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An Improved T-Junction Power Divider Using Linearly Tapered Microstrip Lines

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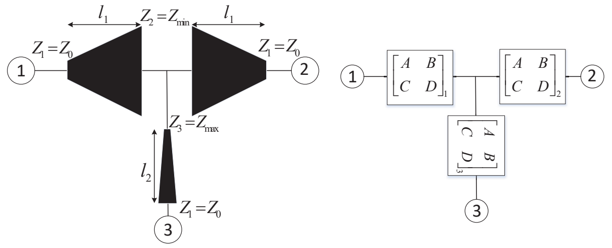
Abstract

In this paper, a T-junction power divider using linearly tapered microstrip lines (MSLs) has been proposed; where the line to port 3 has also been tapered for achieving higher power dividing ratio between the output ports (ports 2 and 3). A method for theoretical analysis of the power divider has been presented approximately. The proposed T-junction power divider exhibits power dividing ratio of more than 10 dB over a broad frequency range of 1.7-5 GHz. The design is simulated in two different EM solvers (HFSS and CST) and their results are in well agreement with each-other which validate the same.

1 Introduction

Power dividers are the passive microwave components used in microwave systems for equal or unequal division of power into the output ports. Such components are commonly realized in the form of microstrip line (MSL) due to simple design, lower cost and easier fabrication. The T-junction power divider is a three-port network which is mainly used as an equal power divider like in antenna array design or sometimes as an unequal power divider like in a case where most of the power is desired in one of the output port and least power in the other output port [1, 2, 3]. In [1], three distinct geometrical configurations of T-junctions have been realized: asymmetrical tee (narrowband cicuit), 2-step tee and linearly tapered tee (broadband circuit). In the paper, different empirical models have been employed to realize these geometrical configurations but they do not provide much physical insight about the device operation.

Nowadays it is highly desirable to design a circuit which can operate in a system over a broad range of frequency like in broadband or ultra-wideband systems. An analytical method has been developed in [2] to find the port parameters of exponentially tapered broadband T-junction power divider. This theoretical method can be employed to achieve power dividing ratios from 2-10 dB over broad range of frequency. However, the cut-off wavelength definition adopted in this paper is incorrect and the analysis with correction has been presented in [3]. A uniform transmission line (UTL) has been used for output port-3 in [2] and [3], which is one of the section need to be investigated for achieving even higher power dividing ratio between the output ports.



(a) (b)

Figure 1. (a) Layout of the proposed unequal T-junction power divider (b) Equivalence of (a) in terms of ABCD parameters of elementary block.

In this paper, the transmission line to port 3 has also been tapered for achieving higher power dividing ratio of more than 10 dB over the broadband frequency. As it can be seen from [4] that the matching characteristics of linear taper is almost similar to exponential taper; the minima in both cases occurs at each multiple of π but amplitude of reflection coefficient for linear taper decreases gradually, unlike exponential taper. Also, the design and fabrication of linear taper is relatively easier than exponential taper. Hence, a T-junction power divider using linearly tapered MSLs has been proposed which exhibits power dividing ratio of more than 10 dB over a broad frequency range of 1.7-5 GHz. An approximate theoretical analysis for the linearly tapered power divider has also been developed; where each of linearly tapered lines are divided into N uniform lines and their ABCD parameters are found and subsequently S-parameters have been obtained [5]. The electromagnetic (EM) simulation of the model has been carried-out using two different EM solvers (HFSS and CST) and their results are compared with each other which validate the same.

2 Design and Analysis

The proposed power divider design consists of three linearly tapered transmission lines as shown in Figure 1 (a). The first two tapered sections are joined at the point where the characteristic impedance is lowest, Z_{min} and at the same point the characteristic impedance of third tapered line is set to maximum, Z_{max}. All ports are terminated with the system characteristic impedance of Z_0.

