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Multi-strip LTCC resonator BPF

Ikuo Awai[1a)], **Yusuke Maeda**[1], **Daisuke Hanatani**[2], **and Masahiro Fujimoto**[2]

[1] *Department of Electronics and Informatics, Ryukoku University, Yokotani, Seta-oecho, Otsu, 520–2194, Japan*

[2] *Hirai Seimitsu Kogyo Corporation Yokosone, Ohgaki, 503–0944 Japan*

a) *awai@rins.ryukoku.ac.jp*

Abstract: Multi-strip resonator BPF is fabricated in the LTCC configuration. The center frequency is 3.5 GHz, fractional bandwidth is 0.1 and 3-stage Chebyshev type is designed. The relative permittivity of the ceramic is 18.3, resulting in the size as small as $2.3 \times 1.6 \times 0.73$ mm. The in-band loss is 3.5 dB, which could be reduced in the stable mass production state. The spurious suppression of more than 30 dB is attained up to the frequency higher than 10 GHz.

Keywords: LTCC, BPF, multi-strip resonator, interdigital configuration, artificial dielectrics

Classification: Microwave and millimeter wave devices, circuits, and systems

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1 Introduction and concept of multi-strip resonator

An artificial dielectric resonator is made of metal strips in the supporting material. One of the present authors has clarified that its large effective permittivity helps to miniaturize the resonator drastically [1, 2, 3]. Since the effective permittivity is proportionate to the polarization of each metal strips, density of metal strips is a key parameter to realize a large permittivity. There is another factor, however, to determine the permittivity, which is the alignment of metal strips. Strong mutual coupling also increases the permittivity quite an amount.

This principle has been diverted to the multi-strip resonators [4, 5], which are made of several metal strips. When we increase the number of strips from one, we do not rely on the concept of material constants, i.e. permittivity or permeability, but the resonant frequency of the coupled strips.

It is well known that the resonant frequency of two identical resonators split into two, when they are coupled. The amount of splitting becomes the larger as the coupling is stronger, which makes the split lower resonant frequency even lower and the higher frequency higher. Now, one can choose the lower one as the fundamental mode and make the higher one, the spurious mode, as high as possible.

Increasing the number of strips, the frequency of the fundamental mode decreases further, and hence, the length of the resonator can be reduced more on condition that the resonant frequency is kept constant. In addition, there is a good side effect in this procedure. The conductor loss decreases, in other words, the unloaded Q increases due to the division of the conduction current into multi-strips [6].

Mutual coupling between strips is controlled by their alignment. According to our analysis for artificial dielectrics, the face-centered tetragonal configuration gives the largest effective permittivity [7]. Therefore we will choose the interdigital alignment for the multi-strip resonator, instead of combline counterpart that corresponds to the simple tetragonal configuration for the crystal structure.

The main issue for the present paper is the implementation of the multi-

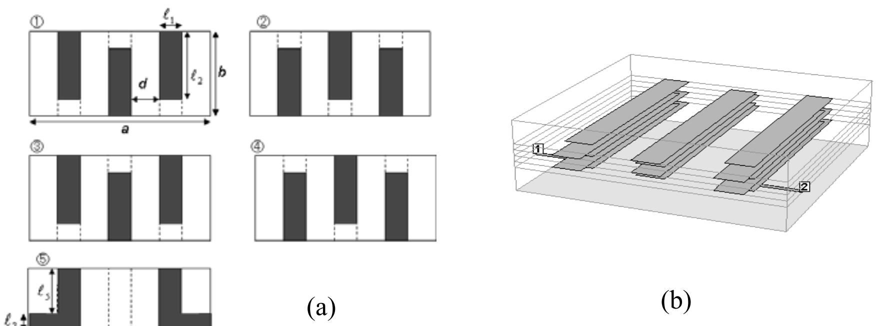

Fig. 1. Structure of 3-stage multi-strip resonator BPF: (a) metal pattern for each layer, (b) rough sketch of configuration

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strip resonator BPF in the LTCC structure. Since discussions on miniaturization, conductor Q and spurious characteristics of the resonator have already been given in the previous paper [6], coupling coefficient and external Q will be obtained for the preparation of BPF design. Then, we will design and fabricate 3-stage BPFs made of 4-strip resonators as shown in Fig. 1. Figure 1 (a) depicts the metal pattern for each layer, while Fig. 1 (b) shows the rough sketch of the fabricated BPF. The resonators are in the interdigital alignment. It will be measured and compared with the simulated result.

2 Coupling coefficient and external Q

Aiming at a miniaturized BPF, we will fabricate it in an LTCC (Low Temperature Co-fired Ceramics) structure. The dielectric sheet has the permittivity 18.3, tan $\delta = 0.005$, and the thickness 0.08 mm. In order to design the fractional bandwidth of a BPF, the coupling coefficient between resonators is to be known. It changes versus the distance of resonators as well as the number and spacing of strips. But, in Fig. 2 (a), only the dependence on the lateral distance of resonators is numerically calculated using Sonnet for the design of LTCC BPF. It is noted that larger distances give smaller coupling coefficient.

Figure 2 (b) shows the external Q as functions of the shift of excitation point of the external line with the resonator, taking the number of strips as 4. The length l_5 is changed in Fig. 1 (a). The strength of coupling with the external circuit, the reciprocal of Q_e, changes from 0.05 to 0.1.

Because of the energy confinement between multi-strips, small external Q is hard to realize for the present resonator. Strong coupling is attained by the direct connection of the external circuit, though the lowest Q_e is still as large as 9.8. Thus, the matching condition is somehow fulfilled for up to the fractional bandwidth 0.1.

