A 60 GHZ-BAND PLANAR DIELECTRIC WAVEGUIDE FILTER FOR FLIP-CHIP MODULES

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Abstract — **A planar dielectric waveguide filter with CPW I/O ports suitable for flip-chip bonding is proposed and demonstrated for 60 GHz-band applications. The filter is formed incorporating via holes in an alumina substrate. In order to improve a stop-band rejection, short-circuited CPW resonators with half wavelength are added to waveguide-to-CPW transitions. A fabricated 4-resonator filter exhibits an insertion loss of 2.8 dB with a 3 dB-bandwidth of 3.0 GHz and a rejection of 35 dB at a 3 GHz-lower-separation from a center frequency of 58.5 GHz. The filter is successfully mounted in a multi-layer ceramic package using flip-chip bonding.**

I. INTRODUCTION

To satisfy recent demands for low-cost millimeter-wave applications, several multichip modules have been developed using a flip-chip technology which provides high reproducibility and good electrical performance in a millimeter-wave range [1]-[3]. Active devices such as amplifiers and oscillators in these modules employ a coplanar MMIC configuration because the coplanar approach is suitable for flip-chip bonding and besides eliminating backside processing. Filters should also have the flip-chip configuration to be easily integrated with CPW MMICs in a module. Millimeter-wave flip-chip filters, however, have never been reported. For the flip-chip filters, a planar configuration and CPW I/O ports are needed. However, CPW filters are seldom used in the millimeter-wave range due to their large insertion losses. It is well known that microstrip filters with wide lines show good performance. However, a microstrip configuration is sensitive to a proximity effect between a chip and a mounting substrate in a flip-chip structure [4]. Therefore, a planar filter with a low loss and less sensitivity to the proximity effect is strongly needed.

In this paper, we propose a planar dielectric waveguide filter with CPW I/O ports for 60 GHz-band applications and demonstrate high performance after flip-chip bonding for the first time. Waveguide-to-CPW transitions of the filter are formed on the waveguide. To improve a stop-band rejection, half wavelength short-circuited resonators are added to the transitions. The filter was mounted in a multi-layer ceramic package with a cavity using flip-chip bonding. The flipped filter showed good performance with a low insertion loss and a high stop-band rejection.

II. WAVEGUIDE FILTER WITH CPW I/O PORTS

The basic structure of the proposed band-pass filter is shown in Fig. 1. The waveguide structure is formed incorporating two lines of via holes in a metalized alumina substrate. The filter is composed of 4 half-wavelength dielectric waveguide resonators. An inductive window between i^{th} and j^{th} resonators consists of a pair of via holes with a spacing d_{ij} in the waveguide. The larger coupling coefficient is obtained for the larger d_{ij}. Waveguide-to-CPW transitions, which lead to CPW I/O ports at both ends of the filter, are patterned directly on the waveguide resonators. External Q is controlled by the length W_t of the transition. The higher external Q is obtained for the shorter length. In order to attain a high stop-band rejection, CPW lines with length of l_{cpw} are added to the transitions so that these lines can act as half-wavelength short-circuited resonators as shown in Fig. 2. Consequently, attenuation poles are introduced in the stop-band to improve rejection characteristics.

We have calculated transmission characteristics of the filters with and without CPW resonators using a 3D-EM simulator. In Fig. 3, calculated transmission characteristics are shown. The filters with and without CPW resonators have the same spacing d_{23}. The spacing d_{12}, d_{34} and the length W_t were tuned so as to compensate the change of the pass-band due to additional CPW resonators. The filter with CPW resonators was designed to have an attenuation pole at the lower side of the pass-band. The

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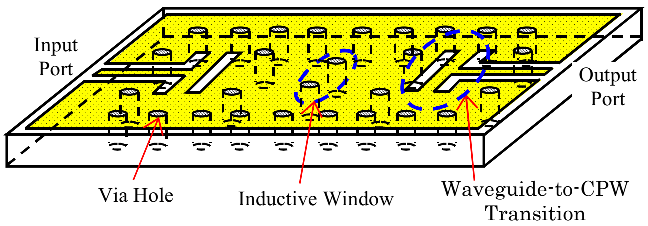
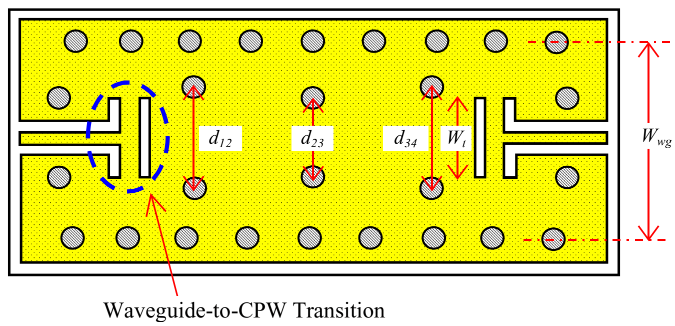


(a)



(b)

Fig. 1 Structure of 4-resonator waveguide filter. (a) overview (b) plane view.

