

# Effect of Adding Input and Output Impedance Transformer on Wilkinson Power Dividers Performance

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**Abstract**— Even though the two-stage Wilkinson N-way power divider is simple to design, realize and test, It has been used with strict restrictions in design and fabrication because it requires a very high impedance microstrip line, i.e., extremely low aspect ratio W/H or very thin line conductor width. To overcome this limitation in realizable characteristic impedance a quarter-wave length impedance transformer section between two lines is used. This research investigates the effect of adding quarter-wave lines impedance transformation to two-stage Wilkinson N-way power divider on the performance parameters.

**Index Terms** — Wilkinson, N-way, impedance transformer, Quarter-wave impedance transformer, Microstrip, power divider, combiner.

## 1 INTRODUCTION

POWER dividers and combiners are used widely in RF/microwave power amplifiers, linearizers, and many kinds of test equipments. Among many sorts of divider, the Wilkinson topology shows the basic concept of N-way power dividing by its simple structure. The two-stage Wilkinson N-way power divider is a typical application of the Wilkinson structure, because it is simple and easy to design, realize, and test [1],[2]. On the contrary to this simplicity of the divider, the two-stage Wilkinson N-way power divider has been used with strict restrictions in design and fabrication because it requires a microstrip line with very high impedance, i.e., very low aspect ratio W/H (ratio of line width W to the substrate thickness H) or very thin conductor width. For example, a four-way Wilkinson divider requires  $141\Omega$  microstrip line. In practice, the characteristic impedance of a realizable microstrip has its limitation at around  $135\Omega$  -  $145\Omega$ , although it depends on the dielectric constant ( $\epsilon_r$ ) and the thickness of the substrate. It is almost impractical to realize a  $141\Omega$  line using the conventional microstrip structure [3],[4]. To overcome this limitation in realizable characteristic impedance a quarter-wave impedance transformer section between two lines was added to the N-way power divider design, which gives a width to the microstrip line conductor than that is required for the same characteristic impedance

able ranges of strip width in the construction of a specific circuit.

The most convenient way of doing this is with the single or multi-section quarter-wave stepped impedance transformer. In its simplest form for narrow band operation, this consists of a quarter-wave section whose impedance is the square root of the ratio of the impedance transformation.

$$Z_B = \sqrt{Z_A \times Z_C} \quad (1)$$

[ZB] is the additional impedance transformer line, [ZC] is impedance required to be transformed to, [ZA] is impedance to be transformed as shown in Fig. 1.



Fig.1 matching transformation lines (transforming A to line C by B)

[ZC] can be a point at the end of the line [B] that will be connected directly to the connector as shown clearly in Fig.2.[2]



Fig.2 matching transformation lines (transforming A to point C by B)

## 2 ANALYSIS

### 2.1 Quarter Wave Impedance Transformer

There are many occasions when it is desirable to transform the impedance of a line from its fundamental impedance to either a higher or lower impedance amount, either for use as a power divider or combiner, or to enhance the aspect ratio of components which are constructed at the higher frequencies. Because of the limited range of impedances available with microstrip construction (20-145) ohms [2],[3], it is also frequently necessary to transpose impedance in order to provide reason-

### 2.2 Microstrip Power Divider Design

The Wilkinson N-way power divider / combiner was presented by Adel A. M. Saleh [5], in this research we were concerned in the two stage fork N-way power divider. Fig. 3 shows the representation of the two-stage power divider; R1 and R2 are the isolation resistors, Zc is the input impedance, Zd is the output impedance. The values of the design line impedances are calculated by:

$$Z_{0,1} = (NZ_c)^{3/4} (Z_d)^{1/4} \quad (2)$$

$$Z_{0,2} = (NZ_c)^{1/4} (Z_d)^{3/4} \quad (3)$$

Where  $Z_{0,1}$  and  $Z_{0,2}$  are the line impedances of the first and second stage in the two-stage power divider respectively and N is the number of divisions of the power divider, as shown in Fig.3.

