Paper

Study on Comb-Line Filters with Coupling Windows on the Grounding Conductor

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This paper proposes a new type of multi-stratified comb-line filters of narrow pass band utilizing conductor-backed coplanar waveguides. It is shown through numerical simulations by means of FD-TD method that the filtering characteristics can be controlled effectively by introducing a grounding conductor with a window between the coupled two resonators. It is demonstrated that, by changing the dimensions of the window on the grounding conductor, we can change, without affecting the odd mode, the input susceptance of the even mode independently and that we can adjust the frequency of attenuation pole. An interesting feature of this filter is that an additional window on the grounding conductor makes another attenuation pole appear around the passband.

Keywords: Comb-line Filter, Atenuation Pole, FD-TD method, Conductor-Backed CPW

1. Introduction

Cellular phones are usually equipped with comb-line filters, which have an advantage that the frequency characteristics around the pass band can be greatly improved by attenuation poles [1], [2]. Besides comb-line filters, some other types of filters which have attenuation poles around the passband have been proposed so far [3]–[7]. Attenuation poles play a significant role not only to compress the transmission level of the stopband, but also to sharpen the passband response. Utilizing the conductor-backed coplanar waveguide (CPW), we have already proposed a dual-plane comb-line filter, which consists of two quarter-wavelength resonators placed face-to-face beyond the substrate [8], [9]. The structure is suitable for miniaturization by utilizing stratifying technology. In addition, attenuation poles can easily be created just around the passband for this structure.

In this paper, we newly propose a 3-layer CPW comb-line filter. This filter has a quarter-wavelength resonator on each of the top and bottom planes and a window on the middle plane which the two resonators are coupled through. We investigate the filtering characteristics through numerical simulations by means of the FD-TD method. This filter has a benefit that an attenuation pole can be created just around the passband and it can be regulated by locating the window appropriately. Furthermore, two attenuation poles can be created just below and above the passband by opening another small window on the middle plane.

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2. Comb-Line Filter with a Window on the Grounding Conductor

Figure 1 illustrates the structure of the 3-layer CPW comb-line filter that we propose in this paper. The relative permittivity of the substrate is assumed to be 10.2. The filter has two quarter-wavelength resonators each one of which is arranged on the top and bottom planes of the substrate. In this paper, we adopt simple straight resonators to clear the principle of creating attenuation poles. However, it has been confirmed that we can obtain similar characteristics when we use stepped impedance resonators (SIRs) instead of straight ones. A window is opened on the middle plane through which the two resonators are coupled to each other. Several segments of thin metal wire penetrate the substrate around the resonators to connect the metallized planes so as to remove both the parallel-plate and slot modes. The whole structure is symmetric with respect to the center axis (the dash-dotted line) in Fig.1.

The metallization pattern on the top (or bottom) plane is shown in Fig.2 in which the location of the window is also illustrated. The width of the window is fixed to be 5.0mm. For I/O ports, a finite length of CPW is connected to each resonator through an appropriate length of tapping wire.

Figure 3 illustrates flow lines of electric field of the even and odd modes of the filter shown in Fig.1.

Only the even-mode fields exist in the window region because the odd-mode fields from the top and bottom planes, which have the opposite phases, cancel each other. Therefore, the dimensions and position of the window affect only the even mode. The bandwidth of a comb-line filter is determined by the difference of resonant frequencies between the even and odd modes, and attenuation poles appear at the frequencies where

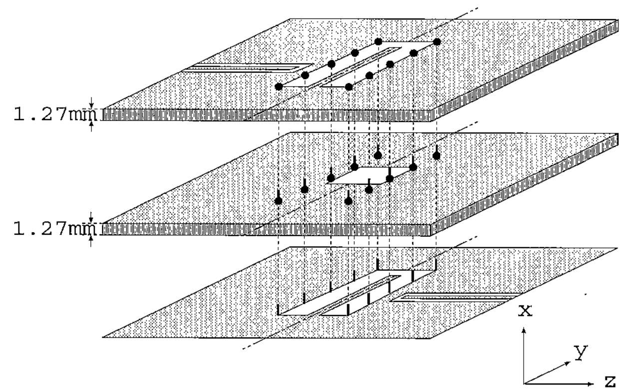


Fig. 1. 3-layer CPW comb-line filter with a window on the middle plane.

