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LOW SIDELOBE SAW FILTERS USING OVERLAP AND WITHDRAWAL WEIGHTED --ETC(U)
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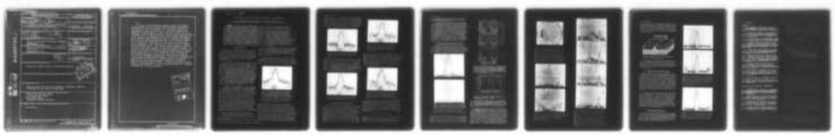

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See Reverse.

In order to avoid frequency spurious signals in bandpass filtering applications, low out-of-band sidelobes are necessary. The purpose of the present paper is to describe in detail the techniques necessary to achieve 60-70 dB sidelobe SAW filters operating in the UHF Region. These techniques include the use of withdrawal weighted (WW) transducers either as both input and output of the filter or in combination with overlap apodized transducers plus a thorough understanding and control of second order effects. The utility of these procedures will be illustrated by a description of the design, fabrication and testing of a 335 MHz, 0.34 percent bandwidth, 15 dB insertion loss, SAW filter on ST quartz having sidelobes and all other spurious (electromagnetic feedthru and "bulk" mode interference) at least 63 dB below the output. In addition, experimental examples of design parameter variations and second order effects will be presented and correlated with theory where appropriate. This will include the effect of correcting for velocity differences between metalized and free substrate surfaces when designing WW transducers, the effect of magnitude and phase diffraction correction of overlap apodized transducets, a comparison of thinned and unthinned transducers and specific means for suppressing "bulk" modes. A second illustrative example, a 0.83 percent bandwidth filter operating at 956 MGz on YZ lithium tantalate, will also be presented.

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LOW SIDELOBE SAW FILTERS USING OVERLAP AND WITHDRAWAL WEIGHTED TRANSDUCERS

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ABSTRACT. In order to avoid frequency spurious signals in bandpass filtering applications, low out-of-band sidelobes are necessary. The purpose of the present paper is to describe in detail the techniques necessary to achieve 60-70 dB sidelobe SAW filters operating in the UHF region. These techniques include the use of withdrawal weighted (WW) transducers either as both input and output of the filter or in combination with overlap apodized transducers plus a thorough understanding and control of second order effects. The utility of these procedures will be illustrated by a description of the design, fabrication and testing of a 335 MHz, 0.34 percent bandwidth, 15 dB insertion loss, SAW filter on ST quartz having sidelobes and all other spurious (electromagnetic feedthru and "bulk" mode interference) at least 63 dB below the output. In addition, experimental examples of design parameter variations and second order effects will be presented and correlated with theory where appropriate. This will include the effect of correcting for velocity differences between metalized and free substrate surfaces when designing WW transducers, the effect of magnitude and phase diffraction correction of overlap apodized transducers, a comparison of thinned and unthinned transducers and specific means for suppressing "bulk" modes. A second illustrative example, a 0.83 percent bandwidth filter operating at 956 MHz on YZ lithium tantalate, will also be presented.

1. Introduction

Using the latest surface acoustic wave (SAW) technology available,[1] it is now possible to make extremely selective bandpass filters.[2,3] These filters are useful in a large variety of electronics applications and can be made to operate over a wide frequency range. The purpose of the present paper is to illustrate the techniques which can be used to realize these high performance filters.

One of the prime considerations in bandpass filter design is the need for low out-of-band sidelobes. Thus the widespread use of overlap or length apodized transducers.[2,3] Unfortunately, a single interdigital SAW transducer is limited (primarily by second order effects) in the level of spurious rejection attainable. Thus in order to achieve 60-70 dB sidelobes it is necessary to weight both transducers of a SAW filter in some way. Since two overlap weighted transducers cannot be utilized in the same filter without severe design difficulties, alternate apodization schemes have been developed - the most successful of which has proven to be withdrawal weighting.[4-7] It is the use of withdrawal weighted transducers in combination with overlap apodization, plus a thorough understanding and control of second order effects, which will be treated in this paper. Emphasis will be on the UHF region.

