Novel Broadband 3-dB Directional Coupler Design Method

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Abstract: — A novel broadband 3-dB directional coupler design method utilizing HFSS® and realization are given in this paper. It is realized in stripline, showing great agreement with the simulation and design format. The unique property of this design method is that it unnecessitates both a feedback from the realization for broadbanding and an additional smoothing of transition between coupled sections of the whole directional coupler. There is also no need for either a specialised CAD tool or a computer program.

Key-words:- digital frequency discriminator, HFSS, APLAC, broadside coupling

1 INTRODUCTION

It is very well known that a pair of parallel coupled lines achieve maximum coupling when they are a quarter wavelength long (*λ/4*) in a TEM system [1]. Additionally, broadbanding is achieved by cascading several *λ/4* coupled sections together. The obvious solution to achieving broader bandwidth is to use a symmetrical multisection coupler [1] which has the unique and valuable property of having constant π/2 phase difference throughout the frequency range. Crystal and Young have presented detailed design data for this type of device [2]. These tables give the required even mode impedance for each section to produce an equiripple frequency response. However, as is well known, the required coupling of the central element(s) in multisection couplers is invariably tighter than that of the overall coupler. Such tight coupling values are impossible to realize, *i.e.*, in microstrip using a multifingered Lange arrangement [3].

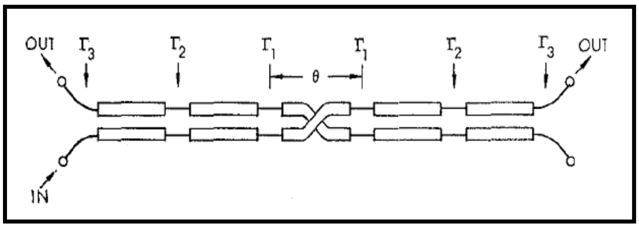

Fig. 1 Symmetrical Multisection Coupler

Another problem stated before with these discrete couplers have jump discontinuities in the coupling coefficient function with corresponding jump discontinuities in the stripline dimensions [4].

In this paper - in the light of these premises -, the design and realization of stripline broadband symmetrical multisection coupler is clarified. The design is started from a previous tabulated coupling profile [1], with division of the tightest coupling element into 3 sections. The values of these extra sections are found by optimisation using ***APLAC®*** — a 2-D analysis tool — with even and odd mode impedances of the ideal coupled lines. These are then converted into broadside coupled line width and offset values. Each coupled section is treated individually without any smoothing procedure. The design process is mainly made on a 3-D analysis program, namely ***HFSS***. Previous suchlike broadband coupler works lean on iterations between simulations and realizations; latter ones constitute a feedback for the former ones [1]. On the contrary, our iterations are only between ***HFSS*** and ***APLAC*** simulations, and final ***HFSS*** simulation provided an almost-similar result with the realization.

2 TOPOLOGY

The basis for the approach is the connection of coupled regions in tandem, the coupled and straight-through outputs of one multisection coupler being used as the isolated inputs to another coupler [5]. A -3 dB coupler is realized by using two -8.34 dB couplers in tandem as in Figure 2 (-3 dB = 20.log sin π/4, and -8.34 dB = 20 log sin π/8). ρ_0, ρ_1, and ρ_N are the 'coupling factor's of each individual *λ/4*-long coupler stages, and given by

$$\rho = \frac{Z_{oe}}{Z_{oo}} \quad (Z_0 = \sqrt{Z_{oe} \times Z_{oo}}) \qquad (1)$$

where Z_{oe} and Z_{oo} are even and odd mode impedances of each coupled lines respectively and Z_0 is 50Ω.

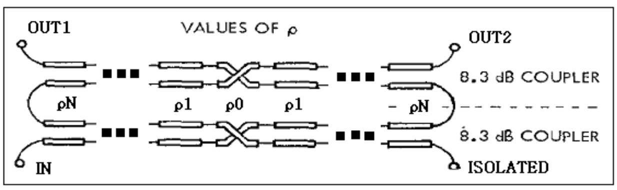

Fig. 2 Tandem connection of two 8.3-dB multisection couplers

3 APPLICATION ENVIRONMENT

Multisection coupler is realized in stripline since - compared to its microstrip counterpart - phase and amplitude dispersion can be much more avoided despite increasing frequency. Along with this structure, "broadside coupling" is selected as realization form for these cascaded couplers because of its appropriateness for achieving high coupling factors (Figure 3). This is especially important for the central elements of the whole structure.