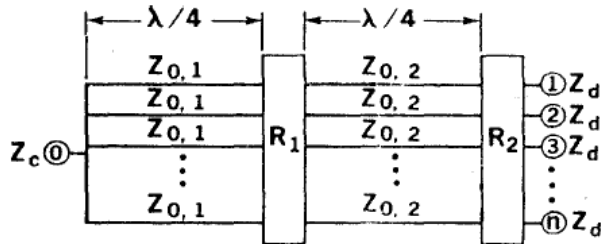


Fig.3 Representation of two-stage Power Divider

Table-1 shows the values of the optimum match and isolation resistors R1 and R2 for the two-stage fork N-way power divider with divisions 2-12 [5].

TABLE 1  
VALUES OF ISOLATION RESISTORS FOR TWO-STAGE N-WAY POWER DIVIDER

| N  | $\left[ \frac{R_1 Z_d}{Z_{0,2}} \right]_{opt}$ | $\left( \frac{Z_d}{R_2} \right)_{opt}$ |
|----|--|--|
| 2  | 1.28719  | 0.17820                                |
| 3  | 0.75   | 0.25                                   |
| 4  | 0.5  | 0.25                                   |
| 5  | 0.39991  | 0.33609                                |
| 6  | 0.36676  | 0.36285                                |
| 7  | 0.39652  | 0.35000                                |
| 8  | 0.52493  | 0.30118                                |
| 10 | 0.52482  | 0.30121                                |
| 12 | 0.52483  | 0.30120                                |

### 2.3 Design and Implementation of Three-Way Two Stage Power Divider

Table-2 shows the design impedances of the 2 to 12 way two stage power divider (Trans 1) is the quarter-wave impedance transform line added to the input impedance  $Z_{in}$  and (Trans 2) is the quarter-wave impedance transform line added to the output impedance  $Z_{out}$ . As can be seen from the table that having a 50Ω input and output impedance is limited to the two, three and four way two stage power divider only and if thinking to build a five till twelve ways a quarter-wave impedance transformer line has to be added either at the input or output or both ports as demanded in the nine, ten, eleven and twelve ways two stage power divider.

A two stage three way power divider is designed on a RT/Duroid 3010 with 10.2 dielectric constant, 0.0035 dissipation factor and 1.25 mm thickness ,with 50 ohms input and out puts impedance, a  $\lambda_g/4$  line at mid band frequency of 2.25 GHz is 1.10 mm wide and 12.71 mm in length. The two stage three way power divider designed by Using equations (2) and (3), had the impedance values

$$Z_{in} = Z_{out} = 50\Omega$$

$$Z_{0,1} = 113\Omega$$

$$Z_{0,2} = 65\Omega$$

TABLE 2  
THE DESIGN IMPEDANCES AND TRANSFORMATION IMPEDANCES FOR TWO STAGE POWER DIVIDERS

| N  | Z in | Trans 1 | $Z_{0,1}$ | $Z_{0,2}$ | Trans 2 | Z out |
|----|------|---------|-----------|-----------|---------|-------|
| 2  | 50   |         | 84        | 59        |         | 50    |
| 3  | 50   |         | 113       | 65        |         | 50    |
| 4  | 50   |         | 141       | 70        |         | 50    |
|    | 30   | 53      | 96        | 62        |         | 50    |
| 5  | 50   |         | 167       | 74        |         | 50    |
|    | 25   | 49      | 99        | 62        |         | 50    |
| 6  | 50   |         | 191       | 78        |         | 50    |
|    | 20   | 43      | 96        | 62        |         | 50    |
| 7  | 50   |         | 215       | 81        |         | 50    |
|    | 20   | 46      | 108       | 64        |         | 50    |
| 8  | 50   |         | 237       | 84        |         | 50    |
|    | 15   | 37      | 96        | 62        |         | 50    |
| 9  | 50   |         | 259       | 86        |         | 50    |
|    | 20   | 50      | 130       | 68        |         | 50    |
|    | 20   | 47      | 115       | 46        | 37      | 30    |
| 10 | 50   |         | 281       | 88        |         | 50    |
|    | 18   | 43      | 103       | 34        | 26      | 20    |
| 11 | 50   |         | 302       | 91        |         | 50    |
|    | 20   | 47      | 112       | 29        | 20      | 15    |
| 12 | 50   |         | 322       | 93        |         | 50    |
|    | 15   | 37      | 96        | 27        | 20      | 15    |

