A DESIGN MAPPING FORMULA OF ASYMMETRICAL MULTI-ELEMENT COUPLED LINE DIRECTIONAL COUPLERS

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ABSTRACT

This paper presents a design mapping formula, which is relation between performance specification and design parameters, for asymmetrical multi-section coupled transmission line directional coupler. Presented mapping function can provide a convenience for its using and accurate design parameters for a given design specification. Simulations and experiments on designed three-, five-, and seven-element coupled line directional couplers with 16dB±0.2dB coupling show the validity of the presented design mapping formula.

I. INTRODUCTION

A TEM-mode coupled-transmission line directional coupler with various configurations and performances is one of the traditional research fields. A single-element TEM-mode coupled-transmission line directional coupler, whether symmetrical or not, has a band-limited property. Thus, in order to obtain a near constant coupling with excellent isolation performance over a wider frequency bandwidth than is possible using a single-element, various trials such as cascading symmetrically or asymmetrically a number of coupled element have been reported. [1]–[4]

This paper presents a new design mapping formula for an asymmetrical multi-element directional coupler to determine the design parameters for a given specifications such as coupling value, ripple level, and equal-coupling bandwidth. By properly choosing the even- and odd-more impedances of the various sections, the operating bandwidth of the directional coupler can be increased. An exact synthesis procedure for asymmetrical multi-element coupled-transmission line directional couplers was published by R. Levy. [1], [2] Furthermore, design theory of optimum symmetrical directional couplers of multi-element was published by E. G. Cristal. [3], [4] These coupler design method is based on an equal-ripple approximation to the mean couplings. In these meanings, this paper is not new one but it willing to promote a convenience for a very complicate design of a multi-element directional coupler by introducing a new design mapping formula. Furthermore, the presented mapping formula can be applicable to symmetrical case due to it is also based on an equal-ripple approximation to the mean couplings. Three-, five-, and seven-element couplers with 16dB±0.2dB coupling specification have been designed by using this design mapping formula to show the validity of this paper. Simulations and measurements on designed multi-element directional couples show excellent agreement with design specification. Moreover, degradation in performances of multi-element directional coupler will be discussed based on the several design examples.

II. DERIVATION OF DESIGN MAPPING FORMULA

Fig.1 shows the typical coupling response of an optimal asymmetrical multi-element coupled-line directional coupler. In order to achieve this performance, the design parameters should be expressed in terms of the design specifications such as the mean coupling C and the coupling tolerance R, which are shown in Fig.1.

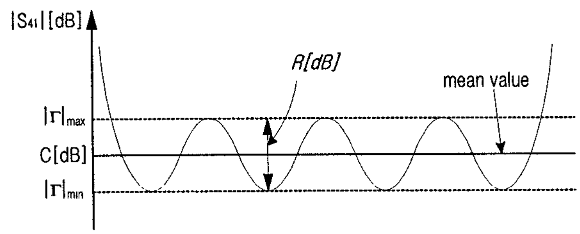

Fig.1 Typical response of a multi-element coupled-line directional couplers.

R. Levy used the following equations to express the relations between the design parameters and specification. [1]

$$C = 10\log_{10}\frac{\sinh 2H}{\sinh 2J} \tag{1}$$

$$R = 10\log_{10}\frac{\tanh H}{\tanh J} \tag{2}$$

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However, H and J are not direct design parameters to determine the design result, the even-mode impedances of multi-element transmission-line section. In order to obtain the design result, β and h, which are defined by R. levy in [1], for given design specifications should be computed by manipulation of several equations including (1) and (2). Unfortunately, analytical synthesis procedures with manipulation of several equations for determining design parameters tend to be very cumbersome even for couplers with a small number of element. For aiding designer, R. Levy has provided design tables for equal-ripple asymmetrical couplers with limited values of coupling and ripple. [2] In order to accommodate convenience of design procedures, this paper presents the mapping formula to compute the design parameter, β and h, for a given coupling and tolerance specifications.

The square of the reflection or the power reflection coefficient for the even-mode excitation is given by

$$|\Gamma|^2 = \frac{\beta^2 - h^2 T^2{}_n}{1+\beta^2 - h^2 T^2{}_n}. \qquad (3)$$

$T^2{}_n$ means square of the chebyshev polynomial, which oscillate between 0 and +1. [1] Ripple of this reflection coefficient is due to the chebyshev polynomials in (3). Thus, the mean value of this reflection coefficient can expressed by

$$|\Gamma|^2{}_{mean} = \frac{\beta^2 - 0.5h^2}{1+\beta^2 - 0.5h^2} = \frac{2\beta^2 - h^2}{2+2\beta^2 - h^2}. \qquad (4)$$

