Improvement of Characteristics Using Cross Patch in the LTCC Filter

Jun Hayashi[*] and Yoshio Nikawa[**]

[*]Soshin Electric Co., Ltd, 664-1 Sarukubo, Saku-si, Nagano, 385-0011, Japan,
E-mail: jhayashi@soshin.co.jp

[**]Graduate School of Engineering, Kokushikan University, 4-28-1, Setagaya, Setagaya-ku, Tokyo, 154-8515, Japan

***Abstract* — A TE_{10} mode dielectric LTCC (Low Temperature Co-Fired Ceramic) filter using the cross patch is proposed. The LTCC filter is designed by lumped circuit without cross patch. The filter is designed by lumped elements and convert to the LTCC filter. The characteristic of filter is simulated by Finite Element Method (FEM). The center frequency of the filter is 6GHz and the bandwidth is 500MHz. The simulated results of the filter is compared with the experimental ones. As the results, the simulation results agree well to the experimental ones. The LTCC filter using the same design procedure is applied to the one using the cross patch. This cross patch is useful making of the attenuation poles. It works as the TEM transmission in the LTCC filter. As the results, it realizes to obtain the attenuation pole. LTCC filter using the cross patch is designed at the center frequency of 25GHz.**

I. Introduction

Conventional microwave and millimeter wave filters have been used waveguide and microstrip lines. The defects of such waveguide filters are large in size, high in cost and hard in mounting. Furthermore, those of microstrip line filters are high insertion loss and therefore they cannot be used for high power. Thought, such filters have been applied only in the specific field. Recent popularization of the cellular phone needs a large quantity of filters. To apply in this field, it is necessary to develop filters in smaller, lighter and lower costs. Since frequency resources are limited, the frequency range will be expected to become higher in the future. In this study, to satisfy those demands, miniaturized waveguide filter using the LTCC is studied. Conventional technique of dielectric waveguide filter has small attenuation at higher frequency. The LTCC filter transmits TE_{10} mode and TEM mode. As the result, it realizes the attenuation pole, therefore high attenuation filter can be realized. The attenuation pole can be made at the position of the phase difference of two transmissions mode. The LTCC filter is simulated FEM at the center frequency of 25GHz.

II. Filter Design without Cross Patch

The first, a TE_{10} mode dielectric LTCC filter is designed without a cross patch. Then, the LTCC filter is designed including the cross patch. The LTCC filter can be designed smaller in size. The size of waveguide length becomes by filling dielectrics whose relative dielectric constant. Fig.1 shows the structure of the LTCC filter. This filter is made from green sheets and electric conductors (This study use green sheets has ε_r=80 of dielectric constant and Silver.). The LTCC filter is designed from the equivalent lumped circuit. The circuit is changed from the prototype low-pass filter to lumped band-pass filter as shown in Figs. 2. This equivalent lumped circuit is change to LTCC filter. For example, It change from Z_{01}/Z_0 or $Z_{n,n+1}/Z_0$ to width of input or output terminal and from Z_{02}/Z_0 to $Z_{n-1,n}/Z_0$ (coupling coefficient of resonators) to width of two via holes.

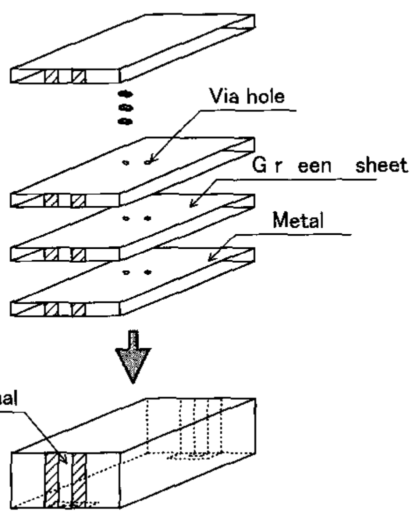

Fig. 1. Structure of filter using the LTCC.

0-7803-7695-1/03/$17.00 © 2003 IEEE

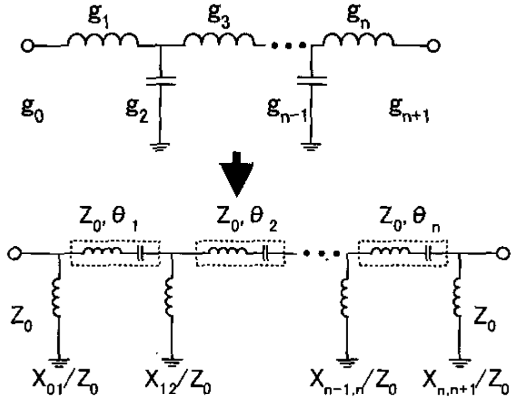

Fig. 2. BPF changed from normalized element value.

