DESIGN OF WIDE BAND SAW COUPLED RESONATOR FILTERS ON QUARTZ

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Abstract – SAW transversely and longitudinally coupled resonator filters (TCRF and LCRF) on quartz normally use a cascade of two sections to obtain the desired number of poles for desirable performance. It is possible to design 3 or 4 pole filters in one section, resulting in lower insertion losses, smaller chip sizes and, most importantly, wider bandwidth. Single cascaded multi-pole coupled resonator filters (CRFs) are commonly implemented by increasing the number of acoustic modes used. In this paper, a new approach is proposed for designing 3 and 4 pole CRFs without cascading. This approach uses several parallel connected coupled resonators (CRs). For each CR only two main acoustic modes are unitized and the CRs all have different grating pitches. It is demonstrated that by choosing apertures and grating pitches of the CR elements properly, optimal filters with 3 or 4 pole responses can be achieved. It is a suitable method for both TCRF and LCRF. The results of investigations are illustrated by experimental responses of a TCRF and an LCRF.

I. INTRODUCTION

SAW transversely and longitudinally coupled resonator filters (TCRF and LCRF) are widely used today. They have extremely small size and very low insertion loss. Basic CRs utilize only two transverse or longitudinal acoustic modes, i.e., symmetric and anti-symmetric modes, so that the filter has two resonances and its response has two poles. Normally two CRs in cascade are used to increase the number of poles to four in order to achieve the desirable filter performance.

Specifically on quartz TCRFs have advantage over LCRFs because they can have shorter layouts. Such filters have very good characteristics [1] but the fractional bandwidth is limited to less than 0.1%, and a precisely tuned external coil between cascades is necessary to achieve a wider bandwidth. The inductance of that external coil increases with bandwidth, hence still restricts maximum bandwidth. Usually the relative bandwidth of such filters does not exceed 0.12% [2].

It is possible to design CRFs of 3 or 4 pole performance without cascading by increasing the number of acoustic modes used. For TCRFs it means pure acoustic coupling between CRs. Such TCRFs can achieve a fractional bandwidth of up to 0.3%. They have good characteristics [3] but two disadvantages. The first is the presence of unwanted high order acoustic modes close to the pass band that reduce selectivity [4]. The second is high output impedance due to the small aperture needed for high order mode actuation [3]. In this paper, another design approach is proposed for designing 3 and 4 pole CRFs without cascading.

II. DESIGN PRINCIPLES

Basic CRs (Fig.1) use only two transverse or longitudinal acoustic modes, i.e., symmetric and anti-symmetric, so that the filter has two resonances and its response has two poles. In Fig.2 the unmatched response is shown in the case where the output impedance of the filter is considerably higher than the load. This is very typical for CRF on quartz with the standard 50Ω load impedance.

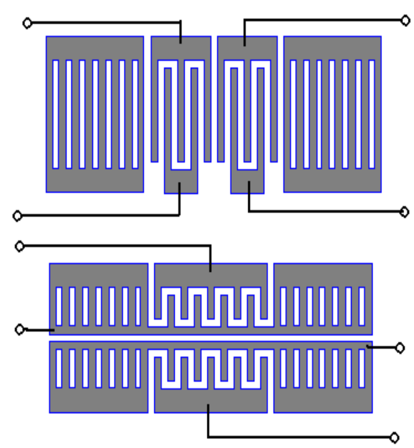

Fig.1. Structures of basic 2 pole TCR and LCR

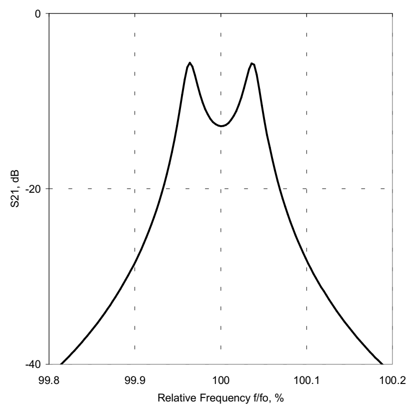

Fig.2. Typical unmatched response of a basic CR.

