ADVANCED MONOLITHIC PACKAGING CONCEPTS FOR HIGH PERFORMANCE CIRCUITS AND ANTENNAS

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ABSTRACT

Unwanted electromagnetic coupling between neighboring elements is a common problem in high frequency planar circuits. This paper reports on the elimination of cross-talk in planar circuits using conformal micromachined packaging. In the 5 to 30 GHz range, a back-to-back right-angle bend in microstrip has cross-coupling as high as -20 dB. The use of monolithic packaging concepts reduces this coupling by as much as 20-30 dB down to the noise level of the measurement system.

1.0 INTRODUCTION

Dense circuit design layouts in many high frequency applications suffer from poor performance due to cross-talk between neighboring elements and lines. In high frequency planar circuits, characterization of the electrical performance of an individual element is achieved using appropriate design and analysis tools. The primary method of evaluation assumes an element operating in isolation while in reality the element operates in a complex environment.

Several design approaches have been implemented to overcome this problem. Sophisticated numerical models have been developed to study the electromagnetic interaction between a variety of planar geometries to determine appropriate component placement [1]. The findings, however, may not produce layouts that are very practical to implement in realistic situationsThe reduction of the electromagnetic coupling has also been explored by decomposing a larger system into smaller units using an approach similar to multi-chip-modules [2]. At high frequencies, however, electromagnetic fields still interact within the substrate resulting in undesirable parasitic effects.

Typical packages provide protection and isolation from the external environment. At the higher frequencies, very few options have been developed to provide isolation to circuit components and usually result in hybrid circuit arrangements. Micromachining, however, has the capability to develop monolithic self-packages for individual elements. These packages can operate at higher frequencies and do not interfere with RF signal propagation [3].

With this capability readily available, lightweight compact designs that offer high performance and increased packing density are now achievable for circuit and array applications. In this work, two applications of self packaged circuits are studied. The electromagnetic coupling and parasitic radiation for a back-to-back right angle bend is investigated and the effect of feedline shielding on an antenna element is studied.

2.0 DESIGN /FABRICATION APPROACH

To illustrate the effect of a micromachined conformal package in the reduction of cross-talk, a back-to-back right angle bend is designed in an open as well as packaged configuration (Figure 1). The conventional microstrip environment is referred to as "open" while the shielded one is referred to as "packaged".

In this work, the circuits and upper cavities are developed on high and low resistivity silicon substrates, respectively, with a thickness of 500 μm. In the packaged circuits the wafer has been thinned locally under the transmission line to 320 μm to provide better propagating conditions (quasi-TEM propagation). Both open and packaged circuits incorporate 50 ohm lines. In the packaged configuration, the bottom wafer supports the planar circuits and lower cavity of the package while the top wafer has the upper cavities (Figure 2). Ground pads have been incorporated on the same plane as the conducting lines for bonding between the upper and lower cavities. These planes are located 380 μm away from the conducting line to ensure a microstrip mode of propagation

For the back-to-back right angle bend, the conformal package is developed using the techniques described in [3]. There are two distinct fabrication issues addressed in this work. First, reduction of wafer thickness under the conducting lines and second, the realization of convex corners around the bends in the upper and lower cavity regions.

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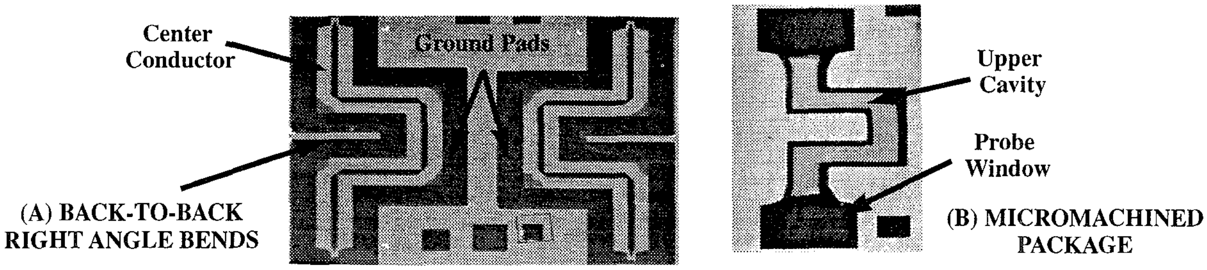
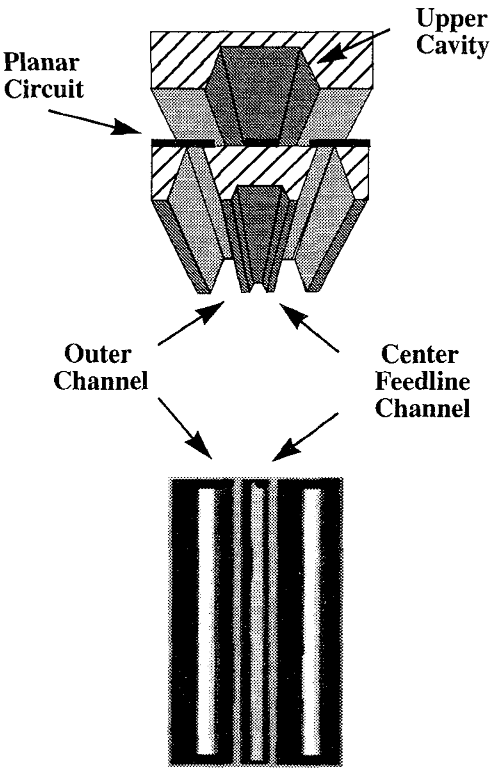