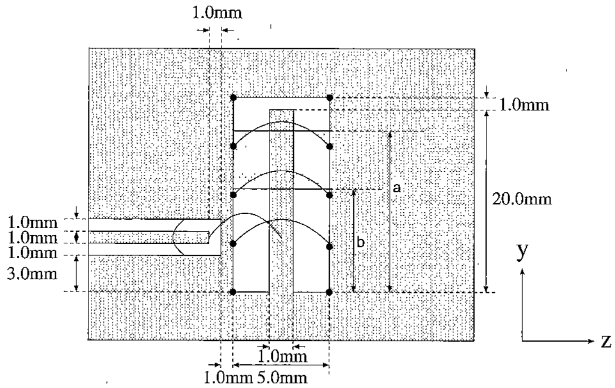
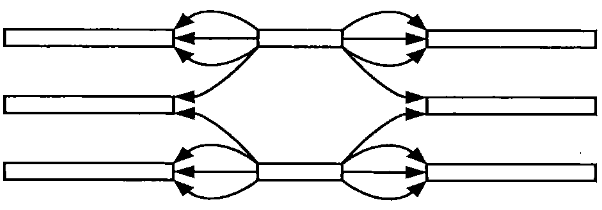
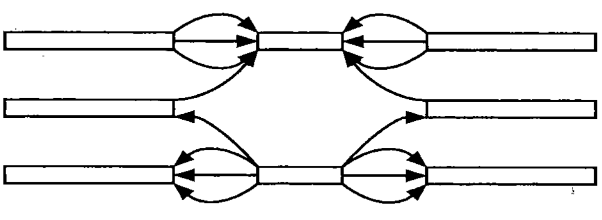


Fig. 2. Metallization pattern on the top (or bottom) plane.



(a)even mode



(b)odd mode

Fig. 3. Flow lines of electric field.

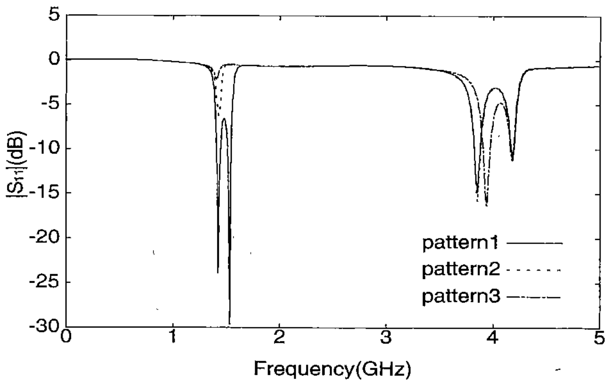
the input susceptances of both modes are equal to each other [9]. Consequently, designing the window appropriately, we can change the even mode alone to regulate the bandwidth and attenuation-pole frequencies of the filter.

Numerical calculations by means of the FD-TD method are carried out with a and b as parameters. Here, a and b, which determine the dimensions and position of the window, are the lengths from the terminated edge of the resonator to the upper and lower frames of the window, respectively, as shown in Fig.2. The filter is modeled on a Yee's mesh consisting of $36 \times 80 \times 110$ homogeneous cells in the FD-TD analysis; each cell size is assumed to be 0.635mm in the x direction and 0.5mm in both y and z directions. Table 1 shows several patterns of the window parameters investigated here. In this table, patterns 1-3 and 4-6 correspond to changing either a or b in Fig.2 while fixing the other parameters.

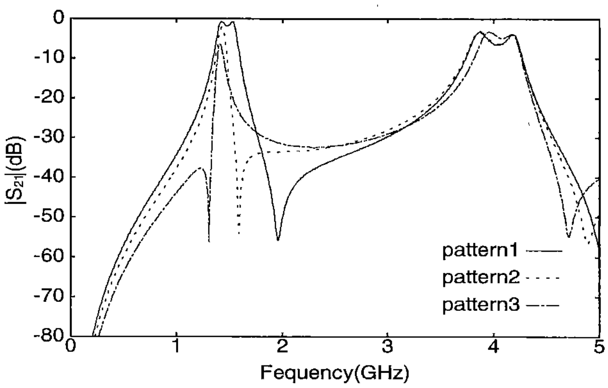
Figure 4 shows the frequency characteristics of scattering parameters for patterns 1-3 in Table 1. It is understood that by decreasing a we can lower the upper cutoff frequency of the passband without changing the lower one ; hence a very narrow passband can be achieved. This is because the even mode has the domination over the upper cutoff frequency whereas the odd mode contrariwise keeps the control over the lower cutoff frequency. It is also understood from Fig.4 that attenuation poles move toward the lower frequency region as a becomes smaller.

Table 1. Window parameters.

pattern	a(mm)	b(mm)
1	18.5	8.5
2	16.5	8.5
3	14.5	8.5
4	18.5	12.5
5	18.5	10.5
6	18.5	8.5



(a)



(b)

Fig. 4. Frequency characteristics of scattering parameters for patterns 1,2, and 3 in Table 1.

