BROADBANDING TECHNIQUES FOR TEM N-WAY POWER DIVIDERS

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Abstract

Broadband TEM power dividers have traditionally involved multi-section or taper designs. However, compensation techniques may be used to achieve broadband designs with a single or fewer sections. The compensating elements may be either lumped or distributed. The suggested techniques involve the transmission lines and the isolation resistors. These principles will be implemented for several practical designs, including broadband lumped-element power dividers.

Introduction

A 2-way multi-section power divider was analyzed by Cohn (1), and extension to N-way hybrids was done by Yee et al (2) and Saleh (3).

This paper presents compensation methods for the transmission lines and the isolation resistors. This approach enables the designer to obtain multi-octave components using single section designs. Normally, large N designs involve impractical values of characteristic impedances for the transmission lines. This paper willl present a large N design with practical transmission lines.

A classical design for N larger than 4 involves a characteristic impedance (larger than 100 ohms). By introducing a compensating circuit, a certain characteristic impedance is transformed into a higher value enabling large N designs.

A TEM transmission line can be approximated by a low-pass π of lumped elements. Combining the approximations with the compensation circuits lead to broadband lumped designs.

While compensation networks have analytic solutions, a rough solution can be derived intuitively from a Smith Chart, and processed with an optimization program.

Broadbanding The Transformer Section

The classical basic configuration of an N-way power divider is well known (1). N quarterwave transformers are connected in parallel in the input. Each one transforms the output from Z_0 to NZ_0 at the input. As N grows, so does the transformation ratio and the bandwidth decreases. For large N, the required characteristic impedance becomes too large to be practical.

One possible circuit which broadbands a $\lambda/4$ transformer appears in Figure 1. It can also be implemented with stubs instead of the lumped-elements. An explanation of the operation is shown in Figure 2. The circuit transforms a high resistance R_2 (point A) to a lower resistance R_1 (point D). The diagram is normalized to $\sqrt{R_1 R_2}$. At resonance, the transformation is complete. The diagram relates to a frequency below resonance.

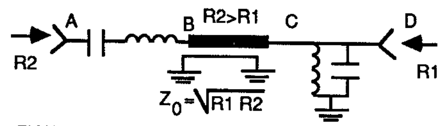

FIGURE 1. DOUBLE COMPENSATED TRANSFORMER

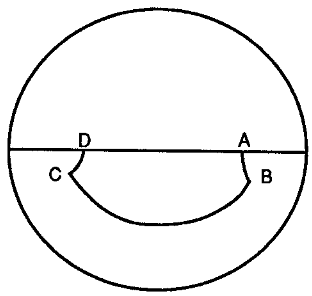

FIGURE 2. COMPENSATION OF TRANSFORMER WITH PARALLEL & SERIES LC

The series LC transforms A to B, the transmission line moves B to C and the parallel LC C to D. The impedance match when properly designed, has three minimums as opposed to only one for the non-compensated transformer. A similar approach can be applied above resonance.

A different implementation for broadband matching is seen in Figure 3. Two L sections are cascaded to a quarter-wavelength transformer, one at each end. One L section is low-pass, the other is high-pass. An explanation is presented within the figure for low frequencies. A 4:1 resistance ratio was matched to 1.1:1 VSWR for an octave bandwidth.