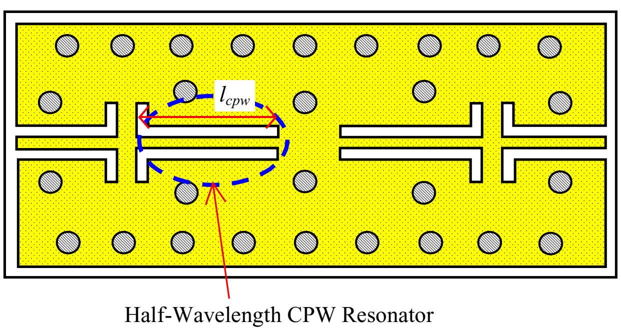


Fig. 2 Structure of 4-resonator waveguide filter with half-wavelength CPW resonators.

rejection in the lower side of the pass-band is remarkably improved by incorporating CPW resonators. The attenuation pole shifts to the lower frequency side as l_{cpw} becomes longer and rejection characteristics can be tuned by controlling the length.

III. EXPERIMENTAL RESULTS

We have fabricated a filter with an attenuation pole at the lower side of the pass-band. Fig.4 shows a photograph of the fabricated filter. The filter was formed in an alumina substrate with a relative dielectric constant of 9.7. The size is 4.7 mm x 3.2 mm x 0.25 mm. The dimension of via holes is 0.15 mm in diameter. Two lines of via

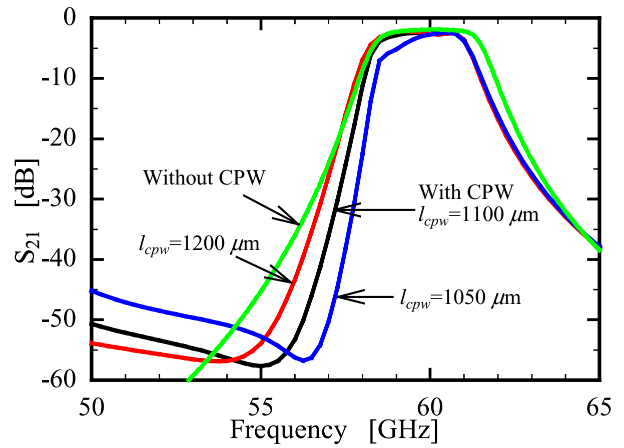


Fig. 3 Calculated transmission characteristics of filters with and without CPW resonators.

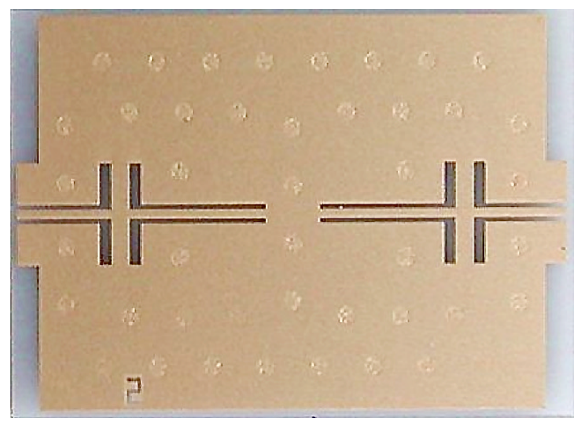


Fig. 4 Photograph of fabricated filter.

holes composing dielectric waveguide walls are formed in pitch of 0.45 mm along the propagation direction and are separated with the distance W_{wg} of 1.6 mm each other. This pitch is much less than half wavelength in the operating frequencies. To reduce radiation loss further, an additional line of via holes is formed at each side of the dielectric waveguide.

Fig. 5 shows the measured transmission and reflection characteristics of the filter using on-wafer probes. The insertion loss was 2.8 dB at a center frequency of 58.5 GHz and the return loss was better than 11 dB in the pass band. The 3 dB-bandwidth was 3.0 GHz. An attenuation pole was successfully introduced at 55 GHz by half wavelength resonators. The rejection at the 3 GHz-lower-separation from the center frequency was 35 dB. This is better than higher-frequency side rejection by 20 dB. Another attenuation pole appeared at 66 GHz. This is caused by peripheral paths outside the waveguide