The equivalent model is shown in Figure 1 (b). To ana-

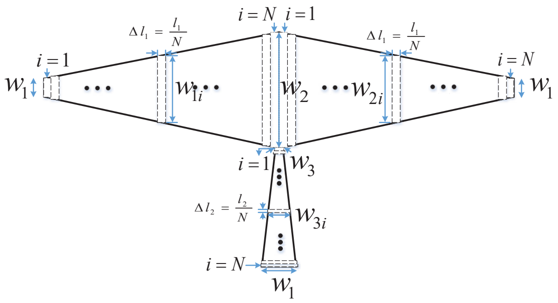


Figure 2. Analysis model of the design.

lyze the model, we need to find the ABCD paraments of each sections first so that we can get the S parameters subsequently.

2.1 An Approximate Theoretical Analysis

This section will describe an approximate theoretical analysis of the proposed power divider. It has been assumed that transmission lines are lossless and ignore the effects of step discontinuities at the junctions. The analysis model is shown in Figure 2, where each of the three linearly tapered lines are divided into N uniform transmission lines with small length of Δl_1 and Δl_2 ($\Delta l_1 = l_1/N$ and $\Delta l_2 = l_2/N$). The ABCD matrix of a lossless uniform transmission line is given as [6]

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} \cos(\beta l) & jZ_0 \sin(\beta l) \\ j\frac{\sin(\beta l)}{Z_0} & \cos(\beta l) \end{bmatrix} \tag{1}$$

Hence, the ABCD matrix for ith section in Figure 2 can be written as

$$[T_i] = \begin{bmatrix} \cos(\beta_i \Delta l) & jZ_{0i} \sin(\beta_i \Delta l) \\ j\frac{\sin(\beta_i \Delta l)}{Z_{0i}} & \cos(\beta_i \Delta l) \end{bmatrix} \tag{2}$$

where $\Delta l = \Delta l_1$ or Δl_2, Z_{0i} is the characteristic impedance of ith uniform MSL element and β_i is their phase constant. They can be calculated from [6] as

$$Z_{0i} = \begin{cases} \frac{60}{\sqrt{\varepsilon_{e,i}}} \ln\left(\frac{8h}{w_i} + \frac{w_i}{4h}\right) & \left(\frac{w_i}{h} \le 1\right) \\ \frac{120\pi}{\sqrt{\varepsilon_{e,i}}[w_i/h + 1.393 + 0.667\ln(w_i/h + 1.444)]} & \left(\frac{w_i}{h} \ge 1\right) \end{cases} \tag{3}$$

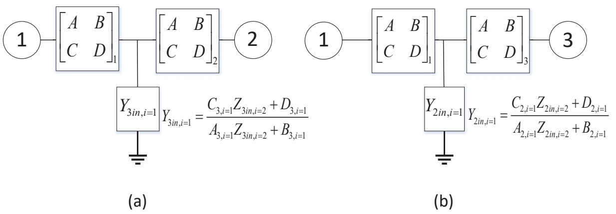
and

$$\beta_i = \frac{2\pi}{\lambda_{e,i}} \tag{4}$$

where h is thickness of the dielectric material, w_i, $\varepsilon_{e,i}$ and $\lambda_{e,i}$ are the width, effective dielectric constant and guided wavelength of the ith uniform MSL element respectively. They can be calculated using (5)-(7) [6],

$$\lambda_{e,i} = \frac{c}{f\sqrt{\varepsilon_{e,i}}} \tag{5}$$

$$\varepsilon_{e,i} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \frac{1}{\sqrt{1 + 12h/w_i}} \tag{6}$$



(a) (b)

Figure 3. Equivalent 2-port network of Figure 1 when (a) Port-3 is terminated with the matched load Z_0 (b) Port-2 is terminated with the matched load Z_0.

The width of the ith small uniform line w_i (for $1 \le i \le N$) can be written in a linear function as

$$w_i = \begin{cases} w_{1i} = w_1 + \frac{(i-1)(w_2 - w_1)}{(N-1)} \\ w_{2i} = w_2 - \frac{(i-1)(w_2 - w_1)}{(N-1)} \\ w_{3i} = w_3 + \frac{(i-1)(w_1 - w_3)}{(N-1)} \end{cases} \tag{7}$$

where w_{1i}, w_{2i} and w_{3i} are the width of ith small uniform line elememt of first, second and third linearly tapered MSL respectively, see Figure 2. w_1, w_2 and w_3 are the width of corresponding impedances Z_0, Z_{min} and Z_{max} respectively. The ABCD matrices of left-side (1^{st}), right-side (2^{nd}) and middle (3^{rd}) tapered MSL can be represented using (8)-(10) as

