A GENERAL DESIGN FORMULA OF MULTI-SECTION POWER DIVIDER BASED ON SINGLY TERMINATED FILTER DESIGN THEORY

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ABSTRACT

A novel design formula of multi-section power divider is derived to obtain wide isolation performance. The derived design formula is based on the singly terminated filter design theory. This paper presents several simulation and experimental results of multi section power divider to show validity of the proposed design formula. Experiments show excellent performance of multi section power divider with multi-octave isolation characteristic.

I. INTRODUCTION

The multi-section three-port hybrid consider in this paper is useful both as a power divider and combiner applications with very wide operating frequency range. Design and analysis methods for single section three-port hybrids such as Wilkinson power divider have been well known through several papers and articles. [1]—[3] However, it has a limited frequency band characteristic. Thus, several efforts for broadband three-port hybrid have been tried and reported. As one of great efforts, S. B. Cohn has reported and summarized the analysis and design method for a class of multi-section three port hybrids. [4] This previously reported design method has been utilized widely to solve limited frequency band problems in single section case.

The multi-section three-port hybrids for broadband frequency performance in this paper differ in that the resistors for broadband isolation characteristic are simply determined. The design formula for determining the resistor can be easily derived based on a singly terminated filter theory. The main design algorithm for multi-section three-port hybrid is based on optimum design of stepped transmission line transformer. [5] Compared to the earlier design method, there is no any performance improvement of multi-section hybrid. However, design procedure is much easier than that of the reported design method. Also, the design formula for determining the resistors is given by closed form for all cases. Simulations and measurements on several design results show the validity of this paper.

II. GENERAL DESIGN FORMULA FOR MULTI-SECTION THREE-PORT HYBRID

Fig.1 shows the schematic of a conventional multi-section three-port hybrid and its even/odd-mode equivalent circuit representations. The power divider circuit is composed of a finite number of resistor and transmission lines with equal line length. The even-mode operation of a multi-section three-port hybrid is identical with a conventional multi-section quarter-wave transformer, which has 100ohm terminated impedance. Thus, each transmission line section of multi-section power divider for optimum performance can be easily determined by a optimum multi-section quarter-wave transformer design theory for a given specification.

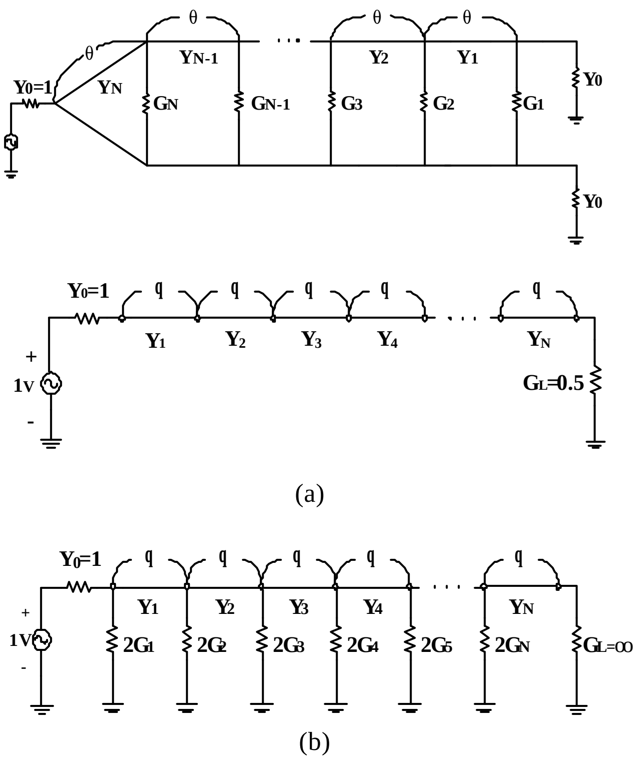

Fig.1 Schematic of multi-section power divider. (a)Even-mode equivalent representation. (b) Odd-mode equivalent representation.