Fig.4 shows the layout of the design and fig. 5 show the photograph of the fabricated divider.



Figure .4 Layout of three-way two-stage power divider on RT/ Duroid 3010 substrate (Dim100mmX45mm)

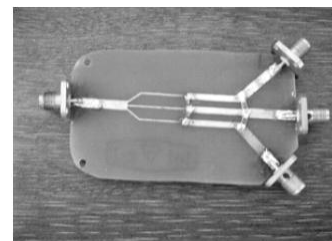


Figure.5 Photograph of three-way two-stage power divider on RT/ Duroid 3010 substrate (Dim100mmX45mm)

The previous design will be compared to another three way two-stage power divider fabricated also on RT/Duroid 3010 substrate but having the quarter-wave impedance transform lines added to the input and the outputs to investigate the effect of the addition

The values of the design impedances by using equations (2) and (3) are

$$Z_{in} = 25 \Omega, Z_{out} = 19 \Omega, Z_{0,1} = 53 \Omega, Z_{0,2} = 26 \Omega, R_1 = 22 \Omega, R_2 = 76 \Omega.$$

The additional transformation matching lines calculated using equation (1) are added,  $\{B\}=35 \Omega$  is inserted in the design to transform the impedance  $\{A\}=25 \Omega$  to  $\{C\}=50 \Omega$ . Also an additional  $30 \Omega$  stub is inserted to transform  $19 \Omega$  output to the  $50 \Omega$  line as shown in fig. 6, [6].

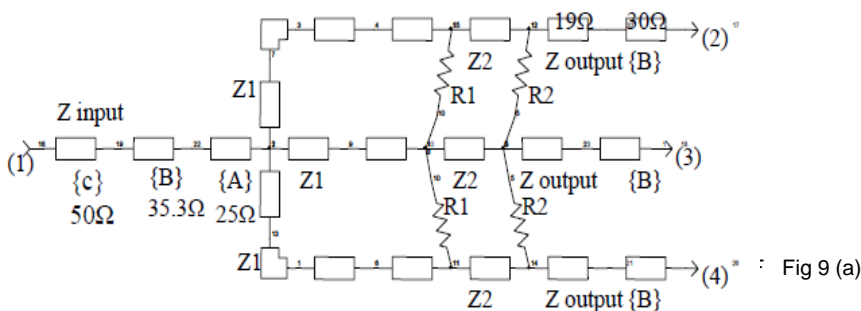


Figure.6 Schematic diagram of three-way two-stage power divider with input and output quarter line transformations

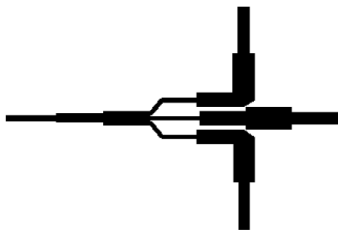


Figure.7 Layout of three-way two-stage power divider on RT/ Duroid 3010 substrate (Dim110mmX60mm)

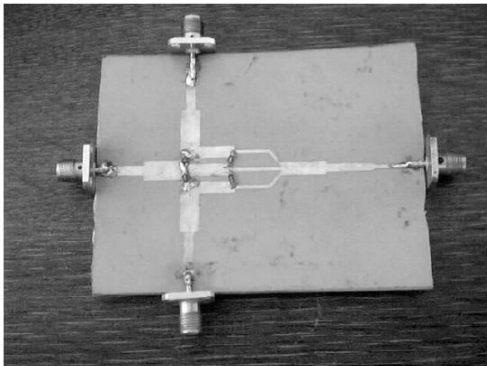


Figure.8 Layout of three-way two-stage power divider on RT/ Duroid 3010 substrate (Dim110mmX60mm)

