DESIGN OF NOVEL MULTILAYER MICROWAVE COUPLED-LINE STRUCTURES USING THICK- FILM TECHNOLOGY

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ABSTRACT

A novel octave band DC block (2.5 -10.5GHz) and a broadband 3dB directional coupler (3-8GHz) have been designed, fabricated and tested using a new multilayer format. The multiple layers of thick-film dielectric and metal were printed on an alumina base and an etching technique used to form the final conductor pattern. The tight coupling required between the coupled lines was realized by overlapping these lines in a multilayer structure. Very good agreement was obtained between measured and simulated data. The results demonstrate that multilayer thick-film techniques provide an efficient method of achieving small size, low cost components having good microwave performance. In particular, the new multilayer approach has been shown to overcome the problem of fabricating very small gaps between coupled lines in a traditional single layer structure.

INTRODUCTION

The trend in the mobile communications industry towards increased miniaturization, combined with requirements for low-cost devices and improved performance, has created a need for new circuit structures and fabrication technologies. Multilayer thick-film technology is a very attractive solution to address these needs. The circuit size is greatly reduced by stacking the conductors, a process that also opens up opportunities for the development of new, three-dimensional structures. One particular advantage of this approach is that it makes possible to achieve very tight coupling of microstrip lines without the need for very fine gaps that are difficult and costly to fabricate. This tight conductor coupling is often required in the design of high-performance microstrip wide bandwidth filters and directional couplers. The required strong coupling can be obtained easily by overlapping conductor lines on different layers.

Thick-film technology is well established for the low-cost manufacture of hybrid microcircuits [1]. In this study we show that this technology can be employed for the fabrication of multilayer structures yielding high performance at microwave frequencies. This has been established through the successful design and fabrication of a broadband DC block and 3dB directional coupler without the need for fine line lithography.

BEHAVIOUR OF BASIC STRUCTURES

Three of the basic elements forming a microwave multilayer structure are shown in figure 1. Figure 1a shows a cross-sectional view of a conductor track on top of a two-layer dielectric. Figure 1b shows a conductor track buried between the two dielectrics and, finally, in figure 1c we see the two conductor tracks on different dielectric layer positioned for close coupling.

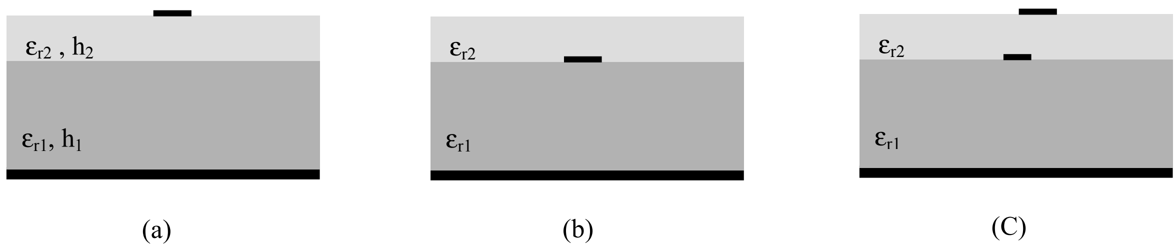


Figure 1. Cross sections of the basic multilayer structures. (a) Conductor track on two-layer dielectric. (b) Buried conductor track. (c) Multilayer coupled-line structure.

The behavior of multilayer structures shown in figure 1 can be studied through the use of an EM simulator, which employs a technique based on the method of moments. This technique was used to examine the width of 50Ω line for different structure. The design data are shown in Table 1.

Type of structure	Microstrip (single dielectric layer, ε_{r1})	Strip on two layers dielectric (Figure 1a)	Microstrip with overlay (Figure 1b)
Width of 50Ω line (μm)	604	735	610

Table 1. Simulated data for a 50Ω line. (ε_{r1}= 9.9, h_1=635 μm; ε_{r2}= 3.9, h_2=27 μm)

It is seen from table 1 that the dielectric layer, which is immediately under the conductor, despite this layer being very thin, significantly affects the characteristic impedance of the top conductor on two dielectric layers. It can be seen that the inclusion of the thin dielectric layer in this situation requires that the track width be increased by 131μm, to maintain a characteristic impedance of 50Ω (this represents a change of around 22%). However, if we consider the conductor buried between the two dielectric layers, we see that the thin dielectric overlay has very little effect. In this case the width of the buried conductor need only be changed by around 1%. The conclusion here is that the top track should be much wider than the bottom track. These results also suggest that, for the coupled section, the widths of the two conductors should be different so as to maintain a good impedance match.

Multilayer DC block

In RF and microwave circuits, a 3-dB backward-wave coupled-line section with open circuit terminations are used instead of a series capacitor as a series DC block[2]. With the traditional single layer arrangement as shown in figure 2, which uses two closely spaced coupled lines, correct RF-DC isolation can only be obtained over a very small frequency range due to the requirements of a very small gap(often less than 20μm) between the coupled lines.

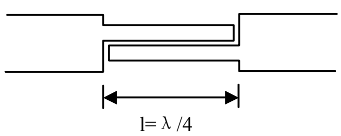


Figure 2. Physical layout of a DC block.

