A Novel Surface-Mountable Millimeter-Wave Bandpass Filter

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***Abstract*—A novel millimeter-wave waveguide bandpass filter structure suitable for surface mounting is introduced. The filter is constructed using a rectangular waveguide formed in MMIC substrate employing recently introduced microstrip-to-waveguide transducer. Input and output of the filter are implemented as microstrip lines. The transitions between the microstrip lines and the rectangular waveguide are implemented by using the microstrip-to-waveguide transition. The waveguide filter structure is surface-mountable as flip-chip and can be manufactured using a MMIC process that makes it extremely accurate. It has potential applications in millimeter-wave systems like local multipoint distribution system (LMDS) and autonomous cruise control (ACC) radar for automobiles.**

***Index Terms*—Microstrip-to-waveguide mode converter, millimeter-wave filters, MMIC integrated waveguide.**

I. Introduction

SURFACE-MOUNT millimeter-wave (mm-wave) and RF components are highly desirable in terms of reducing manufacturing costs, improving repeatability and increasing performance. Such components are widely used in today's modern telecommunications systems such as cellular phones, radios, local multipoint distribution system (LMDS) and autonomous cruise control (ACC) for automobiles.

Recently, a novel microstrip-to-waveguide transducer is introduced in which the RF energy is transferred from a microstrip line to a rectangular waveguide formed in the same substrate [1]–[8]. This transducer has potential use in integrating the existing rectangular waveguide components with microstrip lines in a very compact way [5], [6]. In this paper, we present a novel mm-wave waveguide bandpass filter structure suitable for surface mounting using this recently introduced microstrip-to-waveguide transducer. The filter structure is constructed using iris-coupled rectangular waveguide cavities formed in a microwave integrated circuit (MMIC) substrate material. Input and output of the waveguide filter are transferred to microstrip lines by using waveguide-to-microstrip transducers. By implementing the input and the output of the filter as microstrip lines, the filter block can be surface mounted on another circuit board using flip-chip technology.

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The new rectangular waveguide filter constructed using the MMIC process is extremely cost effective. In addition to that, since the MMIC processes use very accurate photolithographic techniques with respect to the regular laminate board technology, the circuits have extremely high dimensional precision, which is important in mm-wave design. Finally, implementing the filters using rectangular waveguides formed in a dielectric substrate provides potentially low insertion-loss with respect to microstrip filters for the same order provided that the dielectric loss is sufficiently low.

Making rectangular waveguides in dielectric substrates are addressed previously to some extent [9]–[11]. However, in those approaches, the inventors employed closely spaced circular vias to form the walls of the waveguide structures, which is disadvantageous at high frequencies due to increased parasitic coupling. Besides, they did not demonstrate making electrical filters using such structures. In this paper, we are using continuous metalized silicon pedestals that are superior in performance to using closely spaced circular vias. Using continuous metalized silicon pedestals improves the isolation between the adjacent circuit components. Note that closely spaced circular vias are just an approximation to a continuous conductive wall, which is implemented here using silicon pedestals.

II. Design and Manufacturing of the Filter

In order to demonstrate the idea, we have designed and tested a 77–80 GHz iris-coupled waveguide bandpass filter using M/A-COM's proprietary glass MMIC process. The assumed dielectric constant and the thickness of the glass substrate are 4.0 and 127 μm, respectively. The assumed loss tangent of the glass at 77 GHz is approximately 0.002.

The filter design starts with designing the microstrip-to-waveguide transducers for the given substrate. The design procedure for this is previously explained [4]–[6]. Then, position and dimensions of the waveguide irises are determined using standard filter design techniques found in the literature [12], [13]. Figs. 1 and 2 show structure and dimensions of the bandpass filter. The dimensions of the rectangular waveguide are 1696 μm by 127 μm. Note that cross-sections of the silicon pedestals won't be rectangular due to reasons that will be explained briefly. Therefore, full-wave electromagnetic simulations are necessary after the initial design since standard filter-design techniques assume idealized conditions. At this point, it is worthwhile to explain the manufacturing process employed since it highlights some of the important features of the structure.