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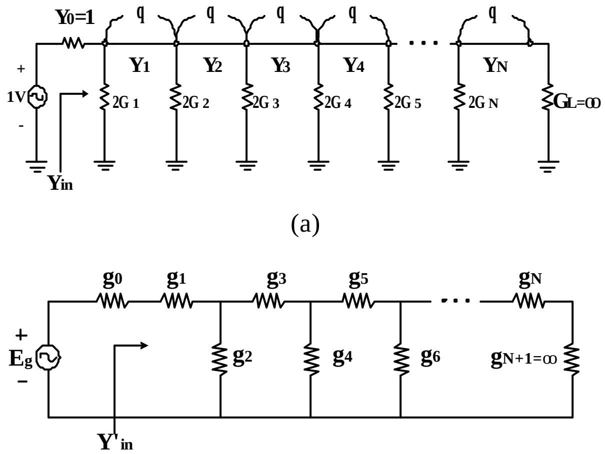
However, the odd-mode operation differs from that of the even-mode. As we can Fig.1 (b), there are a number of parallel conductances for isolation performance of three-port hybrid. The power dividing can be pertinently achieved by determining the multi-section quarter wave transformer. With the characteristic admittances determined, the remainder of the synthesis problem is to compute the parallel conductances. S. B. Cohn has summarized the synthesis method for determining these conductance values. An almost exact synthesis is possible for N=2 case in his research. Furthermore, for N≥3 a set of approximate design formula has been derived heuristically. However, as increase the number of section the synthesis procedure is increasingly difficult for N≥3.

In this paper, a general synthesis method for determining parallel conductances is newly proposed based on the singly terminated filter synthesis theory.



(a)

(b)

Fig.2 (a) Odd-mode equivalent circuit of a multi-section power divider. (b) Singly terminated chebyshev prototype lowpass filter.

Fig.2 shows the odd-mode equivalent circuit of a multi-section power divider and the singly terminated chebyshev prototype lowpass filter. All admittance values in Fig.2 (a) are normalized by source admittance. Electrical lengths of transmission lines are equal to 90 degree. Then the input admittance to the infinite load can be deduced by finite continued fraction as follow

$$Y_{in} = 2G_1 + \cfrac{Y_1^2}{2G_2 + \cfrac{Y_2^2}{2G_3 + \cfrac{Y_3^2}{2G_4 + \cdots + \cfrac{Y_{N-1}^2}{2G_N}}}} \qquad (1)$$

g_0, g_1, g_2, xxx g_N in Fig.2(b) is prototype element values of the singly terminated chebyshev prototype lowpass filter, where g_0 is also normalized source admittance to 1. These prototype element values are given by simple formulas.[6] Then, the input admittance of singly terminated prototype lowpass filter to the infinite load is also given by the following finite continued fraction

$$Y'_{in} = \frac{1}{g_1} + \cfrac{1}{g_2 + \cfrac{1}{g_3 + \cfrac{1}{g_4 \cdots + \cfrac{1}{g_{N-1} + \cfrac{1}{g_N}}}}} \qquad (2)$$

In order to achieve excellent isolation performance of power divider, the input admittance of the odd–mode equivalent circuit in Fig.2 (a) should be matched to source. Fortunately, the singly terminated lowpass filter can provides the matched circuit for infinite admittance or impedance load conditions. Thus, for achieving the excellent isolation performance two circuits shown in Fig.2 should have same input admittance level. In order to simplify the comparison with (2), (1) may be modified as follow

$$Y_{in} = 2G_1 + \cfrac{1}{\cfrac{2G_2}{Y_1^2} + \cfrac{1}{\cfrac{2G_3Y_1^2}{Y_2^2} + \cfrac{1}{\cfrac{2G_4Y_2^2}{Y_1^2Y_3^2} + \cdots + \cfrac{Y_{N-1}^2Y_{N-3}^2 \cdot\cdot Y_2^2}{2G_NY_{N-2}^2Y_{N-4}^2 \cdot\cdot Y_1^2}}}} \qquad (3)$$

In order to have identical input admittance levels, the corresponding terms in (2) and (3) must be equal as follow

$$G_1 = \frac{1}{2g_1}, G_2 = \frac{Y_1^2 g_2}{2}, G_3 = \frac{Y_2^2 g_3}{2Y_1^2}, G_4 = \frac{Y_3^2 Y_1^2 g_4}{2Y_2^2},$$
$$\cdots, G_N = \frac{Y_{N-1}^2 Y_{N-3}^2 \cdots Y_3^2 Y_1^2 g_N}{2Y_{N-2}^2 Y_{N-4}^2 \cdots Y_2^2} \quad for\ N = even \qquad (4)$$
$$G_N = \frac{Y_{N-1}^2 Y_{N-3}^2 \cdots Y_4^2 Y_2^2 g_N}{2Y_{N-2}^2 Y_{N-4}^2 \cdots Y_1^2} \quad for\ N = odd$$

