ALIGNMENT TOLERANT STRIPLINE DIRECTIONAL COUPLERS

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Abstract

The design methodology for a new type of alignment tolerant, broadside coupled, stripline directional coupler is developed. The coupler uses an even number of cascaded, asymmetric, broadside coupled line stages that are electrically short ($<\lambda_g/8$) and have been alternately inverted to achieve nearly symmetric coupling and return loss at all ports. The results demonstrate layer to layer alignment insensitivity that enables coupler designs where misalignment between layers is a critical parameter. Measured S-parameter results for 3dB and 10dB coupler designs are presented and agree well with theory. Coupling range variations less than 0.5dB are achieved for a 3dB alignment tolerant coupler design compared to 0.9dB for a standard, symmetric 3dB design with misalignments of +/-0.25mm (+/-0.010"). An 8.4dB alignment tolerant directional coupler displays a variation of 0.5dB over the same layer to layer alignment range compared to an equivalent 10dB standard design that has a coupling variation of 4.9dB with similar misalignment between layers.

Introduction

Present day printed circuit fabrication techniques for multilayer stripline boards give typical layer to layer alignment ranges of +/-0.13mm (+/-0.005"). The tolerances quoted are usually 3 sigma values, but for 6 sigma designs, alignment ranges of +/-0.25mm (+/- 0.010") should be anticipated for a low cost process. In the case of broad side coupled directional couplers, alignment shifts between layers of this magnitude can result in wide coupling variations at the design frequency. The goal of this particular project is to produce stripline 3dB and 10dB symmetric directional couplers that are insensitive to alignment variations.

Coplanar coupled lines are found to be limited to weak coupling values for low dielectric constant substrates and usually require gaps that are too narrow to be reliably fabricated for 3dB couplers [1]. The multi-layer floating conductor coupler from [2] was also studied but was not applicable in stripline.

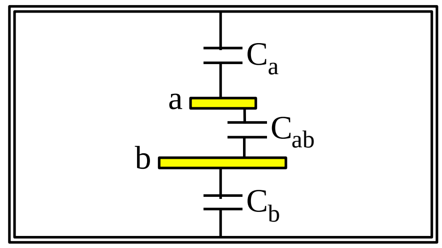

Figure 1. Cross section of an asymmetric coupled line pair in stripline. This type of coupled line is insensitive to lateral alignment as long as line "a" completely overlies line "b".

The asymmetric coupled lines presented in figure 1 are insensitive to lateral alignment shifts as long as the narrow line "*a*" completely overlies the wider line "b". This structure preserves the even mode capacitances (C_a and C_b) as well as the odd mode capacitance per unit length (C_{ab}) of the structure even if the lines are shifted away from center. Unfortunately, using a quarter wavelength long section of this line will produce a directional coupler with different input impedances at the narrow and wide ports. In cases where an impedance transformation is desired, such as with video detectors, this type of coupler is ideal [3] and is alignment tolerant; however, in cases where symmetric responses are desired, a new approach is necessary.

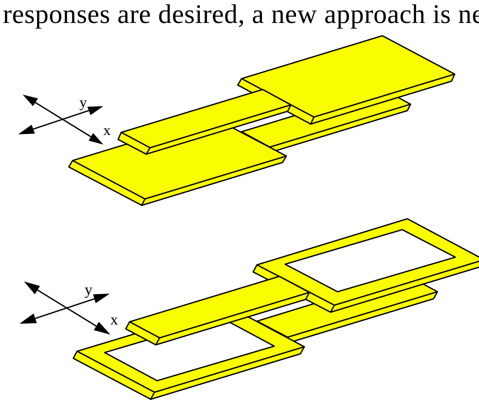

Figure 2. Fundamental cell of the alignment tolerant directional coupler for a) strong coupling b) weak coupling.

