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The control of electrical properties of multilayered LC-filter for 5 GHz applications

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Abstract The effects of design, material and process parameters on the electrical properties and microstructures of laminated LC-filter for 5 GHz applications are described in this paper. The center frequency of bandpass filter can be controlled by the length of loading capacitor and the attenuation characteristics of filter depend on the degree of coupling between resonators. The microstructure of internal electrode and ceramic body strongly depends on the firing condition. Also, the selection and handling of surface roughness of the internal electrode are important to improve the insertion loss.

Keywords 5 GHz · LC-filter · Center frequency · Attenuation · Coupling · Internal electrode

Introduction

Recently, the demand of laminated LC filter is increasing with the miniaturization and light weight of communication devices such as cellular phone, Bluetooth and W-LAN (wireless local area network). In particular, this filter is useful for high frequency (2.4 GHz, 5 GHz, etc.) applications. It is compact, low cost and suitable for mass-production in comparison with dielectric mono-block filter and SAW filter. Insertion loss of laminated LC filter is low in comparison with SAW filter and is similar with dielectric filter. However, the roll-off of laminated LC filter is not so good in comparison with other filters such as dielectric filter, SAW and F-BAW filter. Thus, many researches and developments [1–4] have been performed in order to improve the filter characteristics.

With the rapid increase of the amount of data transfer, application frequency band expands to the higher frequency region for wireless communication systems. The data transfer rate of W-LAN of 5 GHz is 5 times faster than that of 2.45 GHz. Because of excellent high frequency, laminated LC filters are widely used for W-LAN of 5 GHz. But, a few researches have been performed for laminated LC filter in the frequency region of 5 GHz and it is important to raise the unloaded Q by means of materials and filter design in this frequency range.

In this paper, the effects of design, material and process on the filter characteristics such as insertion loss, center frequency are investigated with observing microstructure of ceramic body and internal electrode.

Experiment

Material system of Al_2O_3-SiO_2-CaO-BaO (Thinkcera, Korea) is used for this band pass filter (BPF) and its relative permittivity is 6.8 with the quality factor Q (a inverse of dielectric loss) of 750 at 1 MHz. Figure 1 shows the manufacturing processes of laminating LC-filter. The ceramic powder and binder systems (binder, solvent, plasticizer and dispersant) were mixed in a ball mill for 24 h to make slurry with appropriate viscosity. The tapes were cast on a PET film using doctor blade method. Conductive silver paste was printed on a ceramic sheet with a 350 mesh screen. Properties of silver pastes are shown in Table 1.The next processes were followed by stacking, lamination, cutting and bake-out and firing. The samples were fired as a function of temperature (810–850°C) and time (2–6 h).

The microstructure analyses were accomplished using SEM (model JSM 6400, JEOL) and the surface roughness of a printed green sheet was measured with a Dektak ST (Sloan

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Table 1 Properties of silver pastes

Maker	Model no.	Metal content (%)	Viscosity
Namics	7251S	88.03	100,000 cps
Tanaka	TR-651CM	83.1	200,000 cps

Table 2 Typical filter requirement for 5 GHz W-LAN

Size (mm)	L × W × T = 2.5 × 2.0 × 1.0
Characteristic impedance (Ω)	50
Center frequency (MHz)	5487
Passband (MHz)	5150–5825
Insertion loss (dB)	1.2 Max (25°C) 1.5 Max (−30 −+80°C)
Return loss (dB)	10 Min
Ripple (dB)	0.8 Max
Attenuation (dB)	30 Min (3500–4000 MHz) 20 Min (4100–4300 MHz)

technology). Ra is the average surface roughness which is usually the most commonly used parameter in surface roughness measurement. Graphically, Ra is the area between the roughness profile and its center line divided by evaluation length. Filter characteristics were measured by network analyzer (model E5071A, Agilent).

