

MULTILAYER PHOTONIC BANDGAP INTEGRATED CIRCUITS

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ABSTRACT

In today's industry, efficient and low-cost alternatives to traditional integrated circuit (IC) technologies are fundamental, since engineers have begun to approach the physical limitations of integrated circuits with regard to size and device density per area. This project presents the combination of two novel IC technologies, multilayering and photonic bandgap structures (PBG's), to ultimately reduce the size and cost of an IC, while increasing its efficiency and device density.

The first method involves photonic bandgap structures, which are printed into the groundplane of an IC. Previous research has shown that this type of PBG structure exhibits filtering properties, which simply allows one to replace space-consuming filtering devices.

The second method involves the use of multilayering, a design in which components are stacked upon each other, as opposed to traditional IC design where components are interconnected side-by-side. This 3-D architecture saves space, increases efficiency, and reduces weight, all of which are ideal for IC design.

This paper presents the design, fabrication, and test results of co-planar waveguide structures that were built using photonic bandgap structures and multilayering.

INTRODUCTION

In light of NASA's new push for unmanned space exploration, the production of smaller, lighter, and more efficient machines and structures have been paramount. The miniaturization of microwave and millimeter wave integrated circuits (MMICs) has played a large role in this process because of its numerous applications in satellite communications. Interplanetary missions, like the Mars Pathfinder and the more recent Polar Lander, depend on MMICs for space communication due to low atmospheric attenuation. Due to the numerous applications of MMICs, a lot of time has been devoted to the creation of smaller and more efficient MMICs to counteract the problems of power consumption and power loss.

Presently, integrated circuits are built using two-dimensional architectures. This planar structure of MMICs require that individual components be cascaded next to each other, which creates a less than optimum circuit because of the limitations of circuit size and integration density per unit base area. Although the relative size of MMICs have decreased significantly, these two-dimensional circuits remain inefficient when compared to three-dimensional designs. When incorporating three-dimensional circuitry, several more components can be stacked on top of one another, so that more complicated and multipurpose MMICs may be built.

Photonic bandgap structures (PBG's) will also be implemented into the integrated circuit design to reduce the overall weight and size of the circuit. In circuit design, PBG's can be implemented as filters, due to their passive properties. However, the main benefit of PBG's is

the fact that these structures can be implemented into the groundplane of a structure. The fact that PBG's can be placed in the groundplane of a device means that it won't consume any weight or space. Circuit designers will then be able to decrease the size and weight of an IC by removing a normal space-consuming filter and replacing it with a PBG structure.

In our design, PBG structures were etched onto the ground plane of a coplanar waveguide, alongside the transmission line, as shown in figure 1. The proximity of the photonic bandgap pattern to the transmission line allows the PBG to interact with the signal, since most of the signal in a transmission line resides on the outer edges. The interaction between the signal and the PBG structure will therefore filter out signals that correspond to a half-wavelength with respect to the PBG's periodic pattern.

On the underside of the coplanar waveguide was placed a simple microstrip transmission line, as shown in figure 2. In theory, radiating signals from the CPW will couple with the microstrip line, thus making transmission between layers possible. In this way, the multilayered structure will act as a diplexer, a device that is able to guide the path of signals according to their frequencies. Because the microstrip and co-planar transmission lines are in close proximity to one another, the PBG structure will tend to filter signals along both transmission lines. However, because of the differing characteristics of each line, the frequency at which the PBG will filter out signals will also be different. In this case, the PBG structure will filter out signals from the microstrip line at lower frequencies relative to the coplanar t-line. Since the two transmission lines are able to couple with one another, any frequency that is filtered in the microstrip transmission line will propagate to the co-planar line, and vice versa.

