"SAW RESONATOR FILTERS: APPLICATIONS AND CAPABILITIES"

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ABSTRACT

The current state-of-the-art in multipole SAW Resonator Filters is presented. Applications are discussed including preselector, I.F., and L.O. clean up filers. A brief review of their operation is presented along with a detailed explanation of their capabilities. Various tradeoffs are discussed for filters from 50 MHz to 1 GHz and from 0.02% to 0.2% fractional 3 dB bandwidths. The intermodulation suppression of SAW Resonator Filters is presented in a later section.

INTRODUCTION

Because of their small size low loss and high rejection Multipole SAW Resonator Filters are becoming very popular for narrow band applications throughout the VHF and UHF spectrum.

Figure 1 illustrates the RF chain of a typical communication system and the possible applications for a SAW Resonator Filter (SAWRF). One of the most advantageous uses for the SAWRF is a preselecter in a low cost, single conversion receiver with a 455 KHz IF. Using other types of VHF and UHF filters, the receiver would suffer from images due to the minimal rejection at fo ± 910 KHz.

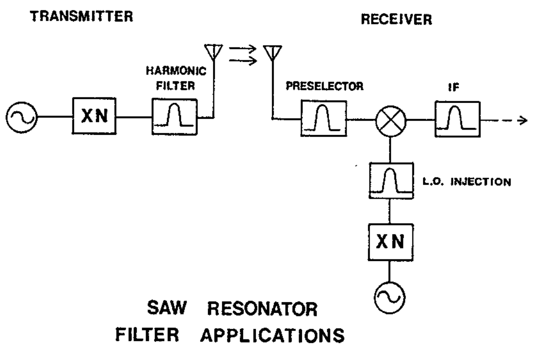

FIGURE 1.

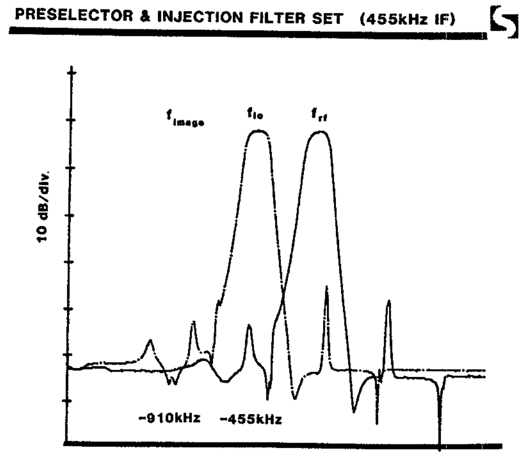

FIGURE 2.

Figure 2 illustrates how the performance of SAWRFs can reduce the image problem. The solid line is a preselector filter in the 200 MHz range. Its rejection at fo - 910 KHz exceeds 45 dB. Also pictured is the matching L.O. clean up filter. This filter cleans up the noise and spurs of a bulkwave crystal multiplier chain or alternatively a synthesizer output. In this case it is desired to have moderate rejection at fo ± 455 KHz. As can be seen, this filter rejects the spurs over 40 dB at these points.

OPERATION

The SAW Resonator Filter is a piezo-electric device as is the bulk wave crystal; however, due to its planar construction its practical frequency range extends from 50 MHz to 1 GHz. A two pole filter is shown in Figure 3. The electro-acoustic conversion is accomplished via an Interdigital Transducer (IDT). Note that the frequency is determined by the line spacing rather than the crystal thickness. Since a photolithographic process is used submicron lines can be fabricated resulting in center frequencies over 1 GHz. The low frequency limit is set only by size. A 50 MHz SAWRF for example is 2 inches long.

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Once the energy is converted into a acoustic wave, it propogates bidirectionally from the IDT until it strikes a reflector. When the cavity length equals an integer number of half wavelengths, a standing wave pattern is established and the filter is said to be in resonance. A SAW device uses a distributed reflector to prevent the surface wave from degenerating into a bulk wave. These distributed reflectors consist of metal strips or grooves $\lambda/4$ wide spaced at $\lambda/2$ intervals. Each strip causes a small reflection; however, at center frequency all of these reflections add in phase to produce a overall large reflection. The reflectors have a finite reflection bandwidth that along with the IDT bandwidth and cavity length ensures single mode operation.

