λ/4 Hairpin 공진기를 이용한 2.4GHz 대역 LTCC 대역통과 여파기의 설계

(The Design of 2.4GHz Band LTCC Bandpass Filter using λ/4 Hairpin Resonators)

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Abstract

In this paper, a λ/4 hairpin resonator is proposed to reduce the size of planar resonators for a LTCC MLC bandpass filter. The λ/4 hairpin resonator operates as stepped impedance resonator (SIR) without changing the width of the planar resonator. It is composed of two sections those are parallel coupled line and transmission line. The characteristic impedance of two sections is different each other. The design formulas of the bandpass filter using the coupling element at the arbitrary position are derived from even and odd-mode analysis. The formulas can take account of the arbitrary coupling of lumped and/or distributed resonators. The advantage of this filter is its abilities to change freely the coupling structure between two resonators. Experimental bandpass filters for 2.4GHz Band are implemented and their performances are shown.

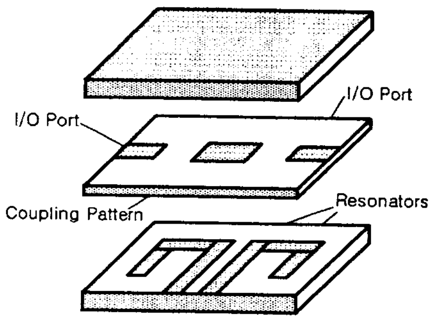
1. Introduction

As wireless network services developed rapidly, the need for compact, low-cost, and high performance filters is increasing. So far, coaxial and monoblock filters have been mainly used for mobile and wireless systems, but the miniaturization becomes marginal. Recently, LTCC MLC filters start to be used widely, the configuration of which is LC chip type or planar chip type.[1]-[3]

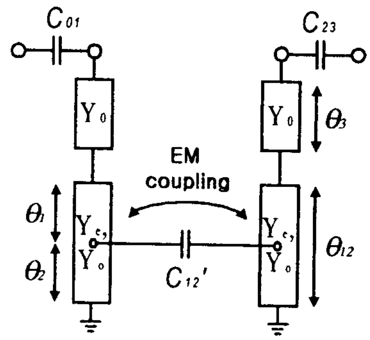
In this paper, a λ/4 hairpin resonator is proposed to reduce the size of planar resonators for a LTCC MLC bandpass filter. The λ/4 hairpin resonator operates as stepped impedance resonator(SIR) without changing the width of transmission resonators. It is composed of two sections those are parallel-coupled line and transmission line. The characteristic impedance of two sections is different each other. By using the π equivalent circuit for parallel-coupled lines, the equivalent circuit of the bandpass filter with λ/4 hairpin resonators can be expressed. And the electromagnetic coupling of the parallel coupled lines and the other coupling element at the arbitrary position of resonators can be transformed to an inverter between two resonators. The design formulas of the bandpass filter with λ/4 hairpin resonators are derived from even and odd-mode analysis and the design procedure is described.

2. Design

Fig. 1(a) shows the LTCC MLC bandpass filter configuration using $\lambda/4$ hairpin resonators. The equivalent circuit of the proposed filter is presented in Fig. 1(b). Each resonator is composed of parallel-coupled line and transmission line, the electrical length of which is θ_{12} and θ_3. The capacitors C_{01}, C_{23} make up the input and output coupling and the capacitor C_{12} and electromagnetic coupling between parallel-coupled lines make up the coupling between two resonators.



(a)



(b)

Fig. 1. (a) Structure of LTCC MLC bandpass filter using $\lambda/4$ hairpin resonators (b) Equivalent circuit.