The utility of the procedures to be discussed will be illustrated by a description of the design, fabrication and testing of a 335 MHz, 0.34 percent bandwidth, 15 dB insertion loss, SAW filter on ST quartz having sidelobes and all other spurious (electromagnetic feedthru and "bulk" mode interference) at least 63 dB below the output. In addition, experimental examples of design parameter variations and second order effects will be presented and correlated with theory where appropriate. This will include the effect of correcting for velocity differences[5,7] between metalized and free substrate surfaces when designing WW transducers, the effect of magnitude[8] and phase[9] diffraction correction of overlap apodized transducers, a comparison of thinned and unthinned transducers and specific means for suppressing "bulk" modes. A second illustrative example, an 0.83 percent bandwidth filter operating at 956 MHz on YZ lithium tantalate, will also be presented.

2. Finger Overlap or Length Apodized Transducers

A straightforward apodization function theoretically yielding 43 dB sidelobes in the frequency domain is the well-known Hamming function[10] or cosine-squared-on-a-pedestal. Advantages of this function include the fact that the minimum overlap in the time domain is only 0.08 times the maximum. The avoidance of time domain nulls has the advantage of avoiding severe SAW diffraction effects.

Applying Hamming weighting to a standard, double electrode SAW transducer, in this case 2.9×10^{-3}m long with individual line widths and spacings of 1.1738×10^{-6}m on ST Quartz results in the frequency response shown in Fig. 1. Here the characteristics of a single transducer

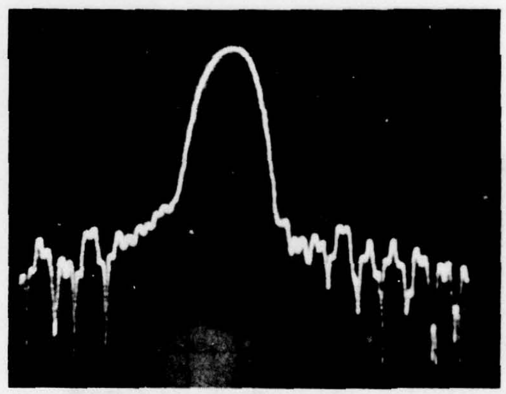

Figure 1. Frequency response of a Hamming weighted, unthinned finger overlap apodized interdigital transducer used in combination with a broadband unapodized output transducer. Center vertical crosshatched line corresponds to 335.4 MHz (f_o=335.4MHz) with 2MHz/div along horizontal scale. Vertical scale 10dB/div with actual filter insertion loss = 26dB.

are shown by using a 10-double-electrode, broadband, output transducer. Insertion loss is minimized by inductive-tuning both transducers to cancel the capacitive reactance at the center frequency. Fabrication of all filters discussed in this paper was by simultaneous reduction and direct optical projection[11] from a 10X master. As evident in Fig. 1 the 43dB theoretical sidelobe level has not been achieved. This can be attributed to a variety of second order effects. For example, although magnitude diffraction correction[8] was used, it is very difficult using existing step and repeat mask generators to vary the individual finger line placement in a transducer to achieve phase corrections. One solution

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to this problem is to adopt a thinned[9] apodized design in which each tap can be diffraction phase (as well as magnitude) corrected.[9] An example of the response of a filter designed according to this procedure is given in Fig. 2. Comparison with Fig. 1 shows improvement over the unthinned case. The importance of diffraction correction can be investigated further by noting that a

