LOW LOSS MULTIPOLE SAW RESONATOR FILTERS

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Summary

Associated with modern rf communications systems is need to perform complex signal processing. Multipole crystal filter technology performs a unique function in these systems. A new type of low loss multipole filter technology using surface acoustic wave resonators is described in this paper. Previous attempts to fabricate coupled resonator filters with more than four poles were frustrated by low Q in these structures. More recent fabrication techniques, to be described in this paper, have led to high Q surface wave structures. Multipole resonator structures with up to eight poles of selectivity are now possible. Applications for narrowband crystal filters have traditionally been limited to the vhf frequency range. Using surface acoustic waves, the frequency range for these types of filters can be extended to the upper UHF range and perhaps into L-band itself.

Introduction

The conventional monolithic crystal filter building block is the two-pole section depicted in Fig. 1a. A classical coupled resonator structure is achieved by coupling two thickness-mode resonances on the same quartz crystal blank. Frequency is determined by the blank thickness and coupling is controlled by the proximity of the resonators and their electrode thicknesses. These types of filters have become common components in rf signal processing at 10.7 and 22.4 MHz. As the frequency of operating goes beyond 30 MHz the bulk wave filters must be designed on harmonics of the crystal because the thickness of the blank becomes prohibitively small for reliable fabrication. Described in this paper is a new type of coupled crystal resonator or monolithic crystal filter using surface acoustic wave (SAW) resonators. The SAW device frequency is independent of blank frequency and the two pole coupled resonator electrode structure, shown in Fig. 1b, can be fabricated at frequencies up to 1 GHz or more. This type of device uses in-line (longitudinal) coupling between resonant cavities formed by reflecting gratings.[1-3] More recent attempts to achieve coupling by either energy trapping[3] or reflective track changers[4,5] have not been as successful as inline coupling and will not be discussed in this paper.

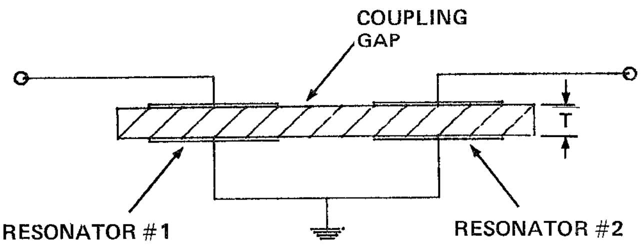


Fig. 1a Bulk wave, monolithic 2-pole crystal filter.

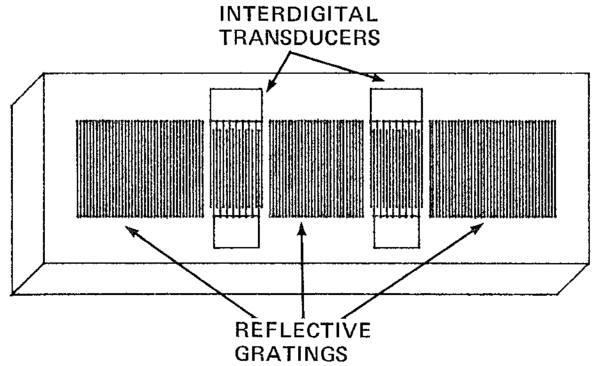


Fig. 1b In-line coupled SAW monolithic 2-pole crystal filter.

Inline Coupled SAW Resonator Filters

Two pole coupled resonator lattice sections or filters are designed using equivalent circuit transmission line models for the individual electrodes in the SAW electrode pattern. Typically the design begins with a bandwidth requirement which sets the amount of transmission or coupling required between the two resonators. The outer two reflective gratings shown in Fig. 1b are normally designed to provide maximum reflection and hence have 300 or more gratings in them. The impedance of the filter is determined by the acoustic aperture width, typically 50 to 150 wavelengths, and the number of electrode pairs in the interdigital transducers. A typical 2-pole filter response is shown in Fig. 2. In this case, the bandwidth was 0.1%, wide for a crystal filter at 300 MHz, and the characteristic impedance was 200 ohms. Spurious responses about the main resonances are due to transversal filtering effects between the two transducers. The rejection level for these effects depends upon the relative bandwidth and impedance level. Narrower bandwidth filters have better rejection and lower impedance.

In order to achieve better selectivity and more rejection of spurious responses it is necessary to design multipole filters. This involves more than just cascading two-pole lattice sections. The design techniques for these types of filters are well known[6] and will not be derived here. However the procedure is to adjust the coupling between lattice section according to Table I. The technique is shown in Fig. 3 where two, 2-pole lattice sections are coupled electrically to achieve a 4-pole filter response. This technique has also been used with three pole lattice sections. Shown in Fig. 4 is the response of a 9 pole filter using three, 3-pole lattice sections.