Design, simulation and measurement

Typical filter requirements for 5 GHz W-LAN are given in Table 2. The dimension is 2.5.×2.0.×1.0 mm and the insertion loss is 1.2 dB Max within the passband (5150–5825 MHz). Figure 2 shows the structure of the laminated LC-filter consisting of six electrode layers. This filter is comb-line filter that consists of three stripline resonators smaller than a quarter-wavelength. The equivalent circuit of the proposed band pass filter is shown in Fig. 3. Input and output electrode are directly connected to the resonator 1 and resonator 3 respectively, creating the inductance L1 and L2. Three resonators which are placed side by side create inter-stage coupling capacitance C4, C4 and a bridge coupling capacitance C6. Three loading capacitors are disposed above and below the resonators layer, creating three loading capacitance C1, C2 and C3. In order to reduce the transmission loss, tapped Input and output transmission lines [6–7] are used, which enhances the magnitude of coupling at the input and output terminals. To make an attenuation pole in front of passband, the inter-resonator coupling is included through the coupling layer.

The procedure for estimation of reflection and insertion loss is as follows. Teflon which has very low loss is used as a test PCB board. Figure 4 (a)–(c) shows the measurement system consisting of network analyzer (HP, E5971A), through PCB for correction, and test PCB board. Before estimating the insertion loss (S21) and return loss (S11) as a function of frequency, standard two port calibration is performed at the end of port cable for measurement in order to diminish the error from measuring cable. After that, through PCB for correction is connected at the end of port cable. Its insertion

