Design of 60-GHz Vertically Stacked Waveguide Filters in LTCC

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***Abstract*-This paper proposes a new type of vertically stacked waveguide filters in a multilayer low-temperature co-fired ceramic (LTCC) structure. The vertical metal walls of the waveguide resonators are realized by closely spaced metal filled vias, while adjacent resonators are coupled vertically by square apertures or narrow slots. Two kinds of filters with chebyshev and elliptical response are designed for 60-GHz-band application. From the results, the circuit area of the filter with chebyshev response can be reduced to 25% as compared to a conventional planar direct-coupled waveguide filter.**

***Index Term*- Chebyshev filters, Elliptical filters, LTCC.**

I. INTRODUCTION

Recently, RF and microwave system-on-package (SOP) modules for wireless communications are increasingly fabricated in low-temperature co-fired ceramic (LTCC) technology [1]. The technology enables the creation of monolithic, three-dimensional, cost-effective microwave circuits/packages [2]. With the multilayer capability of LTCC, it is possible to effective embed passive components such as filters. Therefore the required circuit area can be largely reduced.

Microwave and millimeter wave filters using waveguide structure offer low loss and high quality factor, but usually at the price of large size, weight, and high cost. With the multilayer structure of LTCC, it makes the vertical coupling between resonators in different layers possible. By this mechanism, the filter area can be dramatically reduced.

In this paper, two kinds of the vertically stacked waveguide filters have been designed for 60-GHz-band application. The filters are developed in the multilayered LTCC substrate to achieve compact size.

II. FILTER STRUCTURE

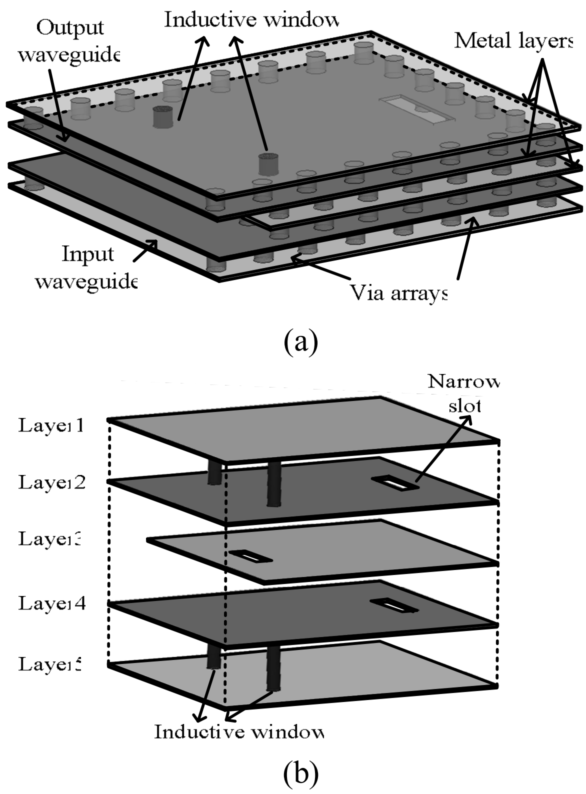

Fig1. The structure of vertically stacked waveguide filter with chebyshev response in a multilayer configuration. (a) Over view. (b) Detailed layer sketch without via arrays.

Fig. 1 shows the configuration of a four-pole chebyshev waveguide filter. It is composed of four rectangular cavities stacked vertically and each cavity is formed by via arrays in dielectric substrate with metal top and bottom surfaces. Each cavity resonates in its fundamental TE_{101} mode at a common center frequency. Adjacent cavities are coupled with each other by a narrow slot in the common wall. Input/output waveguide is coupled to first/last cavity by an inductive window composed of one pair of vias.

To efficiently couple two adjacent cavities, the narrow slot in the common wall is placed near via wall of the cavity where it can largely interrupt cavity surface current [3]. Therefore, the coupling between adjacent cavities is achieved by means of magnetic fields through the narrow slot in the common wall.