Each resonance of that response can be represented as the resonance of an equivalent RLC resonator with high accuracy [5]. In Fig.3 Co is the static IDT capacitance and C is the motional capacitance. For a properly built SAW resonator the $C:Co$ ratio is nearly constant. So C mainly depends on the aperture and the number of electrodes of the IDT in the same way as Co. The inductance L depends on the resonance frequency f as:

$$L = \frac{1}{(2\pi f)^2 C}.$$

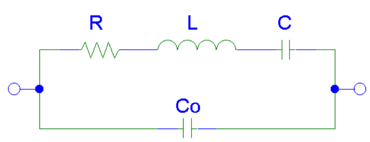

Fig.3. The equivalent RLC resonator.

Design methods for RLC filters are well developed. According to [6] the following is for the optimal pass band filter with 3-pole response (Fig.4(a))

$$C_{CENTER} = 2C_{EDGE}, \tag{1}$$

where C_{CENTER} is the motional capacitance of the equivalent RLC resonator corresponding to the center resonance; C_{EDGE} is the motional capacitance of the equivalent RLC resonators corresponding to the edge resonances.

For the optimal pass band filter with 4 pole response (Fig.4(b))

$$C_1 : C_2 : C_3 : C_4 = 1:2:2:1$$
$$\text{and} \tag{2}$$
$$(f_2 - f_1):(f_3 - f_2):(f_4 - f_3) = 1:2:1$$

where C_n and f_n are the capacitance and frequency of the n-th resonance, counted from left edge of the response to the right.

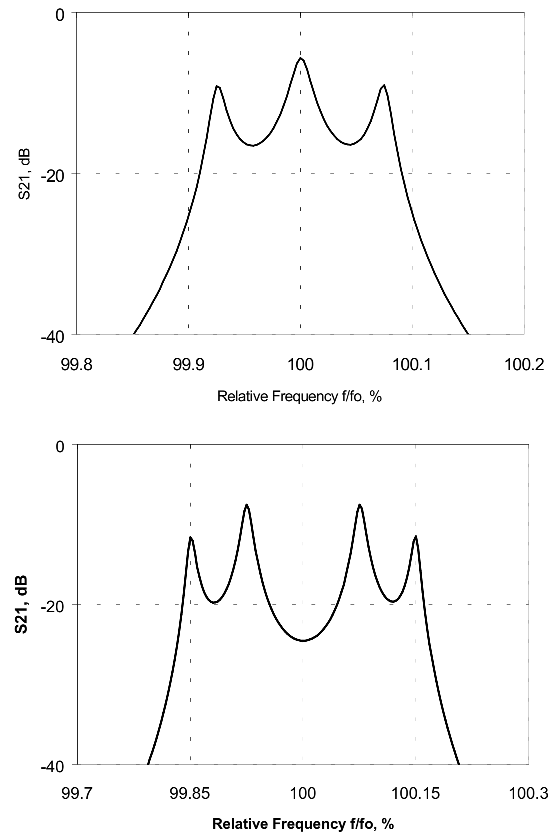

Fig.4. The unmatched responses of an optimal band pass filter with 3-pole (a) and 4-pole (b) responses, respectively.

Such filters have flat pass band and steep skirt characteristic when they are matched (Fig.5).

The design approach proposed in this paper is to utilize several parallel connected CRs with different grating pitches to achieve more poles. The design approach is easily understood for the case of a 3 pole filter where two 2 pole CRs are required. Their respective electrode pitches are designed so that the resonant frequency of the symmetric mode of one CR aligns with the resonant frequency of the anti-symmetric mode of the other CR(Fig.6(a)). By connecting the CRs in parallel the capacitances add together to satisfy Equ. (1). For a 4 pole filter, three 2 pole CRs are needed that exhibit differences between the symmetric mode resonance frequency and anti-symmetric mode resonance frequency. According to Equ.(2) one CR must have twice the mode separation than the others and equal static capacitance. By arranging those 2 pole CRs to abut in frequency (Fig.6(b)) and connecting them in parallel we have the optimal 4-pole filter.