The corresponding mean value of coupling is given by

$$C[dB] = 10\log\frac{1}{|\Gamma|^2{}_{mean}} = 10\log\left(1+\frac{2}{2\beta^2 - h^2}\right). \qquad (5)$$

The ripple value R is the difference between the minimum and maximum value of the power reflection coefficient as shown in Fig.1. The power reflection coefficient has maximum value when the square of the chebyshev polynomial is zero. Furthermore, the power reflection coefficient has minimum value at $T^2{}_n$ =1. Thus, the corresponding ripple value is given by

$$R[dB] = 10\log\frac{|\Gamma|^2{}_{\min}}{|\Gamma|^2{}_{\max}} = 10\log\frac{1}{1-\left[h^2/\left(\beta^2\left(\beta^2+1-h^2\right)\right)\right]} \qquad (6)$$

In order to express the design parameters in terms of coupling and ripple, (5) and (6) are modified as follows

$$10^{0.1C} - 1 = \frac{2}{2\beta^2 - h^2} \qquad (7)$$

$$1 - 10^{-0.1R} = \frac{h^2}{\beta^2\left(\beta^2+1-h^2\right)} \qquad (8)$$

Simple manipulation of the (7) and (8) gives the following formulas for the mean coupling C[dB] and the coupling ripple R[dB].

$$\beta^2 = \left(\frac{1}{2}+\frac{1}{X}-\frac{1}{Y}\right)+\sqrt{\left(\frac{1}{2}+\frac{1}{X}-\frac{1}{Y}\right)^2+\frac{2}{XY}} \qquad (9)$$

$$h^2 = 2\beta^2 - \frac{2}{X} \qquad (10)$$

where $X = 10^{0.1C} - 1$ and $Y = 1 - 10^{-0.1R}$.

III. SIMULATIONS AND EXPERIMENTS

To illustrate validity of the derived design formula in this paper, multi-element coupled-line directional couplers with 16dB coupling specification were designed. Specifications of the examples designed in this paper are as follows; three sections, f2/f1=5, ripple level=0.4dB; five sections, f2/f1=6, ripple level=0.4dB; and seven sections, f2/f1=13, ripple level=0.4dB, where f1 and f2 mean lower and upper operating cutoff frequencies of coupling bandwidth, respectively. Design results, the even-mode impedance values for a corresponding design specification, are shown in Table.1.

Table.1 Design results for C=16dB and R=0.4dB.

Even-mode Impedance	N=3	N=5	N=7
Z_{oe1}	63.34	65.18	65.75
Z_{oe2}	55.46	59.18	61.35
Z_{oe3}	51.54	55.07	53.63
Z_{oe4}		52.43	54.98
Z_{oe5}		50.90	52.13
Z_{oe6}			51.58
Z_{oe7}			50.98

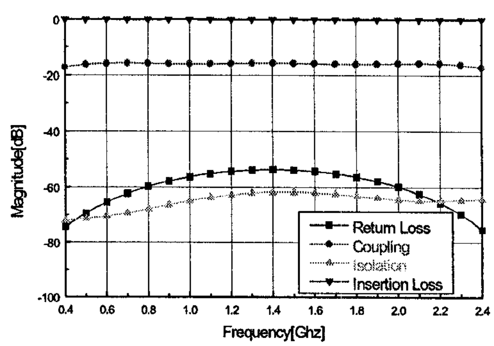

Fig.2 Simulation on the designed three-element coupled-line directional coupler.

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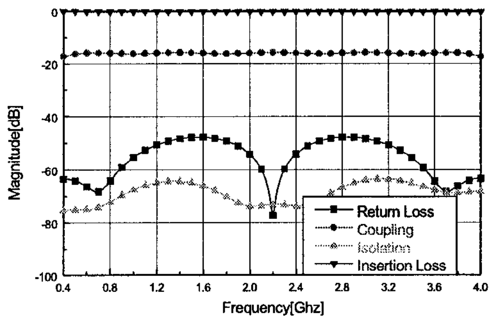

Fig.3 Simulation on the designed five-element coupled-line directional coupler.

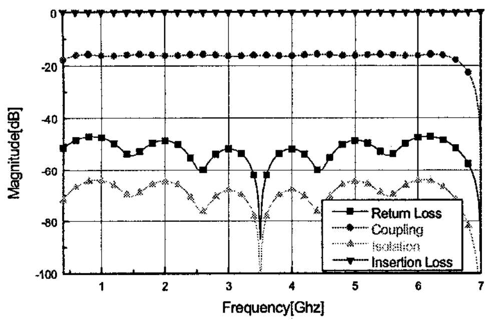

Fig.4 Simulation on the designed seven-element coupled-line directional coupler.