When designing filters, we should calculate the external quality factor Q_{ext} and the coupling coefficient k, which are determined by physical dimensions of coupling structures with a three-dimensional electromagnetic simulator, HFSS. The Q_{ext} is controlled by via pitch of the inductive window between I/O waveguide and first/last cavity. The value of Q_{ext} is calculated by

$$Q_{ext} = \frac{f_0}{\Delta f_{\pm 90^0}} \tag{1}$$

where the numerator is the center frequency of the resonator and the denominator is the 180^0 bandwidth centered at resonant frequency. The coupling coefficient k between adjacent cavities is controlled by the width of the narrow slot, and is calculated by [4]

$$k = \frac{f_e^2 - f_m^2}{f_e^2 + f_m^2}. \tag{2}$$

From the formulations mentioned above, we can obtain the initial dimensions of the narrow slots and the inductive windows according to the specification we want. Due to the slots and the inductive windows on the cavity, we should make an adjustment in the length of each cavity to maintain the same resonant frequency as the original one [5].

Another filter with elliptical-function is designed on LTCC also. The configuration of a four-pole elliptical vertically stacked waveguide filter is shown in Fig. 2. The cavities in the same layer are coupled by an inductive window, while the cavities between different layers are coupled by a square aperture in the center of the common wall or a narrow slot at the edge of the common wall. I/O waveguide is coupled to the first/last cavity by an inductive window also.

The coupling of a square aperture in the center of the common wall is achieved by electric fields, while other coupling mechanisms are by magnetic fields. The couplings produced by means of electric and magnetic fields have opposite signs, which enable realization of elliptic-function filter response [6]. The external quality factor Q_{ext} and the coupling coefficient k are obtained by the same formula in the preceding paragraph.

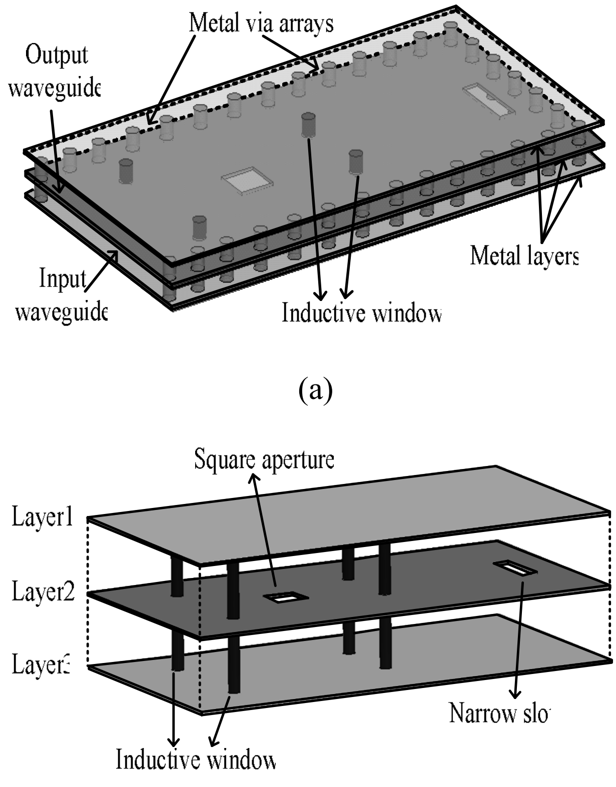

Fig2. The structure of vertically stacked waveguide filter with elliptical response in a multilayer configuration. (a) Over view. (b) Detailed layer sketch without via arrays.

III. RESULTS

Vertically Stacked waveguide filters with chebyshev and elliptical response are designed using LTCC. The specification of each filter is 5% bandwidth centered at 60 GHz with 0.1 dB passband ripple. The corresponding Q_{ext} and k are obtained by the filter design technique [7]. The relative dielectric constant of the substrate is 7.8. Each via has the diameter of 75μm. Each metal layer has the thickness of 5μm. The dielectric thickness between two layers is 83μm. The dimensions of filters are shown in Fig.3 and Fig.4. The three-dimensional electromagnetic simulator is used to simulate the frequency response of the whole structure. The simulation results are shown in Fig.5 and Fig.6, where conductor loss and dielectric loss are neglected. The circuit area of chebyshev-function filter is reduced to 25% as compared to conventional four-pole direct couple chebyshev filter. The results also show that it is possible to realize an elliptical-function filter in LTCC technology.

IV. CONCLUSIONS

Two kinds of vertically stacked waveguide filters with chebyshev and elliptical response have been presented with multilayer structures in this paper. The coupling mechanisms have been described. The simulation results agree quite well with design specifications. With LTCC technology, it is possible to design microwave and millimeter wave filters in a very compact size.

