split in microstrip
(b) Equivalent transmission line circuit

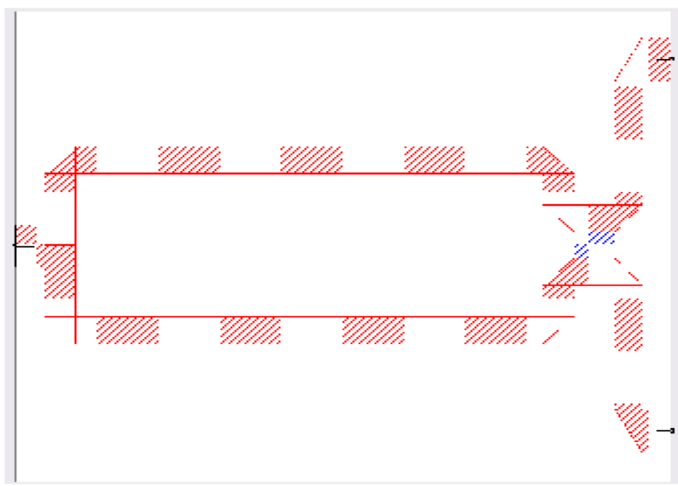

Figure (2): Layout of 2-way WPD

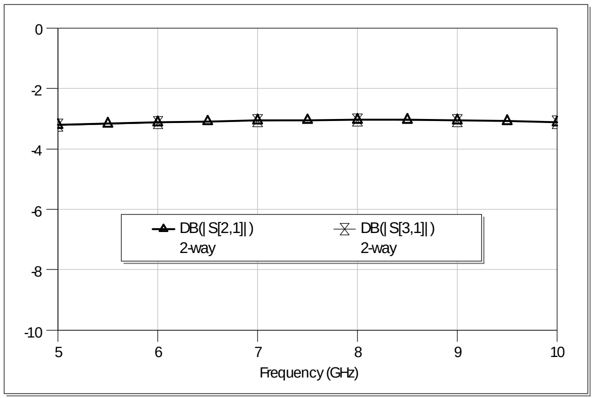

Figure (3): Insertion loss of 2-way WPD

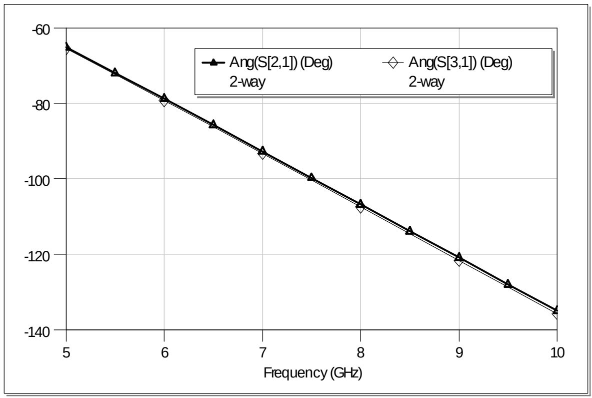

Figure (4): In-phase output ports for 2-way WPD

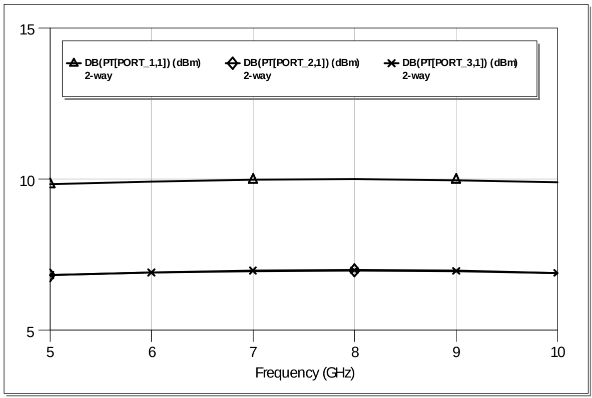

Figure (5): Input and Output power in dBm for 2-way WPD

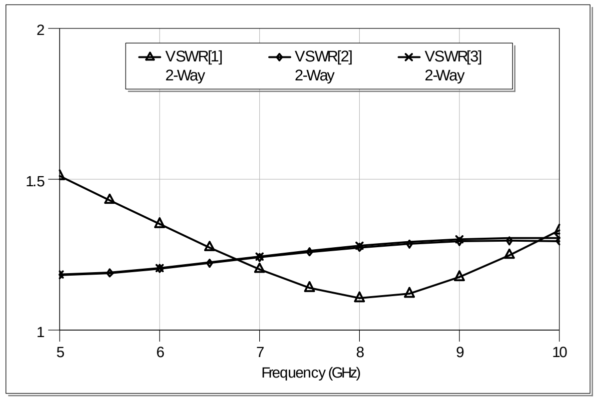

Figure (6): VSWR for 2-way WPD

