# An All 50 Ohm Divider/Combiner Structure

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***Abstract* — A novel microwave power divider/combiner structure is presented in this paper. The analysis of the structure is based on the exact matching conditions at input/output ports and a perfect isolation condition between the dividing/combining arms (ports). To analyze the structure, the necessary set of nonlinear equations is derived first, and then solved. For a special case an all-50 Ω structure is obtained (the characteristic impedances of the transmission line sections and the value of the isolation resistance are all 50 Ω). The presented divider/combiner structure is simulated, and simulation results are seen in perfect agreement with the calculation. As a final step, a planar 3-dB power divider is fabricated on GML 1000 substrate ($\varepsilon_r = 3.05$, $h \cong 0.508mm$) and a good agreement between the theoretical and experimental results is obtained.**

## I. Introduction

Power dividers and combiners are extensively used in various microwave applications, ranging from antenna feed structures to distribution systems. So far quite a number of power divider/combiner structures, for equal or unequal power division, have been proposed and performance improvement efforts are continuing by giving special emphasis to various features. In 1960 Wilkinson [1] introduced a power divider which splits a signal into n-equiphase-equiamplitude signals and in 1965 Parad and Moynihan [2] presented the design equations of a split-tee power divider which provides a constant, arbitrary power division in the two output ports. Later Cohn [3] introduced a class of broadband three-port TEM mode hybrids. To increase the bandwidth of Wilkinson power divider, delay line sections were introduced [4]. At the same time design efforts were extended to arbitrary (complex, in general) impedance terminations [5]. On the other hand, optimization methods were used in the design of non-Wilkinson power dividers [6]. Ahn and Wolf studied both equal and unequal power dividers with arbitrary impedance terminations [7], [8]. In almost all the structures proposed so far, quarter wavelength long transmission line sections have been used as basic building blocks of these power divider/combiners.

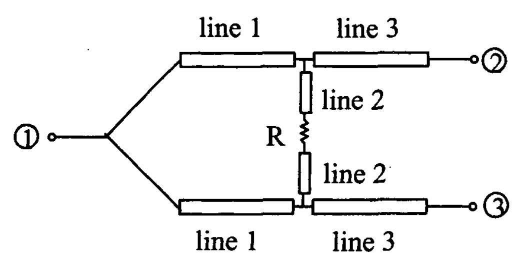


Fig. 1. Proposed power divider/combiner structure

In this paper, we introduce a novel power divider/combiner structure as shown in Fig. 1, based on a study on alternative power divider/combiner structures [9]. This structure is composed of a number of line section whose lengths are variables and can be adjusted to satisfy certain performance criteria. The line sections in Fig. 1 numbered as '2' are used to increase the separation between the arms so that coupling is decreased, in other words the isolation is increased. The same line sections also gives a flexibility for layout design.

On the other hand, in this structure, in addition to line segments, only well-characterized transmission line structures, namely T-sections and mitered corners, are used. In most of the power divider structures, some of which are listed above, are not flexible enough to avoid from junctions in the form of a Y. Such junctions can be characterized using software tools but do not have simple models to be used in the design.

In this first phase of our study, without loss of generality, we carried out the analysis for equal power division which implied a symmetric structure as in Fig. 1. In a special case, which will be presented in this paper, the characteristic impedances of all transmission line sections are found, impressively, as 50 Ω, which is the most common standard.

The analysis is based on the exact conjugate impedance match at both ends and a perfect isolation condition between the dividing/combining arms (ports). The results



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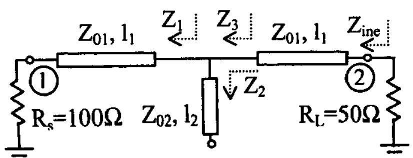


Fig. 2. The combiner structure in even mode.

are verified by fabrication and measurement of a sample microstrip structure.

## II. ANALYSIS

The presented power divider/combiner structure is intended to be an equal power divider/combiner, therefore it is symmetric and the design parameters are the characteristic impedances, $Z_{o1}$, $Z_{o2}$, $Z_{o3}$, and the lengths, $l_1$, $l_2$, $l_3$, of the line sections and the isolation resistance: R.

This structure is intended to be a matched equal power combiner and divider, therefore following four conditions should be satisfied:

i. impedance match ($S_{ii}$=0)
ii. equal power division ($|S_{21}|=|S_{31}|=0.7071$)
iii. equal power combination ($|S_{12}|=|S_{13}|=0.7071$)
iv. isolated ports ($S_{23}=S_{32}=0$)

If the structure is impedance matched at even and odd modes, it is impedance matched at any excitation. Therefore we will impose impedance match at even and odd modes. If the structure is impedance matched, then due to physical symmetry, equal power division is evident. For equal combination and isolation, even and odd mode analysis is necessary.

These conditions are examined in the following parts. However, in order to simplify the calculations, as a first step we have assumed that the first and the third line sections are identical. Analysis proved that, as will be seen in the proceeding sections, this is a reasonable assumption.

