

Multi-strip Resonator BPF with Extended Spurious Suppression in LTCC Structure

-Proposal of New Concept to Suppress Spurious Response in BPF-

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Abstract — A new comprehensive method to suppress the spurious modes in a BPF is proposed taking the multi-strip resonator BPF as an example. It consists of disturbing the resonant frequency, coupling coefficient and external Q of the higher-order modes at the same time. The designed example has shown an extraordinarily good out-of-band responses in the computer simulation.

Index Terms — Multi-strip resonator, BPF, LTCC structure, Spurious suppression.

I. INTRODUCTION

A Multi-strip resonator is composed of $\lambda/4$ metal strips facing each other with broad-side coupling in the interdigital configuration (Fig.1). The strong coupling between metal strips split the resonant frequency so wide that the lowest mode frequency goes down significantly to even 1/10 of the original value. Therefore we can use the lowest mode as the dominant mode for a BPF that is to be miniaturized, whereas other split higher modes constitute spurious modes that should be suppressed.

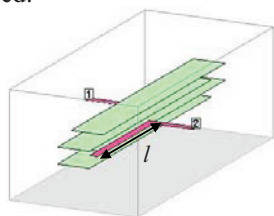


Fig.1. Structure of 4-layered multi-strip resonator (Excitation line is of L-shape and shorted at end)

Our recent investigation has revealed quite interesting characteristics on the resonant frequency, coupling coefficient and external Q of the multi-strip resonator. We have already reported on a new multi-strip resonator BPF with good spurious response based on the big difference in the coupling coefficient for the dominant mode and the spurious modes [1], [2]. But it has only utilized part of the unique characteristics in the multi-strip resonator. Thus, we will comprehensively make use of the knowledge on a multi-strip resonator to suppress the spurious modes. The main idea of the present method is that we design a BPF exactly, using the dominant mode, whereas we design the BPF destructively for the

spurious modes. In order to follow the procedure, it would be required to obtain the resonant frequency, coupling coefficient and external Q for the spurious modes as well as for the dominant mode. All the calculations are carried out with an electromagnetic field simulator HFSS.

II. DESIGN OF PASS BAND AND SPURIOUS BANDS

The fundamentals of BPF design are summarized in Table 1 by referring to the parameters to be determined. The operating conditions of a BPF in the left column determines the parameters of each resonator constituting the BPF in the right column.

Table 1 Correlation of parameters between BPF and resonators

| BPF | Resonators |
|--------------------------------|----------------------|
| Operating frequency | Resonant frequency |
| Bandwidth | Coupling coefficient |
| Matching with external circuit | External Q |

The BPF design is usually carried out using the dominant mode of resonators to form the pass band, while the higher modes form spurious bands even if they are not optimally designed. The present proposal is to design the spurious bands as poor as possible intentionally, and delete those bands substantially.

In order to do that, we need to find the resonant frequency, coupling coefficient and external Q for the relevant resonant modes, including the spurious as well as dominant modes.

(1) Resonant frequency

The resonant frequency of each resonator constituting a BPF is made basically the same except small deviations due to the difference of coupling between the adjacent resonators. Thus, it will be appropriate to deviate the resonant frequency of higher order modes in the spurious bands. Though the best choice to arrange the frequency is not known for now, the frequency should be different each other, at least. The way of changing the higher order mode frequency, while keeping the dominant mode frequency the same, depends on the types of resonator. An example will be shown in the next section.

(2) Coupling coefficient

According to the insertion loss method for the filter design, the coupling coefficient between resonators is specified depending on the number of resonators, fractional bandwidth and the type of BPF such as maximally flat, Chebyshev, and so on. While the dominant mode should obey the design rule, the higher order modes should couple each other weakly or irregularly. Though it is not known what irregularity is best for now, the low coupling coefficient as possible should be fine for the spurious mode suppression at least.

(3) External Q

The external Q is the last parameter for the design of a BPF. After deciding the resonant frequency and coupling coefficient of each resonator, Q_e is chosen to match the BPF with the external circuits. Now, Q_e for the higher order modes should be irregular, again. "How irregular?" is the problem. Under the condition that the best solution is not known, it will be safe to choose the lowest coupling of the higher order modes to the external circuits, highest Q_e at least.

This concept could also be applied for the other types of BPFs in the micro-stripline, coplanar line, waveguide resonators or even dielectric resonators.

III. BASIC PROPERTIES OF MULTI-STRIP RESONATORS

Before going to the design of a BPF, it may be appropriate to know the main features of the resonant frequency, coupling coefficient and external Q of a multi-strip resonator.