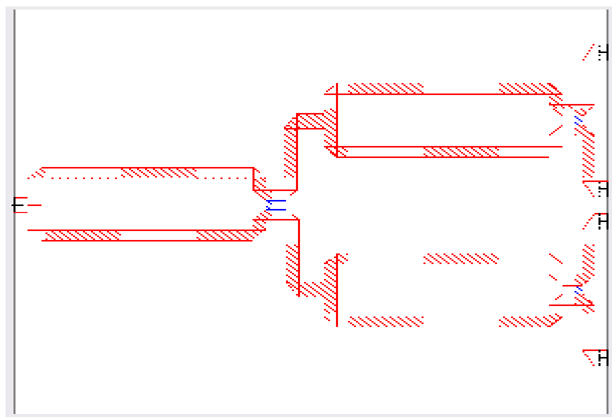

Figure (7): Layout of 4-way WPD

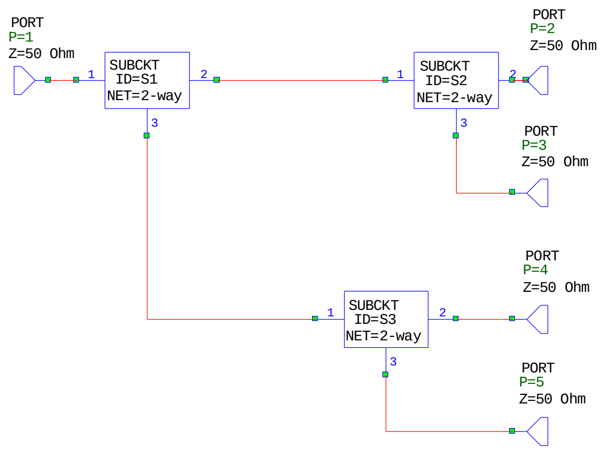

Figure (8): Schematic diagram for 4-way output port of WPD

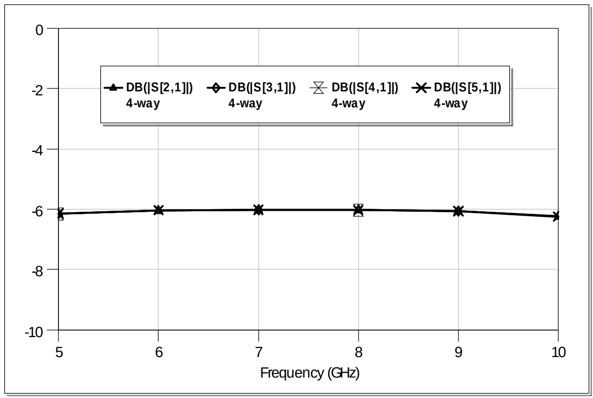

Figure (9): Insertion loss for 4-way WPD

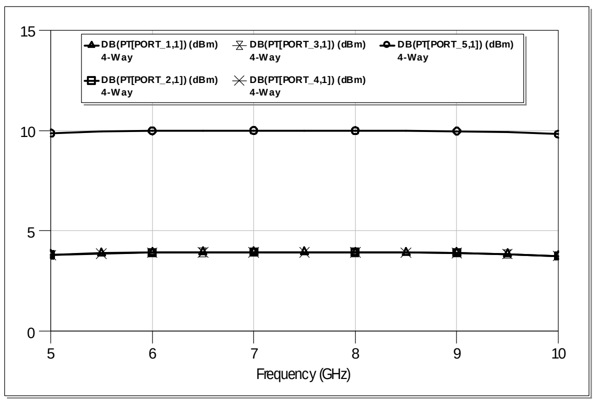

Figure (10): Input and Output power in dBm for 4-way WPD

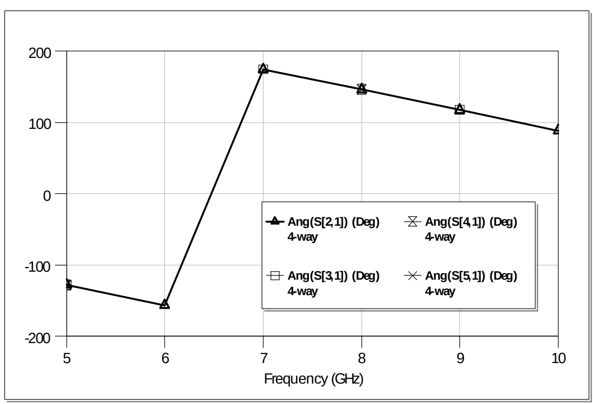

Figure (11): In- phase output ports for 4-way WPD