The design equations of the LTCC filter changed from the prototype low-pass filter to the lamped band-pass filter are shown below [1],[2].

$$\frac{K_{0,1}}{Z_0} = \sqrt{\frac{\pi}{2}\frac{\omega_\lambda}{g_0 g_1}} \quad (1)$$

$$\frac{K_{j,j+1}}{Z_0} = \frac{\pi\omega_\lambda}{2}\sqrt{\frac{1}{g_{j-1}g_j}} \quad \text{i : 1 to n-1} \quad (2)$$

$$\frac{K_{n-1,n}}{Z_0} = \sqrt{\frac{\pi}{2}\frac{\omega_\lambda}{g_{n-1}g_n}} \quad (3)$$

where $\omega_\lambda \approx \left(\frac{\lambda_{g0}}{\lambda_0}\right)^2\left(\frac{\omega_2 - \omega_1}{\omega_0}\right)$

$$Q_{e(01)} = \frac{g_0 \cdot g_1}{\omega_\lambda} \quad (4)$$

$$Q_{e(n,n+1)} = \frac{g_n \cdot g_{n+1}}{\omega_\lambda} \quad (5)$$

g_0 - g_n : Normalized element value
$K_{0,1}$ - $K_{n-1,n}$: Coupling coefficient
Z_0 : Impedance of waveguide
$\omega_0/2\pi$: Center frequency
$\omega_2/2\pi$ - $\omega_1/2\pi$: Bandwidth
λ_{g0} : Wave length of center frequency in the waveguide
λ_0 : Wavelength of center frequency in the freedom space wavelength

and

$$\frac{X_{j,j+1}}{Z_0} = \frac{\frac{K_{j,j+1}}{Z_0}}{1 - \left(\frac{K_{j,j+1}}{Z_0}\right)^2} \quad \text{j : 0 to n} \quad (6)$$

$$\theta_j = \pi - \frac{1}{2}\left[\tan^{-1}\left(\frac{2X_{j-1,j}}{Z_0}\right) + \tan^{-1}\left(\frac{2X_{j,j+1}}{Z_0}\right)\right]$$

[rad] j : 1 to n (7)

$$Lj = \frac{\theta_j \lambda_{g0}}{2\pi} \quad \text{j : 1 ~ n} \quad (8)$$

θ_j : $X_{j,j+1}$ Phase length in the waveguide
L_j : Resonator length

II. MODE CONVERSION

The LTCC filter on the microstrip line is shown in Fig. 3 (a). To excite TE_{10} mode directly in the dielectric loaded waveguide is usually difficult [3]. Microstrip line is applied to excite TE_{10} mode in the dielectric waveguide. The changing from TEM to TE_{10} mode transmission becomes surface terminal. The changing from TEM to TE_{10} mode transmission (electrical field distribution) is shown in Fig. 3 (b). The coupling coefficient is adjusted by the width (W) of surface terminals of side of dielectric resonator (see Fig. 3). The surface terminals are directly attached to the microstrip line. The model (Fig. 3 (a)) is simulated by the Finite Element Method (FEM) [4], and the simulated characteristics are shown in Fig. 4. As the simulation results, when width of surface terminals increase, the pass band is increased.

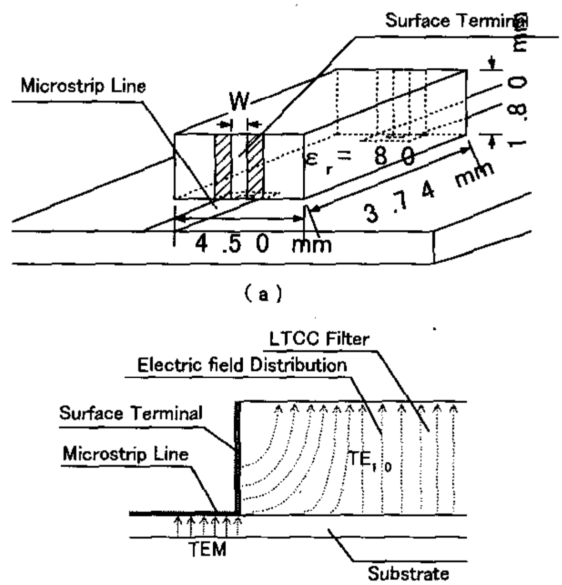

Fig. 3. Structure for exciting the TE_{10} mode.

The relation between the coupling value (External Q) and width of surface terminals depicted in Fig. 4 is shown in Fig. 5. Thus, the width of surface terminals (W) is determined by the eqs. (4), (5) using Fig. 5.