Figure 1 **(a) Photograph of Two Back-to-Back Right Angle Bends. The dark area represents the silicon substrate. (b) Inside view of the micromachined upper cavity wafer with depth of 350 microns.**

(a) Cross-Section of Micromachined Package



(b) Photograph of Bottom of Lower Cavity Wafer

Figure 2 **(a) Illustration of the Package Cross-Section with localized reduced substrate region for the conducting line. (b) Photograph of lower side of package.**

To locally reduce the thickness of the wafer from 500 to 320 μm and provide the necessary DC contact areas, a two step etch procedure was employed. Initially the outer channels of the lower package were removed while the center feedline channel is protected with silicon dioxide. Next, the oxide masking layer is removed and the wafer is etched an additional 170 μm to locally reduce the center regions to 320 microns (See Figure 2). Convex corner undercutting is compensated by including centered squares at the edge of each convex corner [4]. The compensation squares are approximately 1.4 times the desired etch depth. Such a correction has been incorporated in the designs for the upper and lower wafers.

3.0 Results

Measured data are discussed regarding coupling of the planar bend geometries. The coupling of the planar bend geometry to nearby elements is characterized with on-wafer probing. A Short-Open-Load-Thru calibration method is employed using 150 μm pitch Picoprobes from GGB Industries with an 8510C Network Analyzer and Alessi Probe station.

Cross-coupling effects are determined by measuring the input of the bend structure and the output of a neighboring element adjacent to the bend geometry. In Figure 3, the open structure has coupling as high as -20 dB in the 5 to 30 GHz range. Similar measurements have been performed on the packaged structure. The results demonstrate coupling less than -45 dB which is very close to the coupling between the two probes when left out of contact in air.

The performance of the bend in the open and packaged environments is compared in Figure 4. In the lower frequency range the difference in the insertion loss is due to ohmic losses in the cavities of the packaged bend. As frequency increases, however, the loss of the open bend increases noticeably due to parasitic radiation. It is expected that as frequency increases, the open bend performance will degrade rapidly. Figure 5 shows the total loss of the open bend circuit and compares it to the loss of a delay line of similar length (13.392 mm). The oscillation observed above 20 GHz is the result of radiation as explained previously. In contrast, the radiation in the packaged bend has been eliminated as shown by the excellent

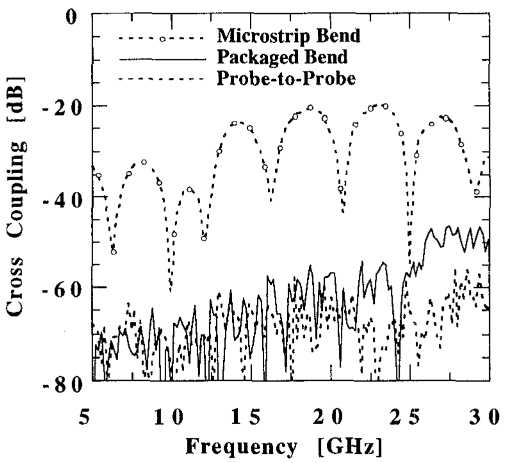


Figure 3 Coupling for an open microstrip and a packaged one. The open structure is a bend adjacent to a through line and the packaged one is a bend adjacent to a bend.

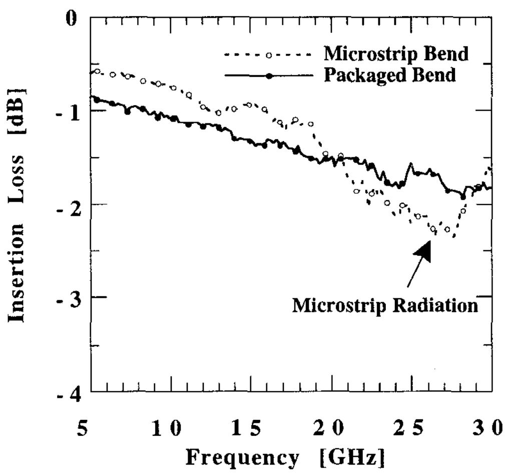


Figure 4 Insertion loss for the open and packaged back-to-back bend.