(1) Resonant frequency

The resonant frequencies are shown in Figs.2(a) and (b) for 4-layered and 6-layered resonators, respectively. It is observed that the originally identical resonant frequency of each strip split into the different values with the same number as that of the strips, and they go apart as the strips come closer.

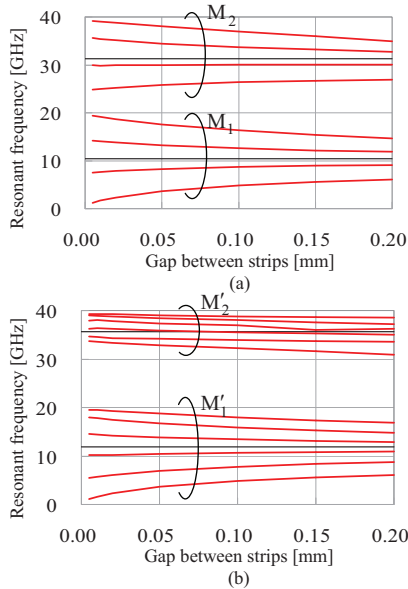


Fig.2. Resonant frequency vs gap between strips (a) 4-layered resonator (b) 6-layered resonator

Since the multi-strip resonator is composed of $\lambda/4$ strips, the original resonant frequencies of each strip are roughly $f_0, 3f_0, \dots, (2n-1)f_0, \dots$. Therefore the split modes make a family around the frequency $(2n-1)f_0$. The mode name M_{ij} thus mean j -th mode in i -th family. Furthermore M_{ij} in Fig.2 stands for 4-layered resonator and M'_{ij} for 6-layered resonator. As is known from Fig.2, the resonant frequency of higher-order modes may be made different in the resonator with different number of metal strips even when keeping that of the dominant mode the same. In addition, there is another method of changing the width of metal strips for adjacent resonators without changing the number of strips, which is not detailed here, though.

(2) Coupling coefficient

Coupling coefficient between adjacent multi-strip resonators is numerically calculated and shown in Figs.3(a) and (b) for 4-layered and 6-layered resonator, respectively. The dominant mode M_{11} demonstrates strong coupling up to 0.3 of the coupling coefficient and it would decrease monotonically to as low as less than 0.01 if one makes the distance larger. This variation range is satisfactory for designing a reasonably wide variety of bandwidth.

The coupling coefficient for the higher-order modes, on the other hand, are far smaller than that for the dominant mode. The reason for this difference is due to the difference in the balance of magnetic and electric coupling for each mode. In the dominant mode, the magnetic coupling dominates, whereas both couplings cancel each other for the higher order modes [2]. They will be suppressed except M_{14} by carrying out the standard design to the dominant mode without considering the higher modes. Since the coupling coefficient of M_{14} is only 1/8 as small as that of M_{11} , its suppression could be hard.

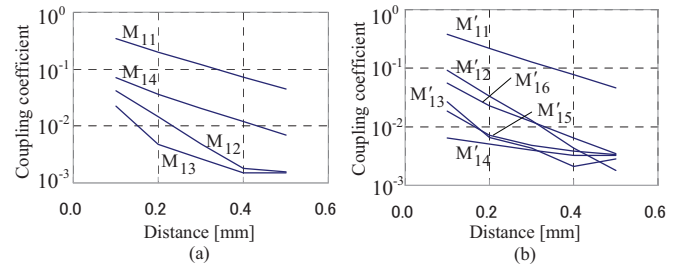


Fig.3. Coupling coefficient vs lateral distance between two resonators

(a) 4-layered resonator (b) 6-layered resonator

(3) External Q

External Q is designed to match the BPF with the external circuit. The calculated Q_e is shown in Fig.4 as functions of the extended line length l in Fig.1. Though it should correspond to the coupling coefficient of M_{11} for good BPF matching, Q_e for M_{14} and M'_{16} should be quite different from the good matching for the spurious modes. Since the value for M_{14} , M'_{16} vary with a big extent in Fig.4, we may be able to make use of it.

