Asymmetric Lumped Element Power Splitters

Bruce Kopp

Avantek Inc., Subassemblies Group
481 Cottonwood Drive
Milpitas, California 95035

Abstract
A new type of asymmetric power divider is described, which utilizes lumped elements to reduce circuit size and realize high impedance levels not possible in microstrip. A new method is also presented to realize asymmetric splitters with a reduced number of transformers. The paper concludes with a presentation of measured data for a 2 to 6 GHz two-way asymmetrical divider.

Introduction

A large amount of theory exists on how to design various types of power dividers that utilize distributed quarter-wave transformers [1,2,3,4,5,6]. A major disadvantage of these structures is that they become increasingly large at low frequencies and when multiple sections are used. To reduce the size of the transformers and increase the range of transformer impedance levels that can be achieved lumped elements can be used. In the past lumped elements have not been commonly employed above a few Gigahertz due to modeling difficulties. Lumped element models have progressed significantly over the past few years, however, and models that are accurate within a few percent up to 18 GHz exist for quasi-lumped inductors and shunt capacitors. By employing these models, low-pass lumped element transformers can be used to greatly reduce the size of conventional power dividing structures. The use of lumped element power dividers also increases the range of characteristic impedance levels possible, which aids in the construction of three-way and asymmetric power dividers.

The first step in designing lumped element power dividers is to define a lumped element model for a quarter-wavelength of transmission line. A lumped element model for an electrical length of transmission line, Ø, which can be derived by equating the Y-parameters for a transmission line to a pi-network is shown in Figure 1.

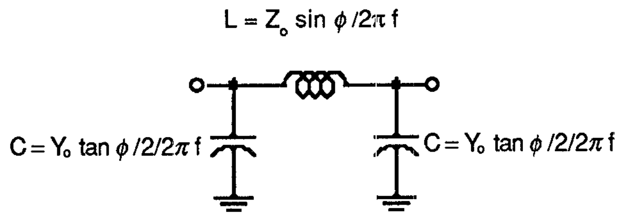

Figure 1 - Lumped element model for a length of transmission line

For a quarter-wavelength line, $L=Z_o/(2\pi f)$ and $C=1/(Z_o{*}2\pi f)=L/(Z_o)^2$. This structure approximates a quarter-wave transformer well at the design frequency, but it has a fairly narrow bandwidth. To increase the bandwidth of the lumped element model, two 45° sections of line can be cascaded to form a second order transformer where $L=.707Z_o/(2\pi f)$ and $C=.414/(Z_o{*}2\pi f)$. Cascading two 45° sections appears to be the most practical method, and cascading three 30° sections to form a third order structure does not provide any significant improvement in bandwidth. The term order as used here refers to the number of inductors in the transformer. The term section will be used later to refer to the number of quarter-wave transformers in one arm of a splitter.

Asymmetric Power Splitters

Parad and Moynihan discussed the design of asymmetrical splitters in their cited paper, but these circuits require three consecutive quarter-wave transformers to obtain optimum performance. The additional output transformers are required because the output ports are not terminated in the system's characteristic impedance level. This is done so that the voltages on the two lines will be the same to permit an odd and even mode analysis to determine the value for the isolation resistor. This paper is concerned primarily with circuit size reductions, and for this reason an approximate method will be presented here to achieve an asymmetric in-phase power split with only one quarter-wave transformer in each arm. In this analysis the voltages on the two lines are not equal, but all the output impedances are equal to the system's characteristic impedance level. The trade-off in this analysis is that the structure only requires one impedance transformer to achieve a match at all three ports, but an exact design for the isolation resistors is not done. An interesting note is that this method can also be used to realize asymmetric three-way splitters. The analysis presented here will begin by determining the impeddance values for the transformers for a desired power split, will continue with an approximate method for determining multi-section transformer impedance values, and conclude with a presentation of design results to show the large increase in bandwidth obtained by using this design.