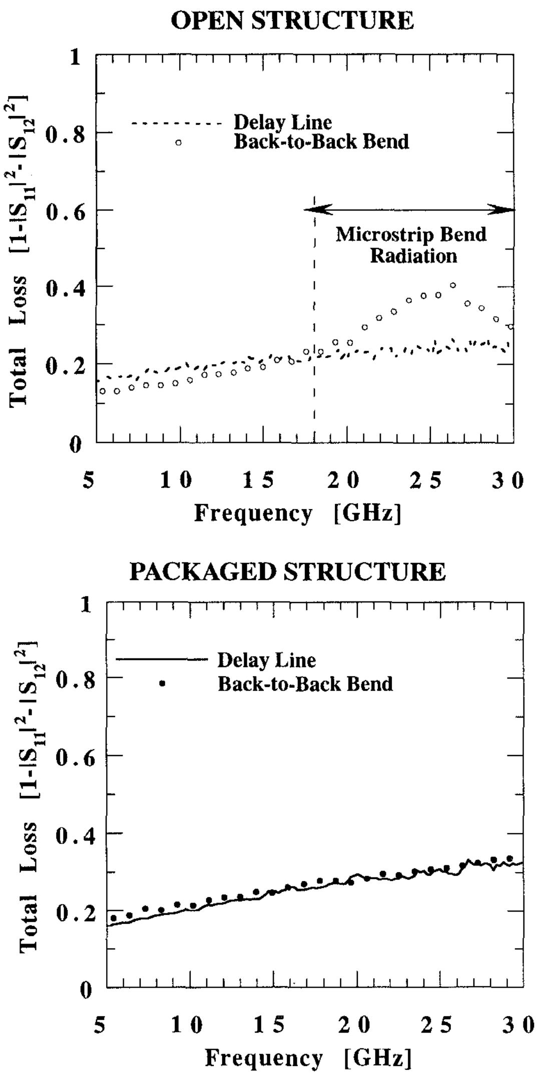


Figure 5 Comparison between an open and packaged microstrip bend and a through line of similar length for both configurations.

agreement between the loss of the bend and delay line of similar length.

To illustrate this packaging approach in an antenna application, a package surrounding the feeding line of a microstrip patch antenna has been incorporated in the design (See Figure 6). In this circuit, only the substrate under the feeding line has been thinned to ensure clean propagation of a dominate microstrip mode. The substrate under the antenna has been left at its original thickness to allow for optimum antenna efficiency. In Figure 7, the performance of the open and packaged design is shown which illustrates that the package provides the appropriate shielding while maintaining the desired strength of the patch resonance. As observed from the measurements, the bandwidth of the packaged antenna is higher than the bandwidth of the open antenna by 110% (VSWR $\leq$ 1.8). This increase results in higher antenna efficiency and is attributed to the fact that the propagation characteristics (β, Z_0) in the package feedline are less sensitive to the frequency due to the improved TEM propagation on the line. Therefore, the resulting package can be easily extended to array applications where feedline radiation can be eliminated.

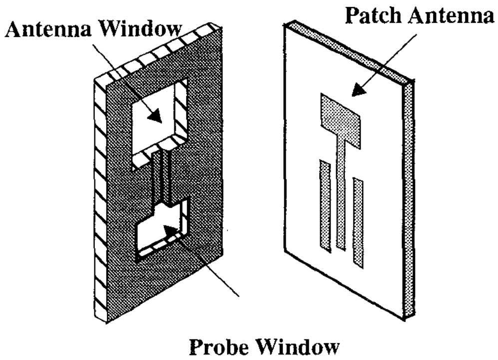


Figure 6 Drawing of Antenna.

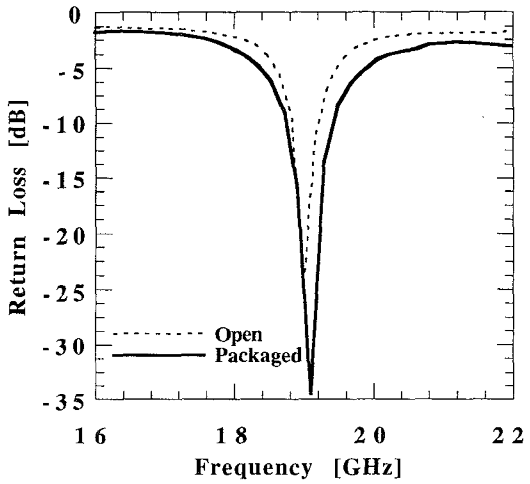


Figure 7 Response of a microstrip antenna for an open and packaged feeding line structure.

4.0 CONCLUSION

This paper has demonstrated the substantial benefits of advanced packaging concepts in planar circuit and antenna design. Specifically we have proven that electromagnetic coupling and parasitic radiation in circuit components and in antenna feed networks can be eliminated through selectively packaging sections of planar circuits. In addition to the benefits of improved performance, monolithic micromachined packages for high frequency circuit designs are lightweight, small in size as well as low in volume, and low cost.

5.0 ACKNOWLEDGEMENTS

This work was performed at The University of Michigan and has been supported by contracts from the Army Research Office and the Office of Naval Research.

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