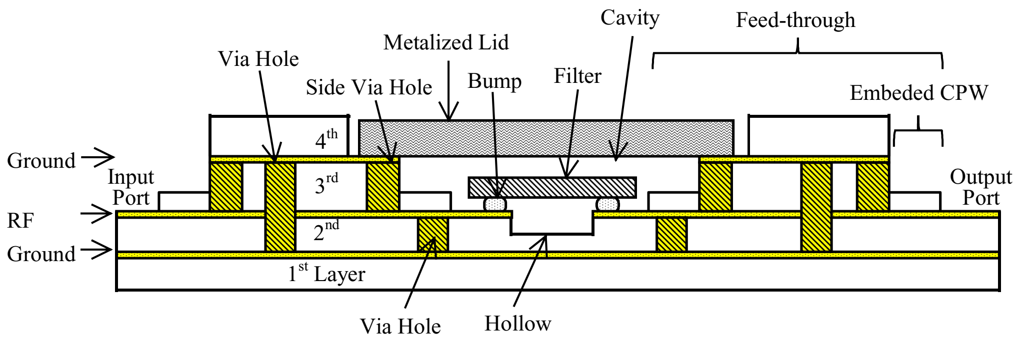


Fig. 6 Cross sectional view of the ceramic package.

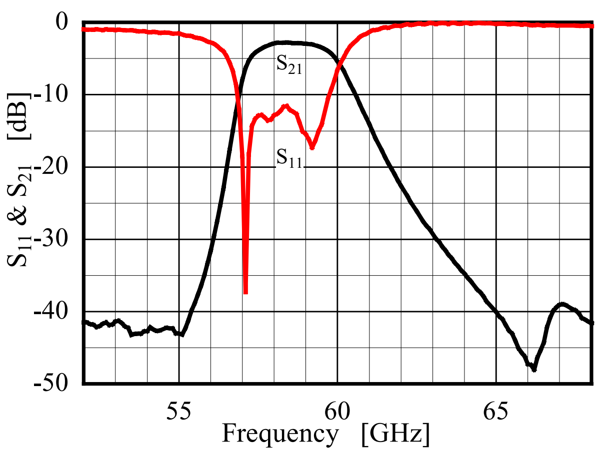


Fig. 5 Measured transmission and reflection characteristics of filter.

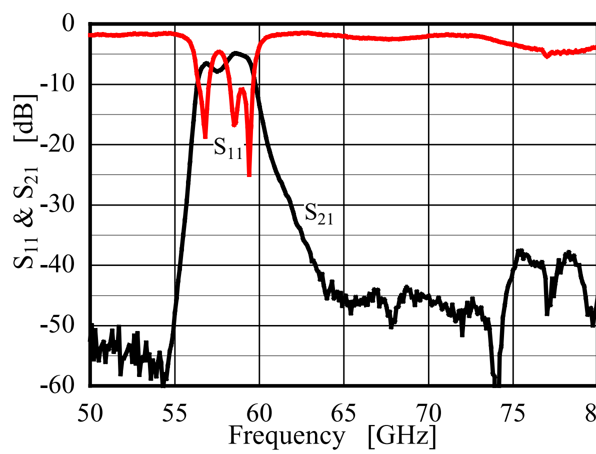


Fig. 7 Measured transmission and reflection characteristics of filter after flip-chip bonding.

structure, which couple directly input with output ports. Among five lots of fabricated filters, the deviation of the center frequency was less than 0.5 GHz.

The filter was mounted in a multi-layer ceramic package using a thermal compression method [5]. A cross sectional view of the ceramic package is shown in Fig. 6. The package consists of a cavity and a pair of feed-throughs to connect external I/O ports. In order to attain high isolation in the stop-band and to reduce a proximity effect due to the substrate, a hollow is formed in the package. The size of package is 13 mm x 10 mm x 1.2 mm. The filter was shielded electrically by attaching a metalized ceramic lid on the cavity. Fig. 7 shows the measured transmission characteristics of the flipped filter. The filter showed excellent rejection characteristics. The stop-band rejection was better than 35 dB from 50 GHz to 80 GHz. The insertion loss of 5 dB at 58.5 GHz is reasonable value considering a loss of two feed-throughs in the package (1 dB x 2). The pass-band characteristic was degraded around 57.5 GHz due to deterioration of matching characteristics and a radiation loss at interconnects between the filter and the package. We have also confirmed the behavior of the radiation and will suppress it in the future work.

IV. Conclusion

A planar dielectric waveguide filter with CPW I/O ports was developed. The fabricated 4-resonator filter showed good performance with a low insertion loss and a high stop-band rejection. The filter flipped in a multi-layer ceramic package was also demonstrated. It is promisingly for this filter to be applied for low cost millimeter-wave systems.

Acknowledgements

The authors wish to thank I. Izumi for fabrication of the filter. Support from T. Sugimoto, Y. Shimada, K. Utsumi, M. Kuzuhara, T. Uji and M. Ogawa is appreciated.

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