### 3 RESULTS OF SIMULATION AND MEASUREMENTS

The two fabricated dividers are analyzed and simulated by Genesys software [7] and their characteristics measured by the network analyzer 8510 HP. The main disadvantage of using the transformation lines is the narrow bandwidth of the overall performance of the circuit as related to a circuit with no transformation lines used and the additional length of the circuit that leads to more insertion loss. Figures 9, 10, 11, are the response curves of the three-way two-stage power divider with no transformation lines used, the (a) figures are the simulated outputs and the (b), (c), and (d) figures are the measured outputs. Figures 12, 13, 14, are the response curves of the three-way two-stage power divider with the transformation lines added (a) are the simulated curves while (b), (c), and (d) figures are the measured responses.

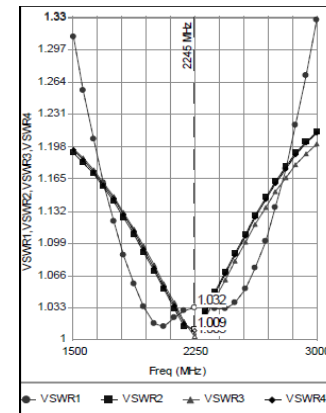


Fig 9 (b)

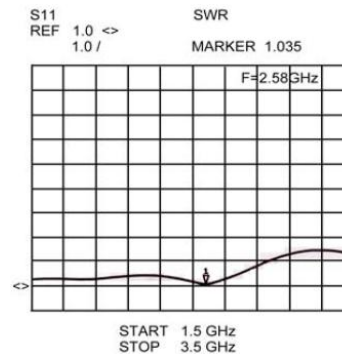


Fig 9 (c)

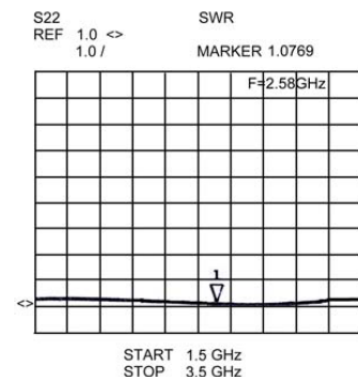


Figure.9 Response curves for three-way two-stage power divider designed on a Duroid 3010 substrate, (a) simulated input VSWR1 and simulated output VSWR2, VSWR3, VSWR4 (b) measured input VSWR, (c) measured output VSW

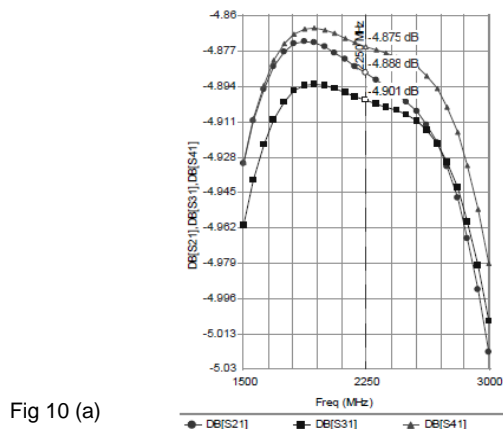


Fig 10 (a)

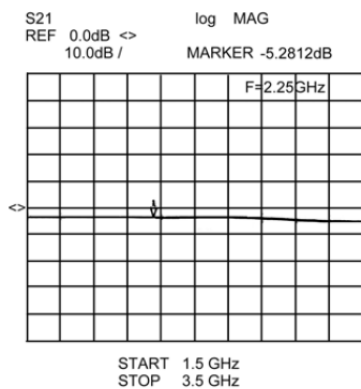


Fig 10 (b)