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix}_1 = [T]_L = [T_1]_1[T_2]_1 \ldots\ldots [T_i]_1 \ldots\ldots [T_N]_1 \tag{8}$$

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix}_2 = [T]_R = [T_1]_2[T_2]_2 \ldots\ldots [T_i]_2 \ldots\ldots [T_N]_2 \tag{9}$$

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix}_3 = [T]_M = [T_1]_3[T_2]_3 \ldots\ldots [T_i]_3 \ldots\ldots [T_N]_3 \tag{10}$$

The input impedance of a uniform transmission line terminated with a load impedance Z_L can be obtained as [3]

$$Z_{in} = \frac{AZ_L + B}{CZ_L + D} \tag{11}$$

where A, B, C and D represent the ABCD parameters of the uniform transmission line.

The ABCD parameters between port-1 and port-2 of the power divider shown in Figure 1 can be obtained by terminating port-3 with matched load Z_0. The equivalent 2-port network for this case is shown in Figure 3 (a). Their ABCD matrix can be expressed as

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix}_{12} = \begin{bmatrix} A & B \\ C & D \end{bmatrix}_1 \begin{bmatrix} 1 & 0 \\ Y_{3in,i=1} & 1 \end{bmatrix} \begin{bmatrix} A & B \\ C & D \end{bmatrix}_2 \tag{12}$$

where

$$Y_{3in,i=1} = \frac{C_{3,i=1}Z_{3in,i=2} + D_{3,i=1}}{A_{3,i=1}Z_{3in,i=2} + B_{3,i=1}}. \tag{13}$$

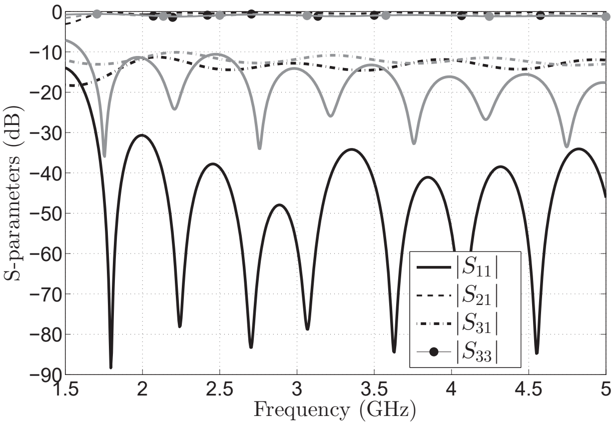


Figure 4. Theory and simulated S-parameters of the power divider. Black lines → theory & gray lines → HFSS results.

The $A_{3,i=1}$, $B_{3,i=1}$, $C_{3,i=1}$ and $D_{3,i=1}$ represent the ABCD parameters of first small uniform line of third (or, middle) linearly tapered line, see Figure 2. $Z_{3in,i=2}$ and $Y_{3in,i=1}$ are the input impedance and input admittance of second and first small uniform line of third linearly tapered line respectively. $Y_{3in,i=1}$ can be found using the technique explained here. The tapered section (3^{rd}) is divided into N small uniform sections with port-3 terminated with matched load Z_0. For $i = N$, $Z_L = Z_0$ and ABCD is found from (1) for a very small length uniform line $\Delta l_2 = l_2/N$. Using these ABCD parameters Z_{in} can be obtained from (11) which in turn becomes Z_L for $i = N-1$ and similarly Z_{in} for $i = N-1$ can be obtained. Finally, following these iterations we can obtain Z_{in} for $i = 1$ and hence $Y_{3in,i=1}$.