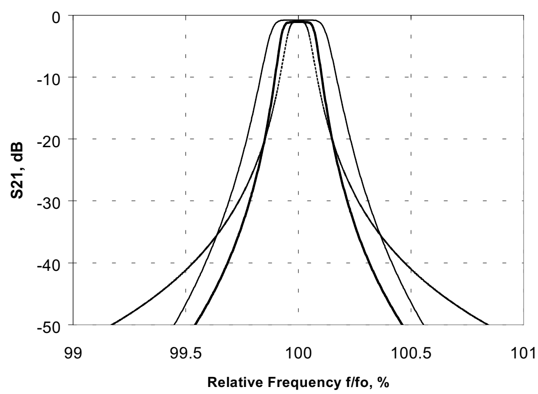

Fig.5. The matched responses of optimal band pass filters with 2-, 3- and 4-pole responses.

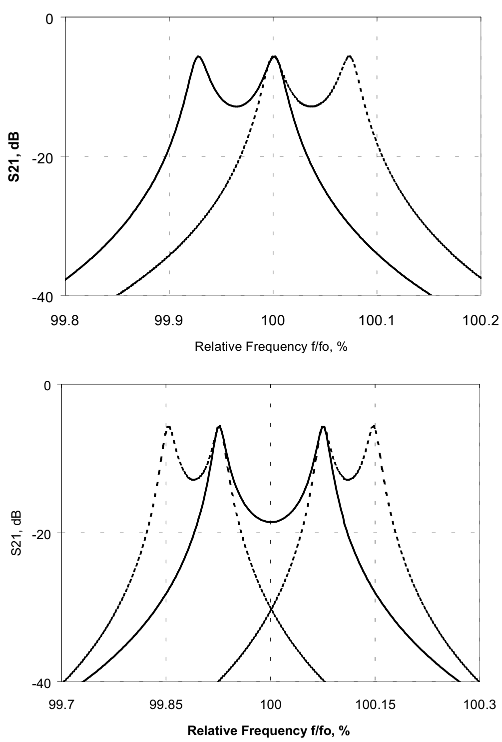

Fig. 6. The schema of parallel-connected CRs arrangement for 3-pole (a) and 4-pole (b) filters.

III. TRANSVERSELY-COUPLED RESONATOR FILTER

The TCRF was designed using the proposed design approach. It uses two parallel connected similar TCRs with different pitches as shown on Fig.6(a). The measured responses of those individual TCRs are shown on Fig.7. The response of the combined filter has 3 poles (Fig8(a)) and the performance coincides with the response of optimal 3 pole band pass filter (Fig8(b), Fig10(a)) very well. The 3 dB bandwith is 0.16% and insertion loss is only about 2dB.

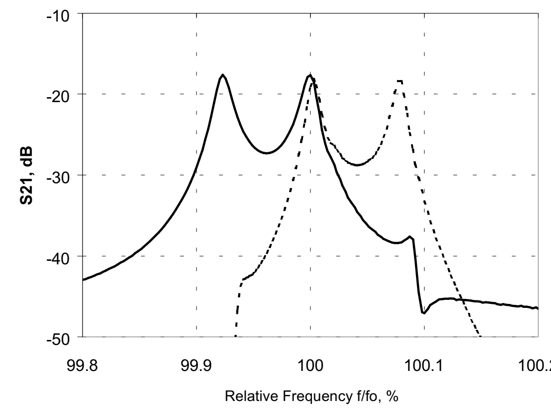

Fig.7. The measured responses of individual TCRs.