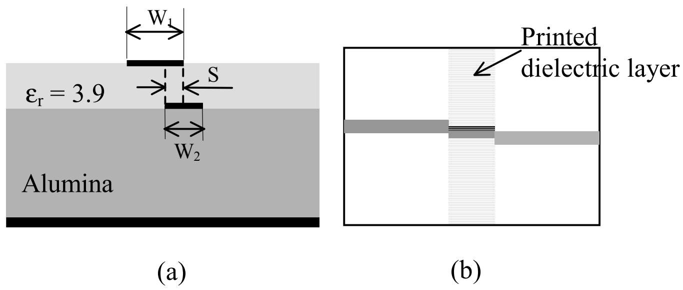


Figure 3. 2-layers DC block (a) Cross-sectional view; (b) Top view

Using a multilayer structure, we have designed a new form of DC block, where the tight coupling is achieved by overlapping conductors on different dielectric layers. Figure 3 shows the cross-sectional and planar views of the new structure. The length of the coupled region was a quarter-wavelength, as in the traditional edge-coupled, single layer circuit.

The device was fabricated using a standard thick-film process, with the conductor and dielectric layers being successively printed and fired. Modifications were made to the widths of the feed lines to account for the effect of the thin dielectric layer as indicated in table 1. In addition, the width of each coupled line was modified, using the results of electromagnetic analysis, to compensate for the changes to the even and odd mode impedance caused by the introduction of the printed dielectric. Table 2 shows the physical dimensions of the final circuit.

Table 2 Physical dimensions of DC block (Unit : μm)

W1	W2	S	l
380	300	180	5080

Where W1, W2 and S are defined in figure 3.

Measured responses are shown in figure 4. Over an octave band, the worst case measured VSWR and insertion loss were about 1.4 and 0.2 dB, respectively.

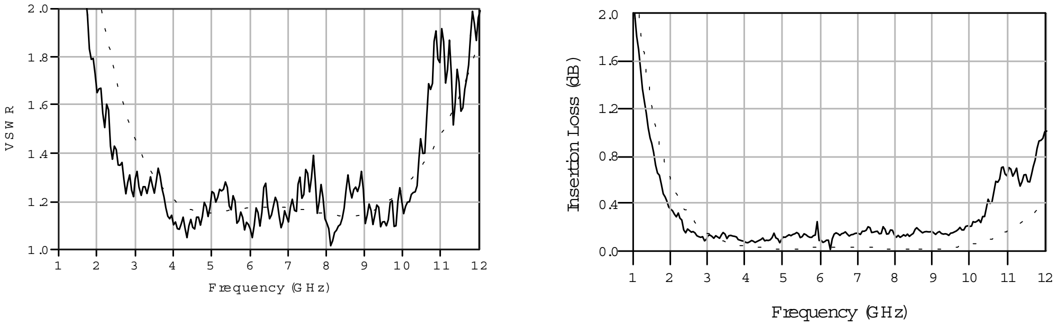
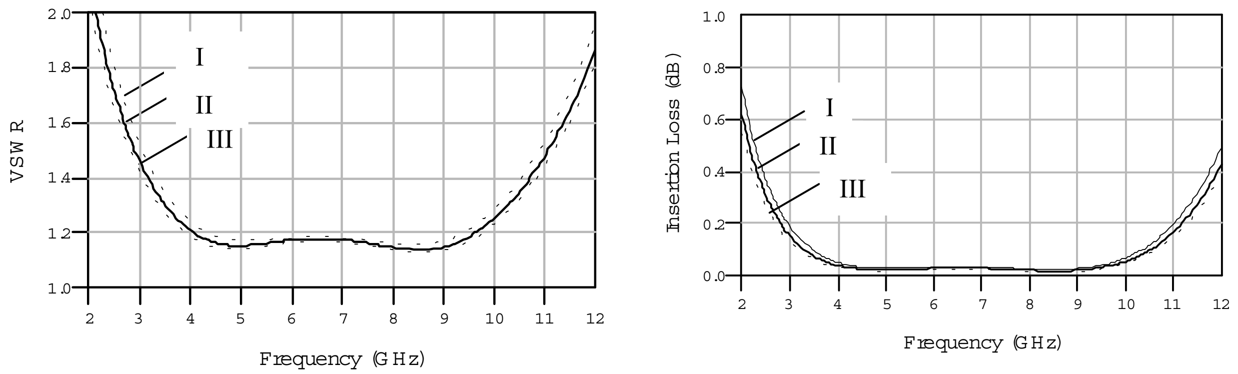
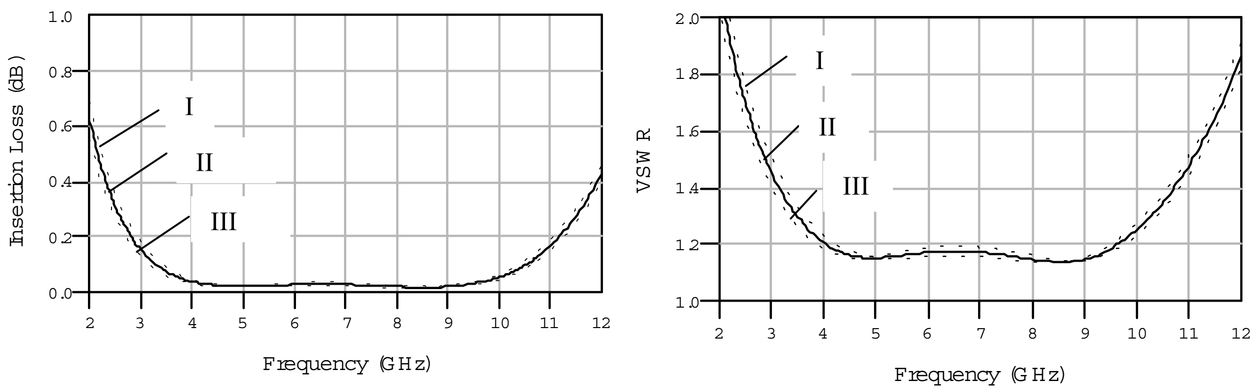


