A VERY SMALL DIELECTRIC PLANAR FILTER FOR PORTABLE TELEPHONES

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ABSTRACT

A high performance dielectric filter with the size of 4.5mm x 3.2mm x 2.0mm has been developed. It has two planar resonators and is made of high permittivity multilayer ceramic in the Bi-Ca-Nb-O system. The performance is distinctive with its attenuation pole. An equivalent lumped circuit is derived to explain the behaviors of attenuation pole quantitatively.

INTRODUCTION

In accordance with the growth of mobile communications these days, compactness of portable telephone is the main concern. Inevitably, miniaturization of high frequency components is important. However, the performance is proportional to its size of a dielectric filter. A technological innovation has been investigated to miniaturize a filter without performance degradation. Recently, an LC chip filter using multilayer ceramic technology has been developed[1]. This LC chip filter is made of relatively low permittivity multilayer ceramic which consists of inductors and capacitors of lumped element.

In this paper, the authors devised a higher performance filter which has planar resonators constructed in a high permittivity multilayer ceramic. Behaviors of attenuation pole will be explained by knowledge of the relation between even-odd mode impedances and the equivalent expression with lumped elements.

OUTLINE OF PLANAR FILTER

Fig.1 shows the outside view of the multilayer planar filter. The dimensions are 4.5mm x 3.2mm x 2.0mm. The measured performance is shown in Fig.2. The insertion loss is less than 1.8dB at 940MHz. The transmission characteristics have an attenuation pole near the pass band.

Fig.3 shows the structure of the multilayer planar filter. The dielectric material of the Bi-Ca-Nb-O system was a newly developed one[2), 3)], the relative permittivity of which is 58. This material is co-fired with silver electrode at 950°C. The internal electrode layers consist of a strip line layer, a coupling capacitor layer and two shield layers.

The equivalent circuit of the filter is shown in Fig.4. The coupling means of planar filter is a combination of electromagnetic coupling and electric coupling through a capacitor, while the coupling means of conventional comb-line filter is electromagnetic coupling[4]. Thus, the transmission characteristic of planar filter is distinctive in the feature of its attenuation pole.

COUPLING FACTOR AND ATTENUATION POLE

From Fig.4, the transmission performance is calculated by using even-odd mode impedances[5),6)]. The calculation procedure is shown as follows. First, the electromagnetic fields around the parallel coupled lines are analyzed. The analysis can

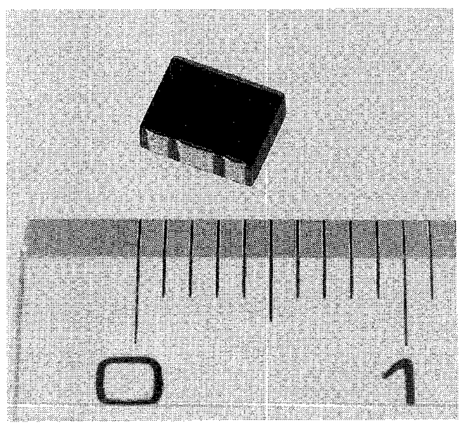

Fig.1 Outside view of multilayer planar filter

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be made by well documented method such as spectral domain method[7]. From the analysis, the exciting impedances are given by

$$z1=-jZ_e\cot(\theta/2) \quad (1)$$
$$z2=jZ_e\tan(\theta/2) \quad (2)$$
$$z3=-jZ_o\cot(\theta/2) \quad (3)$$
$$z4=jZ_o\tan(\theta/2) \quad (4)$$

where Z_e and Z_o are the even and odd mode impedances and θ is the electrical angle of transmission line. Thus the impedance matrix of 4-port parallel coupled strip lines is expressed as