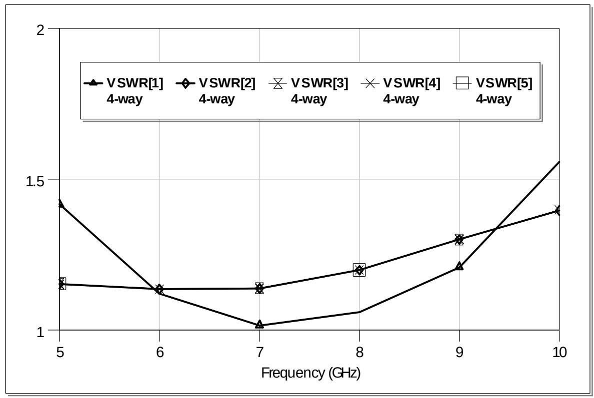

Figure (12): VSWR for 4-way WPD

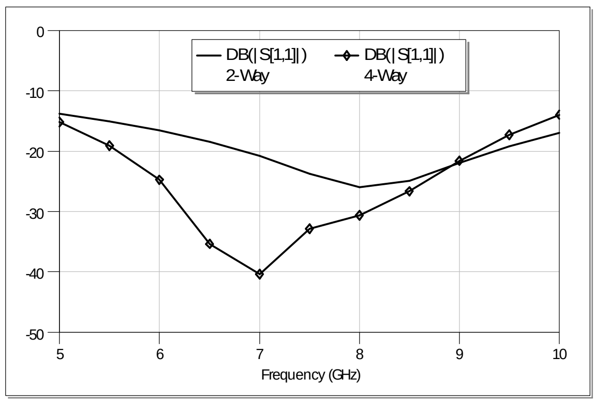

Figure (13): Return loss for 2-way and 4-way WPD

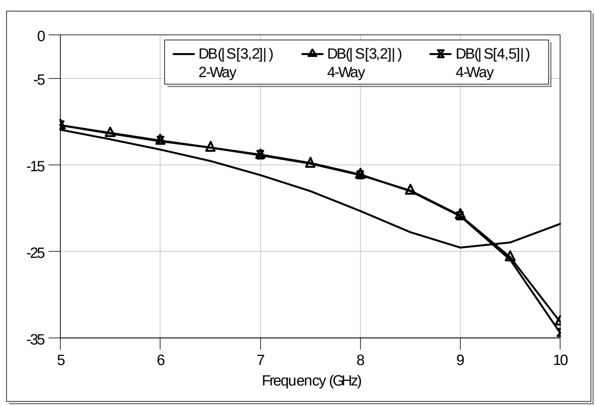

Figure (14): Output isolation for 2-way and 4-way WPD

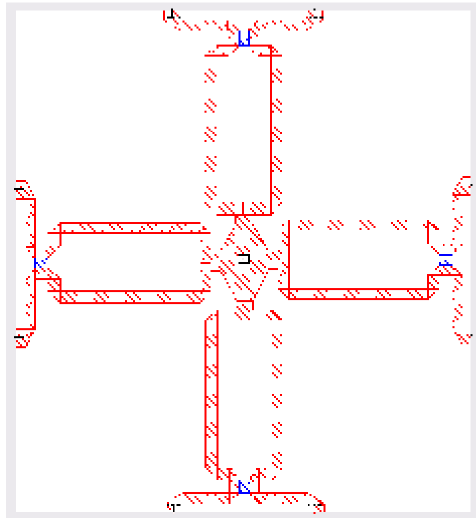

Figure (15): Layout of 8-way WPD

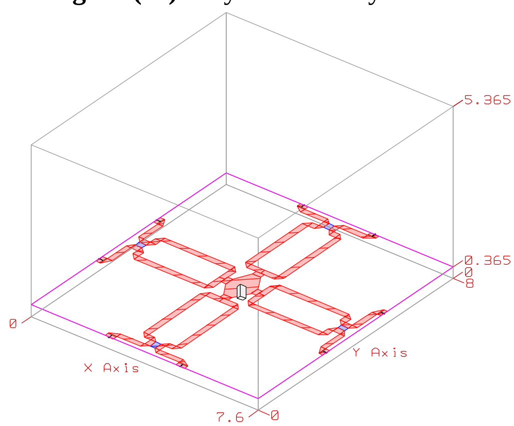

Figure (16): 3- Dimensional Layout of 8-way WPD

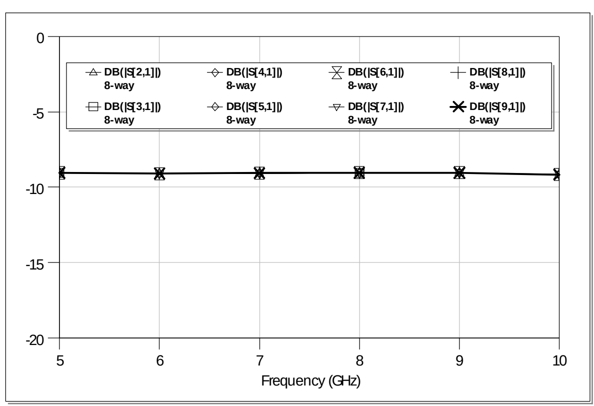

