PCB Substrate Integrated Waveguide-Filter Using Via Fences at Millimeter-wave

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***Abstract* — In this paper, the implementation and the embedding method of the existing air-filled waveguide-filters at millimeter-wave on general Printed Circuit Board(PCB) substrate are introduced by systematically inserting the vias inside waveguide and mathematically manipulating the simple equations obtained from the classical circular-post waveguide the wave propagation. Because the mass production on PCB is possible without fabricating a large-scaled metal waveguide of WR-22 as input/output ports at millimeter-wave, th Bandpass-Filter(BPF) design procedure. Side walls and poles inside the waveguide are realized by placing two series array of via and tuning the via diameters. The each length of x, y, and z axes is reduced in proportion to root square of employed substrate dielectric constant and ,especially, the length of z-axis can be more reduced due to the characteristics of e manufacturing cost can be reduced considerably. Finally, when using multi-layer process like low temperature cofired ceramic(LTCC) for small-sized module, it is one of advantages to use only one layer for the filter fabrication. To evaluate the validity of this novel technique, order-3 Chebyshev BPF centered at 40 GHz-band with a 2.5 % Fractional Bandwidth(FBW) was used. The employed substrate has relative dielectric constant of 2.2 and thickness of 10 mils of Rogers RT/Duroid 5880. According to design and measurement results, a good performance of insertion loss of 2 dB and return loss of –30 dB is achieved at full input/output ports.**

***Index Terms* — Millimeter-wave, waveguide-filter, LTCC**

I. INTRODUCTION

Recently, the development of wireless communication systems brings the fourth generation system with over 100 Mbps data rate from the third generation mainly focused on the voice and image service. In the fourth generation systems, the high-speed data transfer for various multimedia services needs the wideband available in millimeter-wave. In order to achieve the implementation of transceiver operating at millimeter-wave, it costs many efforts and time for the development of millimeter-wave devices. In addition, the system working at millimeter-wave requires low-profile, compact, low loss devices, and highly advanced packaging technology.

As a candidate for the packaging technology in millimeter-wave, high temperature cofired ceramic (HTCC) and low temperature cofired ceramic(LTCC) have been proposed.

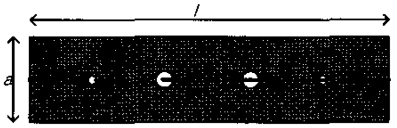
Studies on the design of waveguide-filters in single-layer or multi-layer have been presenting in the literatures[1]-[3]. All metal structures such as side wall for perfect ground plane and circular-posts located at the symmetric axis in the waveguide are replaced with a series array of via and the various via diameters due to the difficulties in the fabrication of vertically installed side wall.

In this paper, the design process and fabrication of waveguide-filter embedded in PCB substrate by applying the design rule of air-filled WR-22 waveguide filters at 40 GHz are introduced. Also, the simulation and measurement results are included in section III.

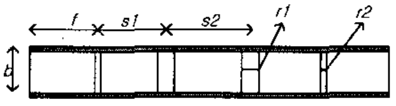
II. THE DESIGN PROCEDURE FOR PCB SUBSTRATE INTEGRATED WAVEGUIDE FILTERS

A. Air-filled Waveguide-Filters with Circular-Posts

First of all, in order to design the conventional air-filled circular-post waveguide-filter, order-3 chebyshev BPF centered at the neighborhood of 40 GHz with a 2.5 % FBW is considered as shown in Fig. 1.



(a) Top View



(b) Side View

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Fig. 1. Conventional circular-post waveguide-filter: diameters of the circular-post r1, r2, distance between the nearest circular-posts *s1, s2*, feeding length *f*, total length *l*, guided wavelength λ_g.

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This structure can be modeled by using the equivalent circuit with two capacitors and a inductor described in Fig. 2[4][5].