Figure 4. Measured responses of DC block. (a) VSWR. (b) Insertion loss
Measured, Simulated.

With the multilayer arrangement, it has been possible to achieve very high coupling between overlapping transmission lines over a wide operating frequency range, thus eliminating the need for fine lines and small gaps. The errors caused by poor conductor registration and variations in the dielectric thickness between the two coupled conductors have been examined. The results are shown in figure 5. It can be seen from this data that registration errors of ±10μm and dielectric thickness variations of ±3μm have very little effect on the circuit responses. Normal manufacturing processes can usually be maintained within these error bounds.



(a) Simulated responses of DC block with different thickness of the printed dielectric layer
I --- 30μm, II --- 27 μm, III --- 25 μm.



(b) Simulated responses of DC block with different overlapping.(I --- 200μm, II --- 210μm, III --- 220μm.)

Figure 5. Simulated responses showing the effect of fabrication tolerances

MULTILAYER DIRECTIONAL COUPLER

Directional couplers with coupling of the order of 3dB are required for a number of applications. To achieve this level of coupling with a single layer structure is very difficult because of the very small gap that is required. This gap is both difficult to fabricate and is also very sensitive to fabrication errors. Dimensional tolerances have to be held at a level that makes the device difficult to fabricate in a production environment [3]. To attempt to overcome these limitations, a 3dB directional coupler using a multilayer structure has been designed. Figure 6 shows the top view of the multilayer coupler. The measured response is shown in figure 7. The 3dB coupling is maintained in the frequency range 3 to 8 GHz. Compared with Lange coupler, which is often used traditionally to achieve strong coupling, this multilayer directional coupler is easier to fabricate, and more reliable since there is no need for any wire bonding.

To further support the argument that the multilayer directional coupler is less sensitive to fabrication tolerances, the simulations were performed to show how the coupling and VSWR were affected by variations in the spacing, S (see figure 6).

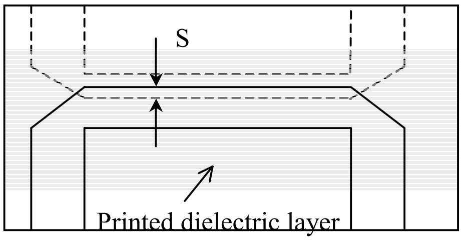


Figure 6. Multilayer construction of the directional coupler.

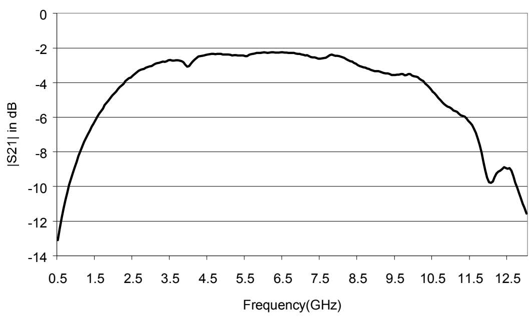


Figure 7. Measured response of a multilayer directional coupler

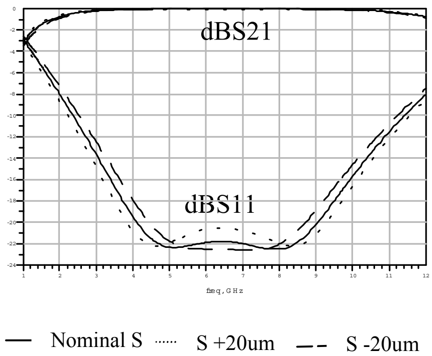


Figure 8. Simulated response of a directional coupler with different S

CONCLUSION

The "multilayer " concept has been shown to be an efficient method of realizing tight coupling between strip conductors over a wide frequency range. The novel DC block shows a very significant improvement in performance compared with conventional single layer circuits, while the circuit structure remains simple and easy to fabricate.

The current work has also shown that multilayer structure, in conjunction with low-cost thick-film technology offer the possibility to produce small size, low-cost high performance microwave circuits easily, and with high reliability.

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