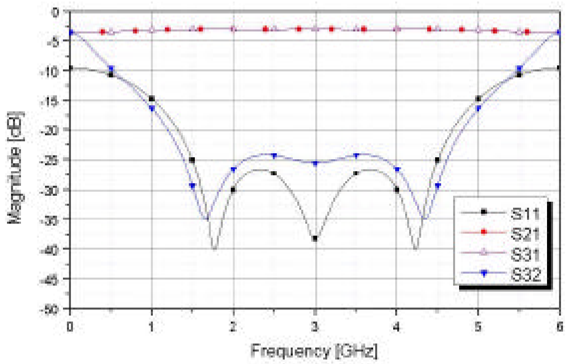
With the use of (4), the generalized conductance formula for multi-section power divider can be deduced by

$$G_1 = \frac{1}{2g_1} and\ G_i = \frac{Y_{i-1}^2 g_{i-1} g_i}{2G_{i-1}}, \text{where } i = 2,3,\cdots N \qquad (5)$$

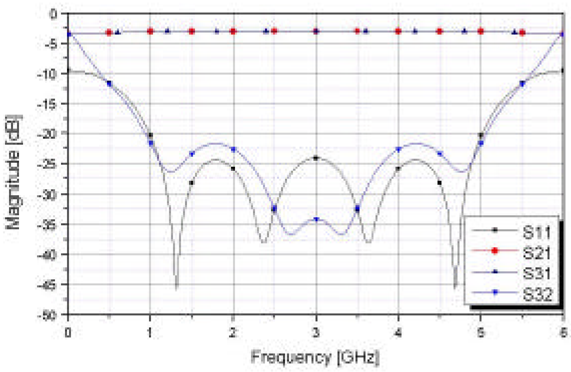
One thing we have to consider when we compute the conductance is that the ripple level of singly terminated prototype lowpass filter must be equal to that of the optimum multi-section quarter-wave transformer. Because the transmission line sections have a corresponding admittance values to given passband ripple level and cutoff frequency.

III. SIMULATIONS AND EXPERIMENTS

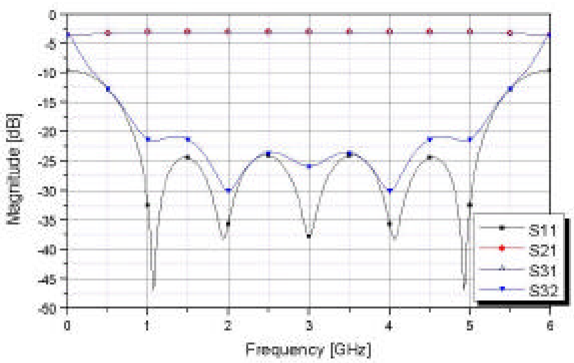
We have designed a set of multi-section power dividers by using generalized design formula. Some of the examples designed in this paper are as follows; three sections, f2/f1=3, ripple level=0.01dB; four sections, f2/f1=4, ripple level=0.01dB; five sections, f2/f1=6, ripple level=0.01dB; six sections, f2/f1=8, ripple level=0.01dB; and seven sections, f2/f1=10, ripple level=0.01dB. Furthermore, we fabricated three-, five, and seven sections power dividers. Fig.3 shows the simulated results for designed multi-section power dividers. As shown in Fig.3, each simulation shows good agreements with design goals.