Similarly, the ABCD parameters between port-1 and port-3 of the power divider shown in Fig. 1 can be obtained by terminating port-2 with matched load Z_0. The equivalent 2-port network for this case is shown in Figure 3 (b). Their ABCD matrix can be expressed as

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix}_{13} = \begin{bmatrix} A & B \\ C & D \end{bmatrix}_{1} \begin{bmatrix} 1 & 0 \\ Y_{2in,i=1} & 1 \end{bmatrix} \begin{bmatrix} A & B \\ C & D \end{bmatrix}_{3} \tag{14}$$

where

$$Y_{2in,i=1} = \frac{C_{2,i=1} Z_{2in,i=2} + D_{2,i=1}}{A_{2,i=1} Z_{2in,i=2} + B_{2,i=1}} \tag{15}$$

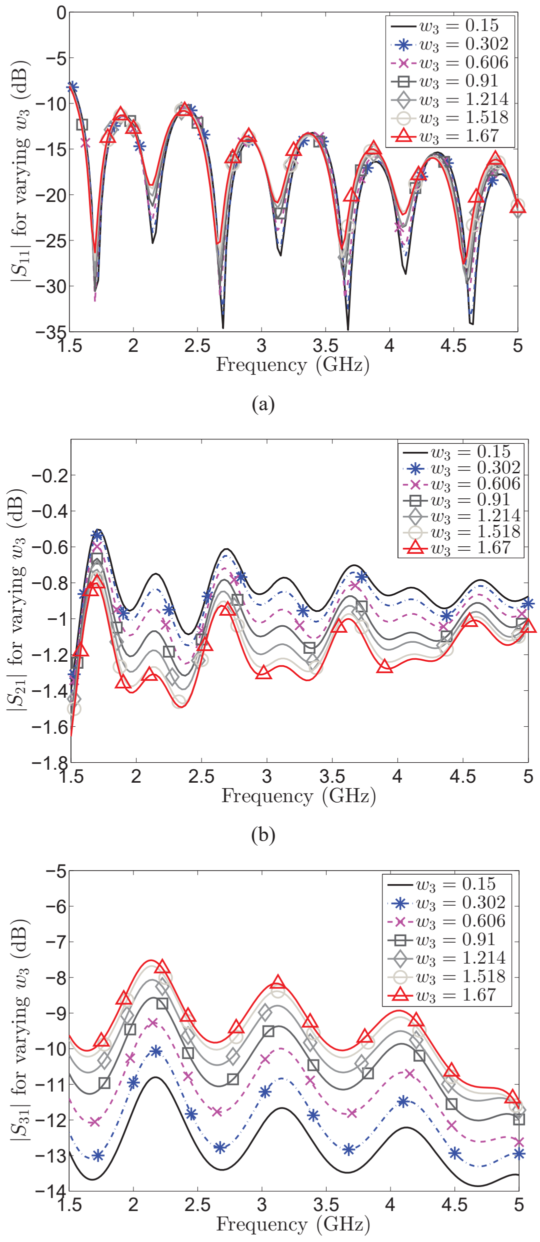
which can be calculated following the above technique for $Y_{3in,i=1}$.

Finally, S-parameters can be obtained from ABCD parameters of (12) and (14) as [3]

$$S_{ii} = \frac{B_{ij} - Z_0^2 C_{ij} + Z_0 \left(A_{ij} - D_{ij}\right)}{B_{ij} + Z_0^2 C_{ij} + Z_0 \left(A_{ij} + D_{ij}\right)} \tag{16}$$

$$S_{jj} = \frac{B_{ij} - Z_0^2 C_{ij} - Z_0 \left(A_{ij} - D_{ij}\right)}{B_{ij} + Z_0^2 C_{ij} + Z_0 \left(A_{ij} + D_{ij}\right)} \tag{17}$$

$$S_{ji} = S_{ij} = \frac{2 Z_0}{B_{ij} + Z_0^2 C_{ij} + Z_0 \left(A_{ij} + D_{ij}\right)} \tag{18}$$



(a)

(b)

(c)

Figure 5. Simulated S-parameters for varying w_3 in mm.

where $i, j \in \{1, 2, 3\}$. This process completes the analytical analysis of the model approximately.