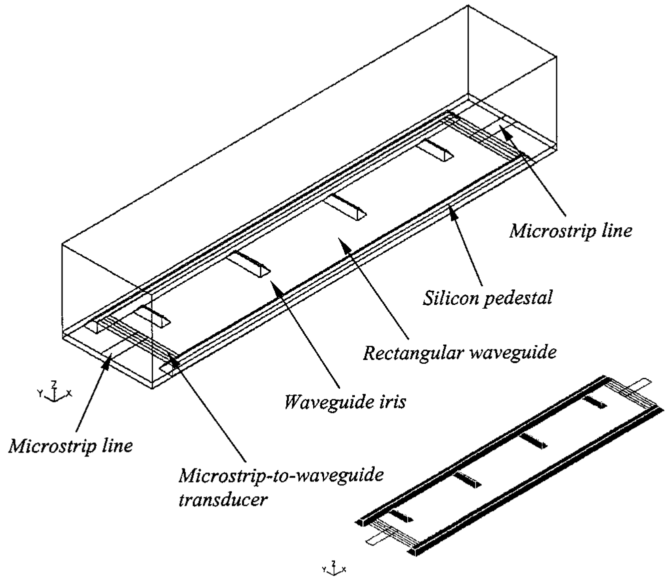
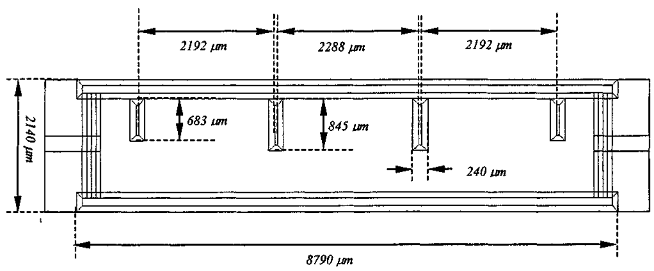
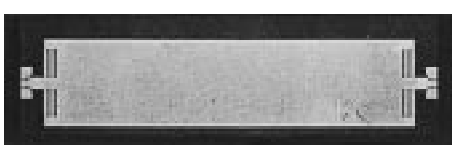


Fig. 1. Agilent HFSS model of the novel waveguide filter structure. Microstrip-to-waveguide transducers are used to transfer the RF energy from microstrip lines to the rectangular waveguide formed in the MMIC substrate.



(a)



(b)

Fig. 2. (a) Top view of the filter structure given in Fig. 1 showing the dimensions for the 77–80 GHz bandpass filter. (b) Picture of the manufactured filter.

The first step in the M/A-COM's proprietary glass MMIC manufacturing process is to take an appropriate silicon wafer and etch the required pedestals according to the shape of the filter (i.e., form the waveguide and iris walls). Note that the waveguide walls and the irises are all implemented as metalized silicon pedestals, rather than trenches or closely spaced vias. The cross-section of these walls is not exactly rectangular but has a trapezoidal shape with 54° angle at the bottom because of the crystal profile of the silicon material and the etching plane used. The waveguide walls and the irises will form the sidewalls of the filter and the resonator sections, respectively. Then, surface of the etched silicon is coated with silver to increase conductivity. After this step, a glass wafer is pressed down on to the etched silicon under high temperature and high pressure. As a result, the glass fills all the spaces but the volume occupied by pedestals, creating a continuous dielectric filled waveguide.