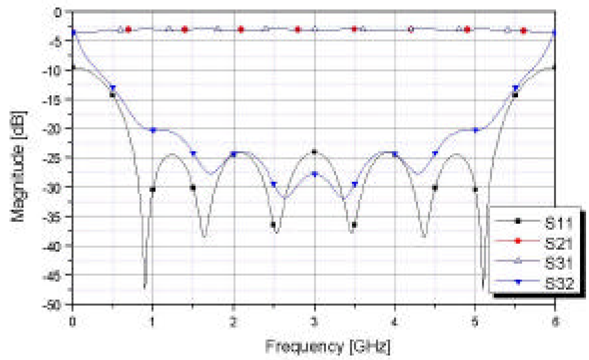
(a) Three-sections



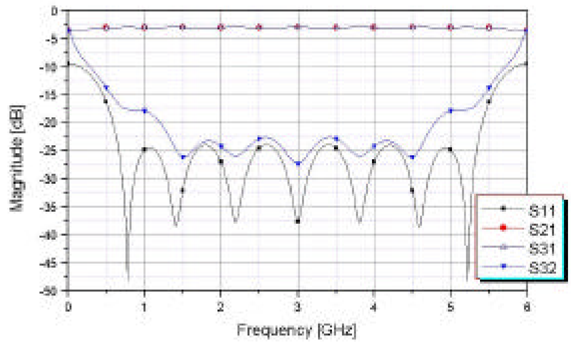
(b) Four-sections



(c) Five-sections



(d) Six-sections

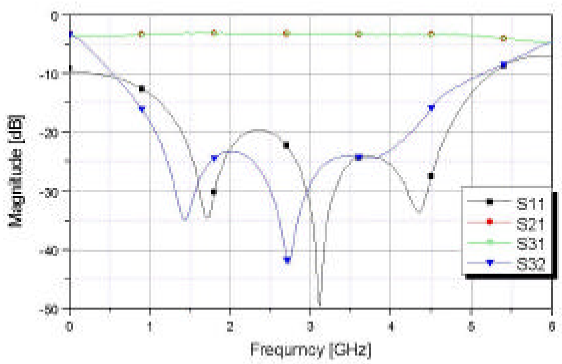


(e) Seven-sections

Fig.3 Simulations on designed multi-section three-ports hybrids

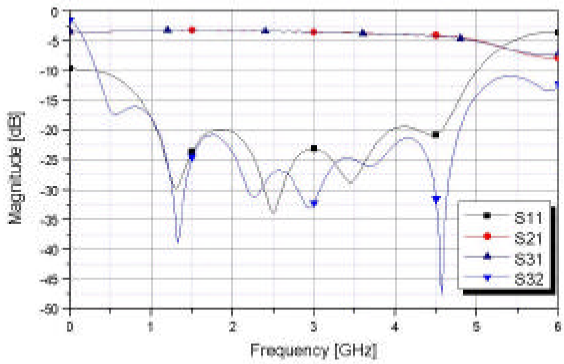
However, as increase the number of section there is some degradation of isolation characteristics due to the slop parameters of each transformer section. In order to improve the isolation performance, the slop parameters of each transformer section may be considered for computing the parallel conductances.

Fig.4 shows the measurements on designed multi-section power dividers. As we can see in measurements, the excellent isolation and matching performance support the utility of the derived design formula in this paper.

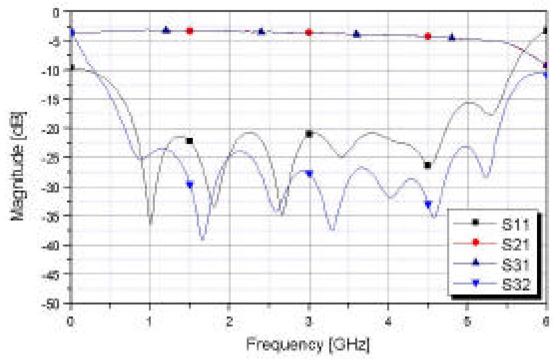


(a) Three-sections

Fig.4 Measured results for designed multi-section three-ports hybrids(to be continued)



(b) Five-sections



(c) Seven-sections

Fig.4 Measured results for designed multi-section three-ports hybrids

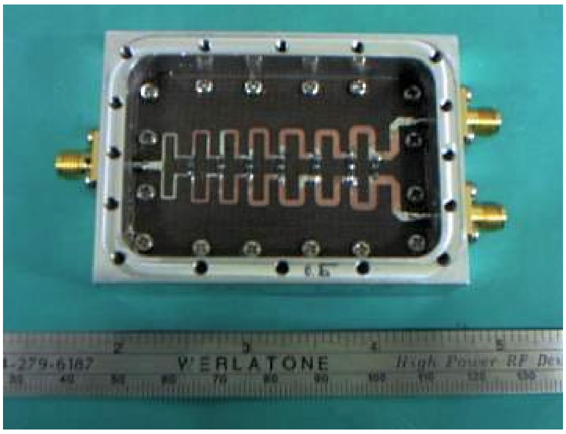


Fig.5 Photograph of the fabricated seven-sections hybrid power divider.

IV. CONCLUSION

It is well known that the operating bandwidth of the hybrid power divider increases with its number of section. Furthermore, the synthesis method of multi-section hybrid power divider is based on the well-known optimum quarter-wave transformer theory.

This paper has newly proposed simple synthesis method based on singly terminated chebyshev prototype lowpass filter for determining parallel conductance for achieving excellent isolation performance. The derived design formula in this paper is also approximate formula because the singly terminated chebyshev prototype lowpass filter uses also approximate polynomials. However, the use of the presented formula is very simple. Furthermore, considering the slop parameters of transformer section for computation of the conductances may improve the isolation performance of multi-section hybrid power divider.

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