To synthesize an asymmetrical splitter the first step is to determine the values of the impedance levels for the two arms. For a two-way splitter let k represent the percentage of power in the first arm, which will have a characteristic impedance, Z1. Let the second arm have a characteristic impedance, Z_2, and the percentage of power in the second arm will be 1-k. A relation between Z_1 and Z_2 can be determined from the relationship

$$k = Z_2/(Z_1+Z_2) \quad (1).$$

Expressions relating the input impedances Z_{1in} and Z_{2in} of the two quarter-wave transformers to Z_1 and Z_2 can then be written for a system of characteristic impedance, Z_o, as

$$(Z_1)^2 = Z_o{*}Z_{1in} \quad (2)$$

and

$$(Z_2)^2 = Z_o{*}Z_{2in} \quad (3).$$

The input impedances of each transformer can then be written in terms of one of the characteristic impedances, Z_1 or Z_2. These values can then be substituted into the expression

$$(Z_{1in}{*}Z_{2in})/(Z_{1in}+Z_{2in})=Z_o \quad (4)$$

to give values for both Z_1 and Z_2. General resulting equations for Z_1 and Z_2 can then be written as

$$Z_2=(1+(k/(1-k))^2)^{.5}(Z_o) \quad (5)$$

and

$$Z_1=((1-k)/k)Z_2 \quad (6).$$

The next step in the design of the asymmetric power divider is to determine the value of the transformer sections if multiple sections are desired. To achieve a broadband transformation Chebyshev polynomials can be used. The example considered here will only have two sections, though, so binomial transformers will be adequate[7]. The binomial approximate theory used here has an error that increases with the size of the transformation ratio so a different transformation method should be used for large asymmetric splits. A design example will be considered for a desired 2/3,1/3 power split, that is for k=1/3, Z_1=111.8Ω, and Z_2=55.9Ω. A two-section splitter for this example will use 167Ω and 74.8Ω transformers for the 111.8Ω arm and 59.1Ω and 52.9Ω transformers for the 55.9Ω arm. The isolation resistors for both cases will be set equal to the symmetrical values as a first approximation. The measured results will show that this is an excellent approximation. The results for the two-section second order splitter are shown in Figures 2, 3, and 4. These results include a loss model so that they can be compared with a fabricated circuit.

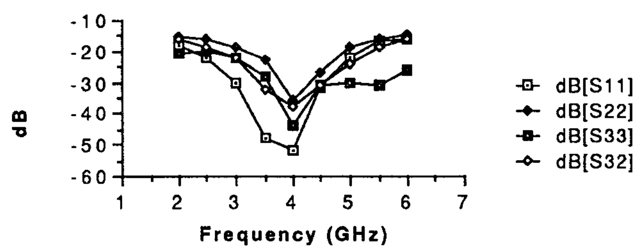

Figure 2 - S_{11}, S_{22}, S_{32}, and S_{33} for an asymmetric second order two-section splitter

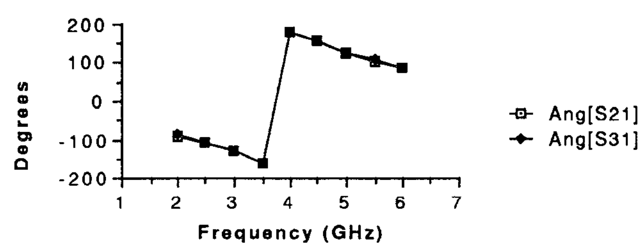

Figure 3 - Ang[S_{21}] and Ang[S_{31}] for an asymmetric second order two-way splitter

From these results it can be seen that the asymmetric splitter has excellent performance over an approximately 100% usable bandwidth. The loss model added about .5 dB insertion loss to both arms. To test the theory presented here the preceding asymmetric circuit was fabricated on an alumina substrate. The results are shown in Figures 5 and 6. The launchers have not been de-embedded from the data.