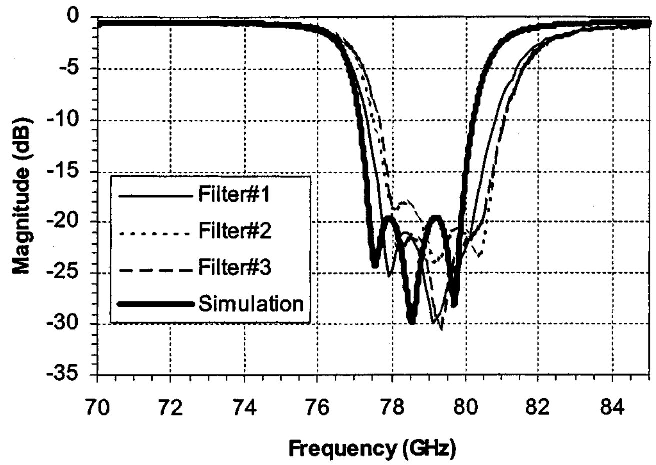


Fig. 3. Simulated and measured reflection loss of the iris-coupled waveguide bandpass filter shown in Fig. 2.

After this, top of the glass is lapped and polished until the surfaces of the pedestals are exposed. Finally, the top metallization is deposited and patterned and the dies are cut with appropriate tools.

Note that, in implementing the filter structure, one needs silicon pedestals that ideally intersect with each other with right angles. This situation occurs in case of connecting an iris wall to the waveguide wall. Since we are using wafer glass, these corners may not be filled completely during pressing down the glass wafer resulting void formation at the intersections. In that case, small gaps should be provided between the two pedestals intersecting at right angles to release the pressure. These gaps must be accounted in designing the filter irises for accurate response. Note that, although we have used the glass as a substrate material, the technique is also applicable with any substrate materials (Alumina, LTCC) as long as its process has the capability of implementing continuous metallic walls.

III. Measurement Results and Summary

Simulated and measured responses of the manufactured bandpass filters are given in Figs. 3 and 4. A total of three filter structures were tested. As can be seen from the figures, there is good agreement between the measured and simulated results. The reflection loss is better than 15 dB and the insertion loss is around 3 dB in the frequency band of interest. The slight shift in the center frequency can be due to change in the dielectric constant of the material or the change in the gaps between the iris walls and the waveguide wall. It was verified through EM simulations that if the dielectric constant of the substrate material were 3.95 instead of 4.0, the shift in the response would be compensated. It should be noted that, although most of the nonideal effects and parasitic couplings are included through full-wave EM simulations, the structure needs further investigation to understand the process variations in detail. Besides, it is necessary to modify the filter design algorithm to accommodate the undesired gaps between the iris walls and the waveguide wall, which was explained before.

In this paper, we have introduced a novel surface-mountable millimeter-wave waveguide filter structure. The filter is

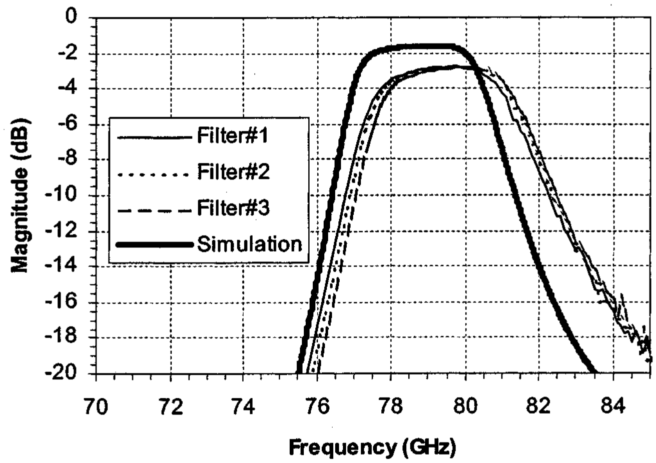


Fig. 4. Simulated and measured insertion loss of the iris-coupled waveguide bandpass filter shown in Fig. 2.

constructed using a rectangular waveguide formed in a MMIC substrate. Input and output of the filter are implemented as microstrip lines. The transitions between the microstrip lines and the rectangular waveguide are implemented by using the recently introduced microstrip-to-waveguide transducers. The filter structure is surface-mountable as flip-chip and can be manufactured using MMIC process that makes it extremely accurate and cost effective.

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