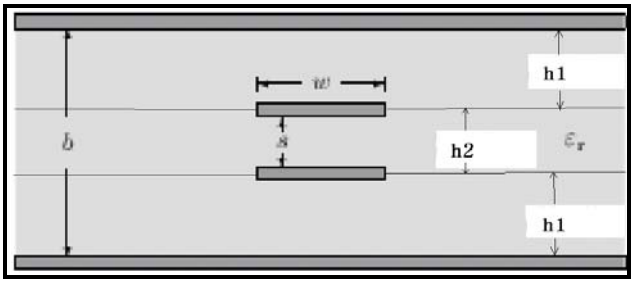

Fig.3 Stripline Broadside Coupling

Since the bandwidth of the coupler is to be maximised, the highest possible centre section coupling factor (ρ_0) must be achieved. It follows that the separation of the inner conductors must be minimised, and the separation of the two ground planes be maximised to provide maximum coupling. A low dielectric constant maximises the highest coupling possible [5].
The choice of ground plane separation is dictated by the presence of higher order modes in the triplate. Vendelin has proposed that the maximum usable frequency for a particular ground plane separation is given by [6],

$$F_{\max} = \frac{30}{\sqrt{\varepsilon_r}\left(2W + \frac{\pi b}{2}\right)}(GHz) \qquad (1)$$

where ***W*** is the inner conductor width in *cm*, and **b** is the total substrate thickness in *cm,* as in Figure 3.

4 SIMULATION PROCEDURE

It is obvious that selected multisection coupler requires a structure with corresponding jump discontinuities (Figure 4) and hence constitutes a 'coupling profile', *k(x)*, - which is defined as the value of coupling factor as a function of distance along the coupler's axis of propagation – an example of which is given in Figure 4.

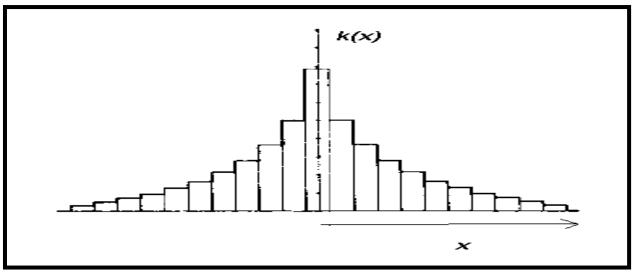

Fig.4 A generic coupling profile example of a symmetrical multisection coupler

With this motivation, [1] supplied us a coupling profile of a 47-section 8.34-dB coupler (Figure 5). In [1], coupling profile is optimized to be smoothed-out, giving the desired result in 0.5-26 GHz range. In an effort to remove the problems associated with the jump discontinuities in *k(x)*, it naturally attempts to " round off " the corners and thereby allows a more gradual transition from the region of tight coupling to the region of zero coupling at the ends of the coupler ports.

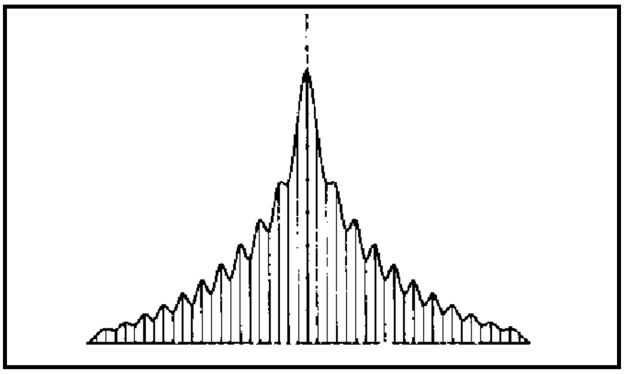

Fig.5 0.5-26 GHz 8.34 dB coupler coupling profile

But for our structure, not requiring smoothing-out, the coupling profile values (in terms of Z_{oe} and Z_{oo}) of 46 sections are taken directly from [1] with equal length *l* (*l* is chosen as λ/4 at the band center) and the central section is divided into 3 sections with lengths *l/3*. Z_{oo} and Z_{oe} values of the center element is taken to be the maximum coupling values achievable with chosen substrate ε_r and height. In order to find the Z_{oe} and Z_{oo} of the added sections, the element values are optimised using ***APLAC*** for 2-18 GHz.
The adopted simulation procedure, not necessitating a feedback from the hardware realization employs ***HFSS***, 3-D simulator. In this method, ***HFSS*** and ***APLAC*** are used in conjunction. The optimized Z_{oe} (hence Z_{oo}) values in ***APLAC*** are converted to stripline width and offset values using ***LineCalc***® for each coupled section to be simulated in ***HFSS***. As indicated, 3-D analysis result supplies the necessary feedback for how to align each section's Z_{oe} (Z_{oo}) values. This means that we alter Z_{oe} (Z_{oo}) values of the coupled sections — especially those of the ones near the center section — to obtain the 3-D analysis' graphical result. For example, in APLAC optimization, Z_{oe} of a coupled line section turns out to be 75 Ω. After obtaining HFSS optimization result for the whole structure, we align the first APLAC even (odd) mod impedance values to achieve this HFSS result. Following the alignment process, i.e., if we find the Z_{oe} value of this coupled section as 79Ω (it means that the synthesised width and offset values using ***LineCalc*** realizes 79Ω), it can be said that if it is realized as $\left(\frac{75}{79}\right)\times 75 = 71.2\Omega$ in stripline, we can reach our goal.
A few controlled iterations (*i.e.* preventing 'very' different values for nearby sections) guided by this mentality takes us to 3-dB goal throughout the 2-18 GHz frequency range. As seen, no additional smoothing process is necessitated at the end and no more than one

hardware iteration is required when HFSS is taken for granted.