### A. Matched Ports and Equal Division

In this case the structure is fed from ports 2 and 3.

In the case of even mode excitation, part of the network looks like in Fig. 2. The other part is exactly the same as this part. In Fig. 2 the indicated impedance, $Z_{ine}$, is readily obtained as:

$$Z_{ine} = \frac{Z_{o1}(Z_3 + jZ_{o1}t)}{Z_{o1} + jZ_3 t} \qquad (1)$$

where, $t = \tan\beta\ell_1$ and $Z_3$ is the parallel combination of $Z_1$ and $Z_2$ as shown in Fig. 2.

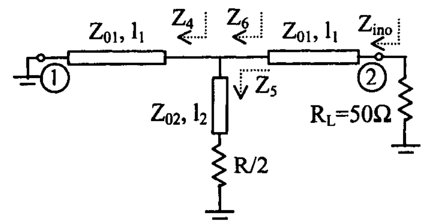


Fig. 3. The combiner structure in odd mode

In order to have a complex conjugate matching we must have $Z_{ine}$= 50 Ω, or, in terms of real and imaginary parts we must have, in closed form:

$$\mathrm{Re}[Z_{ine}] - 50 = 0 \qquad (2)$$

$$\mathrm{Im}[Z_{ine}] = 0 \qquad (3)$$

In the case of odd mode excitation, part of the network looks like in Fig.3. The other part is exactly the same as this part. Carrying out the similar calculations as were done in the even mode case we obtain the following impedance equation:

$$Z_{ino} = \frac{Z_{o1}(Z_6 + jZ_{o1}t)}{Z_{o1} + jZ_6 t} \qquad (4)$$

where, $t = \tan\beta\ell_1$ and $Z_6$ is the parallel combination of $Z_4$ and $Z_5$ as shown in Fig. 2.

In order to have a complex conjugate matching we must have $Z_{ino}$= 50 Ω, or, in terms of real and imaginary parts we must have, in closed form:

$$\mathrm{Re}[Z_{ino}] - 50 = 0 \qquad (5)$$

$$\mathrm{Im}[Z_{ino}] = 0 \qquad (6)$$

### B. Isolation and Equal Combination

In even mode, a voltage of $V_G/2$ is applied at Ports 2 and 3. In this case voltage at Port 2 is:

$$V_{2e} = \frac{Z_{ine}}{Z_0 + Z_{ine}}(V_G/2) \qquad (7)$$

where, $Z_o$= 50 Ω. Due to symmetry, voltage at Port 3 is:

$$V_{3e} = V_{2e} \qquad (8)$$

In odd mode, we have $V_G/2$ and $-V_G/2$ at Ports 2 and 3, respectively. Voltage at Port 2 is:

$$V_{2o} = \frac{Z_{ino}}{Z_0 + Z_{ino}}(V_G/2) \qquad (9)$$

where, $Z_o$= 50 Ω. By virtue of odd-order symmetry voltage at Port 3 is:

$$V_{3o} = \frac{Z_{ino}}{Z_0 + Z_{ino}}(-V_G/2) \quad (10)$$

Using superposition, total voltages at Ports 2 and 3 can be obtained as follows:

$$V_2 = V_{2e} + V_{2o} = (\frac{Z_{ine}}{Z_0 + Z_{ine}} + \frac{Z_{ino}}{Z_0 + Z_{ino}})\frac{V_G}{2} \quad (11)$$

$$V_3 = V_{3e} + V_{3o} = (\frac{Z_{ine}}{Z_0 + Z_{ine}} - \frac{Z_{ino}}{Z_0 + Z_{ino}})\frac{V_G}{2} \quad (12)$$

For complete isolation, when we applied $V_G$ at Port 2, we must have $V_3 = 0$. Imposing this requirement, from (11) and (12) we have:

$$\frac{Z_{ine}}{Z_0 + Z_{ine}} = \frac{Z_{ino}}{Z_0 + Z_{ino}} \quad (13)$$

or, rearranging the terms, we have the following isolation condition:

$$Z_{ine} = Z_{ino} \quad (14)$$

This equation is also implied by (2), (3) and (5), (6).

It is obvious that, in the even mode all the input power is transferred to the termination impedance at port 1 and in the odd mode isolation resistance dissipates the input power. In both modes, all ports are matched and in each mode equal power is given from the input ports. This implies that if ports 2 and 3 are isolated and matched, then $|S_{12}|^2=|S_{13}|^2=0.5$ which correspond to equal power combination.

In summary, (2), (3), (5) and (6) are the necessary and sufficient conditions to have matched equal power combiner and divider structure with isolated ports.