3 Simulation Results

With the same material properties and design parameters as in [2, 3] (except the 3^{rd} line is tapered here), a broadband T-junction power divider using linearly tapered lines has been designed and investigated. As it can be seen from [4], the minimum reflection at a port for the first resonance frequency will occur at a half wavelength or electrical length of π in each case of linear and exponential tapers. Hence, we can approximate the length l_1 for linear taper same as

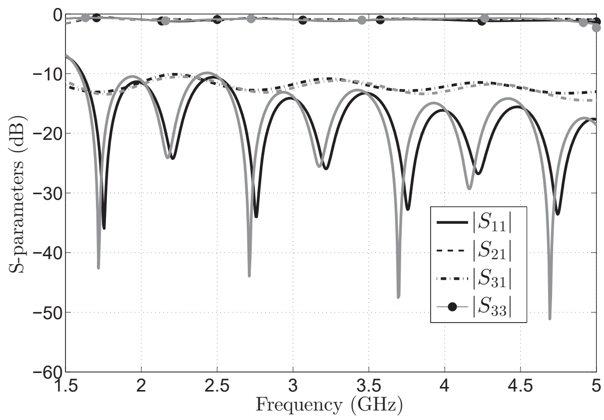


Figure 6. Simulated S-parameters of the power divider. Black lines → HFSS results and gray lines → CST results.

[3], Eqn. (6). The first resonance frequency is chosen as $f_0 = 1.7$ GHz and the characteristic impedance of each port as $Z_0 = 50\ \Omega$, the lowest impedance as $Z_{min} = 9\ \Omega$ and the maximum impedance of $Z_{max} = 112\ \Omega$. The length of each tapered lines are 84.88 mm ($l_1 = l_2 = 84.88$ mm). The approximate theoretical results using (16)-(18) for the design are plotted using MATLAB and compared with HFSS results, as shown in Figure 4. The results show the power dividing ratio between the output ports (ports 2 and 3) of about 11.5 dB in whole broadband frequency range of 1.7-5 GHz. Note that we have assumed that transmission lines are lossless as well as ignored the dielectric and other losses in case of approximate theoretical analysis, hence there is some difference in the HFSS simulated and analytical results. But the reflection zeros are located at approximately same frequencies for both HFSS simulation and analytical results. The third port can just only be used for reception or monitoring of the signal propagating between primary ports, the matching at port-3 is not of interest like in [2, 3].

A parametric study of the design has been carried-out using HFSS where width of the third transmission line at the junction is changed from 1.67 mm (corresponds to the uniform 50 Ω line) to 0.302 mm (for $Z = Z_{max} = 112\ \Omega$) and their S-parameters have been observed as shown in Figure 5. It can be noted that the power dividing ratio is greatly improved when the tapering of the third line is increased towards the junction, without much affect of matching at port-1.

The two EM simulations (HFSS and CST) of the design are plotted in Figure 6. The average power dividing ratio between the output ports are around 11.5 dB in whole frequency band of 1.7-5 GHz and both (HFSS and CST) results are in well agreement with each other which validate the same. Table 1 shows the comparison of power dividing ratio with existing literatures [1, 2, 3]. The first two lines in [1] are linearly tapered while in [2, 3], they are exponentially tapered and third line in each of them is considered of 50 Ω uniform line. As in our case, each of three lines are linearly tapered and hence a higher power dividing ratio has been achieved. Such a simple power divider design could be very useful for a passive signal cancelation in a system where coupling ratio of more than 10 dB are desired.

Table 1. Comparison of power dividing ratio with existing T-junction power dividers

References	Power dividing ratio ($\lvert S_{21}\rvert - \lvert S_{31}\rvert$) (dB)	Frequency range (GHz)
[1]	<6	1-8
[2]	9.2	1.75-3.5
[3]	7.5	1.7-5
This work	11.5	1.7-5

4 Conclusion

A T-junction power divider using linearly tapered microstrip lines has been proposed. By tapering the transmission line to port-3 too, a higher power dividing ratio between the output ports can be achieved. An approximate theoretical analysis of the power divider has also been presented. The proposed T-junction power divider exhibits power dividing ratio of more than 10 dB over a broad frequency range of 1.7-5 GHz. The power dividing ratio is greatly improved when the tapering of the third line is increased towards the junction. The HFSS simulated results of the power divider are compared with approximate theory and CST simulated results, which are in well agreement of each-other and hence validate the proposed design.

References

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