IF-TH-61

A Novel Directional Coupler for PCB and LTCC Applications

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***Abstract* — A new coupled-line directional coupler, convenient for PCB and LTCC applications, is proposed. The coupler covers −10 dB to −2.7 dB coupling coefficient, being always theoretically compensated. The novel structure is not sensitive to lateral misalignment of conductive layers, and not sensitive to thickness and dielectric permittivity tolerances of applied dielectric substrates. Promising experimental results are presented.**

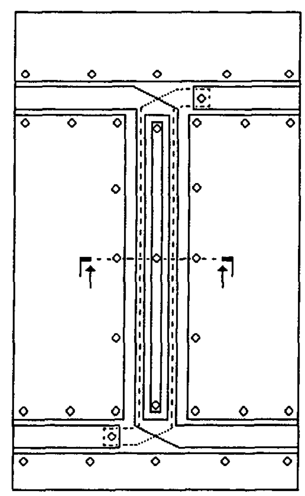
I. Introduction

Advances in substrate technologies have led to the development of multilayer RF/microwave circuits. The integration of RF, high speed digital and D.C. power circuits in multilayered assemblies using printed circuit board (PCB) or low temperature cofired ceramic (LTCC) technologies, has become common practice [1], [2]. In most cases, especially for wireless applications, the board is made of the same dielectric material.

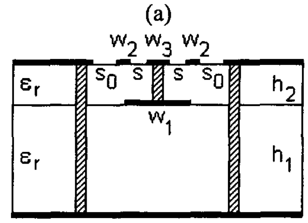
Multi-layer coupled-line directional couplers are realizable as embedded passives. They suffer from poor directivity and different techniques are used for purposes of compensation. Among many techniques that can be used to compensate a coupler, one can mention the use of an overlay dielectric media [3], stratified substrate of different materials [4], suspended substrate [5], and a parallel slot or a tuning septum in the ground plane [6], [7]. Wiggled coupled lines [8] and external compensation with lumped capacitors [9] can also be used, however, the latest one allows only narrow frequency band compensation. Practically none of these techniques can be applied to compensate a microstrip/coplanar line coupler built on a multilayer printed board, made of the same dielectric material. Suspension of the board is not convenient from the mechanical point of view; wiggled lines can be applied only for weak couplings.

The intention of this work was to find a coupled-line structure allowing compensation in the multilayer printed board environment, having wide-range of realizable coupling coefficients, and being sensitive neither to lateral misalignment of conductive layers, nor to thickness and dielectric permittivity tolerances of applied dielectric substrates. The geometry of the proposed structure is shown in Fig. 1 [10]. It is configured as four coupled, conductor-backed, coplanar lines. Two external lines on the top conductive layer are connected planarly, and are connected to the first pair of input/output lines. The middle line is connected to the bottom one through via-holes, and connected to the second pair of input/output lines. The second pair of input/output lines reaches the top conductive layer utilizing via-hole connection. The input/output lines can be connected to the coupled-line structure in such a way that the output signals are on the same side of the coupler. This feature is important for balanced circuits design.

Areas of achievable coupling coefficients, tolerance behaviour, and tuning properties, are shown in the following chapter. Measurements of 2.7 dB and 8.34 dB directional couplers, manufactured in PCB technology, are also presented.



(a)



(b)

Fig.1. A plain (a) and cross-section (b) view of a novel directional coupler.

2002 IEEE MTT-S Digest

II. ANALYSIS

The coupled-line structure shown in Fig. 1 belongs to a family of asymmetric couplers. It is known, that the asymmetric coupled-line coupler is ideally impedance matched and perfectly isolated (compensated), if only the inductive k_L and capacitive k_C coupling coefficients are equalized and if the coupler is properly impedance terminated [11], [12]. This way, a quasi-ideal coupler can be realized [4]. In our analysis, which was performed using the quasi-static spectral-domain method [13], we calculated the geometrical dimensions of the 50 Ω matched directional coupler, and the corresponding coupling coefficients k_C and k_L, aiming to fulfill the condition of $k_C = k_L$. These calculations were carried out for two different dielectric materials: BT-Epoxy, $\varepsilon_r = 4.2$ (PCB) and Du Pount 951 or NTK GC-11, $\varepsilon_r = 7.8$ (LTCC), and the results are shown in Fig. 2, and Fig. 3, respectively. The structural dimensions are normalized to the thickness of the first dielectric substrate ($h_1 = 1$). It is clearly visible that the couplers are compensated in the range of coupling coefficients from −10 dB (-8 dB) to −2.7 dB (let us notice the difference between the s_0 limits in Fig. 2 and Fig. 3). The physical behaviour of the "tuning" process of the 50 Ω matched coupler made in BT-Epoxy, is shown in Fig. 4. The point of compensation K is searched by altering the width of the lines w_1, w_2 and w_3. w_2 and w_3 are chosen in such a way that the coupler is always impedance matched. When w_1 is small, the coupling coefficients k_C and k_L are different, and the corresponding isolation of the coupler is low. With the increase of w_1, the difference between the coupling coefficients diminishes, and the coupler is compensated at point K. Corresponding isolation is very high. Let us remark, that there is no equalization of coupling coefficients at point O; k_C reaches point P, and k_L - point M.