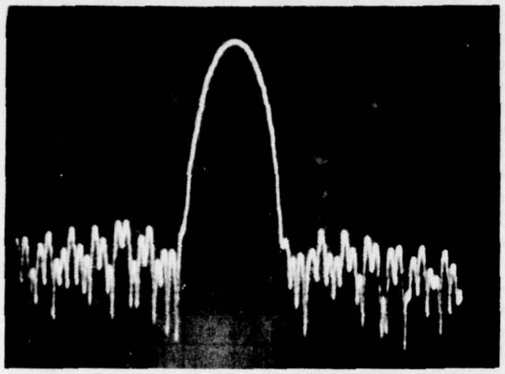

Figure 2. Same as Figure 1 except apodized transducer is thinned and actual insertion loss = 29.5dB.

diffraction corrected transducer such as the one used for Fig. 2 is nonsymmetric, since by definition one end must lie further from the input. Thus reversing the transducer provides some information as to the overall effect of diffraction correction. Data corresponding exactly to Fig. 2 but with the apodized transducer reversed is illustrated in Fig. 3. The higher sidelobes demonstrate the importance of diffraction correction with length apodized interdigital transducers.

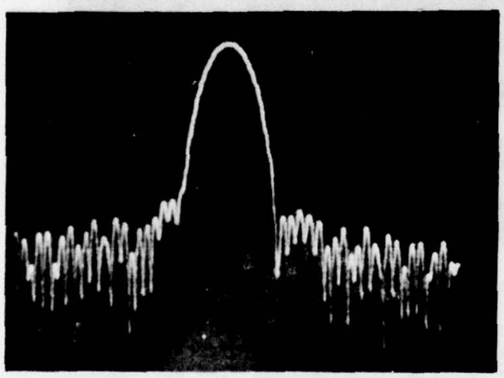

Figure 3. Same as Figure 2 except apodized transducer is reversed from correct sense.

3. Withdrawal Weighted Transducers

The improvement obtained by diffraction correction is still not enough to realize desired rejection levels because of other small competing effects. Thus, as mentioned in the introduction, it is necessary to combine the length apodized transducers of the previous section with withdrawal weighted (WW) transducers[4-7] if low sidelobes (60-70dB) are to be achieved. The frequency response of a single WW transducer (again using a broadband output transducer) is shown in Fig. 4. A comparison with Fig. 1 or 2 shows the excellent performance attainable using WW transducers. Because the acoustic aperture of a WW transducer is constant along

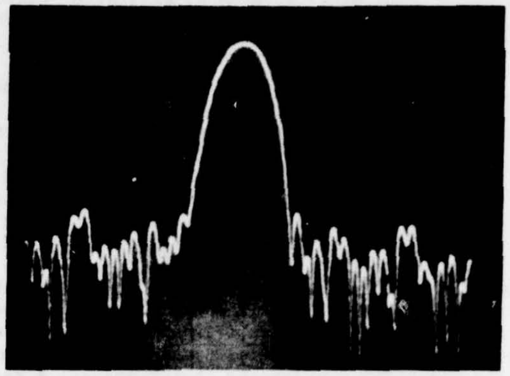

Figure 4. Frequency response of Hamming weighted WW transducer with broadband unapodized output transducer. 2MHz/div with f_o= 335.4MHz and 10dB/div. Actual insertion loss = 26.5dB.

its length, no first order diffraction correction is required. However, since by its very nature a WW transducer is nonperiodic, it does require correction for the SAW velocity difference between a free substrate and a metalized region[5] which of course includes mass loading effects.[1] The improvement obtained by correction is evident from comparing the frequency response of an uncorrected WW transducer in Fig. 5 with the corrected version shown in Fig. 4.

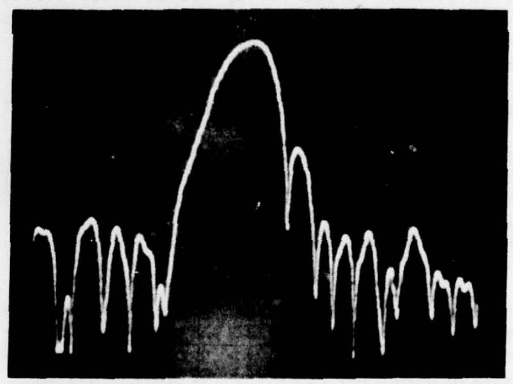

Figure 5. Same as Figure 4 except electrode placement within withdrawal weighted transducer has not been corrected for velocity differences between free and metalized surfaces.