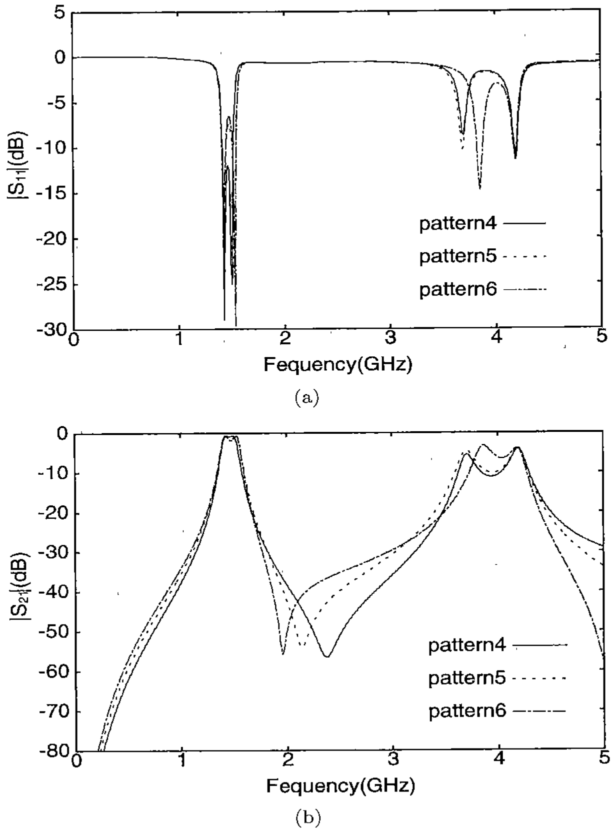


Fig. 5. Frequency characteristics of scattering parameters for patterns 4,5, and 6 in Table 1.

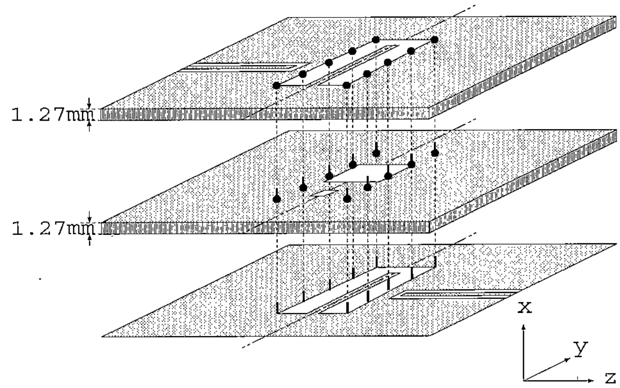


Fig. 6. 3-layer CPW comb-line filter with two windows on the middle plane.

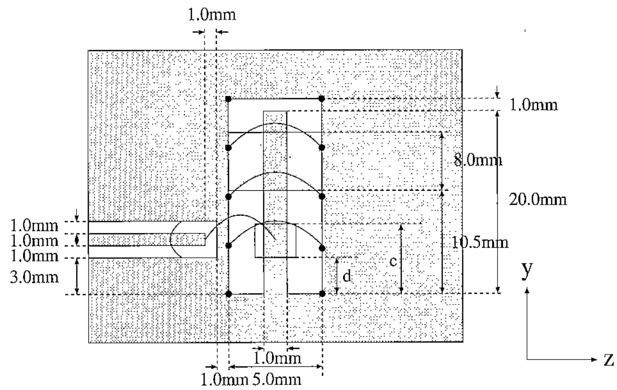


Fig. 7. Metallization pattern on the top (or bottom) plane.

Figure 5 shows the frequency characteristics of scattering parameters for patterns 4-6 in Table 1. As shown in this figure, by decreasing b we can make the attenuation pole frequency coming down with keeping the passband unchanged. As a result, for the filter shown in Fig.1, the frequencies of passband can be regulated by a, the upper frame of the window, and the frequency of attenuation pole by b, the lower frame of the window.

3. Comb-Line Filter with two Windows on the Grounding Conductor

In this section, we propose a 3-layer CPW comb-line filter with two windows on the middle plane, as shown in Fig.6, to create additional attenuation poles. To improve the filtering characteristics shown in Fig.5, it is desirable to create another attenuation pole just below the passband without diminishing one on the upper side. Here, another small window is punched in the middle plane to achieve this. This small window slightly changes the input susceptance of the even mode in the frequency range below the passband. Considering the flow lines of electric field for the odd mode, opening another window on the middle plane never alters the odd mode also in this case. As a result, the input susceptances of both modes become equal to each other at the frequency below the passband, where an attenuation pole appears. This is confirmed later through numerical results of the input susceptance.