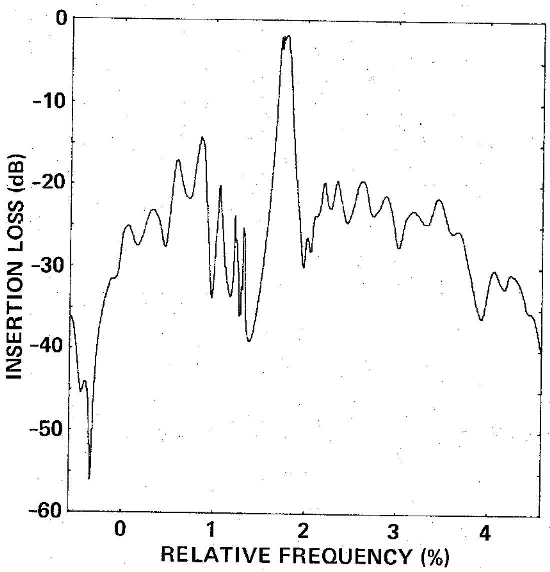


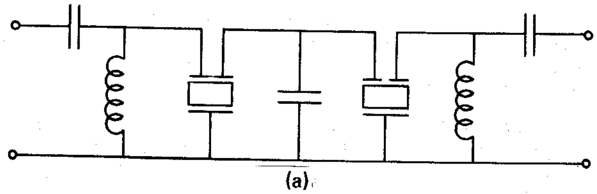
Fig. 2 Matched 2-pole SAW lattice section showing <3 dB loss and 0.1% bandwidth.

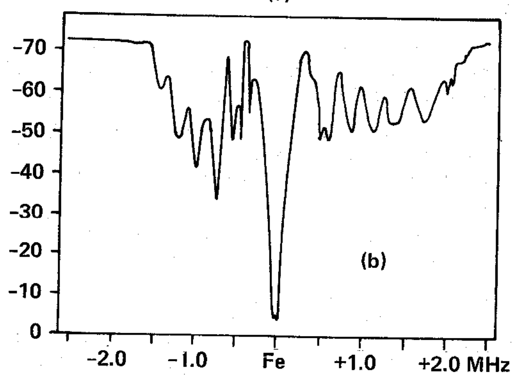
Table I Intercavity Coupling

Number of Poles*	k_{12}	k_{23}	k_{34}	k_{45}	k_{56}	k_{67}	k_{78}
2	0.7106						
3	0.6539	0.6667					
4	0.7234	0.5200	0.6826				
5	0.7416	0.4546	0.6428	0.5770			
6	0.7632	0.3864	0.6350	0.5390	0.5997		
7	0.8053	0.5081	0.5615	0.3855	0.7284	0.4611	
8	0.8850	0.5685	0.5092	0.4885	0.4817	0.5022	0.7364

*0.1 dB ripple, Chebyshev response

$\frac{Q_L}{Q_0} = 30$





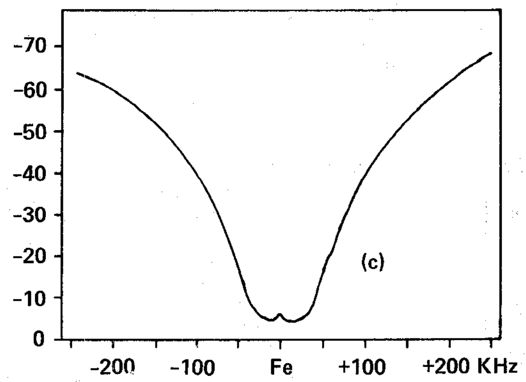


Fig. 3 Four pole monolithic crystal filter using electrically coupled 2-pole SAW lattice sections. F_0 = 80 MHz.

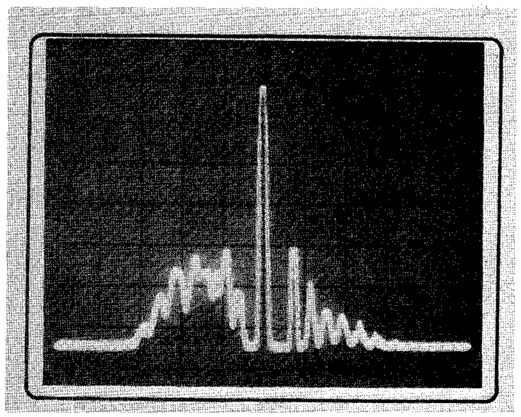


Fig. 4 9-pole filter using three 3-pole lattice filters.