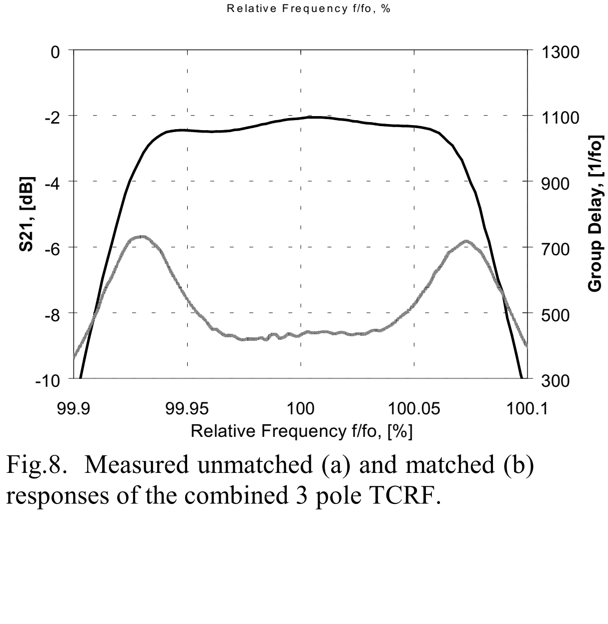

Fig.8. Measured unmatched (a) and matched (b) responses of the combined 3 pole TCRF.

One problem with this filter, however, is the capacitance that exists between IDT electrodes connected to input and output ports (Fig.9). It is easy to eliminate its influence on filter response by using a balanced connection. In fact, one balanced port is sufficient to provide the common mode rejection needed to significantly improve the rejection response. In Fig.10, the response measured with a single-ended input and balanced output is shown (bold line). For an unbalanced connection, the ultimate rejection level could only be lowered to about 45dB value (Fig.10 dotted line).

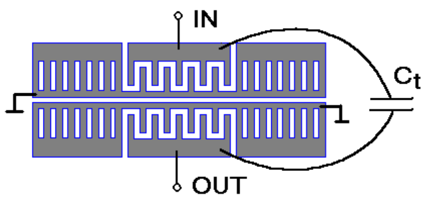

Fig.9. Capacitance across input and output ports C_t.

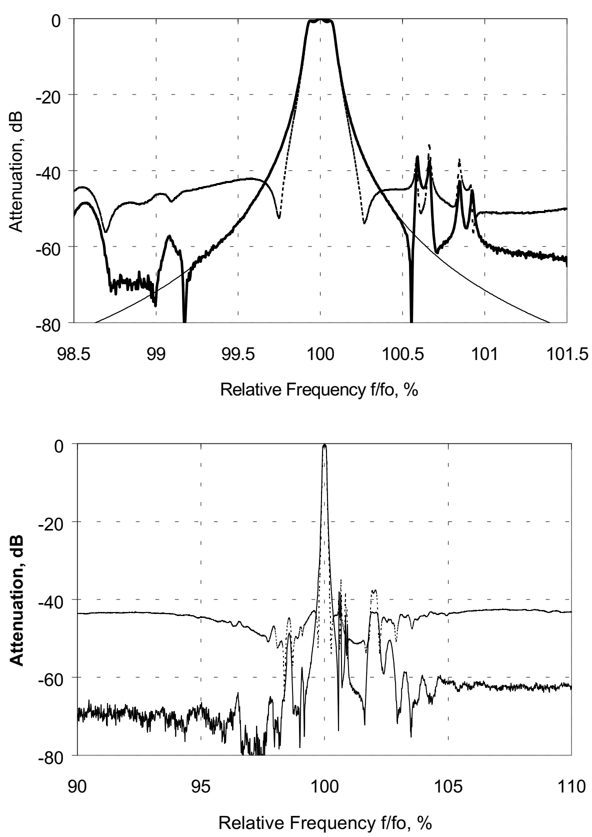

Fig.10. The measured responses in balanced (bold line) and unbalanced (dotted line) connections and the simulated response of optimal 3-pole filter (thin line).

When compared with a TCRF having pure acoustic coupling [3], the present filter has two advantages: The first is a lower level of spurious resonances [4] because only two primary resonances are used. The second is a much lower output impedance because bigger aperture of CRs is required and all the CRs are connected in parallel, so the output capacitance is about 5 to 7 times larger .