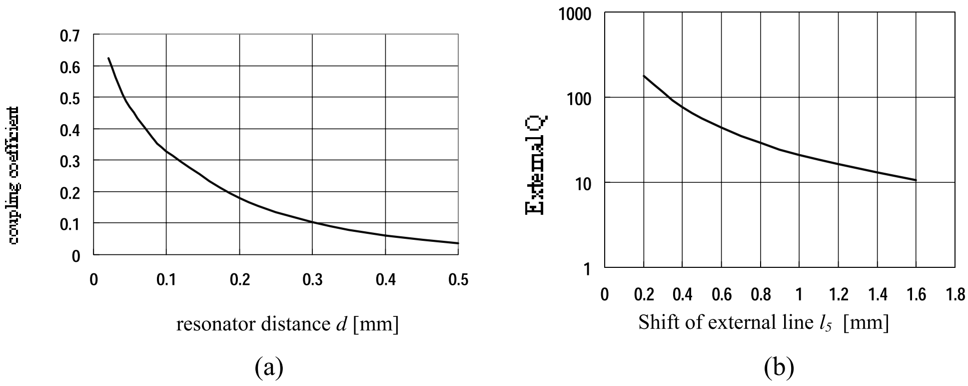

Fig. 2. Coupling coefficient and external Q of multi-strip resonator shown in Fig. 1 (a) coupling coefficient, (b) external Q

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3 Design of LTCC bandpass filter

The number of strips is taken to be 4 and the number of resonators is 3. A rough sketch of the designed BPF is shown in Fig. 1.

The coupling coefficient is calculated to comply with the required fractional bandwidth as functions of resonator distances as shown in Fig. 2 (a). It varies from 0.8 to 0.04 according to the distance between resonators d. Since the narrow bandwidth needs weak coupling, the distance d and hence the total size of BPF may increase to an unacceptable level. For those cases, a special measure such as shielding via holes may be introduced to control the coupling.

The means for attaining the circuit matching are proper control of external Q adjusting the location of external lines as shown in Fig. 1 (a). It also varies by around 20 times according to the external line location, which suggests the possibility of wide matching range. The designed center frequency and fractional bandwidth are 3.5 GHz and 0.1, respectively. The dimensions of the BPF are determined to realize those values consulting with Fig. 2 (a) and (b). The filter type is Butterworth.

4 Simulated and experimental results

An E/M simulator Sonnet is used to calculate the frequency characteristics of the BPF designed above. The first simulated result has shown a poor behavior. The reason could be many neglected effects in the design, e.g. jump coupling between 1st and 3rd resonators, parasitic capacitances to the side walls and the frequency shift due to the external circuit connections. A trimming has been carried out in a trial-and-error manner using Sonnet, and we have obtained the dimensions that gives a reasonable simulation result as shown in Fig. 3 (a). The maximum dimensional change from the original design was around 10%.

The following data have been transferred to Hirai Seimitsu Corp. for trial production; Referring Fig. 1 (a), $a = 1.88$ mm, $b = 1.78$ mm, $c = 0.65$ mm, $d = 0.36$ mm, $\ell_1 = 0.2$ mm, $\ell_2 = 1.6$ mm, $\ell_3 = 0.04$ mm, $\ell_4 = 0.28$ mm, $\ell_5 = 1.46$ mm. The shrinkage of the green sheets has been taken into account

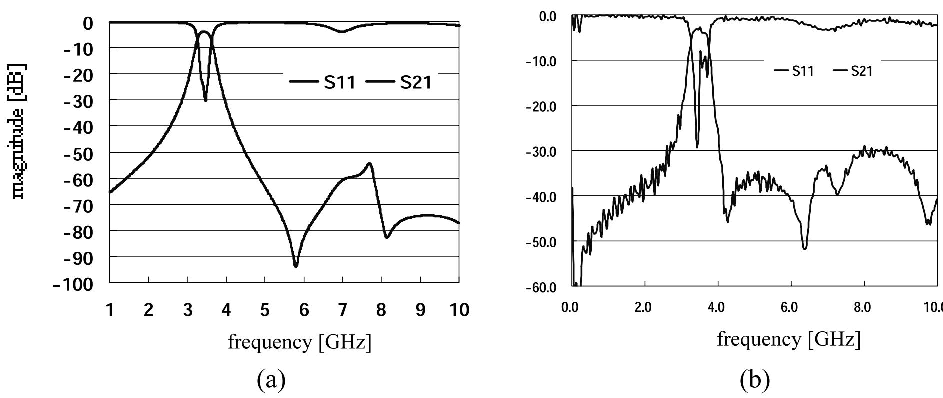

Fig. 3. Simulated and measured results for LTCC BPF (a) simulation (b) measurement

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in advance. The total dimension is $2.3 \times 1.6 \times 0.78$ mm, which is sufficiently small for 3-stage BPF.

The measured result for one of the samples is shown in Fig. 3 (b), a satisfactory result for the first trial. The center frequency is not deviated, the fractional bandwidth is 1.3 times of the design and the insertion loss is 1.5 times of the simulation. Though the out-of-band characteristic is deteriorated than the simulation in Fig. 10, it is still under −30 dB up to 10 GHz or more.

5 Conclusion

Since we verified the possibility of miniaturization, loss reduction and improvement of spurious characteristics of the multi-strip resonators [6], we have fabricated a 3-stage BPF using them in the LTCC configuration by way of trial. The result was quite satisfactory as the first trial. We will analyze the reason of the discrepancy from the design and try to improve the total behavior of the new LTCC BPF.

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