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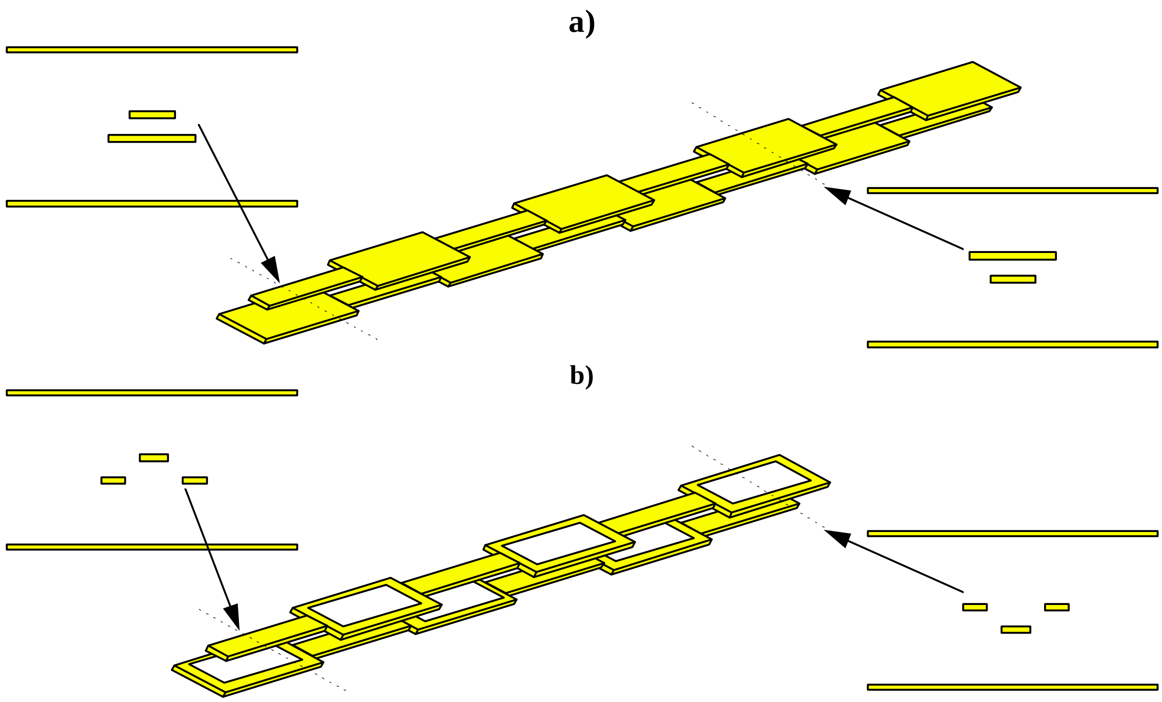

Figure 3. Alignment tolerant directional coupler consisting of eight asymmetric coupled line sections for a) strong coupling and b) weak coupling.

Figure 2 displays the fundamental element of the alignment tolerant stripline directional coupler. The cell consists of two asymmetrically coupled lines with the wider line completely overlying or underlying the narrower line. The fundamental elements are kept electrically short ($<\lambda_g/8$) so that a quarter wavelength coupler design has a nearly symmetric response (return loss, coupling value, insertion loss and directivity) at all ports. The smaller these sections are with respect to a guided wavelength, the more symmetric the response. These cells are then cascaded to the appropriate length as shown in figure 3.

The design of these types of directional couplers is accomplished by using PDEase^{TM} (a 2-D finite element partial differential equation solver) to determine the even and odd mode capacitances (C_a, C_b and C_{ab}) of each line. A static numerical solution of Laplace's equation and a path integral of the displacement field on the surface of each conductor biased at 1V or 0V provides the capacitances of interest. Next, these capacitances are used with the analytic equations for asymmetric coupled lines from [3] that have been coded into an HP EEsof Libra^{TM} senior model to determine the coupling values of the cascaded structure.

As an example, a standard 10dB symmetric broadside coupler is compared to an alignment tolerant design using the same substrate: 3.30mm (0.130") thick stripline layer structure with a centered 0.25mm (0.010") thick layer using Rogers Duroid RO3003^{TM} (εr=3.02). The standard quarter wavelength single stage design (two 1.70mm wide lines with a center to center offset of 1.87mm) gives 10 dB of coupling, 35.6dB of return loss and 45.2dB of isolation (simulated). The alignment tolerant design consists of eight cascaded ($\lambda_g/32$) sections of asymmetric coupled lines that span one quarter of a guided wavelength. The first line is 1.50mm wide and the second slotted line is 3.70mm wide with a 2.70mm wide centered slot. From 2D electrostatic simulations, the even mode capacitances for the centered coupler are found to be 69.0pF/mm (C_a) and 89.1pF/mm (C_b) with an odd mode capacitance of 37.2pF/mm (C_{ab}). It should be noted that C_{ab} is capacitance of line *a* to line *b* when line a is set to 0V and line b is set to 1V. The alignment tolerant design gives 10.0dB of coupling, 25.7dB return loss and 35.1dB isolation (simulated). The coupling variation for the alignment tolerant design is less than 0.4dB over misalignment ranges of +/-0.25mm compared to 5.1dB for the standard broadside coupled design. The measured results from this coupler are presented in a later section.