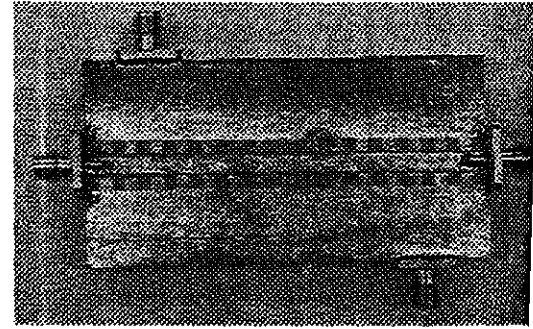


Figure 1: Coplanar Transmission Line w/ PBG structure

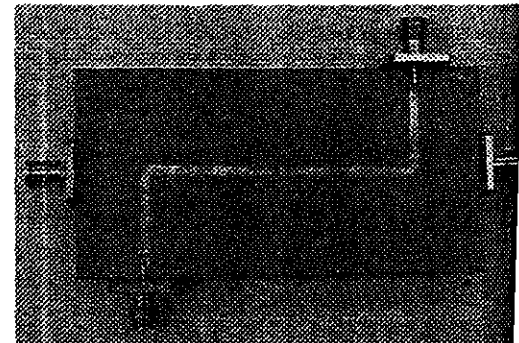


Figure 2: Microstrip Transmission Line placed below CPW

METHODS OF ANALYSIS

Transmission Line and Photonic Bandgap Designs

For instrumentation purposes, the coplanar waveguide was designed with a characteristic impedance of 50Ω . This was to ensure that there wouldn't be any loss of power between the equipment and the circuit, since the test equipment has an impedance of 50Ω . Simulation programs that could calculate the proper dimensions of a 50Ω CPW were not available, iterative calculations were done using coplanar transmission line formulas. Dimensions of CPW were calculated using Mathcad using the dielectric constant, and thickness of the material we planned to work with.

The photonic bandgap structure was designed for a stopband frequency of approximately 4.75 GHz. This procedure was simple enough, since the basic requirement for a PBG structure are periodic interruptions in the groundplane spaced half-wavelengths apart. This is to ensure that reflected signals created by the interruptions travel a full wavelength and get added constructively with one another.

The microstrip transmission line, just like the coplanar waveguide, was designed with a characteristic impedance of 50Ω for the same reasons. However, this design was done using a microwave integrated circuit design program called PUFF.

Sonnet Simulations

Sonnet is an electromagnetic simulation program that is capable of drawing, analyzing, and visualizing the results of high frequency circuits. Using Sonnet, the coplanar transmission line was simulated for comparative analysis. The simulation was repeated again, this time with the addition of the photonic bandgap structure alongside the edge of the transmission line. Results of the simulations are shown below in figures 3 and 4. As expected, the transmission of the coplanar line is relatively flat, meaning the transmission is relatively constant at all frequencies. With the addition of the PBG, there is a definite stopband in the transmission at a frequency of approximately 4.75 GHz, as indicated by the sharp spike in the plot down to minus 30dB.

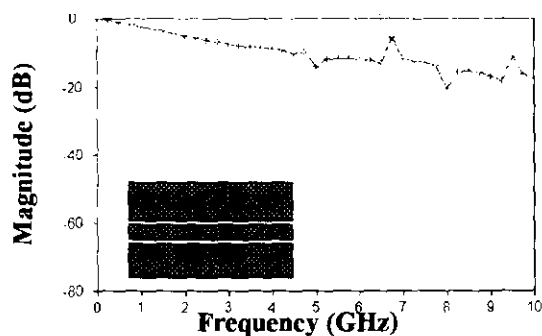


Figure 3: Simulated CPW transmission parameters

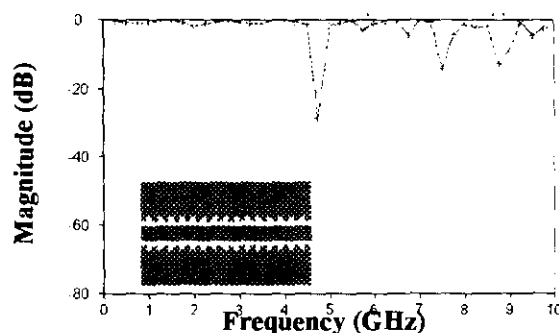


Figure 4: Simulated CPW transmission parameters w/ PBG

Photolithographic Fabrication

Circuits were composed of RT/duroid 6006 ($\epsilon_r = 2.2$, $t = 0.050''$) circuit board covered with 1oz. of rolled copper. Transmission lines were fabricated out of the duroid using Kepro's[®] Dry Film Photoresist and Copper Etchant. A mask was created onto the circuit board (duroid) by exposing selected areas of the dry film photoresist to UV light. The unexposed areas of the photoresist were then removed using developer, leaving a photoresist mask. The mask was then etched away using copper etchant, leaving the desired IC pattern.