The center reflector allows a small but controlled amount of energy to leak into the second cavity where it can be reconverted into electrical energy by the IDT. The filter bandwidth in this two pole structure is determined by the length of the center reflector in conjunction with the metal thickness or groove depth. As Figure 4 illustrates, this basic building block can be cascaded into higher order filters. Alternatively, filters up to 4th order can be realized in a monolithic form by the introduction of additional acoustic coupled poles. A 4 pole building block reduces the number of packages required and in general reduces the average insertion loss per pole as well as eliminating undesired matching elements.

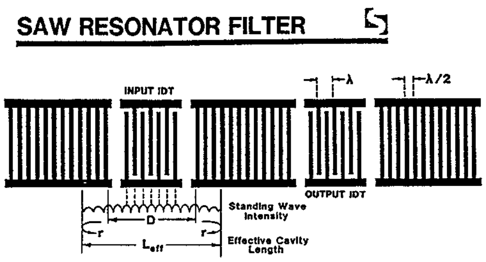

FIGURE 3.

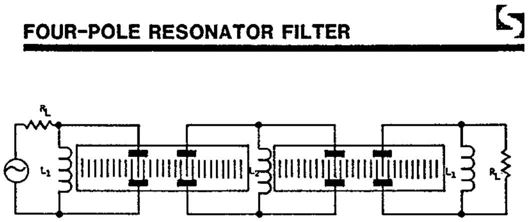

FIGURE 4.

CAPABILITIES

As mentioned previously, the practical range of frequencies for SAWRFs is 50 MHz to 1 GHz. The 3 dB bandwidth is limited on the low side to 0.02% by thermal stability and manufacturing tolerances. The maximum bandwidth limitation is 0.20% to 0.25% due to practical limits on reflector bandwidth and port impedance.

The Insertion Loss of a SAWRF varies from 1.0 to 3.0 dB per pole depending on the frequency and bandwidth. Most designs tend to have increased loss when narrow bandwidths are required. This effect is common in resonator filter technology and results from finite pole Q's. The insertion loss also increases at higher frequencies, although a two pole filter at 960 MHz with internal matching achieves less than 4 dB of insertion loss (1).

The rejection not only depends on the number of poles as indicated in Figure 5, but also on the center frequency. A typical 4 pole response is shown in Figure 2. Notice the rejection drops monotonically to the rejection level with only a few spurious responses. The overall level is generally limited by crosstalk and is hence dependent on the packaging and center frequency. Typical values are 80 dB at 50 MHz and 35 dB at 800 MHz.

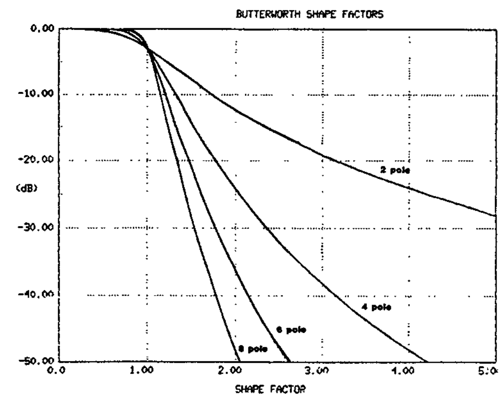

FIGURE 5.

Figure 6 illustrates a 2 pole response. Here the out of band rejection is determined by the delay line response. Referring to Figure 4, one can see that off resonance, where the reflectors are relatively transparent, the two IDTs talk directly to each other as in a SAW delay line. Fortunately, the impedance of the delay line is significantly different from the resonant impedance so the near in rejection level ranges from 10 dB to over 20 dB for a 2 pole section. The out of band rejection or "flyback level" varies with bandwidth as shown in Figure 7. As