Figure. 10 Response curves for three-way double stage power divider designed on a Duroid 3010 substrate. (a) Simulated coupling (b) measured coupling

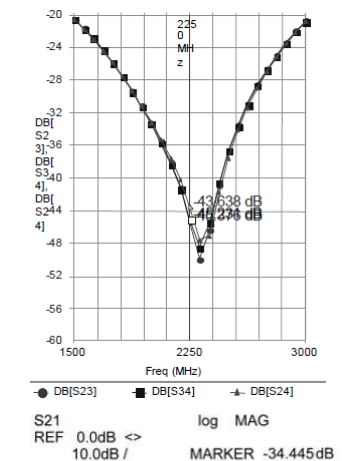


Fig 11 (a)

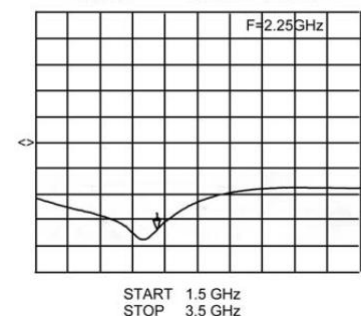


Fig 11 (b)

Figure.11 Response for three way double stage power divider designed on a Duroid 3010 substrate, (a) Simulated isolation (b) Measured isolation

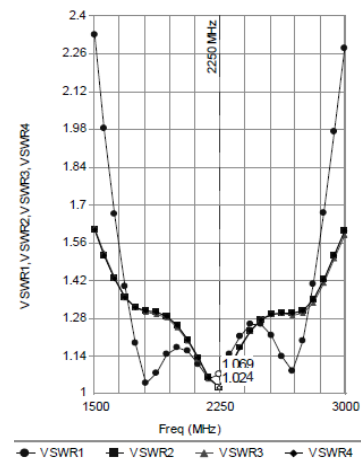


Fig 12 (a)

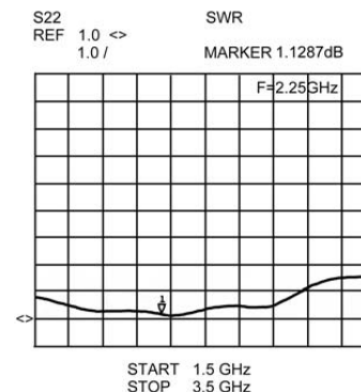


Fig 12 (b)

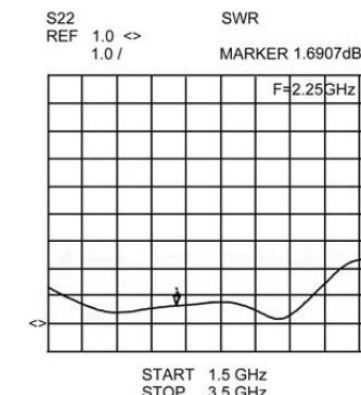


Fig 12 (c)

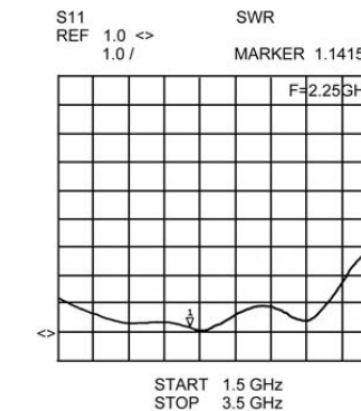


Fig 12 (d)

Figure. 12 Response curves for three-way two-stage power divider designed on a Duroid 3010 substrate (a) Simulated output and input VSWR (b), (c) and (d) measured VSWR

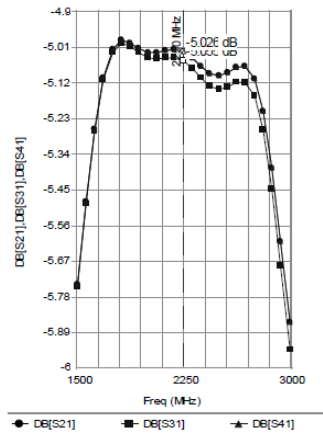


Fig 13 (a)