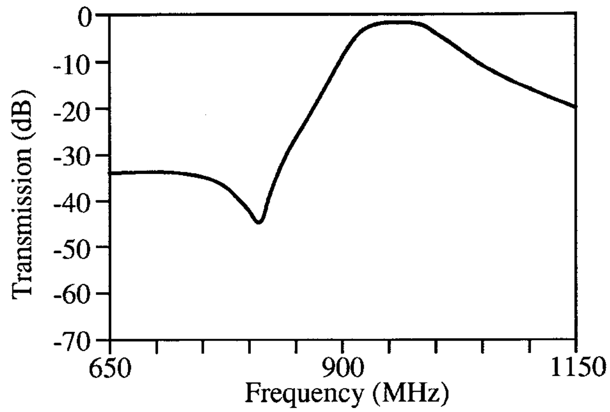


Fig.2 Measured performance

$$\mathbf{Z}=\begin{bmatrix} j(t-1/t)(Z_e+Z_o)/4 & j(t-1/t)(Z_e-Z_o)/4 & -j(t+1/t)(Z_e+Z_o)/4 & j(t+1/t)(-Z_e+Z_o)/4 \\ j(t-1/t)(Z_e-Z_o)/4 & j(t-1/t)(Z_e+Z_o)/4 & j(t+1/t)(-Z_e+Z_o)/4 & -j(t+1/t)(Z_e+Z_o)/4 \\ -j(t+1/t)(Z_e+Z_o)/4 & j(t+1/t)(-Z_e+Z_o)/4 & j(1-1/t)(Z_e+Z_o)/4 & j(t-1/t)(Z_e-Z_o)/4 \\ j(t+1/t)(-Z_e+Z_o)/4 & -j(1+1/t)(Z_e+Z_o)/4 & j(t-1/t)(Z_e-Z_o)/4 & j(t-1/t)(Z_e+Z_o)/4 \end{bmatrix} \quad (5)$$

where t denotes $\tan(\theta/2)$.

If the one end of each strip line is shorted, the matrix reduces to the 2-port impedance matrix given by

$$\mathbf{Z}=\begin{bmatrix} j(Z_e+Z_o)t/2 & j(Z_e-Z_o)t/2 \\ j(Z_e-Z_o)t/2 & j(Z_e+Z_o)t/2 \end{bmatrix} \quad (6)$$

The transmission characteristics are calculated by taking an inverse of (6), and by adding the admittances of the capacitors.

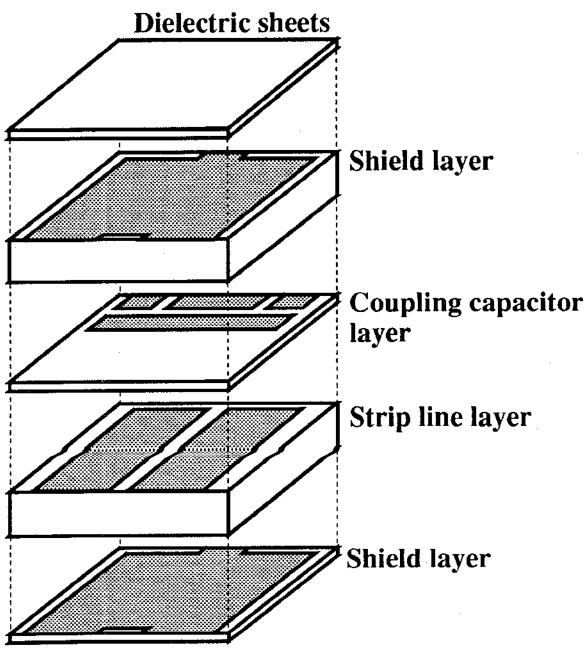


Fig.3 Structure of multilayer planar filter

The calculated results are shown in Fig.5 regarding to different values of inter-resonator coupling capacitance and different gaps between strip lines.

EQUIVALENT EXPRESSION WITH LUMPED ELEMENTS

Since the transmission of planar filter has an attenuation pole and its frequency depends on the coupling, the inter-resonator coupling may be regarded as a parallel resonator. Thus, an equivalent circuit consisting of lumped elements shown in Fig.6 is introduced.