5 REALIZATION

In the realization, substrate used has an ε_r = 2.94 and — using Equation (2) — h_1= 0.06" and h_2=0.005" are selected for F_{max}=18 GHz. Figure 6 gives the resulting view in the HFSS.

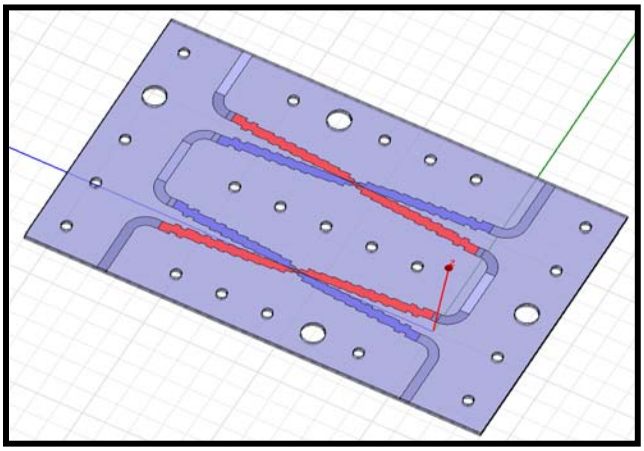

Fig. 6 2-18 GHz coupler HFSS view

After synthesizing the whole 3-dB broadside coupler (in Figure.6, *red* and *blue* shows different broadside layers), a number of guide and normal pin holes are drilled and simulated for appropriate grounding and mounting purposes. Figure 7 gives the ultimate HFSS simulation result of 2-18 GHz stripline coupler. As seen, coupled and through magnitude characteristics show a maximum rippling characteristic of ±0.8 dB at the end of the whole band where reflection and isolation characteristics are, both, finer than 11 dB.

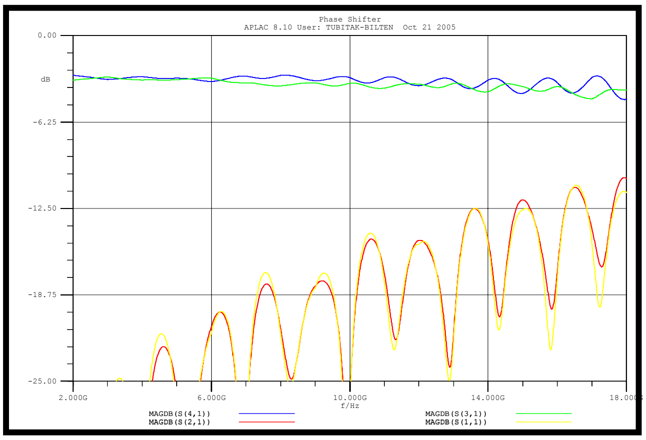

Fig.7 2-18 GHz coupler HFSS simulation result

Figure.8 gives the realization result which shows a great agreement with that of the simulation. The top line shows how much two port (coupled and through) magnitude results are diverged from eachother (a maximum of ±0.84 dB=1.68 dB). Reflection and isolation characteristics herein are, both, finer than 10 dB, where phase difference turns out to be 90º±9º.

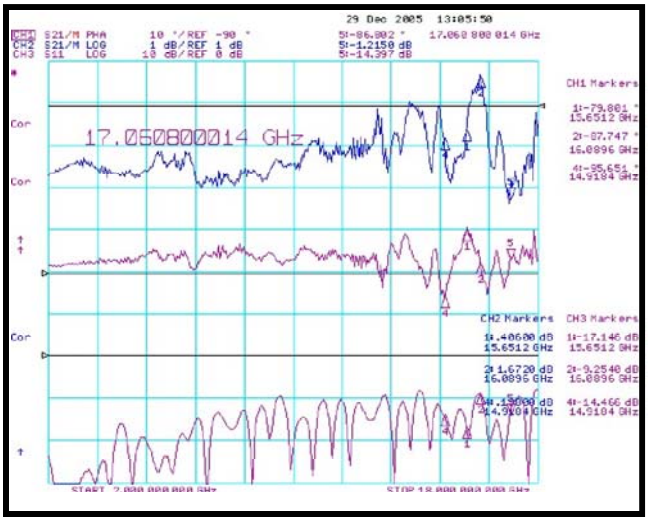

Fig. 8 2-18 GHz coupler realization result

6 CONCLUSION

A novel broadband 3-dB directional coupler design method and realization are given in this paper utilizing HFSS®. It is, additionally, realized in stripline — showing great agreement with the simulation and design format. The unique property of this design method is that it unnecessitates both a feedback from the realization/specialized CAD tools for broadbanding and an additional smoothing of transition between coupled sections of the whole directional coupler. More detailed information will be given in the full paper.

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