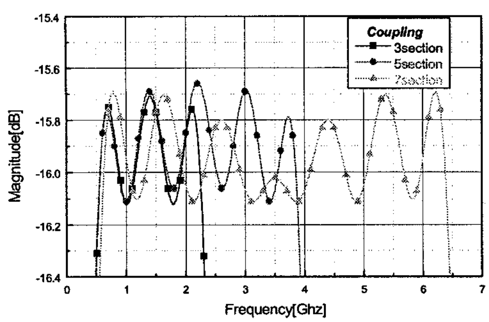

Fig.5 Comparison of simulated coupling ripple characteristics of designed multi-element coupled-line directional couplers.

The simulated S-parameters on designed three-, five-, and seven-element coupled-line directional couplers are shown in Fig.2, Fig.3, and Fig.4, respectively. Meanwhile, Fig.5 shows the comparison of simulated mean coupling values, as well as coupling ripple values of designed multi-element coupled-line directional couplers. The designed five-element coupled-line directional coupler was fabricated with a conventional strip-line configuration and then measured. Fig.6 and Fig.7 show the measurements on fabricated five-element coupled-line directional coupler. Simulated and measured coupler performances show good agreements with the theoretic results. Mean coupling values and ripple values show very small deviations from its design specifications. However, the degradation in isolation performance at higher frequencies is severe. The degradation in isolation performance and the deviation in coupling characteristics are believed to be caused mainly by very small junction capacitances between adjacent even-mode transmission lines. It has been assumed that the junction capacitances due to discontinuity in the stepped even-mode transformer of coupled-line directional coupler are zero. This would be approximately true in low frequencies, but not in higher frequencies. The presence of the junction capacitances has two effects. The lesser effect is a small increase in the magnitudes of the individual step reflections. Thus, the mean value of coupling becomes higher than that of the original specification as shown in Fig.5.

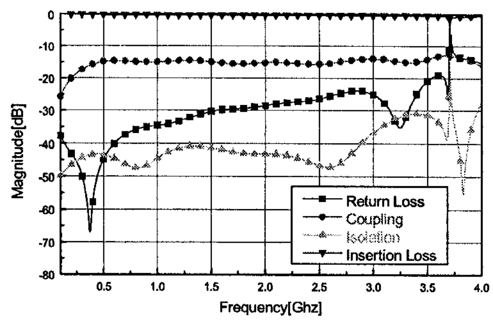

Fig.6 Measured results on the fabricated five-element coupled-line directional coupler.

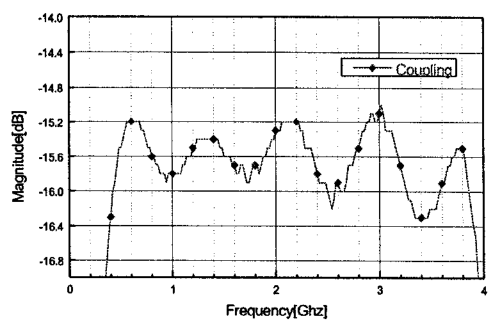

Fig.7 Measured ripple performance of the fabricated five-element coupled-line directional coupler.

The greater effect is the introduction of phase angles in reflection and transmission coefficients of the steps. This phase angles of even-mode transformer mean that difference between even- and odd-mode phase velocities may be increased at higher frequencies. Thus, degradation in isolation performance at higher frequencies might be introduced by this phase velocity difference as shown in Fig.6. [5] In order to correct the degradation in performances of multi-element directional coupler, the junction capacitances due to step discontinuity are compensated. [5], [6] This is an another research issue.

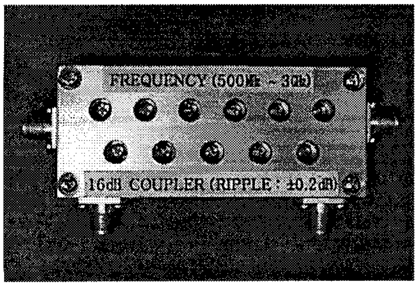

Fig.8 Photograph of the fabricated five-element coupled-transmission line directional coupler.

IV. CONCLUSION

We have presented a new design mapping formula for an asymmetrical multi-element directional coupler to calculate design parameters for a given specification. Several examples have been designed by using this design mapping formula to show the validity of this paper. Both simulations and measurements on designed multi-element directional couples have demonstrated that the proposed formula is good enough to provide an accurate design results for given design specification and to promote a convenience for a very complicate design procedures of a multi-element coupled-transmission-line directional couplers. Moreover, degradation in performances of multi-element directional coupler has been investigated through the discussion on the simulated and measured results of the several design examples.

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