Figure (17): Insertion Loss of 8-way WPD

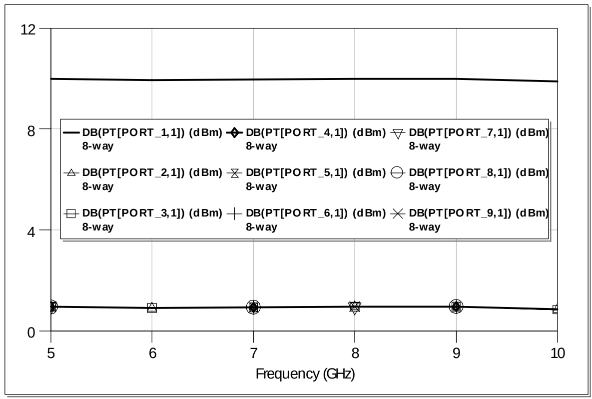

Figure (18): Input and Output power in dBm for 8-way WPD

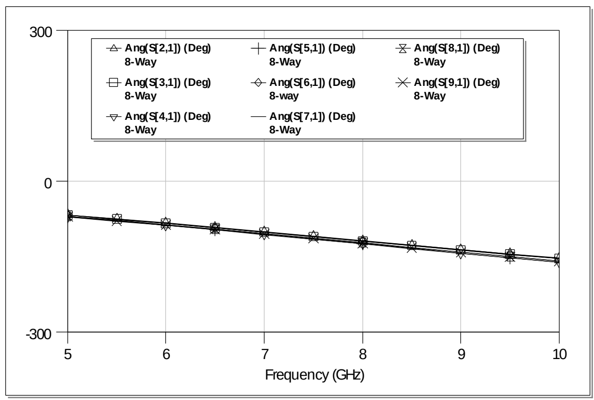

Figure (19): Equal phase between output ports for 8-way WPD

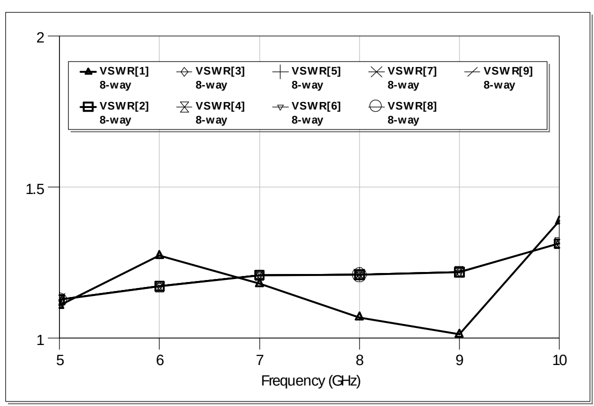

Figure (20): VSWR for 8-way WPD

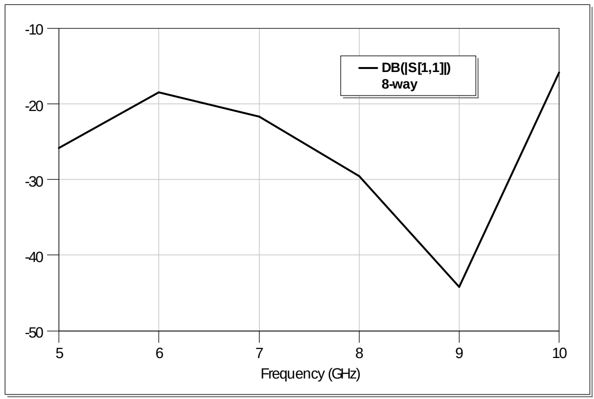

Figure (21): Return Loss for 8-way WPD

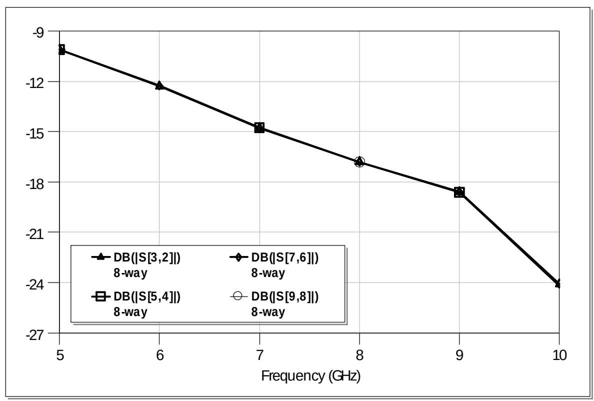

Figure (22): Output isolation for 8-way WPD