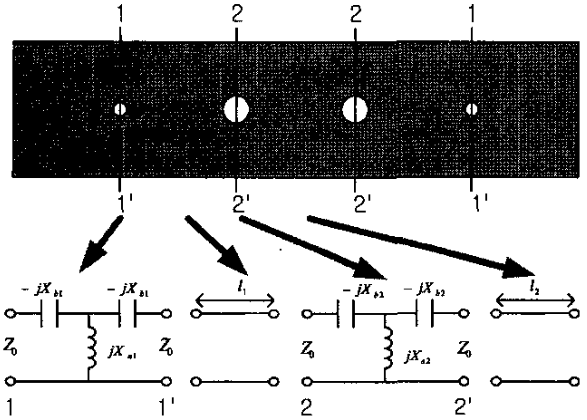


Fig. 2. Equivalent circuit of circular-post waveguide-filter.

Since the available via diameters are very limited at most of manufacturing processes in general, the design rules optimized at the specific manufacturing process must be taken into account to obtain predictable results. The optimized parameters are listed in Table I.

TABLE I

40 GHZ-BAND WAVEGUIDE-FILTERS : Q-BAND WR-22(axb = 5.7x2.85 mm) RECTANGULAR WAVEGUIDE, 4 RESONATORS, AND 1/100 mm PROCESSING ERROR. (UNIT: mm)

X_{a1}	X_{b1}	X_{a2}	X_{b2}	l_1	l_2
19.2	2.4	4.6	14.2	0.48	0.56
r1	*r2*	*s1*	*s2*	*f*	*l*
0.444	1.184	4.46	5.045	2.5175	19

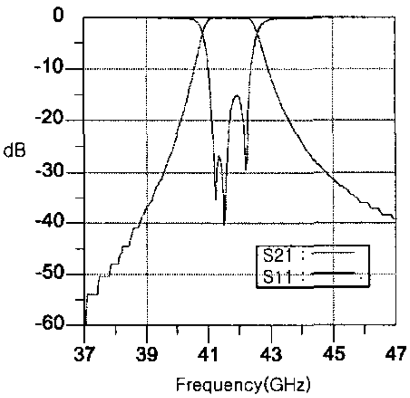


Fig. 3. Simulation result of typical circular-post waveguide-filter.

Fig. 3 shows the full-EM simulation result obtained from the optimized values in Table I and commercial software package MW Studio based on FDTD algorithm.

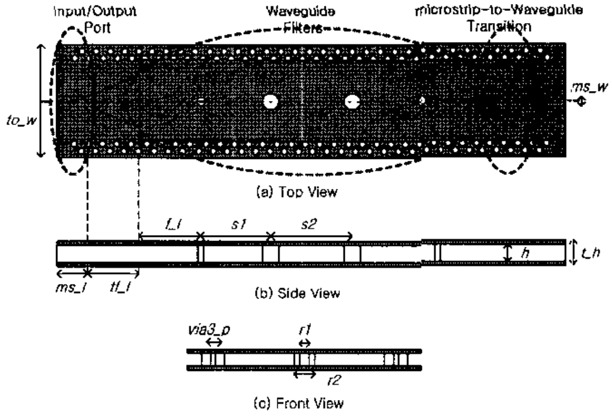
B. The Design Procedure of Waveguide-Filter filled with Dielectric Materials

To design waveguide-filters using PCB process with above-mentioned conventional waveguide-filter, the total size of air-filled waveguide-filter must be inversely proportional to $\sqrt{\varepsilon_r}$ from the following simple equation (1) with assumption of $k >> k_c$ at millimeter-wave(30 ~ 300 GHz)[6].

$$\lambda_g = 2\pi / \beta = 2\pi / \sqrt{k^2 - k_c^2}, \qquad (1)$$

where $k = \sqrt{\mu \varepsilon}$ and $k_c = \sqrt{(m\pi / a)^2 + (n\pi / b)^2}$. Here, λ_g is guided wavelength, β is propagation constant, k is medium wavenumber, and k_c is cutoff wavenumber.