HP 8510 Network Analyzer

The fabricated structures were then tested using Hewlett Packard's 8510 Network Analyzer, a precise instrument that measures the transmission (S_{21}) and the reflection (S_{11}) parameters over a range of frequencies. By connecting the fabricated structure to the network

analyzer, properties of the integrated circuit were analyzed, such as the stopband frequency of the photonic bandgap structure, along with any coupling of signals from the coplanar waveguide to the microstrip transmission line. The resulting transmission graphs are shown below in figures 5 and 6.

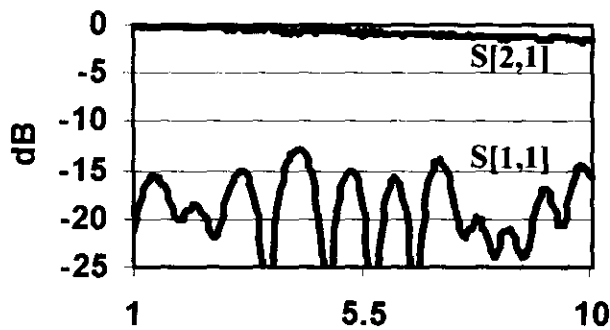


Figure 5: Transmission and Reflection coefficients for coplanar transmission lines

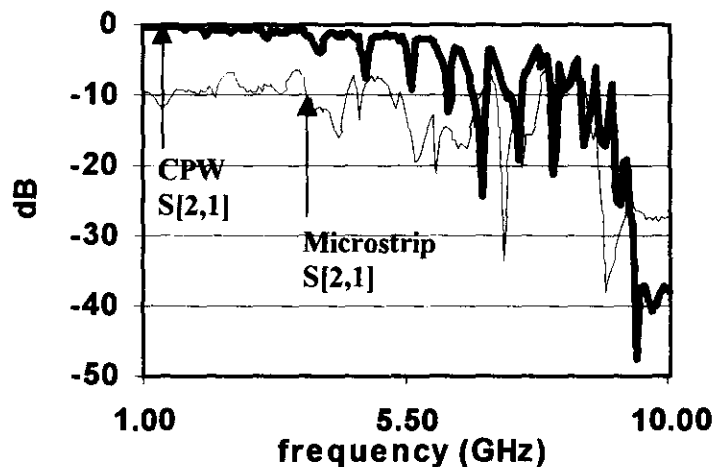


Figure 6: Transmission coefficients for CPW and Microstrip w/ PBG

DISCUSSION

As shown in figures 5 and 6, the network analyzer tests were inconclusive. The coplanar transmission line proved to be an almost perfect transmission line, as demonstrated by the plot in figure 5. The addition of the photonic bandgap structure to the CPW, however, didn't provide us with the frequency dependent stopband we were hoping for. Instead, the PBG structure resulted in a lowpass filter, attenuating signals with frequencies of 9.5 GHz and up. There was definite coupling between the coplanar line and the microstrip transmission line, as indicated by figure 6. However, since the photonic bandgap structure performed like a lowpass filter, we did not expect a rise in the power of the coupled signal corresponding to a decrease in the CPW signal.

Despite the disappointing results, there were a few promising results. With the introduction of the photonic bandgap structure to the CPW, there was attenuation in the signal at frequencies higher than 9 GHz. As indicated by the comparison between figures 5 and 6, there is an obvious dip in the transmission due to the PBG.

Another promising result was the cutoff frequency of the CPW and the microstrip. In figure 6, the transmission parameters of the CPW and the coupled microstrip transmission line

are superimposed on one another. As expected, the coupled signal along the microstrip transmission line has a lower cutoff frequency cutoff than the CPW by about 500 MHz, due to the differing geometrical characteristics of the two structures. If the photonic bandgap structure had acted more like a stopband filter, the IC may have had the diplexer properties we were looking for.

CONCLUSION

In this paper, a novel approach to integrated circuit design was designed, simulated, and tested. Expected results for the designed circuit included the operation of a diplexer through the introduction of photonic bandgap structures and multilayering. However, tests proved to be inconclusive, as we did not notice any frequency selective coupling between the two different transmission lines. The photonic bandgap structure was also ineffective, providing the characteristics of a low-pass filter with a stop frequency of 9.46 GHz, instead of a stop-band filter at the simulated 4.75 GHz.

Differences between the simulated and test data can be attributed to many factors, including coaxial connections, fabrication inaccuracies, and an accidental misconception about the validity of the coplanar photonic bandgap structures. Future tests may include the operation of a multilayered, photonic bandgap microstrip integrated circuit, since PBG's have been proven to work with microstrip transmission lines.

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