The metallization pattern on the top (or bottom) plane is shown in Fig.7 in which the locations of the two windows are illustrated as well. We investigate the filtering characteristics with c as a parameter while fixing d. Here, c and d are the lengths from the terminated edge of the resonator to the upper and lower frames of the additional small window, respectively, as shown in Fig.7.

Figure 8 shows the frequency characteristics of scattering parameters with c as a parameter when $d = 2.0mm$. It is understood that an attenuation pole is created below the passband with one on the upper side being maintained. It is difficult, however, to regulate the attenuation pole frequencies at will because the addition of the small window also affects the electromagnetic coupling through the first window.

Figure 9 shows the frequency characteristics of the input susceptances for both even and odd modes. Input susceptances are calculated from $S_{11}(f)$ at the observation point on the input port [9]. For the even mode, we excite electric fields in phase on the excitation planes set in the input and output ports at the same distance from the dash-dotted lines in Fig.6 so that we have an equal voltage on both resonators on the top and bottom planes. On the other hand, electric fields having the opposite signs are excited on both resonators for the odd mode. From Fig.9, it is confirmed that the input susceptance of the even mode slightly changes depending on c

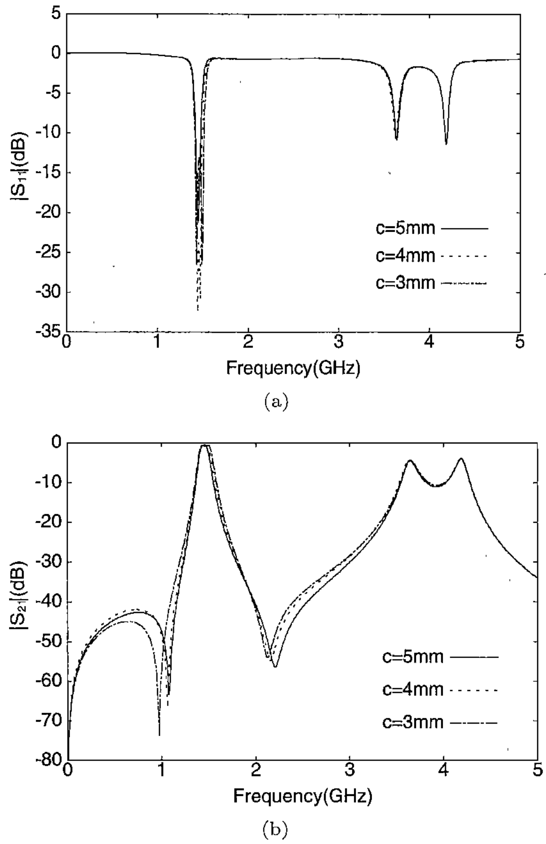


Fig. 8. Frequency characteristics of scattering parameters with c as a parameter when $d = 2.0$ mm: $|S_{11}|$ in (a) and $|S_{21}|$ in (b).

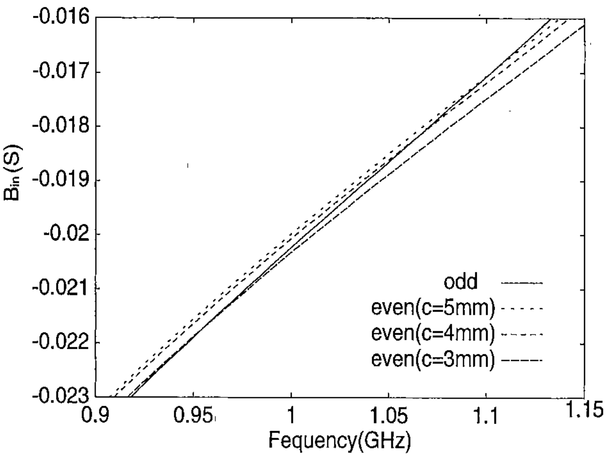


Fig. 9. Frequency characteristics of the input susceptances for the even and odd modes with c as a parameter.

in the frequency range below the passband. As a result, the intersection of the input susceptances between the even and odd modes, where the attenuation-pole exists, moves toward the lower frequency region as c becomes smaller.

4. Conclusions

In this paper, we have proposed a 3-layer CPW combline filter, which has one quarter-wavelength resonator on each of the top and bottom planes and a window on the middle plane which the two resonators are coupled through. The filtering characteristics have been investigated through numerical simulations by means of the FD-TD method. It has been shown that this filter has an attenuation pole around the passband and it can be regulated by adjusting the dimensions and location of the window. Furthermore, it has been demonstrated that two attenuation poles can be created just below and above the passband by opening another small window on the middle plane.

(Manuscript received June 10, 2002)

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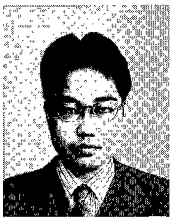

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