In this paper, RT/Duroid 5880 substrate of relative dielectric constant, ε_r=2.2, and thickness, h=10 mils, are used to evaluate the performance of waveguide embedded in dielectric substrate. Since TE_{10} mode is usually used as a fundamental mode and main propagation mode, the reduction of z-axis has little effects on the entire electromagnetic performances[7]. The size-reduction of z-axis makes a good contribution to small-sized packaging technology.



(a) Top View

(b) Side View

(c) Front View

Fig. 4. PCB substrate integrated waveguide-filter.

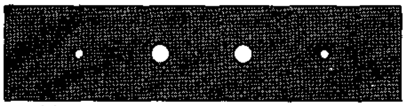
Fig. 4 depicts that the waveguide filter proposed in this paper consists of the following three parts; 1) 50 ohms microstrip line input and output parts, 2) microstrip line-to-waveguide transition part, 3) waveguide filter part having bandpass filter characteristics.

The finally-optimized parameter values of PCB substrate integrated filter obtained from Table I and equation (1) are listed in Table II.

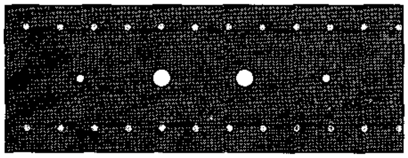
TABLE II
PHYSICAL PARAMETERS TO IMPLEMENT AND EMBED WAVEGUIDE FILTERS ON PCB(UNIT: mm)

to_w	*wg_w*	*r1*	*r2*	*s1*	*s2*
7.7	3.85	0.3	0.8	3.016	3.409
via1_p	*via2_p*	*via3_p*	*h*	*h+t*	*f_l*
0.6	0.3	0.6	0.254	0.274	1.704

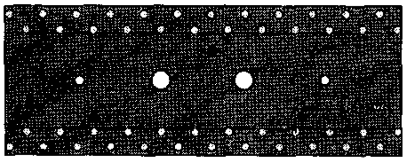
The conventional waveguide-filter surrounded by perfect electric conductor at the side wall is described in Fig. 5(a). In the PCB and LTCC integrated filters, the via fences in Fig. 5(d) are located at the side wall with periodic shapes to prevent the leakage from the space between the nearest vias and to increase the isolation level caused by the adjacent devices.



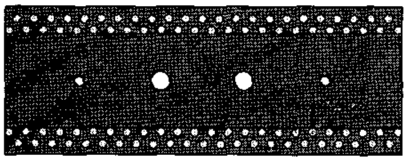
(a) Perfect conductor metal on the side wall



(b) Conventional via fences having a single array of via



(c) Via fences with two zigzagged array of via



(d) Via fences with two zigzagged array of via and shorter period than (c)

Fig. 5. Waveguide-filters having various side wall.

Fig. 6 shows simulated results according to various structure of Fig. 5. The insertion loss of Fig. 5(c) is lower than that of Fig. 5(b), because of the reduction of energy leakage from the space between the nearest vias. As the pitch between vias becomes narrow, the insertion loss characteristic gets better and the frequency separation between the center frequencies of Fig. 5(a) and (d) becomes closer. This frequency shift is thought to be the increment of guided wavelength caused by using via side wall.

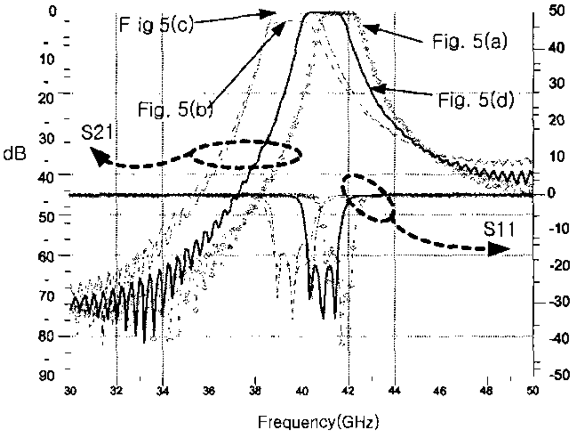
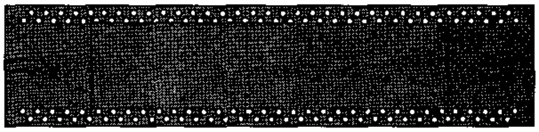