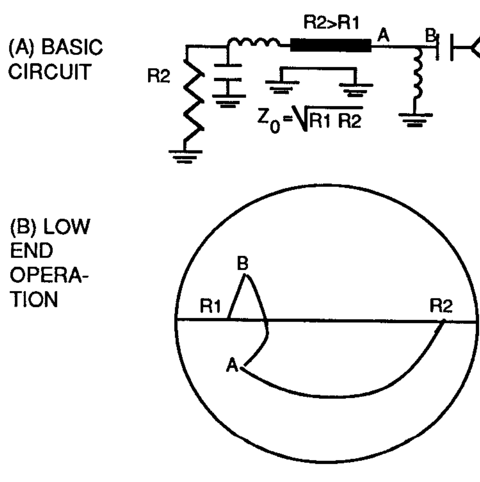

FIGURE 3. HP-LP TRANSFORMER COMPENSATION

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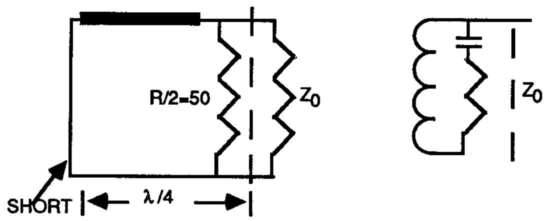
Isolation Improvement Compensation

Isolation analysis as suggested by Cohn (1) is performed by bisectioning the circuit into even and odd mode excitations. The odd mode model (where N=2) for a single section appears in Figure 4. The isolation between the output ports is:

$$(1) \qquad t_{23} = 0.5(\rho_e - \rho_o)$$



(A) AT CENTER FREQUENCY (B) COMPENSATED BELOW CENTER FREQUENCY

ODD MODE EXCITATION, WILKINSON DIVIDER N=2
FIGURE 4

In the previous section, the effort was spent to minimize ρ_e. At the center frequency, obviously $\rho_o = 0$. Below center frequency, the isolation resistor is loaded by a parallel inductor and the impedance is decreased. A capacitor, in series with the resistor, might increase and resonate the total impedance. Similarly, above the center frequency a series inductor would be required. Thus, it seems that the addition of a series resonant LC to the isolation resistor would reduce the coupling between the output ports. From simulation and optimization for N=2, a single section design, 11 dB improvement was observed over a 1 octave range. The new computed isolation resistor has a lower value and the isolation response has two dips instead of one in the center frequency as in a classical design.

Other Implementations For Transmission Lines

Two other schematics can be used to design broadband components.

While designing dividers for large N, impedances higher than 100 ohms are required. They might be generated by an appropriate loading of standard lower impedance values. Synthesizing a new value of Z_o to an existing transmission line requires some reactive loading. The loading may be either lumped or distributed.

The characteristic impedance of a transmission line is given by:

$$2) \qquad Z_o = \sqrt{L/C} \ ; \ \theta \sim 1/LC$$

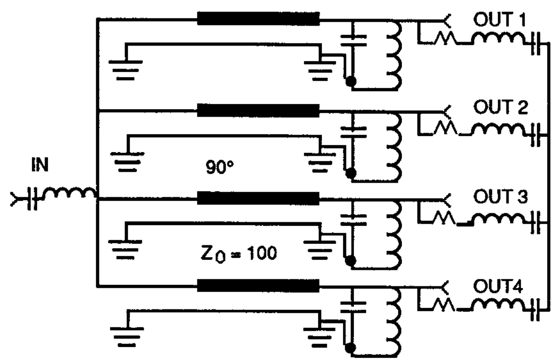
A series inductive loading will increase Z_o.

Naturally, a perfect match is achieved for a spot frequency. Still, the approximation is valid as long as θ is not too large. For 1 octave bandwidth and for a maximum ratio of 1.5 between the new and the old Z_o, one loading element is enough for each $\lambda/4$ length. A 35 ohm loaded line was synthesized to achieve 50 ohm response for 1 octave bandwidth. In this example a 72 loaded line has a 90 response.

The other proposed schematic involves replacing each $\lambda/4$ transmission line section with lumped- elements. Lumped-element approximations are performed by transforming each quarter wavelength transmission line section with a low-pass π. An optimization was performed to simulate a $\lambda/4$ 50 ohm line with a lumped π. Acceptable performance was achieved for almost 1 octave. Each section in a divider can be replaced with a lumped π. Some optimization may be necessary. Yet, the π sections tend to interact well with the broadbanding circuits as the design examples will prove.