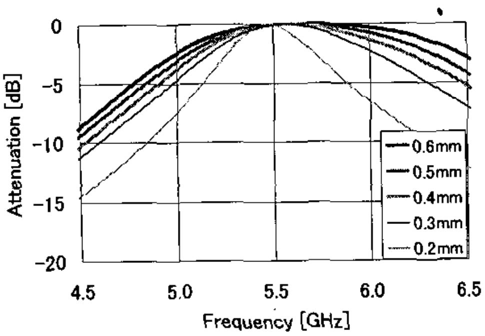

Fig. 4. Attenuation of the resonator.

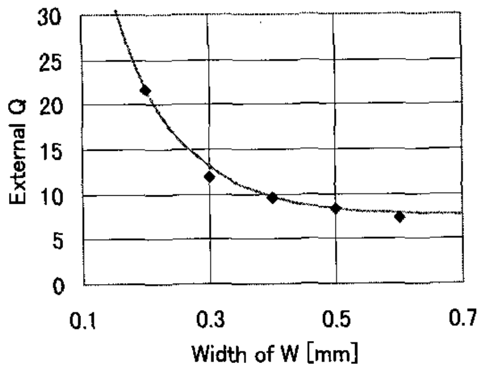

Fig. 5. Coupling coefficient of the resonator.

III. Evaluation of the LTCC Filter

Two-pole-filter was designed from the above method. The filter model is supposed using green sheets that has via hole, layering these sheets and they are co-fired at the same time (see Fig.1). The relative dielectric constant of the sheets is 80. The via hole has the diameter of 0.1 mm. All the exteriors are covered by metal, and interiors are made of layered structure. The dimension of the filter is shown in Fig. 6. A frequency characteristic of the LTCC filter is shown in Fig. 7 which is a result using FEM.

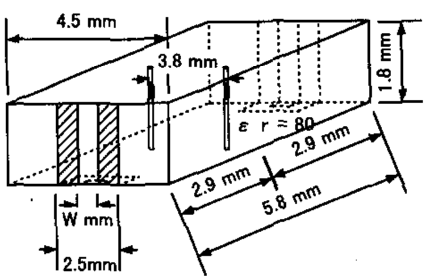

Fig. 6. Dimensions of LTCC filter.

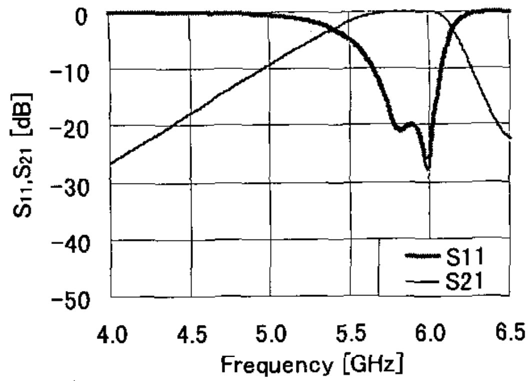

Fig. 7. Simulation caracteristics of LTCC filter.

The LTCC filter is experimented with this method and FEM simulation. Fig. 8 shows the picture model of the filter by using the LTCC technology. The frequency characteristics are shown in Fig. 9.

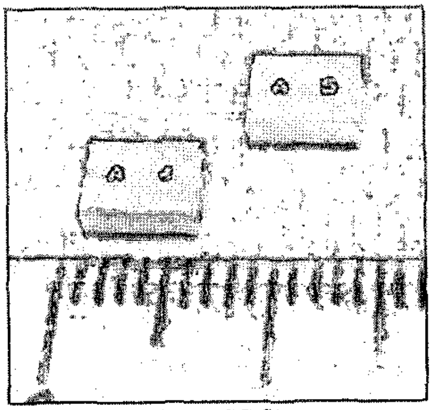

Fig. 8. The Picture of the LTCC filter.

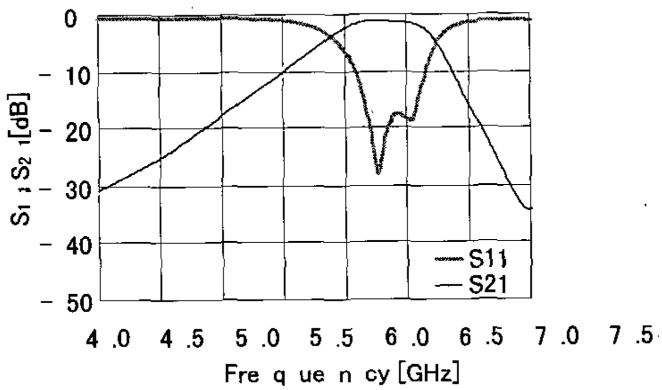

Fig. 9. Characteristics of the LTCC filter.

