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

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Contents

- Abstract

I. Introduction

II. The design procedure for PCB substrate integrated waveguide filters
   - A. Air-filled waveguide-filter with circular-posts
   - B. The design procedure of waveguide-filter filled with dielectric materials
   - C. Microstrip line-to-rectangular waveguide transition

III. Simulation And Measurement Results

IV. Conclusion

References
Abstract

- Circular post waveguide filter at millimeter-wave on general PCB
- Side walls is realized by placing two series array of via
- Poles is realized by tuning the via diameters
- The each length of x, y, z axes is reduced in proportion to root square of employed substrate dielectric constant
- Use multi-layer process like low temperature cofired ceramic (LTCC) for small-sized module
- Evaluation
  - Order-3 Chebyshev BPF centered at 40 GHz band with a 2.5% FBW
- Characteristics
  - Insertion loss of 2 dB and return loss of –30 dB
1. **Introduction**

- The system working at millimeter-wave requires low-profile, compact, low loss devices, and highly advanced packaging technology.

- The difficulties in the fabrication of vertically installed side wall:
  - Side wall for PEC is replaced with a series array of via
  - Circular posts located at the symmetric axis in the waveguide is replaced with the various via diameters

- The design process and fabrication of waveguide-filter embedded in PCB and LTCC substrate
II. The Design Procedure

A. Air-filled Waveguide-Filter with Circular-Posts(1)

- Order 3 Chebyshev BPF centered at 40 GHz band with 2.5 % FBW

Fig. 1. Conventional circular-post waveguide-filter: diameters of the circular-post $r_1$, $r_2$, distance between the nearest circular-posts $s_1$, $s_2$, feeding length $f$, total length $l$, guided wavelength $\lambda_g$.

Fig. 2. Equivalent circuit of circular-post waveguide-filter.
A. Air-filled Waveguide-Filter with Circular-Posts(2)

- Order-3 Chebyshev BPF centered at 40 GHz band with 2.5% FBW

### TABLE I

40 GHz-band waveguide-filters: Q-band WR-22 (axb = 5.7x2.85 mm) rectangular waveguide, 3 resonators, and 1/100 mm processing error. (unit: mm)

<table>
<thead>
<tr>
<th>$x_{a1}$</th>
<th>$x_{b1}$</th>
<th>$x_{a2}$</th>
<th>$x_{b2}$</th>
<th>$l_1$</th>
<th>$l_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.2</td>
<td>2.4</td>
<td>4.6</td>
<td>14.2</td>
<td>0.48</td>
<td>0.56</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$r_1$</th>
<th>$r_2$</th>
<th>$s_1$</th>
<th>$s_2$</th>
<th>$f$</th>
<th>$l$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.444</td>
<td>1.184</td>
<td>4.46</td>
<td>5.045</td>
<td>2.517</td>
<td>19</td>
</tr>
</tbody>
</table>

Fig. 3. Simulation result of typical circular-post waveguide-filter.
B. The Design Procedure of Waveguide- Filter filled with Dielectric Materials(1)

- The total size of air- filled waveguide- filter must be inversely proportional to \( \sqrt{\varepsilon_r} \) from equation (1)
  - assumption of \( k >> k_c \) at millimeter- wave(30~300GHz)

\[
\lambda_g = \frac{2\pi}{\beta} = \frac{2\pi}{\sqrt{k^2 - k_c^2}} \quad (1)
\]

- Where \( k = \sqrt{\mu / \varepsilon} \) and \( k_c \). Here, \( \lambda_g \) is guided wavelength, \( \beta \) is propagation constant, \( k \) is medium wavenumber, and \( k_c = \sqrt{(m\pi / a)^2 + (n\pi / b)^2} \) is cutoff wavenumber
- Relative dielectric constant, \( \varepsilon_r = 2.2 \), and thickness, \( h = 10 \) mil
- The reduction of z- axis has little effects on the entire electromagnetic performances
  - Contribution to small- sized packaging technology
B. The Design Procedure of Waveguide-Filter filled with Dielectric Materials(2)

- Waveguide filter proposed in this paper

![Diagram of Waveguide Filter]

**Fig. 4. PCB substrate integrated waveguide-filter.**

| 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 |
B. The Design Procedure of Waveguide-Filter filled with Dielectric Materials (3)

- Via fences are located at the side wall

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

Fig. 6. Simulated results according to the structures described in Fig. 5.
B. Microstrip Line- to- Rectangular Waveguide Transition(1)

- Zigzagged via arrays in two rows for side wall of waveguide

Fig. 7. Structure and simulated results of microstrip line-to-rectangular waveguide transition.
III. Simulation & Measurement Results

*Waveguide Filter Using the PCB Substrate*

(a) PCB substrate integrated waveguide- filters

<Measurement Results>

Insertion Loss : -2 dB@40.5GHz
Return Loss : -30 dB@40.5GHz

Fig. 8. The fabricated PCB waveguide- filter photograph with measured and simulated results.
Fig. 9. The fabricated LTCC waveguide-filter photograph with measured and simulated results.
IV. Conclusions

- The Design method of PCB and LTCC substrate integrated waveguide- filters
  - Side wall using the continuous via arrays
  - Circular- post using the various via diameters

- The advantages
  - The overall size of waveguide- filter can be reduced
  - Small- sized transceiver module and highly advanced packaging technology