## III. Results and a Sample Structure

There are five parameters of the structure $Z_{o1}$, $Z_{o2}$, $l_1$, $l_2$, and R. The conditions are imposed by four equations. This means that there are infinite number of solutions, or in other words, there is one degree of freedom to determine the parameters. This freedom is another and an important benefit of the presented structure. Depending on special conditions of the design, different sets of parameters can be chosen. In other words, to optimize a certain behavior of the structure, such as bandwidth, noise, layout, etc., a proper set can be used.

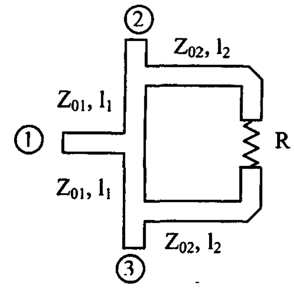


Fig. 4. Schematics of the all 50Ω power divider/combiner structure.

As an example we have preset $Z_{01}$ to 50 Ω. This is a wise choice, indeed; because with this choice the transmission line sections, numbered as line 3, can be eliminated without affecting overall performance of the network. This means simplification and size reduction.

Under this condition, the rest of the parameters are found as: $Z_{02} = 50\,\Omega$, $R = 50\,\Omega$, $\tan(\beta\ell_1) = \sqrt{2}$, $\tan(\beta\ell_2) = -1/\sqrt{2}$. Those values, together with the chosen value of $Z_{01} = 50\,\Omega$, are the parameters of the design.

We designed the sample structure given in Fig. 5, operating at the center frequency of 3 GHz, using GML 1000 substrate material ($\varepsilon_r = 3.05$, h=0.508mm). In order to reduce the overall area, layout of the structure is arranged as given in Fig. 4. The picture of the design is given in Fig. 5.

As can be seen from the figure, in our design the transmission line transitions are made up of only well-defined sections, namely T-sections and mitered sections and whole design is based on analytical results including all the effects like T junctions and miters. In that respect, no optimization is performed.

The S-parameters of the designed structure have been measured and a good agreement between the measured and theoretical findings is observed as can be seen in Fig. 6. The observed frequency offset and slight difference in the frequency characteristics of the S-Parameters are assumed to be due to the fabrication processes of the structure, connectors, and measurement inaccuracies.

## IV. Conclusion

A novel power divider/combiner structure is presented. This structure has a number of benefits compared to the present ones in the literature. The apparent one is the flexible layout possibility. This layout also improves the isolation. The second apparent advantage is the use of only analytically well characterized sections, which

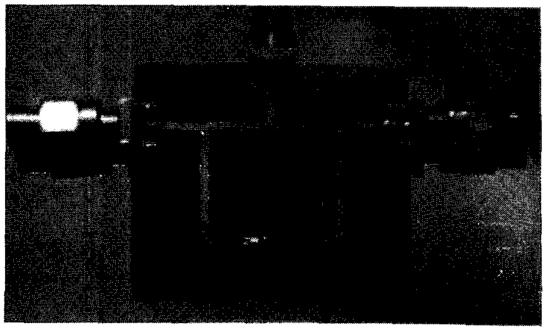

Fig. 5. Picture of the sample all 50Ω structure

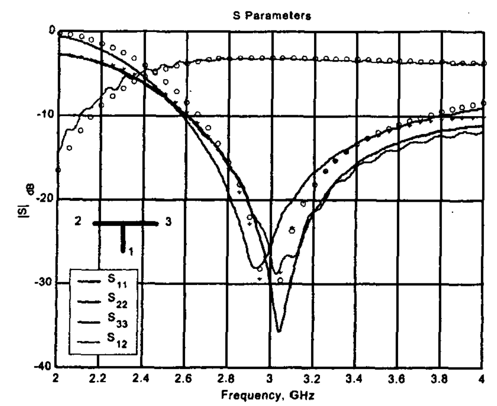


Fig. 6. Comparison of the simulation (indicated by the small circles) and measurement results (lines indicated as in the legend)

improves the initial design and lessen the need for post production optimization.

Analysis of the structure is presented for a symmetric case and this analysis highlighted the third advantage; there is a degree of freedom in the parameters of this structure which can be utilized for special purposes.

Although the method of analysis we follow is quite general, the proposed power divider/combiner structure, which is given in Fig.1 was analyzed for a special case, i.e. for $Z_{01}$=50 Ω. This special case led us to an all 50 Ω structure.

The main advantage of the presented structure is the use of only 50-ohm transmission line sections in the combining/dividing arms and additionally the isolation resistance has a value of 50 Ω.

The overall size of the proposed structure remains comparable with that of the conventional Wilkinson power divider. Additionally we have a better orientation for avoiding possible coupling effects between the combining arms. The analysis and measurements showed that presented structure offers a comparable performance with a conventional Wilkinson power divider structure.

On the other hand, if miniaturization is the main objective, then optimization can be done with a desired length of either transmission line sections, this length being a free parameter instead of $Z_{01}$. In this case, the characteristic impedances of the transmission line sections will not necessarily be 50Ω.

Current efforts are towards extending this study to the general design equations for equal and unequal combiner/divider structures.

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