To illustrate how filter requirements may be determined using multipole SAW resonator filters, we consider as an example a Chebyshev filter response with the following characteristics: maximum peak to peak ripple in the passband is 0.1 dB; filter insertion loss is allowed to increase 1 dB for every pole lattice section, e.g., a 4-pole filter is allowed a maximum insertion loss of 4 dB, N=6 is allowed 6 dB etc. The achievable Q's of quartz SAW resonators are known[7] and may be used with filter synthesis design tables[6] to determine the minimum achievable 3 dB bandwidth. Figure 5 shows the minimum fractional bandwidth for frequencies up to 500 MHz. The dashed-line (100 ppm) indicates the frequency drift of quartz resonators over an operating range of 100°C, and should be considered as an absolute minimum bandwidth specification in the absence of over temperature controls. Figure 6 is a design nomograph[6] indicating how much sidelobe suppression pertains to a given shape factor Ω (Ω = stop-bandwidth to 3 dB bandwidth ratio). This nomogram can be used to determine the minimum number of poles needed to achieve a given filter shape factor.

In general these filters are characterized by low loss and low impedance compared to conventional bulk wave crystal filters which must operate on harmonics in the upper VHF-UHF ranges. Typical losses for two and three pole lattice sections have been less than 2 dB and in some cases less than 1 dB. The loss achievable in multipole filters is a complex function of many variables, however if the Q of the individual resonators is high enough, the filter loss is zero.

Recent advances in SAW resonator fabrication[7] have shown that Q's approaching the material limits for quartz are achievable.

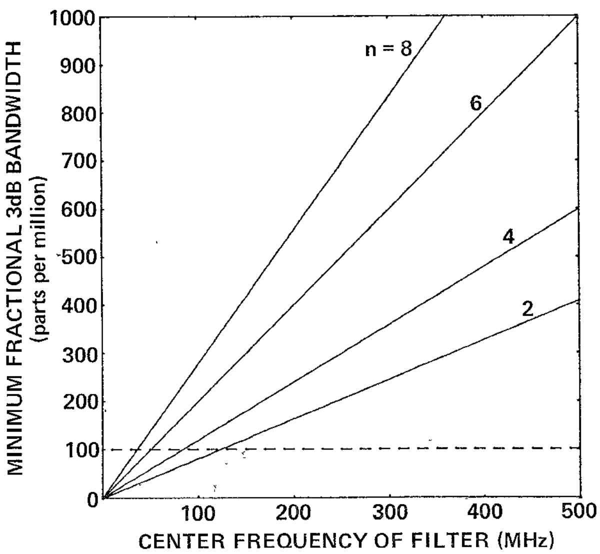


Fig. 5 Minimum achievable 3 dB bandwidth for multi-pole Chebyshev passband filter with 0.1 dB maximum.

Conclusions

Surface acoustic wave structures with responses similar to monolithic crystal filters have been achieved which show extremely low insertion loss in the VHF-UHF range. These types of devices are made possible due to the ability to fabricate high Q resonant electrode structures for surface waves. Applications for these filters include the following: front-end filters for single channel receivers, image rejection filters for mixer outputs in the UHF range, and oscillator/multiplier chain output filters. The availability of low loss, narrow-band, 8-pole monolithic crystal filters in the UHF range will enable rf signal processing normally performed at 10.7 MHz to be done at much higher frequencies. Because the SAW device is a "chip" component these types of filters are well suited to hybrid fabrication techniques necessary at these frequencies.

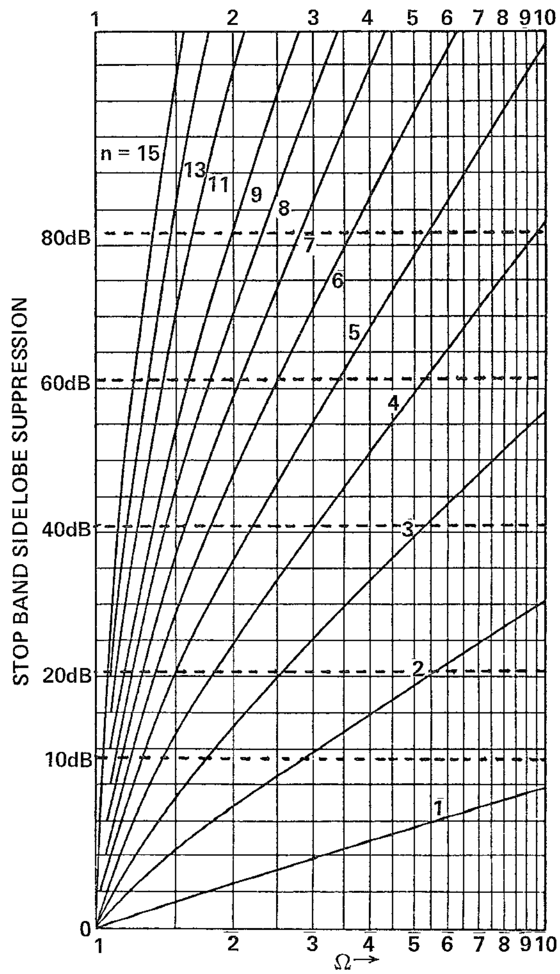


Fig. 6 Nomograph for Chebyshev filters having 0.1 dB of passband ripple. Ω is the ratio of the minimum stop bandwidth to the 3 dB pass bandwidth.

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