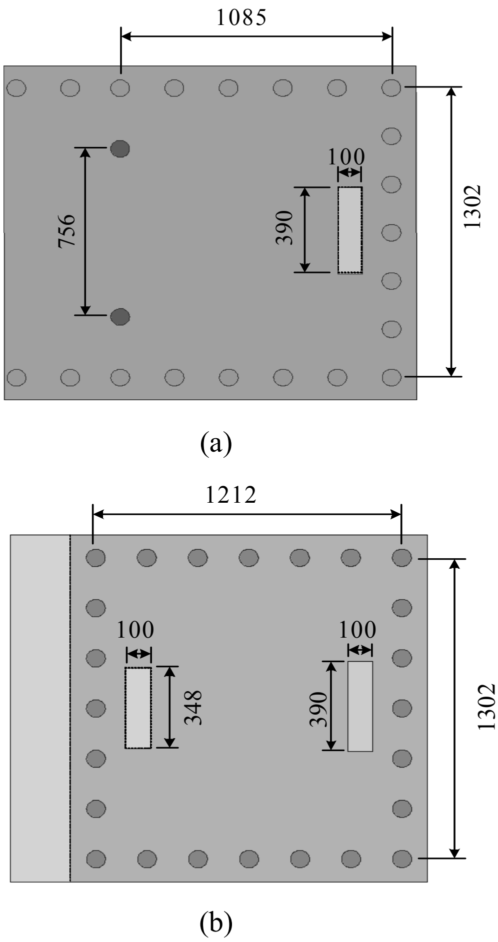

Fig.3 Dimension of chebyshev filter. (unit: μm) (a) Top view of the cavity between layers 1 and 2 or layers 4 and 5. (b) Top view of the cavity between layers 2 and 3 or layers 3 and 4.

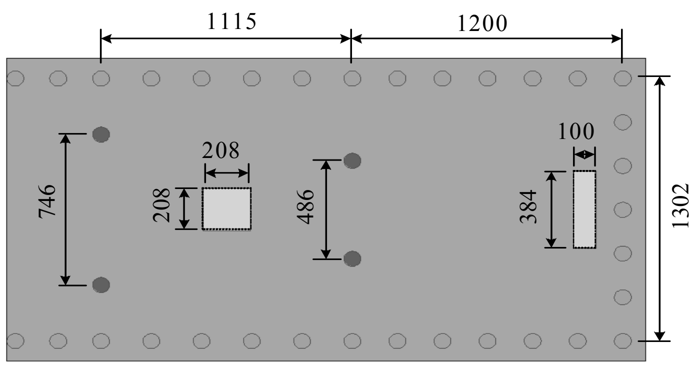

Fig.4 Dimension of elliptical filter. (unit: μm) (a) Top view of the cavity between layers 1 and 2 or layers 2 and 3.

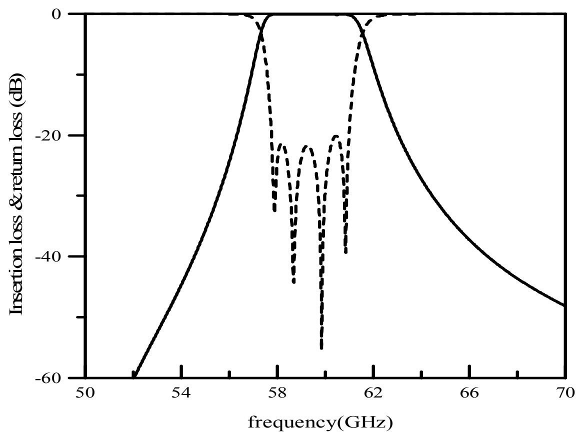

Fig.5 Frequency response of chebyshev filter.

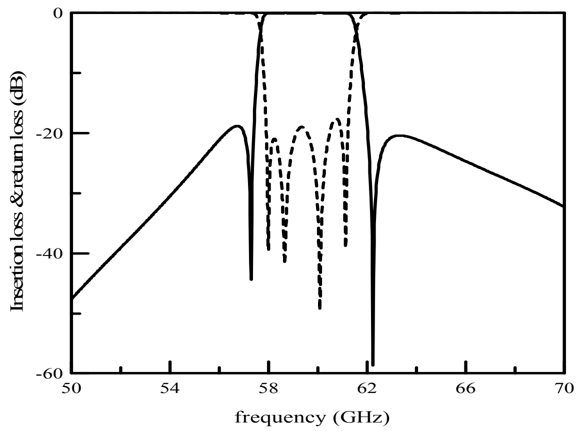

Fig.6 Frequency response of elliptical filter.

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