IV. LONGITUDINALLY-COUPLED RESONATOR FILTER

A LCRF was also designed using the proposed design approach. Two frequency shifted but otherwise identical LCRs are used in parallel conection and the combined filter has 3-pole response (Fig.11). An unwanted longitudinal mode mars the low frequency skirt. Such unwanted modes are a common problem for LCRF. That's why TCRFs have advantages over LCRFs on quartz, because they can have shorter layout and lower spurious mode level. The LCRF exhibits a large passband with flat group delay. The passband with 100nS group delay variation is 250 KHz or 0.15%. It is very difficult to reach such a wide passband by using a traditional LCRF.

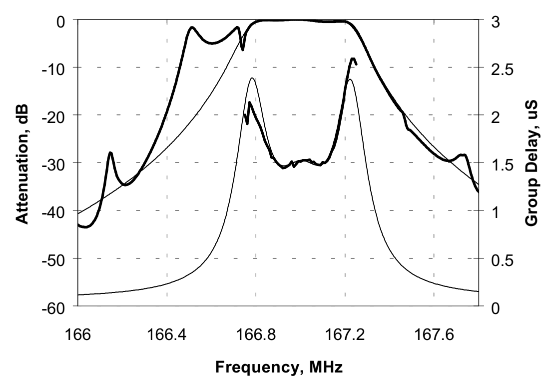

Fig.11. The comparison for measured LCRF (bold lines) and optimal 3 pole pass band filter (thin lines) responses.

V. CONCLUSIONS

A new design approach has been proposed for 3 and 4 pole CRFs without cascading. The approach uses several parallel connected CRs. Each CR employs only two main acoustic modes and all the CRs have different grating pitches. It is a suitable method for both TCRFs and LCRFs. Examples of a TCRF and a LCRF were designed by using the proposed design approach.

For LCRF it is much easier to form optimal pass band filter by using the proposed design approach comparing with the traditional LCRF.

In comparison with TCRF with pure acoustic coupling, the new design approach has two advantages. First is a lower level of spurious resonances because only two main resonances are used. Second is a much lower output impedance because bigger aperture of CRs is required and all the CR elements are connected in parallel, so the output capacitance is 5-7 times bigger. However, capacitance across input and output ports that cannot be avoided by parallel connecting of TCRs limits ultimate rejection to 45dB value for single-ended application. It is possible to eliminate this capacitance influence on filter response by using it balanced on at least one port.

REFERENCES

[1] V.B. Chvets, V.S. Orlov, A.N. Rusakov, A.L.Schwarz, “Design of Narrow-Band Transversely Coupled and Balanced Bridge Resonator Filters Using Equivalent Circuit and P-Matrix Models”, IEEE 2000 Ultrason. Symp. Proc., pp.79-82.

[2] J. Tsutsumi, O. Ikata and Y. Satoh, “Transversaly Coupled Resonator Filters with 0.1% Fractional Bandwith in Quartz”, IEEE 1996 Ultrason. Symp. Proc., pp.65-69.

[3] V.B. Chvets, A.L.Schwarz and V.S. Orlov, “Design of Wide Band Transversely Coupled Resonator Filters on Quartz”, IEEE 2002 Ultrason. Symp. Proc., pp.73-77.

[4] M. Solal, J. Knuuttila, M.M. Salomaa, “Modelling and Visualization of “Diffraction Like” Coupling in SAW Transversaly Coupled Resonators Filters”, IEEE 1999 Ultrason. Symp. Proc., pp.95-100.

[5] D.P. Chen, M-A. Schwab, C.Lambert, C.S. Hartmann and J.Heighway, “Precise Design Technique of SAW Transversely Coupled resonator Filters on Quartz”, IEEE 1994 Ultrason. Symp. Proc., pp.67-70.

[6] G.E.Hansell, “Filter Design and Evalution”, Van Nostrand Reinnold Company, New York, 1969.