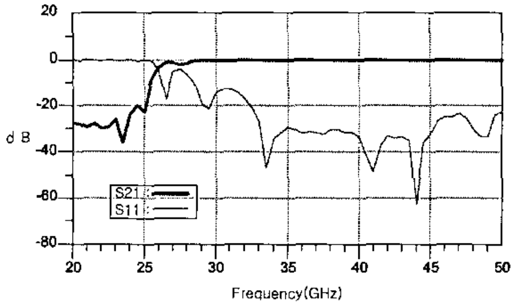
Fig. 6. Simulated results according to the structures described in Fig. 5.

C. Microstrip Line-to-Rectangular Waveguide Transition

Transition part is essential to match the impedance of embedded waveguide-filter to that of the microstrip line for measurement, interconnection, and package[8].



(a) Microstrip line-to-rectangular waveguide transition structure



(b) Simulated results

Fig. 7. Structure and simulated results of microstrip line-to-rectangular waveguide transition.

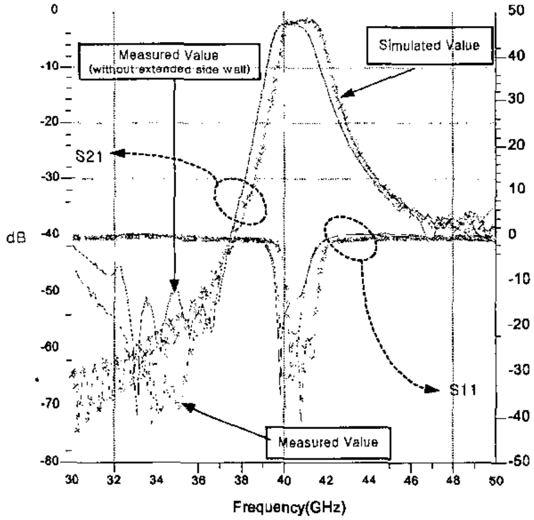
Fig. 7(a) shows that the zigzagged via arrays in two rows for side wall of waveguide are extended in order to reduce to leakage generated from the transition part. Fig. 7(b) also shows the simulated results with insertion loss of 0.2 dB and return loss of −30 dB.

III. SIMULATION AND MEASUREMENT RESULTS

Fig. 8(a) shows the fabricated waveguide-filters embedded in PCB substrate using via fences at the side wall and central signal via at the symmetric axis. This structure is composed of mainly two parts; one of them is the microstrip-to-waveguide transition part at the input and output ports. Another is the waveguide-filter with two kinds of vias of 0.3 mm and 0.8 mm diameters. To evaluate the validity of extended side wall replaced with vias, two kinds of filters with and without extended side wall have been implemented as shown in Fig. 8(a).

With the measured results, we can see that waveguide-filters with additional vias at the transition parts have better performances than those without vias in respect of insertion loss and return loss.

(a) PCB substrate integrated waveguide-filters



(b) Comparison of measured results and simulated data

Fig. 8. The fabricated photograph with measured and simulated results.

Fig. 8(b) shows good agreements between simulation and experimental results with 0.3 dB deviation in insertion loss and 500 MHz frequency shift from the designed value. The measurements have been realized with a Anritsu 37397C Vector Network Analyzer.

IV. CONCLUSION

This paper deals the design method of PCB substrate integrated waveguide-filters by using via fences on the basis of the design rule of the conventional air-filled waveguide filter and the performance verification. It is found that the side wall and circular-post inside waveguide can be easily constructed by using the continuous via arrays and the various via diameters in the commercial PCB substrate.

The advantages obtained from the proposed structure are that the overall size of waveguide-filter can be reduced in proportion to the inversely square root of dielectric constant at the expense of dielectric loss and especially, the z-axis can be reduced considerably due to the characteristics of wave propagation. From the flexibility of height in waveguide-filter, it is seen that the proposed filter are suitable for small-sized transceiver module and highly advanced packaging technology.

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