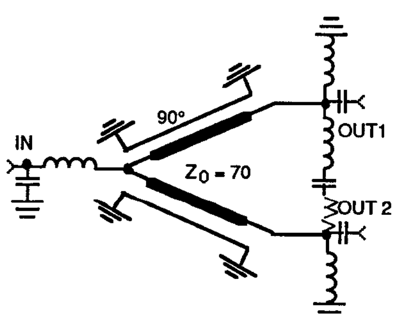
Numerical Results and Design Examples

Single Section Designs - A N=4 single section design was computed for 1 octave bandwidth. This design included the three compensation networks mentioned in the paper. The electrical schematic appears in Figure 5. The component was manufactured for operation within the 200 MHz to 400 MHz range. A good correlation was found between the measured results and the computed results. A second design using a single compensated section for N=2 was modeled. Satisfactory results were achieved for a 2 octave bandwidth.



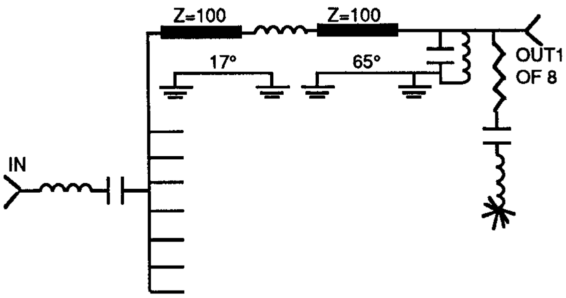
COMPENSATED 4-WAY DIVIDER, 1 OCTAVE
FIGURE 5

Almost similar performance was achieved for the single section 2-way divider using the compensation configuration of Figure 3. The design has been verified experimentally and appears in Figure 6.



2-WAY DIVIDER, 2-OCTAVES, 1-SECTION
FIGURE 6

For N=8, normally the design would consist of 140 ohm impedance and a narrow bandwidth. Using the transformation proposed, an octave design with 100 ohm lines was obtained (Figure 7).

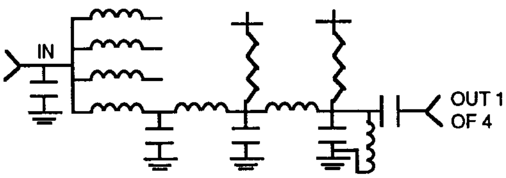


8-WAY, 1 OCTAVE, 1-SECTION DIVIDER
FIGURE 7

Two Section Designs - Employing two sections enables one to achieve still larger bandwidths. A component which achieves a 5:1 frequency ratio for N=2 was designed. A two octave design was also achieved for N=4. Both examples would normally require 3 sections.

Lumped-Element Designs - Replacing $\lambda/4$ sections of transmission lines with low-pass π is possible. An optimization program is required to achieve best performance.

Two (2) octave lumped-element dividers for N=2 and N=4 were computed. These designs were fabricated and conformed well to the design. Figure 8 depicts a 4-way, 2-section, 2-octave design.



LUMPED 4-WAY, 2-SECTION, 2-OCTAVE
FIGURE 8

Conclusions

The techniques described within the scope of the paper enable the designer to achieve large bandwidths with 1 or 2 section designs. These techniques might be advantageous in lowering insertion loss and reducing design costs. The broadbanding circuits make large N dividers practical for a single section design. Traditionally, these dividers were produced with TEM lines. Lumped-element designs are efficient solutions for low frequencies and large bandwidths. Certainly, similar designs are possible with ferrite-loaded transformers. The broadbanding networks can be either lumped or distributed. The experimental components which were fabricated based on these principles conformed well to the computed results.

References

1. S. B. Cohn; A Class of Broadband Three Port TEM-Mode Hybrid, MTT-16, No. 2, Feb. 1968, pp. 110-116

2. Yee et al; N-Way TEM-Mode Broadband Power Dividers, MTT-18, No.10, Oct. 1970, pp. 682-688

3. Saleh; Planar Electrically Symmetric N-Way Hybrid Power Dividers, MTT-28, No. 6, June 1980, pp. 555-563