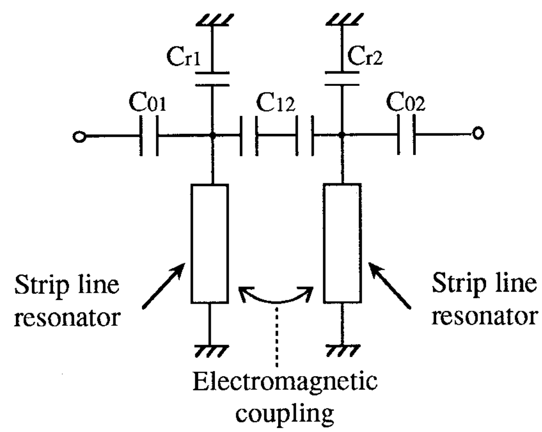
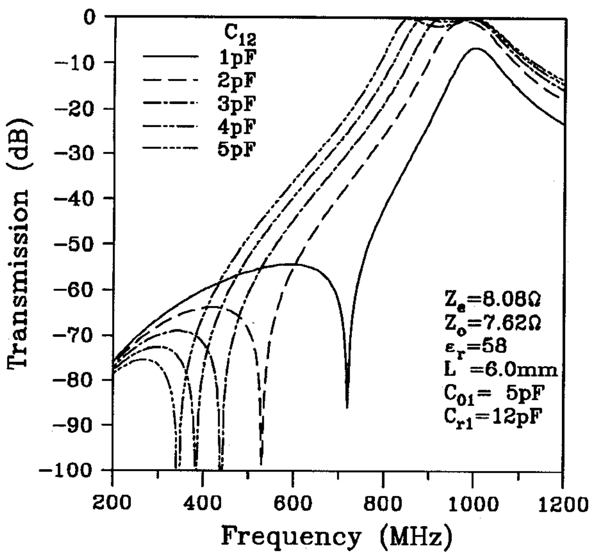
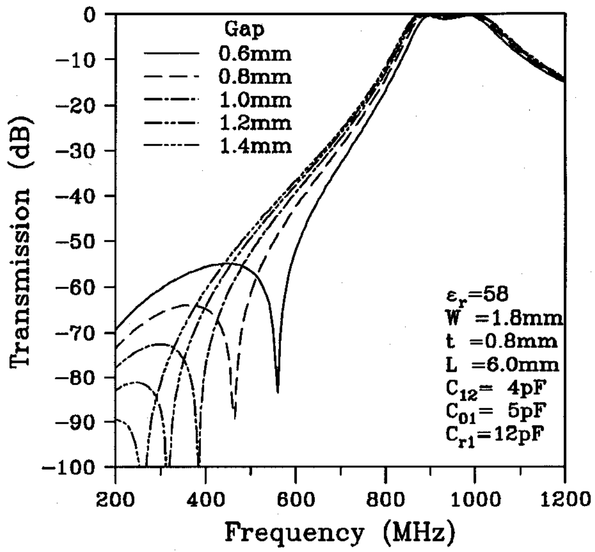


Fig.4 Equivalent circuit of planar filter



(a) transmissions for different coupling capacitors



(b) transmissions for different gaps between strip lines

Fig.5 Transmission characteristics
(calculated from even-odd mode impedances)

The pole frequency fp should be determined by the condition of the admittance between two ports being equated to zero :

$$2\pi f \tan\left(\frac{2\pi fl}{ck}\right) - \frac{Ze - Zo}{2Ze\,Zo\,C_{12}} = 0 \tag{7}$$

where l is the length of the strip line, c is the velocity of light, k is the propagation velocity ratio and C_{12} is the coupling capacitance. Then, the inter-resonator coupling is approximated by a parallel LC resonator at the frequency fp. By equating the admittance and its derivative to those of the equivalent circuit, capacitance C_3 and inductance L_3 is derived as

$$C_3 = \frac{Ze - Zo}{8\pi ZeZo}\left\{\frac{2\pi l}{ck\sin^2\left(\frac{2\pi fpl}{ck}\right)} - \frac{1}{fp\tan\left(\frac{2\pi fpl}{ck}\right)}\right\} \tag{8}$$

$$L_3 = \frac{2Ze\,Zo}{\pi fp^2\,(Ze - Zo)\cdot\left\{\frac{2\pi l}{ck\sin^2\left(\frac{2\pi fpl}{ck}\right)} + \frac{1}{f_p\tan\left(\frac{2\pi fpl}{ck}\right)}\right\}} \tag{9}$$