Results

Figure 4 displays the measured versus modeled results from a stripline 3dB alignment tolerant directional coupler on Rogers Duroid RO3003^{TM} (εr=3.02). Total substrate height is 3.3mm (0.130") with a centered dielectric spacing layer 0.25mm (0.010") thick. The coupler consists of eight asymmetric sections 2.92mm (0.115") long with a narrow line width of 0.80mm (0.031") and a wide line width of 1.30mm (0.051"). The numerically simulated even and odd mode capacitances from PDEase™ are 32.5pF/mm (C_a), 62.4pF/mm (C_b) and 118.0pF/mm (C_{ab}). The agreement between measured and modeled is excellent for the coupling, directivity and return loss. The isolation is not accounted for as well in the model because discontinuities from steps and bends, overlapping end regions as well as losses were not taken into account in this ideal model.

Figure 5 displays the measured 3dB coupler directivity and coupling coefficient at several alignments (centered and +/-0.25mm). At the design frequency (1.85 GHz), a shift of 0.5 dB is observed over this range of alignments while the ideal model predicts a shift of 0.4 dB over this range. A model of a standard 3dB coupler designed with symmetric line widths predicted a shift of 0.9dB over the same alignment range. Table I summarizes the results from these tests.

Table I: 3 dB Coupler Results at 1.85 GHz

Alignment	Coupling (dB)	Ret. Loss (dB)	Isolation (dB)
Δ*l*=0mm	3.0	26.5	35
Δ*l*=+/-0.13mm	3.2	25	33
Δ*l*=+/-0.25mm	3.4	24	31

Two 10dB coupler designs were fabricated and tested using the weak coupling configuration in figure 3b. Both designs had the same fundamental cell geometry and identical total length but one design had two cascaded sections while the other design had eight cascaded sections. Figure 6 displays the results from the eight section coupler. The first solid line is 1.50mm wide and the second slotted line is 3.70mm wide with a 2.70mm wide centered slot. From 2D electrostatic simulations, the even mode capacitances for the centered coupler are found to be 69.0pF/mm (C_a) and 89.1pF/mm (C_b) with an odd mode capacitance of 37.2pF/mm (C_{ab}). The two section design produced a 9.1dB coupler with 17.0dB return loss and an isolation of 14.7dB while the eight section coupler produced an 8.4dB coupler with 16.5dB return loss and 15.0dB of isolation. The higher measured coupling than the ideal model predicted is mostly due to the extra coupling introduced by the crossover regions and by overlapping input and output lines. Future designs should try to minimize this overlap or include it within the model for weak coupling structures. The alignment tolerance of these two coupler designs was tested and found to vary by 0.4dB over misalignments in the range of +/-0.25mm.

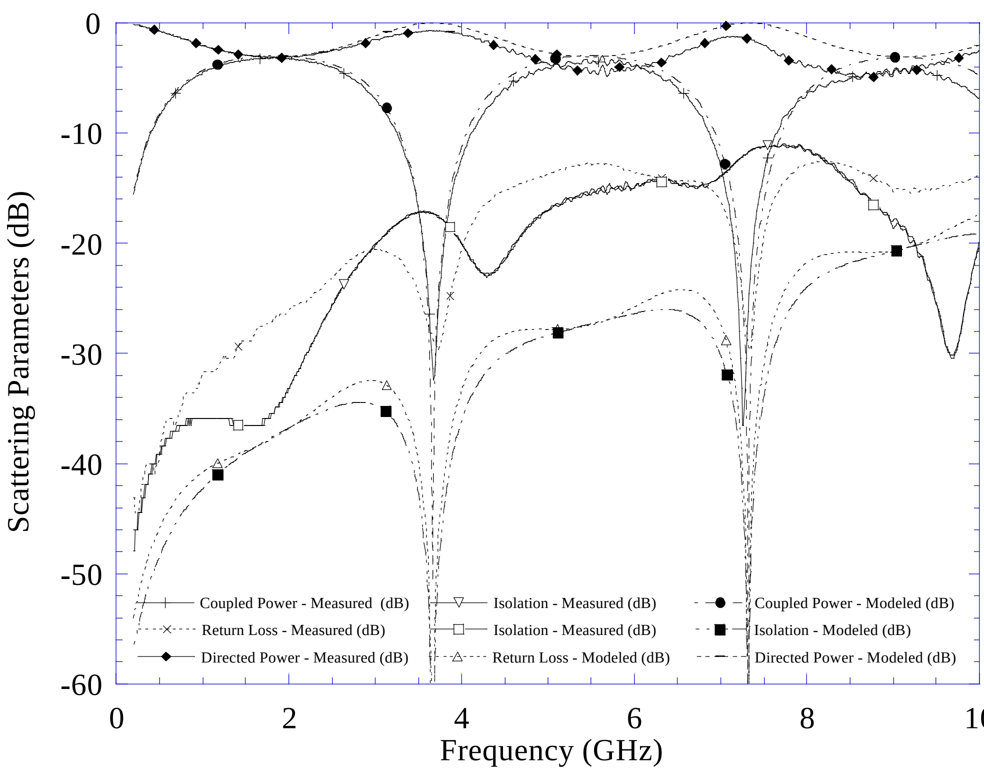

Figure 4. Measured and modeled S-parameters of a 3dB alignment tolerant directional coupler with w1=0.80mm and w2=1.30mm on Rogers Duroid RO3003™ (εr=3.02). Total substrate height is 3302µm with a centered 254µm thick dielectric spacing layer. This coupler had eight coupled line sections with a total length of 4311µm.