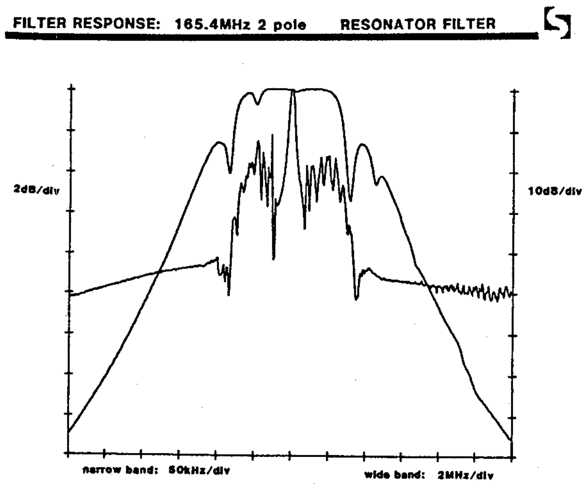

FIGURE 6.

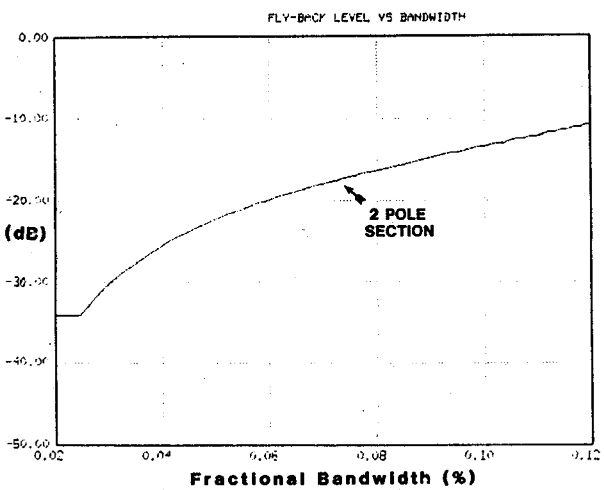

FIGURE 7.

the bandwidth increases, the impedance at the resonant response increases, approaching that of the delay line response. Matching to this higher impedance also improves the match of the delay line thereby degrading the flyback level. Since this flyback is caused by the frequency response of the IDT these IDTs can be weighted to provide wide band rejection of 50-60 dB in the two pole case (2). Adding additional poles or decreasing the bandwidth will also improve the near in rejection.

SAW Resonator Filters are able to handle moderate power levels without catastrophic effects; typically little if any effect is noticed at the +20dBm level. At higher levels some increased aging is observed but the destruction level is usually in excess of +30 dBm. The non-linear properties of these filters are also well behaved. The third order IM level of these filters for a 0 dBm two tone test ranges from -40 dBc to -95 dBc.

INTERMODULATION

The IM distortion depends on several factors. In most cases, the in-band IM is related to power density and therefore center frequency. Additionally, because the impedance is related to the bandwidth, IM distortion worsens for narrow bandwidths. Figure 8 illustrates the in-band IM of various filters. The 50 MHz device has a bandwidth of 0.05% while the others average from 0.08% to 0.10%. As can be seen, the IM performance in the VHF and low UHF is quite good even at high power levels, in general good IM performance is maintained by using an appropriate design, maximizing the bandwidth, and, as in bulk wave technology, avoiding surface contamination.

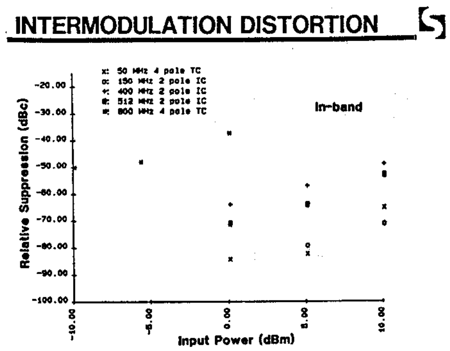

FIGURE 8.

EXAMPLES

Figure 9 illustrates a 4 pole 243 MHz filter. Packaged in two TO-8 cans, it achieves >70 dB of rejection at fo ± 910 KHz with an insertion loss of 5 dB. Figure 2 illustrates a 4 pole monolithic filter in the same frequency range. It is packaged in a single TO-5 or HC-18 and has loss of <4 dB. Figure 10 illustrates two different 50 MHz filters. The filter corresponding to Figure 10a is a monolithic 4 pole packaged in a single 2" DIP package. The filter in Figure 10b is constructed from two pole building blocks as illustrated in Figure 4. Because of the requirement for external coupling components, this filter is packages in two 2" DIPS. Finally, Figure 11 describes a four pole TC 800 MHz filter. It exhibits a loss of 8.5 dB with 35 dB of rejection in a TO-5.