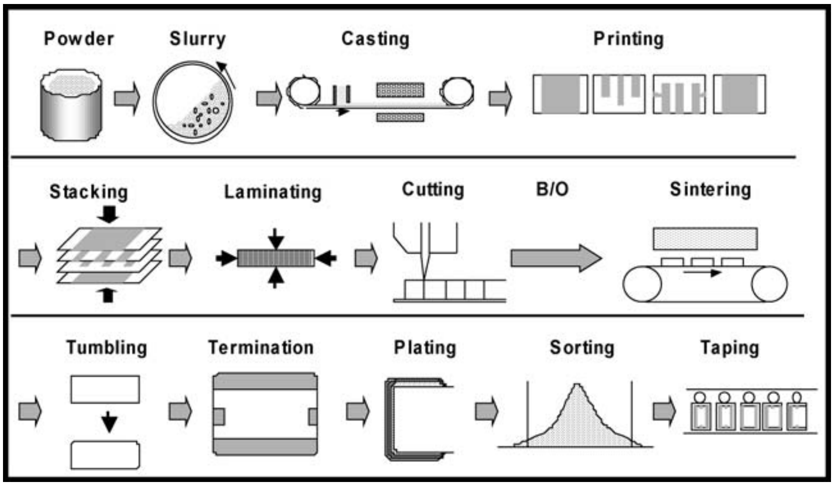


Fig. 1 Manufacturing processes of laminated LC filter

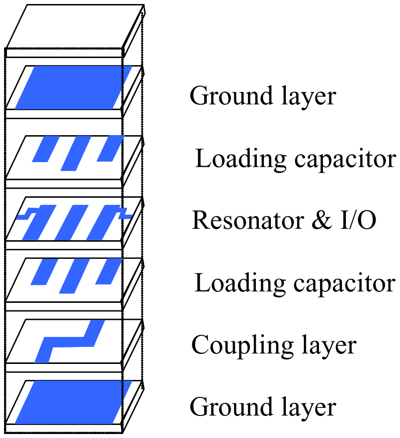


Fig. 2 Structure of the laminated LC filter

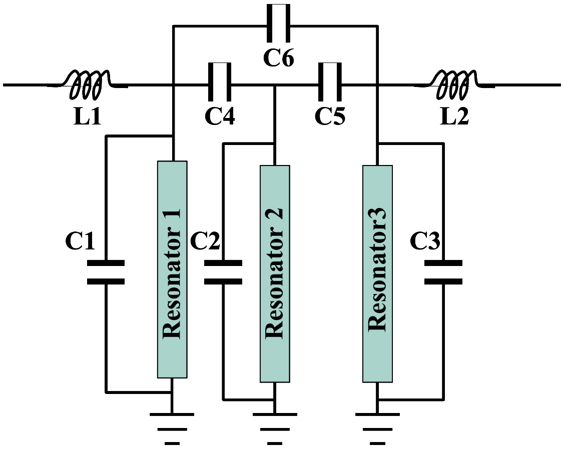


Fig. 3 Equivalent circuit of the laminated LC filter

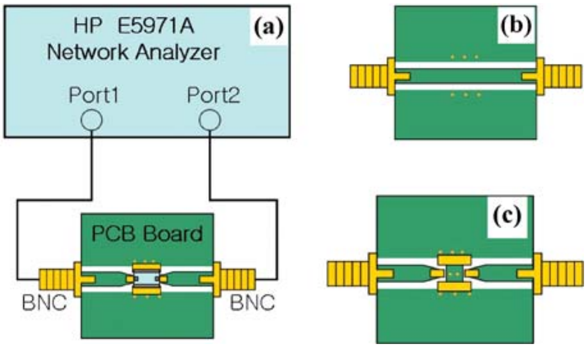


Fig. 4 The measurement system for insertion and return loss (a), through PCB board (b), and test PCB board (c)

and return loss are measured and memorized. The insertion and return loss of test PCB board including filter sample are measured. The insertion and return loss of filter sample are obtained by means of subtracting S21, S11 of through PCB from S21, S11 of test PCB board including filter sample respectively.

Simulations and optimization of the design were performed using commercial software packages (model Cerenade and HFSS, An-soft). Simulation procedure to design filters is as follows. The first step is to construct the equivalent circuit having appropriate filter type. After that, circuit parameters are guessed considering the required specifications and optimized by circuit simulator. 3-D simulator is used in order to obtain physical parameters. The simulated and measured filter responses are shown in Fig. 5.It should be noticed that measured (simulated) insertion loss and return loss are 1.01(0.62) dB and 18(16) dB within the passband. Attenuation near the passband satisfies the specifications in Table 1.

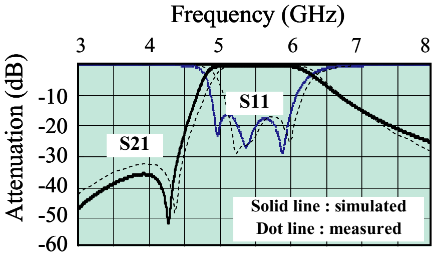


Fig. 5 Simulated and measured transmission and reflection characteristics. Simulated (measured) values are 0.62 (1.01) dB at 5150–5825 MHz, 36(33) dB at 3500–4000MHz, and 37(34) dB at 4000–4300 MHz for S21 respectively and 16 (18) dB within 5150–5825 MHz for S11

Results and discussion

Effect of loading capacitor on filter characteristics

It is important to control the center frequency exactly for mass production. Figure 6(a) shows the variation of center frequency and insertion loss as a function of the change of length (ΔX) for the loading capacitor. The original lengths of two side and a middle loading capacitors are 980 and 1090 um respectively as shown in Fig. 6(b). The center frequency and insertion loss decrease monotonically with increasing the length of loading capacitors. However, the frequency response (S21) within the passband remains nearly unchanged.

The effect of the dielectric thickness between a resonator layer and a loading capacitor layer on the position of an attenuation pole is investigated. Figure 7(a) shows the frequency response (S21, S11) for two different dielectric thicknesses of 60 and 90 um. As the dielectric thickness increases from 60 to 90 um, the first attenuation pole shifts to higher frequency and the second attenuation pole shifts to lower frequency, which improves attenuation at 4 GHz. The movement of attenuation poles is related with the magnitude of inductive (magnetic) coupling between stripline resonators. For stripline resonators, the section of short-end side is coupled mainly by magnetic coupling and the section of open-end side is coupled mainly by electric coupling. Thus, the inter-resonator coupling at the center frequency can be selected in either being inductive or capacitive by controlling the

Fig. 6 (a) Variation of center frequency and insertion loss as a function of the change of length (ΔX) for the loading capacitor and (b), the original lengths of two side and a middle loading capacitors, 980 and 1090 um respectively