Next, the resonance frequency fo is calculated from a resonance condition of a resonator enclosed with the dashed lines shown in Fig.6. Thus, fo is determined as

$$2\pi f\left\{\frac{C_{01}}{1 + (2\pi fC_{01}/Go)^2} + C_3 + C_{12} + C_{r1}\right\} - \frac{1}{2\pi fL_3} - \frac{1}{Ze\tan\left(\frac{2\pi fl}{ck}\right)} = 0 \tag{10}$$

where C_{01} is the input/output coupling capacitance, G_0 is the source/load conductance, C_{r1} is the loaded capacitance. The strip line resonator is then represented by a parallel LC resonator in the proximity of fo. C_1 and L_1 are given by

$$C_1 = \frac{1}{4\pi Ze}\left\{\frac{2\pi l}{ck\sin^2\left(\frac{2\pi fol}{ck}\right)} - \frac{1}{fo\tan\left(\frac{2\pi fol}{ck}\right)}\right\} \tag{11}$$

$$L_1 = \frac{Ze}{\pi fo^2\left\{\frac{2\pi l}{ck\sin^2\left(\frac{2\pi fol}{ck}\right)} + \frac{1}{fo\tan\left(\frac{2\pi fol}{ck}\right)}\right\}} \tag{12}$$

The calculated results for the equivalent circuit with lumped elements is shown by the dashed line in Fig.7. The solid line is the transmission calculated from even-odd mode impedances. They are in excellent agreement.

CONCLUSION

A very small dielectric planar filter which has two planar resonators and is made of high permittivity multilayer ceramic has been developed. It is confirmed that the planar structure can be represented with lumped element circuit or ladder type circuit. The transmission calculated for the ladder type circuit shows excellent agreement with that calculated for the original structure. From the results, analytical design of planar filter is possible. The same planar configuration is adopted to a 1.9GHz filter, which exhibits 1.2dB insertion loss.

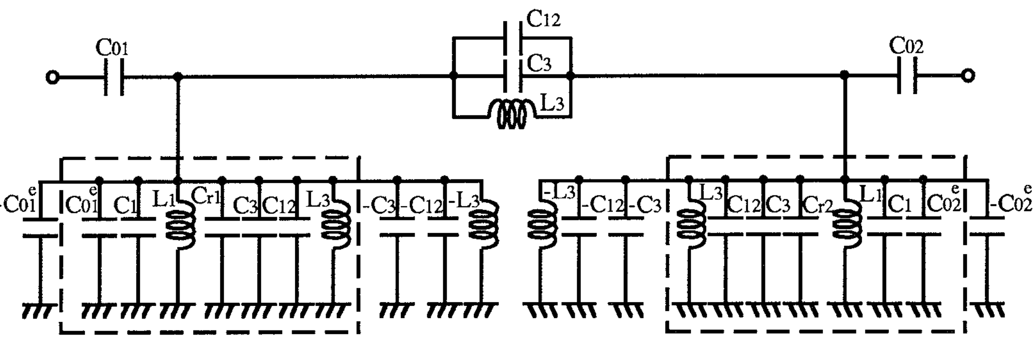


Fig.6 Equivalent circuit with lumped elements

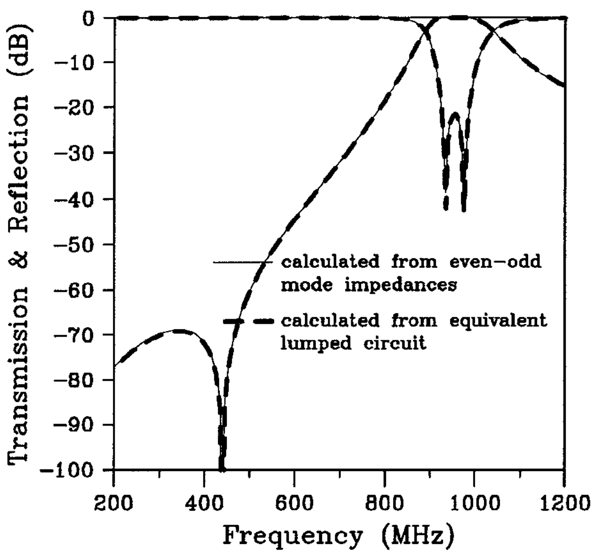


Fig.7 Transmission characteristics

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