Simulated and Measured Results from a Duroid-Based Planar MBG Cavity Resonator Filter

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***Abstract*—A planar Microwave Band Gap (MBG) cavity resonator filter that is completely compatible with current commercial printed circuit board (PCB) fabrication techniques has been designed, fabricated and tested. This filter provides a 1.33% bandwidth passband response at 10.67 GHz with a corresponding insertion loss of 2.17 dB. Design considerations and equations are presented which demonstrate that the resonant frequency and Q of the resonator can be adjusted as desired.**

***Index Terms*—MBG cavity resonator, planar high Q filter.**

I. INTRODUCTION

PHOTONIC bandgap (PBG) crystals adapted to the microwave regime (microwave bandgap or MBG) have received much interest recently. Although there is much debate over terminology with respect to these structures [1], MBGs typically consist of periodic arrangements of metallic or dielectric elements forming a structure that alters the allowed modes of electromagnetic propagation [2]. With this technology, high Q band-pass and band-stop filters have been realized for many frequency bands [3]–[5]. Often these crystals are three-dimensional structures with feeds not compatible with planar integrated circuits. Additionally, many of these filters are difficult to fabricate and require significant machining or other specialized processes to fabricate. This has limited the practical use of MBG filters.

Because of the high Q responses that can be achieved, there is significant interest in the development of MBG structures compatible with planar circuits. Additionally, structures that can be constructed using current manufacturing technologies are highly desirable, enabling rapid, low-cost fabrication.

To address these issues a low-cost, low-loss MBG cavity resonator has been designed, fabricated and tested. Unlike planar cavity resonators constructed with solid side walls [6], this design allows the possibility of reconfigurable devices through the use of electronically switched post elements [4]. Additionally, solid wall designs, while planar, are not easily fabricated using standard printed circuit board (PCB) fabrication techniques. This resonator is *completely* compatible with current PCB fabrication technology, and can be easily mass-produced at any commercial board house capable of 3-layer circuit construction.

II. MBG DESIGN

The MBG filter presented is based upon the design of a rectangular cavity microstrip coupled resonator [6]. The side walls of the cavity have been replaced with a periodic lattice of metallic rods forming a stop-band structure at a specified operating frequency which corresponds to the resonant frequency of the enclosed cavity (see Fig. 1). The resonant frequency of the MBG cavity can be easily found by approximating its edges as PEC side walls. In this case, using the TE_{101} mode, the resonant frequency can be approximated as [7]

$$f_{res} = \frac{c}{2\pi\sqrt{\varepsilon_r}}\sqrt{\left(\frac{\pi}{L}\right)^2 + \left(\frac{\pi}{W}\right)^2} \tag{1}$$

L and W being the effective length and width of the cavity. Additionally, using the metal-wall cavity analogy, the unloaded Q of the cavity, not including dielectric losses can be found to be approximately [7]

$$Q_c = \frac{(kLW)^3 H\eta}{2\pi^2 R_m(2W^3H + 2L^3H + W^3L + L^3W)} \tag{2}$$

where

W, L, and H	effective cavity width, length and height, respectively;
η	wave impedance;
k	wave number, and the effective resistance;
R_m	$= (\pi f_{res}\mu/\sigma)^{1/2}$.

The dielectric loss can then be accounted for using [9]

$$Q^{-1} = Q_c^{-1} + Q_d^{-1} \tag{3}$$

where $Q_d^{-1} = \tan(\delta)$.

The cavity is formed by enclosing a rectangular volume of dielectric with the MBG lattice, and covering the top and bottom of the structure with ground planes. In order to feed the resonant cavity, two coupling slots are etched in the ground plane that closes the top of the cavity structure. A microstrip line terminated in a short at the coupling slot, or terminated in an open, a quarter wavelength away from the slot center can be then used to excite the cavity filter (see Fig. 1). The coupling slots are located approximately $(1/4)L$ from the cavity edge (SP in Fig. 1), and the coupling slot width (SW) is approximately one quarter of the guided wavelength, λ_g[6].