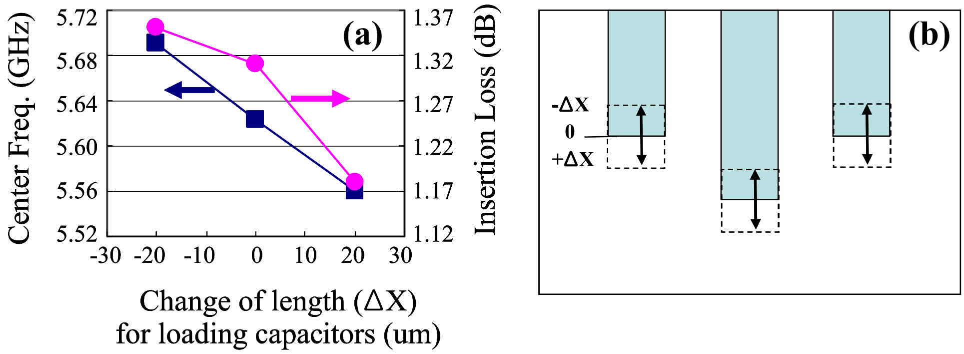
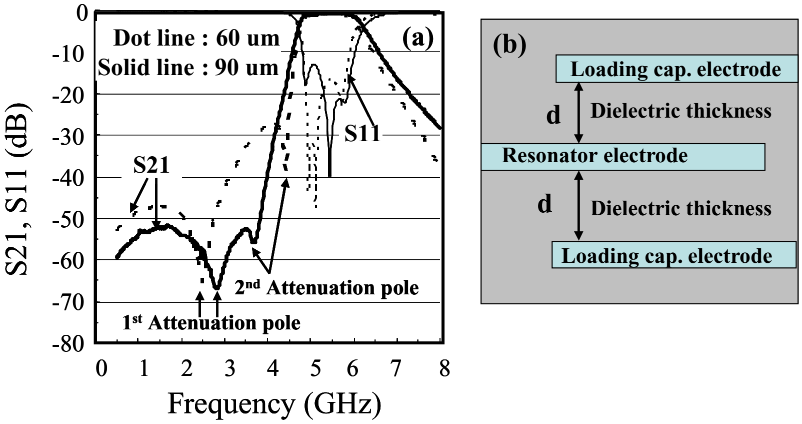


Fig. 7 (a) Transmission and reflection characteristics related with the dielectric thickness (d) between resonator layer and loading capacitor layer, and (b) schematic diagram showing stacking layers of two loading capacitors and a resonator



couplings of three stripline resonators independently. It becomes possible to control the position of an attenuation pole near the passband.

Effect of firing condition and conductive paste

The unloaded Q factor of stripline resonator is lower than that of co-axial resonator. The current at high frequency concentrates on the surface layer of the internal electrode. Thus, it is important to control the surface roughness and density of electrode layer for low loss at high frequency. Figure 8(a) and (b) show the fractured microstructures of the laminated LC filter fired under different conditions such as high temperature firing (850°C, 2 h) and low temperature firing (810°C, 6 h) using conductive silver paste of 7251S. The fractured surface of co-fired ceramic and electrode shows smaller size of pores and denser microstructure for low temperature firing compared to high temperature firing, which seems to be due to the trapped pore. Lower insertion loss was achieved in case of low temperature firing than high temperature firing. While the conductive layers have same thickness of 15 um before firing, the thickness of conductive layer decreases to 14.2 um for the high temperature firing and 11.3 um for the low temperature firing. The reason why the shrinkage for the high temperature firing is lower appears to be related with the earlier shrinkage of ceramic body before the binder gas

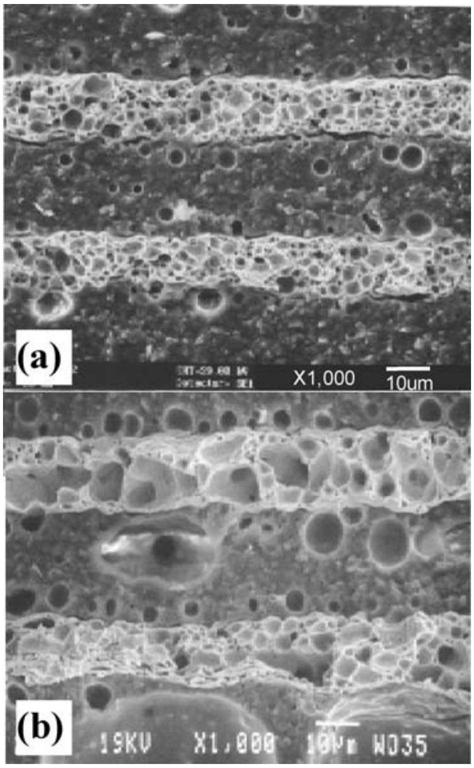


Fig. 8 Fractured microstructure of the laminated LC filter fired at these conditions; (a) 810°C, 6 h and (b) 850°C, 2 h. The magnifications of SEM micrograph are equally ×1,000 for Fig. 8(a) and (b)