IV. Effects of Cross Patch

The cross patch is inserted in the TEM transmission between input and output terminal. The electromagnetic pattern is shown in Fig. 10. The magnetic field does not have an effect of TE_{10} mode transmission and the electric field has coupling between frequency control patch and cross patch. The cross patch has in parallel to the transmission of TEM and TE_{10} mode. The equivalent circuit of the structure is shown in Fig. 11.

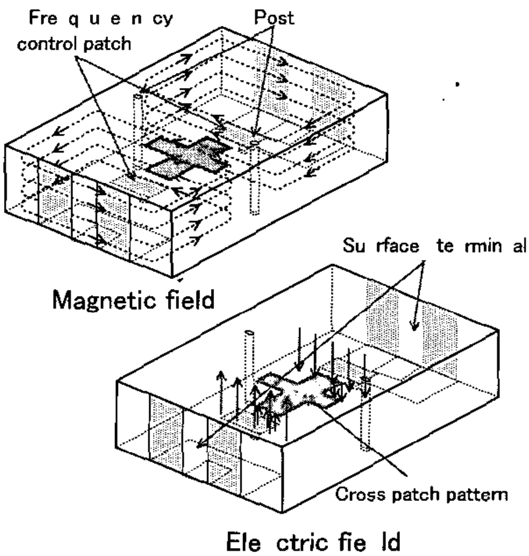

Fig.10. Electromagnetic field of LTCC filter.

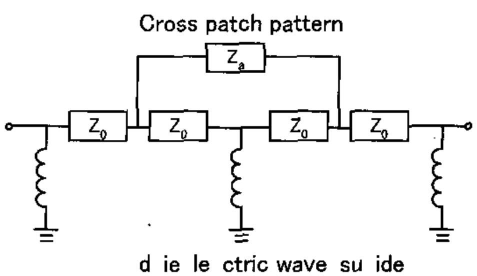

Fig. 11. Equivalent circuit of the LTCC filter.

This model is simulated by FEM and characteristics of transmission and reflection is shown in Figs. 12 and 13, respectively. From Figs. 12 and 13, it is found that the effect of cross patch generates the attenuation pole. The attenuation with cross patch becomes higher compared to the results one.

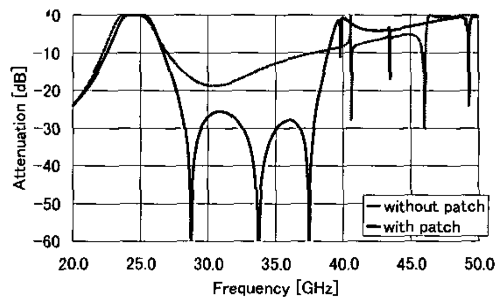

Fig.12. Characteristics of transmission.

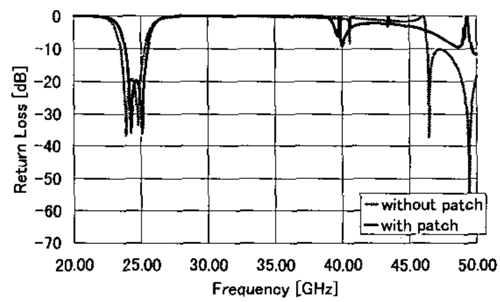

Fig.13. Characteristics of reflection.

V. Conclusions

It is found that using the LTCC, a microwave band-pass filter can be realized. Multiple layer structure can be realized by using the LTCC technology. Using this technique, smaller size microwave and millimeter wave filter can be composed. The proposal of the cross patch gives the attenuation pole in the LTCC filter. When multiple layer structure is applied, it is found that various microwave and millimeter wave devices can be miniaturized using dielectric loaded waveguide technology. Furthermore, the application of the cross patch in the LTCC filter can realize to obtain higher characteristic filter with high insertion loss in the stop band.

References

[1] G. Matthaei et al. ed., "Microwave filters, Impedance Matching Networks, and Coupling Structures", Artech, 1980.

[2] N. Marcuvitz ed., "Waveguide Handbook", McGraw-Hill, 1951.

[3] T.S. Chu, T. Itoh and Y. Shih, "Comparative study of mode-matching formulations for microstrip discontinuity problems," IEEE Trans. Microwave Theory Tech., vol. MTT-33, 10, pp.1018-1023, Oct. 1985.

[4] J. Jin, "The Finite Element Method in Electromagnetics", John Wiley & Sons, New York, 1993