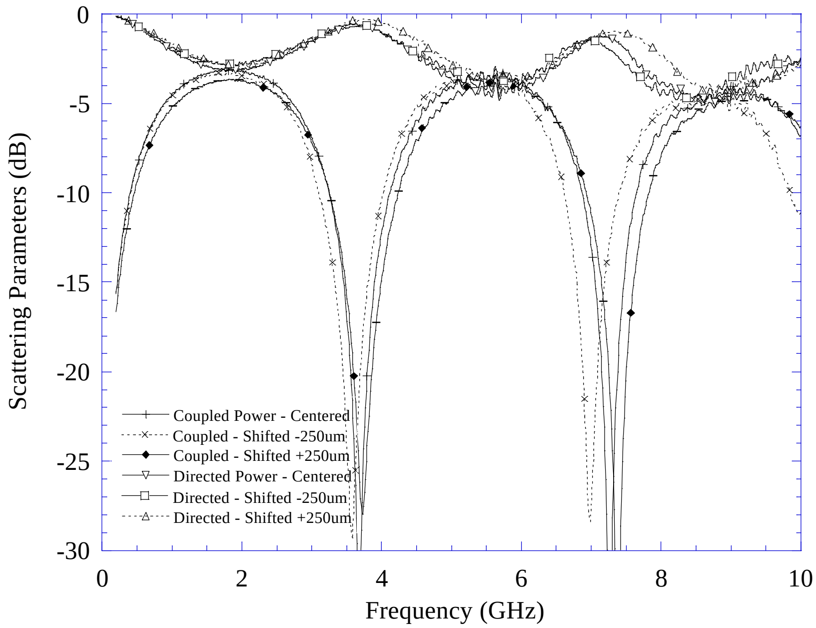

Figure 5. Measured S-parameters of a 3dB alignment tolerant directional coupler from figure 4 at various positions. Coupling value varies by 0.5dB over +/-0.25mm of layer to layer misalignment compared to a simulated 0.4dB coupling range. The corresponding standard 3dB design had a coupling range of 0.9dB for the same misalignment range.

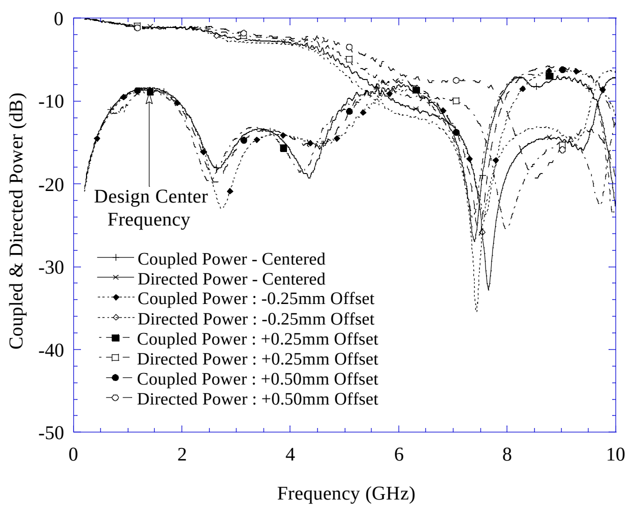

Figure 6. Measured S-parameters of an eight section 10dB alignment tolerant directional coupler at various positions. Actual coupling value was 8.4dB due to increased coupling in the overlapping regions. Coupling varies by 0.5dB over +/-0.25mm of layer to layer misalignment compared to a simulated 0.4dB coupling range. The corresponding uniform width standard 10dB design had a coupling range of 4.9dB for the same misalignment range.

Conclusions

The alignment tolerant directional coupler designs presented in this paper allow the use of low cost printed circuit board techniques for the fabrication of stripline broadside coupled directional couplers that are insensitive to misalignment between layers. Compared to standard symmetric broadside coupled designs (equal line widths), the designs presented in this paper demonstrate lower coupling shifts for the identical misalignments. This significant advance should enable high frequency (>10 GHz) coupler designs using thin (<0.25mm) substrate layers along with standard printed circuit board fabrication tolerances. Although the center frequency of these designs is centered at 1.85GHz, the dimensions of the stripline structure are easily scaled to higher frequencies with a geometric scaling factor.

Acknowledgments

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