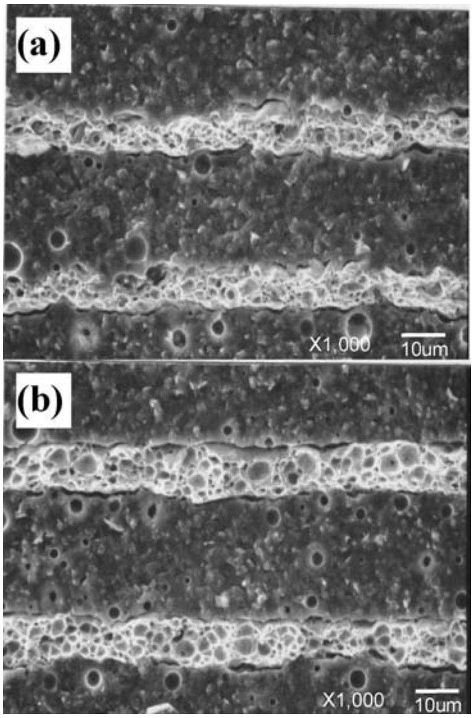


Fig. 9 Fired microstructures of the laminated LC filter manufactured with two conducting pastes of (a) TR-651CM, (b) 7251S. The magnification of SEM micrograph is ×1,000

escapes sufficiently from electrode. Therefore, it is necessary to reduce the porosity and surface roughness of internal electrode for achieving high Q and low loss.

The insertion loss depends on Q of the ceramic and electrode materials. The electrode material with low Q has greater influence on the insertion loss than ceramic material. Figure 9(a) and (b) show the microstructures of the laminated LC filter manufactured under the firing condition (810°C, 6 h) with different conducting pastes of 7251S and TR-651CM. It is shown that the surface roughness of 7251S paste is better than that of TR-651CM paste. The insertion loss of 7251S paste is lower in comparison with TR-651CM. The printed thickness and surface roughness (Ra) of printed layer is respectively 15 um and 3.72 um for 7251S, and 16 um and 3.55 um for TR-651CM. Both of these conductive paste layers are similar thickness of 11.3 um for 7251S and 11.2 um for TR-651CM before firing. But, surface roughness of electrodes is different in view of the analysis of microstructure. Therefore, the reason for good insertion loss for 7251S seems to be due to the difference of surface roughness and porosity of fired conductive layer.

Summary

From this study, the effects of design parameters, firing condition and conductive paste on the filter characteristics and microstructure were investigated. The center frequency can be obtained by controlling the length of loading capacitor. The dielectric thickness between the resonator and loading capacitor layer has a great influence on the position of attenuation poles. In order to obtain the dense microstructure with small pore, firing condition of low temperature and long time is more useful than that of high temperature and short time. It is important to select the conductive paste for the reduction of the insertion loss.

References

1. Ki-Mann, S.-K. Ko, D.-C. Park, and S.-Y. Hong, *Asia-Pacific Microwave Conference Proc.*, p. 809 (1997).
2. T. Ishizaki and T. Uwano, *IEEE MTT-S Digest*, p. 617 (1994).
3. T. Ishizaki, M. Fujita, et al., *IEEE Trans. Microw. Theory Tech.*, **42**(11), 2017 (1994).
4. T. Kitamura, M. Geshiro, et al., *IEICE Trans. Electron.*, **E81-C**(12), 1793 (1998).
5. J.S. Hong and M.J. Lancaster, *Electron. Lett.*, **31**(11), 891 (1995).
6. J.S. Hong and M.J. Lancaster, *Electron. Lett.*, **31**(24), 2085 (1995).
7. J.S. Hong and M.J. Lancaster, *IEEE Microw. Guided Wave Lett.*, **5**, 371 (1995).