The novel structure is not sensitive to lateral misalignment of conductive layers. Present day printed circuit fabrication techniques give typical layer to layer alignment ranges +/-0.13 mm [14]. Computations have shown that coupling coefficient of the tightly-coupled coupler changes from −2.89 dB to −2.77 dB, and the coupler mismatches to VSWR = 1.04 over $dx/h_1 = 0.2$ of layer to layer misalignment.

The computations have also proven that: (i) The novel structure is not sensitive to variation of dielectric permittivity. The coupling coefficient is almost constant and the impedances vary by +/-1 Ω within the range of ε_r from 4.0 to 4.4, for any coupling level. (ii) Tight couplings can be achieved for a wide range of thickness h_2. This feature makes the structure flexible on composition of the board.

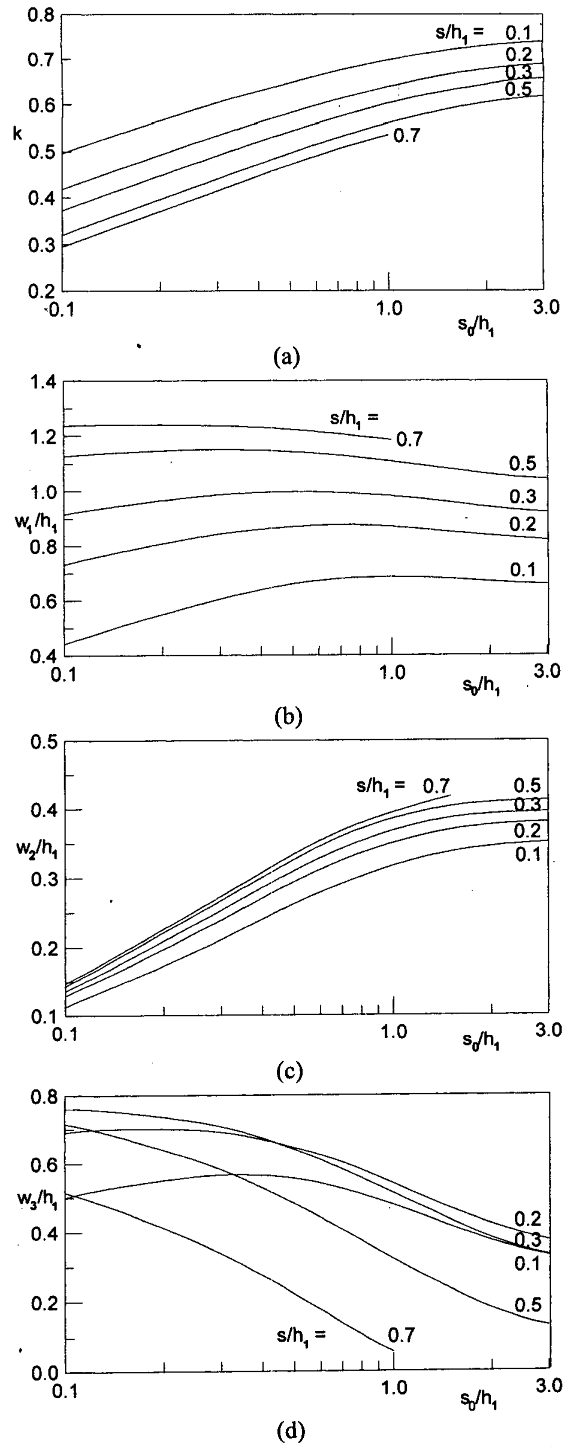


Fig. 2. (a) $k = k_C = k_L$, (b) w_1, (c) w_2, (d) w_3 for the 50 Ω matched coupler made in BT-Epoxy; $\varepsilon_r = 4.2$, $h_2/h_1 = 0.2$.