In the equivalent circuit of Fig. 1(b), the symmetrical parallel-coupled lines can be analyzed by bisectional method.[4] There is a symmetrical reference plane in the parallel-coupled line structure as shown in Fig. 2(a). If the lines are excited by symmetrical voltages with respect to the plane, the characteristic admittance of the lines equals the even mode admittance Y_e. Thus the even mode input admittance of the coupled lines is as follows:

$$Y_{oc} = -jY_e \cot\theta \quad (1)$$

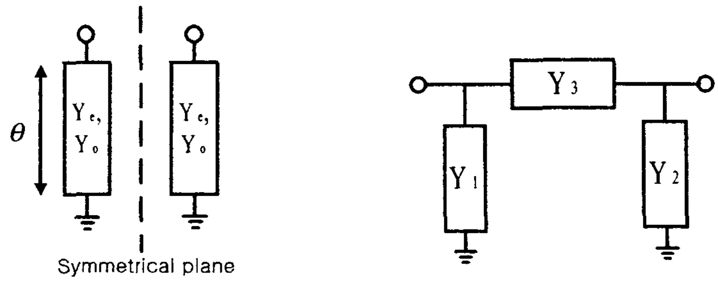
And, if the lines are excited anti-symmetrically with respect to the plane, the characteristic admittance of the lines equals the odd mode admittance Y_o. The odd mode input admittance of the coupled lines is as follows:

$$Y_{sc} = -jY_o \cot\theta \quad (2)$$

The elements of p equivalent circuit for parallel-coupled lines shown in Fig. 2(b) are as follows:

$$Y_1 = Y_2 = Y_{oc} = -jY_e \cot\theta \quad (3)$$

$$Y_3 = \frac{Y_{sc} - Y_{oc}}{2} = -j\frac{Y_o - Y_e}{2}\cot\theta \quad (4)$$



(a) (b)

Fig. 2. (a) 2-port parallel-coupled lines, (b) π equivalent circuit.

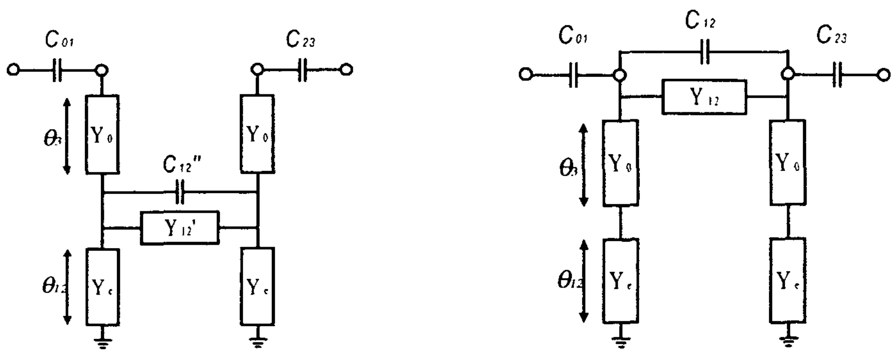
By using the π equivalent circuit for parallel-coupled lines, the equivalent circuit of proposed bandpass filter with $\lambda/4$ hairpin resonators can be expressed as shown in Fig. 3(a). The series element of π equivalent circuit is given as follows:

$$Y_{12}' = -j\frac{Y_o - Y_e}{2}\cot\theta_{12} \quad \theta_{12} = (\theta_1 + \theta_2) \qquad (5)$$

In order to convert an inverter between resonators, C_{12}' of Fig. 1(b) can be transformed to C_{12}'' [5], as shown in Fig. 3(a), which is given by:

$$C_{12}'' = \frac{Y_o C_{12}'(\tan\theta_1 + \cot\theta_1)}{(\cot\theta_1 + \cot\theta_2)(Y_o + Y_o\tan\theta_1\cot\theta_2 - 2\omega C_{12}'\tan\theta_1)} \qquad (6)$$

In Fig 3(a), each resonator is made up of two sections of a transmission line, the characteristic admittances of which are Y_0 and Y_e. And coupling elements are composed of Y_{12}' and C_{12}''. The circuit of Fig. 3(a) can be transformed again to a new equivalent circuit, as shown in Fig. 3(b). The relations between elements of two circuits can be derived from even and odd-mode analysis.[5] The capacitance of coupling capacitor and the admittance of series coupling stub of Fig. 3(b) are calculated by following equations:



(a) (b)

Fig. 3. (a) Equivalent circuit of LTCC MLC bandpass filters including π equivalent circuit (b) Equivalent circuit with an inverter composed of two elements, C_{12} and Y_{12}.