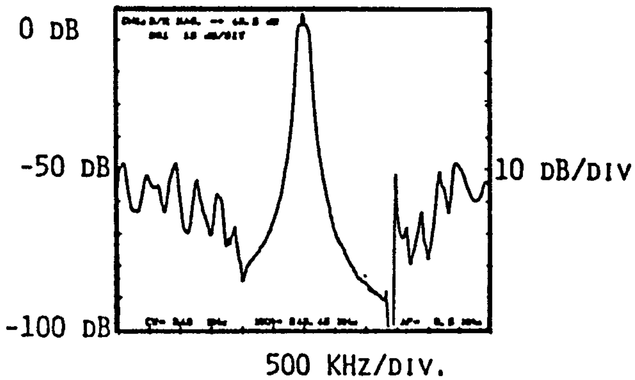

FIGURE 9.

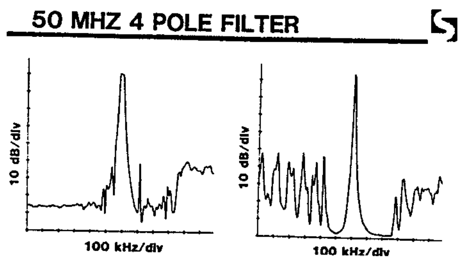

FIGURE 10a **10b**

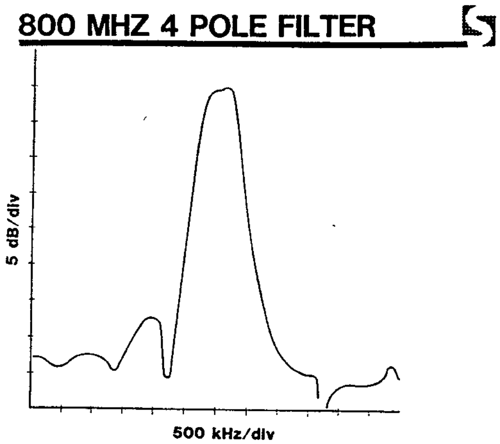

FIGURE 11.

SPECIFYING THE FILTER

To specify the filter, the number of poles and the bandwidths must be determined. In order to pass the information bandwidth under all conditions, the passband must be increased by the frequency set accuracy, temperature drift, aging, and bandwidth set accuracy. In most cases, only the first two are significant. The frequency set accuracy ranges from ± 150 ppm for a minimum cost device to less than ± 50 ppm for a higher performance device. The thermally induced frequency shift is parabolic and can be conservatively estimated by the following equation:

$$\Delta f\ (\mathrm{Hz}) = [((T_H - T_L)/2 + 10)/5.4]^2 \times f_o\ (\mathrm{MHz})$$

Since it is one sided the center frequency is usually offset upwards by one half of this amount. These tolerances should be totaled with the information bandwidth to obtain the design bandwidth, likewise their tolerances must be subtracted from the rejection bandwidth to obtain the design rejection bandwidth. Finally the required number of poles is found by dividing the rejection bandwidth by the pass bandwidth and using Figure 5.

The insertion loss, size, and ultimate rejection can now be estimated from the bandwidth and number of poles. Ripple is a complex function of several other parameters but generally ranges from 0.25 dB to 1 dB peak to peak. A typical SAWRF has good VSWR over most of the passband but near the band edges it will degrade to 2.0 to 2.5 dB. When reduced VSWR is necessary either the bandwidth can be widened or the ports can be resistively loaded. In other words, one can improve the VSWR by either accepting a wider rejection bandwidth or higher insertion loss.

CONCLUSION

Typical performance levels and tradeoffs indicate that a SAW Resonator Filter is a practical device for a wide range of applications. IM distortion is very low allowing high power operation. The rejection and insertion loss of these filters exceed the performance of other comparable technology.

ACKNOWLEDGEMENTS

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