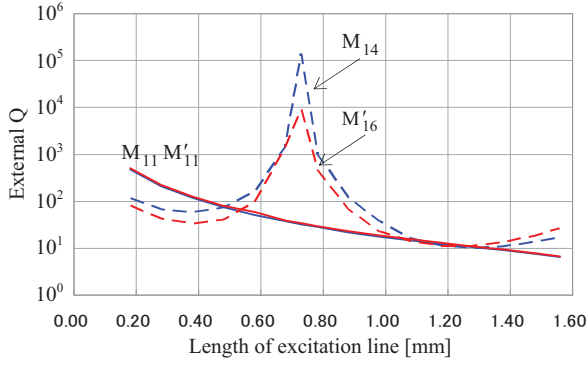


Fig.4. External Q of M_{11} , M'_{11} , M_{14} and M'_{16} modes vs length l of excitation line

IV. CONTROL OF RESONANT FREQUENCY AND EXTERNAL COUPLING COEFFICIENT

For the multi-strip resonators, the coupling coefficient between resonators is almost close to the ideal condition, in other words, it is strong for the dominant mode while it is weak for the higher-order modes, and thus, the other two parameters mentioned in §2 will be studied here so as to improve the out-of-band property.

(1) Resonant frequency

If one equates the resonant frequency of each dominant mode M_{11} and M'_{11} for 4 and 6 layered resonators by adjusting the overlapping dimensions of each resonator, the other spurious modes such as M_{12} , M_{13} get dispersed as shown in Fig.5. The effect of the frequency detuning has not been studied for the spurious band suppression so far. Even if a certain mode is detuned, its E/M field may skip the resonators to be detected at the output. Therefore, combinational study with the coupling coefficient could be more effective. But we will simply examine the effect of frequency detuning alone in the next section.

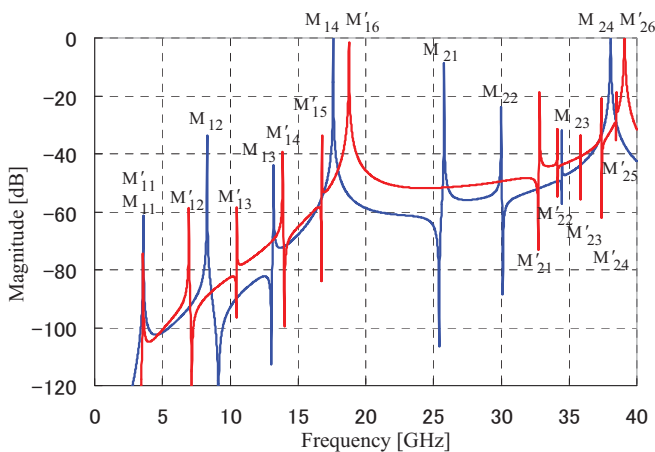


Fig.5. Resonant frequency of higher-order modes in 4 and 6 layered resonators with condition of same dominant mode frequency

(2) External coupling

Though the quantity, external Q is widely used for BPF design, it is for adjusting the coupling to the external circuits with the internal resonator coupling in order to attain the circuit matching. The quantity Q_e was probably introduced in analogy with unloaded Q (Q_u) which is the reciprocal of loss in a resonator. In fact, the reciprocal of Q_e show the loss in external circuits. But in spite of the fact that Q_u represents the quality of a resonator, Q_e does not at all, but it represents the coupling to the external circuits.

Thus, we would like to introduce the external k, k_x instead of Q_e as its reciprocal. This quantity is quite convenient to compare the coupling of the outermost resonator to the external circuit for various resonant modes. Besides that, its common use for BPF design at large will give simpler understanding that stronger coupling between resonators requires stronger coupling to the external circuits.

The k_x for 4 and 6-layered resonators is depicted in Fig.6 as the reciprocal of Fig.4. The significant feature is that k_x becomes zero for M_{14} and M'_{16} at some length of the external coupling line. It may be due to cancellation of magnetic and electric coupling just as the case in coupling between resonators. Since this sort of phenomenon has never been reported, it needs to be clarified as soon as possible.

Though small k_x will be effective for the spurious suppression, it is necessary to vary that for the dominant mode according to the demand for variety of bandwidth. But since we can not shift its position on the abscissa for now, we will design a BPF using k_x in Fig.6 as it is.

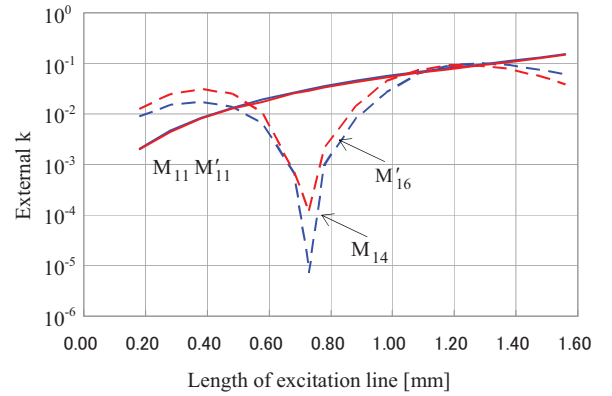


Fig.6. External k of M_{11} , M'_{11} , M_{14} and M'_{16} modes vs length l of excitation line

V. DESIGN OF BPF

In Fig.7, coupling coefficient between 4 and 6-layered multi-strip resonators is depicted as a function of the lateral distance between them.