$$C_{12} = \frac{Y_0^2 C_{12}''(1+\tan^2\theta_3)}{(Y_0 + Y_o\cot\theta_{12}\tan\theta_3)(Y_0 + Y_o\cot\theta_{12}\tan\theta_3 - 2\omega C_{12}''\tan\theta_3)} \quad (7)$$

$$Y_{12} = \frac{Y_0^2 Y_{12}'(1+\tan^2\theta_3)}{(Y_0 + Y_e\cot\theta_{12}\tan\theta_3)(Y_0 + Y_e\cot\theta_{12}\tan\theta_3 + j2Y_{12}'\tan\theta_3)} \quad (8)$$

Therefore, each resonator of the proposed bandpass filter becomes a stepped impedance resonator(SIR), equivalently, without changing the width of transmission lines. In Fig. 3(b), the input admittance of resonators, Y_i is given as follows [6]:

$$Y_i = jY_0\frac{Y_0\tan\theta_{12}\tan\theta_3 - Y_e}{Y_0\tan\theta_{12} + Y_e\tan\theta_3} \quad (9)$$

The resonance condition from Y_i=0 can be described as follows:

$$\tan\theta_{12}\tan\theta_3 = \frac{Y_e}{Y_0} = R_Z \quad (10)$$

where R_Z is impedance ratio. The electrical length of resonator is given as follows:

$$\begin{aligned}\theta_T &= \theta_1 + \theta_2 + \theta_3 = \theta_{12} + \theta_3 \\ &= \theta_{12} + \tan^{-1}\frac{R_Z}{\tan\theta_{12}}\end{aligned} \quad (11)$$

The design procedure for the bandpass filter using $\lambda/4$ hairpin resonators is as follows:

1) Choosing Z_e, θ_{12} and R_Z, we can determine θ_3 and Z_0 by Eq. 10 and 11,

2) J-inverter, J_{12} can be calculated from the design specification,

3) C_{12} and Y_{12} is determined by the notch frequency, w_p and following equation:

$$J_{12} = |\omega C_{12} - jY_{12}|$$

4) C_{12}' and Y_{12}' can be calculated by Eq. 6, 7 and 8 and then, Z_o is determined by Eq. 5. Then, we can determine the width and gap of parallel-coupled lines from the even and odd impedances.

3. Results and Discussion

The second-order LTCC MLC bandpass filter using $\lambda/4$ hairpin resonators is designed at the center frequency of 2.45Ghz. The bandwidth is 100Mhz with a ripple level of 0.1 dB. The relative permittivity of the substrate is 32, Z_0 is set to 17.42Ω, R_Z is set to 0.63 and θ_{12} is set to 29.3°. The design parameters are calculated by using the procedure of the previous chapter. The simulated and measured frequency responses are shown in Fig. 4. The center frequency and the bandwidth of measured results satisfy the requirement specification. The insertion loss and return loss are 1.7dB and 17dB each at the center frequency. The measured result agrees well with the simulated result. The dimension of the filter is 2.5*2.0*1.0 ㎣.

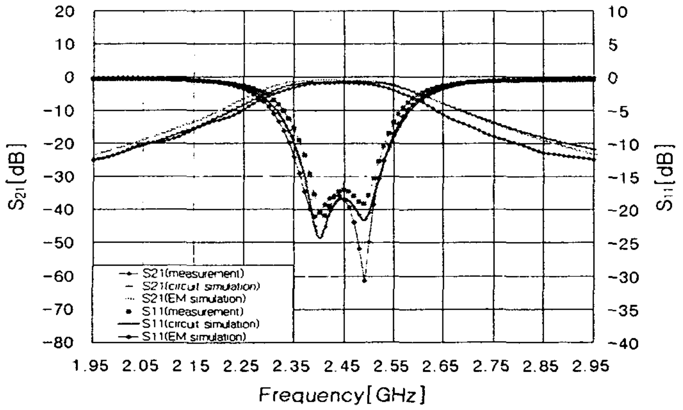


Fig. 4. Simulated and measured frequency response

4. Conclusion

The design procedure for the LTCC MLC bandpass filter using $\lambda/4$ hairpin resonators was presented. It is confirmed that the proposed planar structure can be represented as a prototype bandpass filter with inverter. The $\lambda/4$ hairpin resonator with uniform line width has characteristics of stepped impedance resonators, equivalently. Therefore it reduces the size of resonators less than uniform impedance resonators. The measured performance of the filters exhibited good agreement with the simulated results.

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