III. EXPERIMENTAL RESULTS

Two couplers, 2.7 dB and 8.34 dB, have been designed using Arlon 25FR laminates. The computed structural parameters are as follows: $\varepsilon_r = 3.58$, $h_1 = 1.47$ mm, $h_2 = 0.25$ mm, and $s_0 = 2.29$ mm, $s = 0.13$ mm, $w_1 = 1.19$ mm, $w_2 = 0.54$ mm, $w_3 = 0.79$ mm, and $s_0 = 0.25$ mm, $s = 0.86$ mm, $w_1 = 1.93$ mm, $w_2 = 0.27$ mm, $w_3 = 0.93$ mm, for the

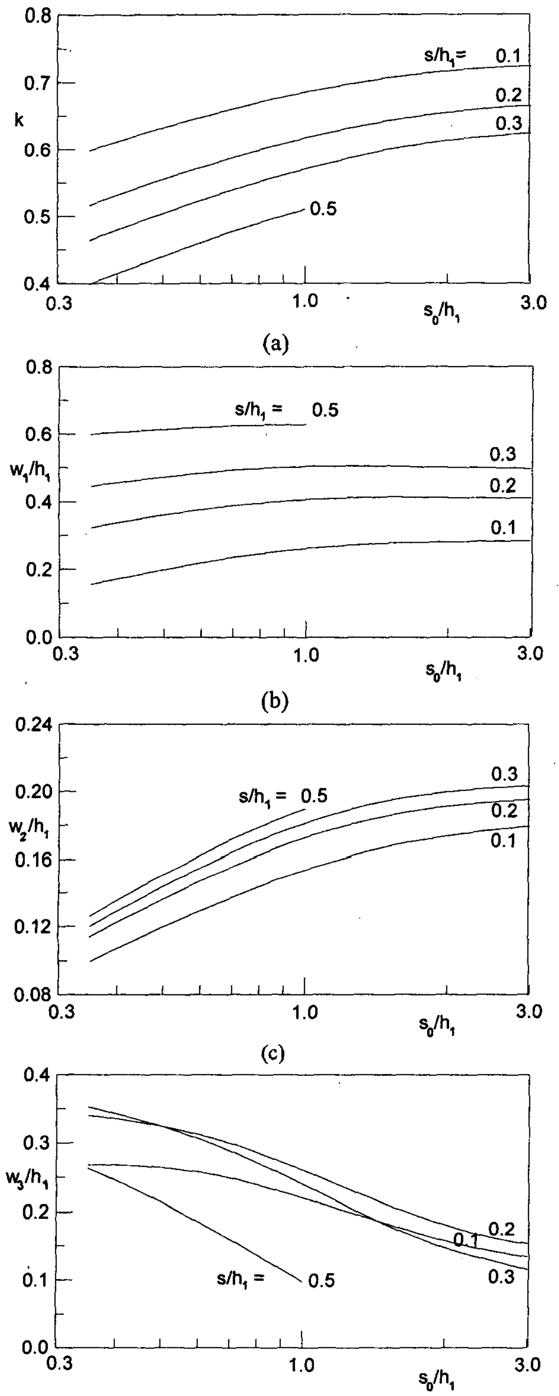


Fig. 3. (a) $k = k_C = k_L$, (b) w_1, (c) w_2, (d) w_3 for the 50 Ω matched coupler made in LTCC; $\varepsilon_r = 7.8$, $h_2/h_1 = 0.2$.

first and the second coupler, respectively. The thickness of the metallization was taken into consideration in the design using LINPAR software [15]. The measured responses are shown in Figs. 5 and 6. The coupling of the 2.7 dB