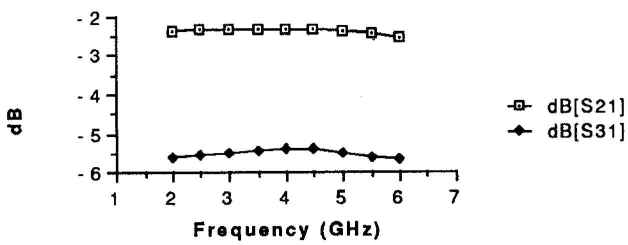

Figure 4 - S_{21} and S_{31} for an asymmetric second order two-way splitter

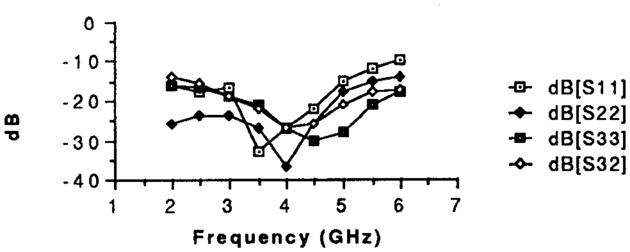

Figure 5 - Measured S_{11}, S_{22}, S_{32}, S_{33} for an asymmetric second order two-section splitter

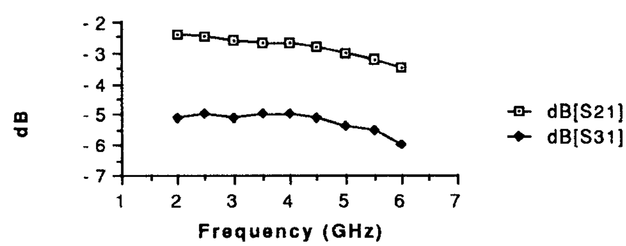

Figure 6 - Measured S_{21} and S_{31} for an asymmetric second order two-way splitter

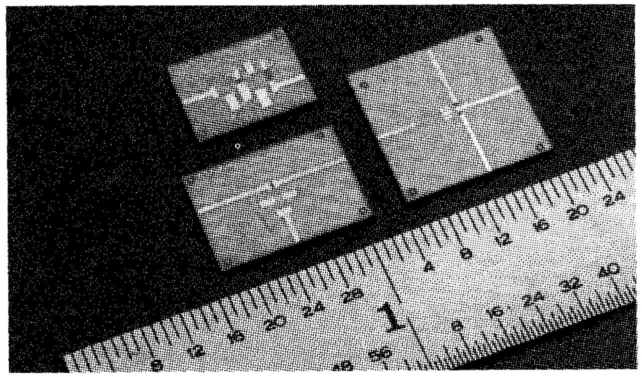

Figure 7 - An asymmetric, two-way, and three-way splitter

The data that was obtained matches well with the theory presented, but S_{21} and S_{31} start to roll off after about 5 GHz. This could be due to a variety of reasons. The first and foremost reason was that the coupling between the splitter's arms was not modeled. Figure 7 shows the actual asymmetric circuit along with lumped element symmetric two-way and three-way splitters. From this picture it can be seen that, unlike the two and three-way splitters, a multi-conductor coupling model would be necessary to accurately model the asymmetric splitter at higher frequencies. However, the asymmetric splitter performed well for a first cut, and it should prove to be a valuable tool for circuit and system designers.

Conclusions

The availability of accurate lumped element models allows lumped element power dividers to be used in place of conventional distributed dividers. These splitters are much smaller than their distributed counterparts, and they provide greater flexibility in circuit design due to the wide range of impedance values that they can achieve. The design of the lumped element transformers is simple, but care should be taken to make sure that the minimum number of inductors is used to take full advantage of the circuit's size reduction capabilities. Asymmetric and three-way splitters that would not be feasible in microstrip due to the high impedance transformers required can also be built using lumped elements, and circuit designers should take advantage of the many new applications made possible by these circuits.

Acknowledgement
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