III. SIMULATIONS

The resonant frequency of the cavity was chosen to be around 10.5 GHz. Equation (1) was then used to design the cavity. The

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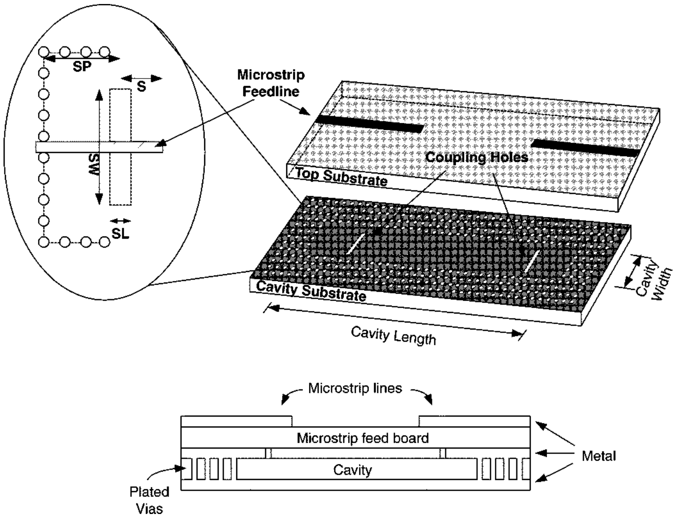

Fig. 1. MBG cavity schematic and cross section.

cavity dimensions were then adjusted to correspond to a whole number of MBG posts. With this modification, (1) was then re-evaluated and the predicted resonant frequency was found to be 10.4 GHz. Using methods outlined in [6] the other relevant circuit dimensions were chosen, and are shown in Table I (refer to Fig. 1).

The spacing and size of the cylindrical metallic posts used to define the edge of the cavity was selected to create a stop-band in the MBG at the operating frequency. This is achieved by limiting the gap between the posts to no more than $(1/2)\lambda$ at the highest frequency of interest, however, much smaller gaps result in an overall size reduction of the blocking MBG, and are therefore desirable. A whole number of posts was used to create the desired cavity dimensions in all cases. Several post configurations, including staggered (triangular lattice) and unstaggered (square lattice) rows were tested. Simulations indicated the square lattice had slightly better performance. For this case with dimensions shown in Table I, two rows of posts were found to be sufficient for adequate cavity containment. The resulting structure was simulated using Ansoft's High Frequency Structure Simulator (HFSS).

IV. FABRICATION

Initially, it may appear that the metallic rods utilized for the MBG are not easily fabricated. However, this is not the case. Standard printed circuit fabrication technology can be used to fabricate thru-board vias. Typically, these vias are created by drilling holes in the PCB substrate prior to etching the circuit pattern on the board. The board is then plated using one of several copper plating techniques. Finally the circuit pattern is etched, resulting in a circuit board with vias connecting traces on the top of the board to traces on its bottom. Often vias are not used in prototype circuits because of the extra processing required. Copper plating vias can be a difficult task for noncommercial board fabricators. Fortunately, a relatively inexpensive and simple process is available [8], and can be easily setup using readily available equipment in almost any board prototyping lab. Using this process the vias of the MBG filter were fabricated.

TABLE I
MBG CAVITY FILTER DIMENSIONS

Width	11.34 mm	S	1.29 mm
Length	18.90 mm	Via Diameter	0.79 mm
SP	5.12 mm	Via Spacing	1.89 mm
SW	3.48 mm	MBG Rows	2
SL	0.34 mm		

The prototype MBG cavity filter tested was fabricated with Rogers 6010 ($\varepsilon_r = 10.8$) for the top (microstrip) circuit board, and Rogers 5880 ($\varepsilon_r = 2.2$) for the bottom (cavity) board. Any board material could be used with appropriate adjustment of the stub length, or through the use of vias to create shorts at the coupling slots.

The low dielectric material was chosen for the bottom board because of its low-loss characteristics. The cavity loss and, therefore, the resonator loss is often dominated by the loss of the dielectric in the cavity [9], however in this case, because the cavity height is small (31 mil), metal loss is the dominant loss mechanism. Rogers 5880 has a very low loss tangent (0.0009) and fabricates easily. Therefore, it is a good choice for this design. Other low loss board materials can be used. If higher dielectric material is chosen (e.g., Alumina) the overall filter size can be reduced significantly for a given frequency [9]. The thickness of the bottom board was 31 mil, and was also selected because of availability and because it is in the range of board thicknesses typically used in industry. Using (2) and (3), the unloaded cavity Q (the cavity Q without the effect of the microstrip loading) was estimated to be 490. Other board thicknesses could be utilized and would result in different Q values for the cavity. A thicker cavity substrate would result in less metal loss and therefore higher Q's.