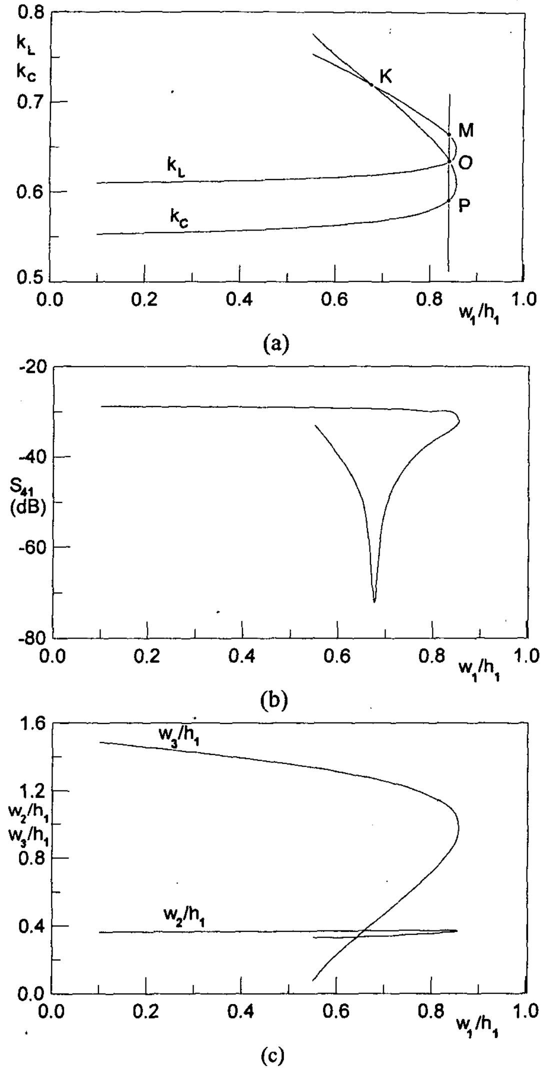


Fig. 4. Tuning process: (a) coupling coefficients, (b) isolation, (c) corresponding w_2 and w_3; $h_2/h_1 = 0.2$, $s_0/h_1 = 1.5$, $s/h_1 = 0.1$.

coupler equals to 2.87 dB, and its return loss and isolation are greater than 27 dB at the center frequency. The 8.34 dB coupler has coupling equal to 8.51 dB, and its return loss and isolation are greater than 22 dB at the center frequency. These results are remarkably good. The quasi-static design can be used as a very good starting point for full-wave design, where some corrections, due to discontinuities, should be taken into consideration, especially for higher frequency designs. Experimental results for 3 dB coupler in LTCC technology will be shown at the Symposium presentation.

IV. CONCLUSION

The investigated structure of directional coupler seems to be promising for PCB and LTCC applications, where the dielectric layers of the same dielectric permittivity compose the board. The structure is not sensitive to variations of technological parameters. Compensation of tightly coupled lines can be also achieved in the microstrip version of the structure for a specified width relation between strips w_1 and w_3.

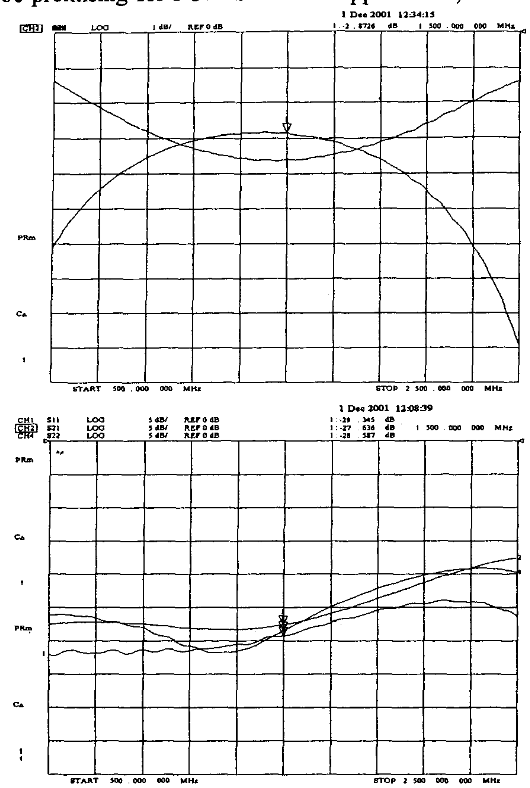


Fig. 5. Measured responses of the 2.7 dB coupler.

ACKNOWLEDGMENTS

The authors are grateful to Elzbieta Szulc for careful layout drawings and to Hannes Medelius for help to find LTCC manufacturer.

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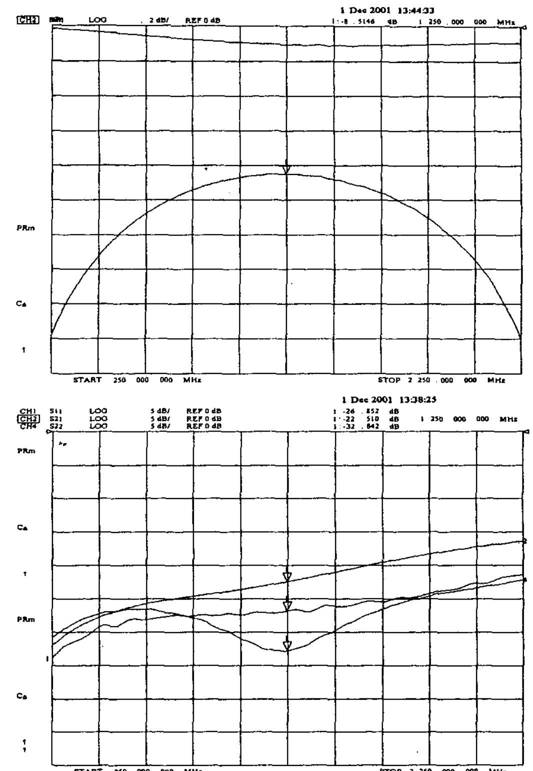

Fig. 6. Measured responses of the 8.34 dB coupler.

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