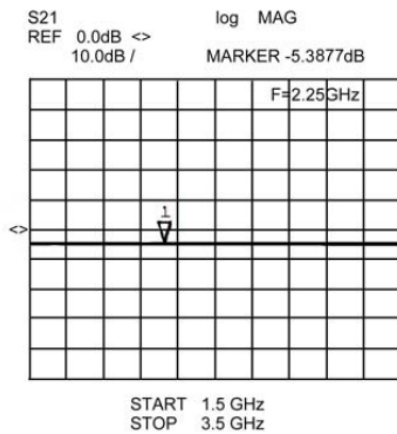


Fig 13 (b)

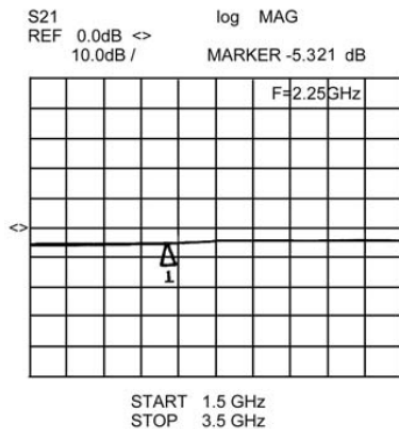


Fig 13 (c)

Figure. 13 Response curves for three way double stage power divider designed on a Duroid 3010 substrate, (a) Simulated coupling (b), (c) Measured coupling

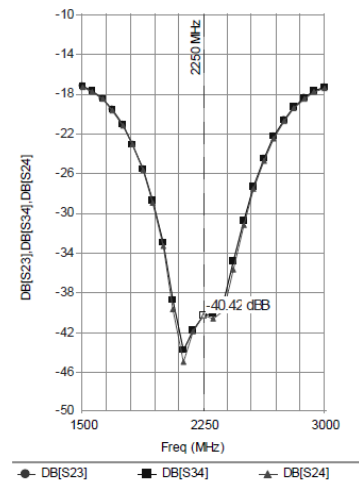


Fig 14 (a)

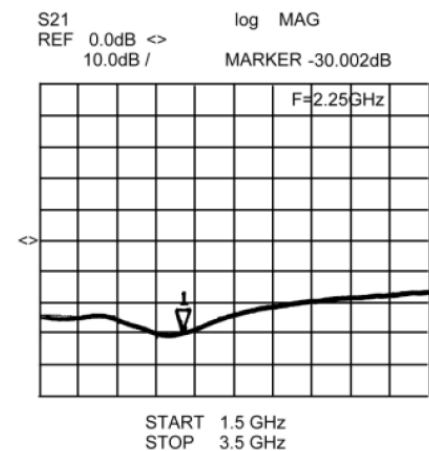


Fig 14 (b)

Figure. 14 Response curves for three way double stage power divider designed on a Duroid 3010 substrate, (a) Simulated isolation (b) Measured isolation

## 4 DISCUSSION

Comparing the previous simulated and measured curves for both the two stage three way power divider with and without quarter transformation lines it can be concluded that the main parameter effected was the insertion loss due to the additional lines added in the case of adding the quarter wave transformation lines, and the other parameter changed was the bandwidth that was less in the case of adding the quarter wave transformer lines to the power divider.

## 5 CONCLUSIONS

Adding the quarter wave transformation lines was a simple and cheap way to overcome the difficulties and limitation of fabricating N way power dividers which has high impedance related to high number of division. The effects of transformation lines on two-stage Wilkinson N-way power dividers were studied. Two-stage Wilkinson two to twelve way power divider was analyzed. Two prototype of three way two-stage power divider were designed, implemented and tested. The results of simulation and measurements were plotted and discussed. Mainly bandwidth and insertion loss were affected negatively when adding transformation lines as was shown in the simulated and measured results.

## 6 REFERENCES

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