V. MEASUREMENTS

Following fabrication of the circuit boards, the MBG cavity resonator was placed on an SMA-launch microstrip test fixture. An HP8510 network analyzer was used to collect S-parameter data. A thru section of line was used to determine the feed line and connector losses. These losses were then removed from the data. The measured and simulated filter responses are shown in Fig. 2. Table II shows a summary of the measured and simulated data for the 2-row MBG cavity resonator band-pass filter. The unloaded cavity Q (Q_c) is calculated from the measured external and loaded Q values [6]

$$Q_{loaded} = \frac{f_o}{\Delta f} \tag{4}$$

$$Q_{external} = 10^{-([S_{21}(\mathrm{dB})/20])} \cdot Q_{loaded} \tag{5}$$

$$Q_c^{-1} = Q_{loaded}^{-1} - Q_{external}^{-1}. \tag{6}$$

The corresponding measured unloaded Q of the MBG cavity was obtained with a low-coupling version of the circuit as described in [6]. Both 4-row and 2-row versions were measured. As expected, two rows of posts were sufficient to make losses due to leakage less significant than the metal losses, and therefore the results were similar for both filters.

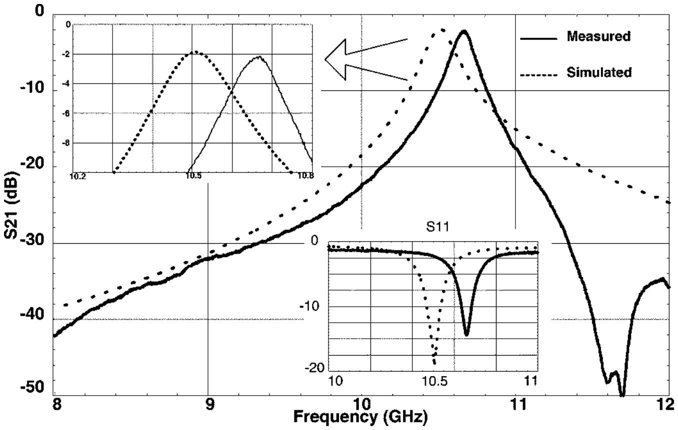

Fig. 2. Measured and simulated filter response.

TABLE II
RESULTS FROM THE MBG CAVITY RESONATOR

	Simulated	Measured	Difference
$f_{resonant}$	10.51 GHz	10.67 GHz	1.5%
Bandwidth	1.65%	1.33%	0.3%
Ins. Loss	1.82 dB	2.17 dB	0.35 dB
Unloaded Q	300	293	2.3%

Generally the simulated and measured results agree well, with the exception of the high-frequency roll-off shown in Fig. 2. It is believed that the main source of discrepancies between the simulated and measured responses are related to assembly issues. Many of these issues could be eliminated through professional board fabrication. It is important to point out that these results are for a 31 mil high cavity resonator. Other resonators in the literature utilize substantially taller cavities (six times taller or more) [10] and therefore demonstrate somewhat higher Q's. With this resonator, the Q can be selected (within reason) by the designer's choice of board thickness.

VI. CONCLUSIONS

An extremely narrow band, reduced size, planar, MBG cavity resonator has been designed, simulated and tested. Results comparable to resonators with fully conducting walls were obtained using a 31 mil high cavity. A bandwidth of 1.33% with an insertion loss of less than 2.2 dB was shown for a 10.67 GHz resonator. The topology used in this structure provides circuit designers with a means to create planar, high Q filters using the fabrication techniques currently available at any commercial board house. Additionally, the cavity filter can be utilized in microstrip circuits without modification. Through the use of the closed form rectangular cavity resonance equation, the physical parameters of the filter can be computed easily and directly. Final optimizations can be performed using commercially available simulation tools. The flexibility of this design is further enhanced through the availability of circuit board materials. Dielectric constants and board thicknesses can be chosen to alter the filter properties, or to facilitate integration with other system components. This design also allows for the construction of reconfigurable filters by electronically or mechanically "turning off" rows of posts enclosing the resonant cavity. Future research will focus on this capability, and on construction using silicon micromachining techniques.

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