For a two-stage maximally-flat BPF with the fractional bandwidth of 0.10, the following coupling coefficient and external k are needed;

| | | |
|----------------------|---|------|
| Fractional bandwidth | : | 0.10 |
| Coupling coefficient | : | 0.07 |
| External k | : | 0.07 |

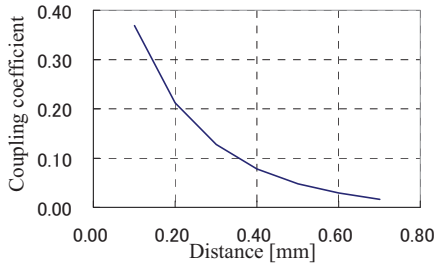


Fig.7. Coupling coefficient between 4 and 6-layered resonators vs lateral distance between resonators

Looking up Figs.7 and 6, we can determine the spacing between two resonators and the length of excitation line. The simulated response of the designed LTCC (low temperature co-fired ceramics) BPF is shown in Fig.8, showing a good out-of-band characteristics in spite of the large external k . It is mainly because of the detuned resonant frequency for M_{14} and M'_{16} modes. Figures 9 and 10 give the simulated response for BPFs with the fractional bandwidth 14% and 4%. The latter corresponds to the minimum point of k_x in Fig.6, and thus, it shows extraordinarily good spurious response. The many spikes in Fig.10 disappear with introduction of slight practical loss as shown in Fig.11.

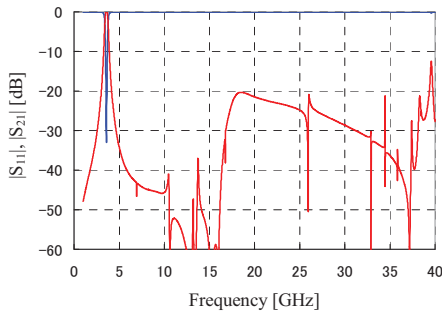


Fig.8. Simulated response of designed BPF (fractional bandwidth $w=0.10$)

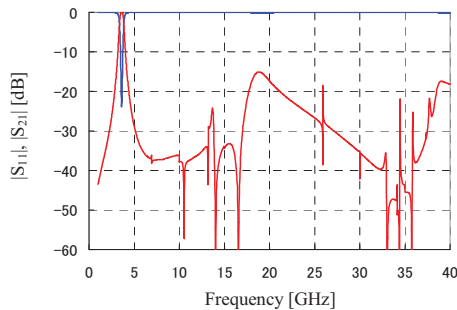


Fig.9. Simulated response of designed BPF ($w=0.14$)

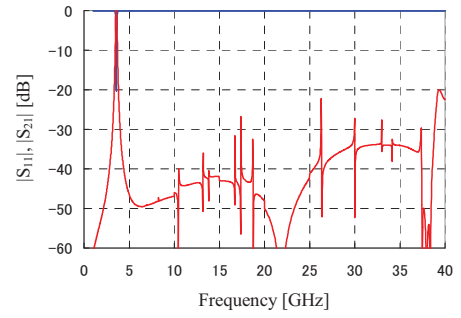


Fig.10. Simulated response of designed BPF ($w=0.04$)

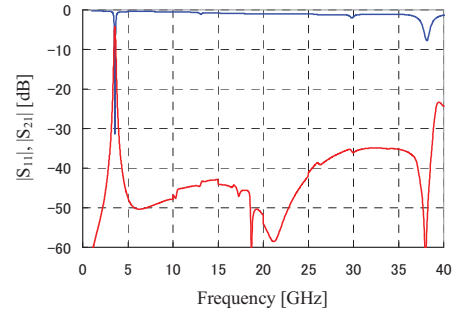


Fig.11. Simulated response of designed BPF with resonator loss ($w=0.04$)

VI. CONCLUSION

We have designed a two-stage multi-strip resonator BPF with extraordinarily wide spurious suppression. It was carried out by a new principle that disturb the resonant frequency, coupling coefficient and external Q of higher-order modes in the constituting resonators.

By way of the design procedure, we have introduced a new parameter, k_x , as the measure to describe the coupling between the resonator and the external circuit. It is convenient for the design of matching for various resonant modes.

Experimental confirmation is under way and it will be presented at the venue.

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