Since the velocity and impedance differences between free and metalized portions of substrates cannot yet be determined theoretically, correction of WW transducers is a two-step process. First, an uncorrected device is fabricated and tested. A match to its frequency response is then obtained by using a transducer computer analysis program[12] with an empirical mass loading parameter, DELTERV. In our notation the perturbed SAW velocity is expressed as

$$V_{met} = V_o\ (1-k^2/2 - \text{DELTERV}) \qquad (1)$$

where the effective velocity V_{met} is related to the free surface velocity V_o by k^2, the well-known[13] electromechanical coupling coefficient which accounts for electrical changes, and DELTERV which accounts for mass loading changes (including geometric effects) plus second order electrical changes.

For example, DELTERV was varied in the transducer analysis program[12] with results shown in Fig. 6 until a good correspondence with the experimental data of Fig. 5 was obtained. DELTERV = 0.0048 was then used in a correction program. This program repositions the electrodes according to the synthesis procedure outlined by Wagers.[5] This relocation process is necessary because the periodic electrodes, distributed unevenly along the transducer length, cause irregular time delays or phase distortions of the incoming acoustic wave. Electrode pairs are then individually repositioned to compensate for nonlinear time delay, but the basic overall weighting sequence remains the same.

4. Double Electrode Complete Filters

Combining the magnitude diffraction corrected length apodized (unthinned) transducer of section 2 with the velocity corrected WW of section 3 in a single filter results in the frequency characteristics illustrated in Fig. 7. Performance is excellent with the maximum sidelobe at least 63dB down. Corresponding theoretical results are shown in Fig. 8--agreement with experiment is quite good. The two "extra" sidelobes visible in Fig. 8 result from a slight inadvertent difference in transducer center frequencies (also present in the experiment). These sidelobes were assumed to have "filled-in" under experimental conditions. Smith Chart input impedance characteristics of each of the four transducers discussed in this paper are given in Fig. 9.

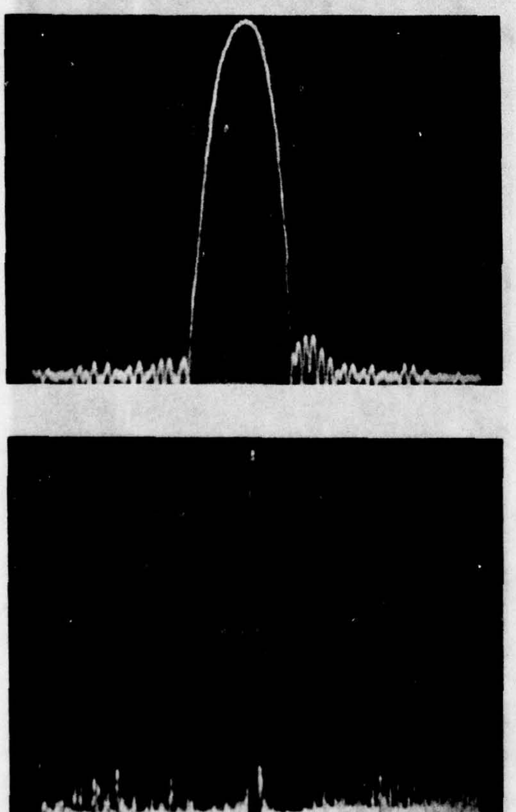

Figure 7. Frequency response curves of Hamming weighted combination overlap apodized and withdrawal weighted transducer SAW filters. Vertical scale 10dB/div f_o= 335.4MHz. Top: 2MHz/div, actual filter insertion loss not available. Bottom: 20MHz/div, actual filter insertion loss = 14 dB.

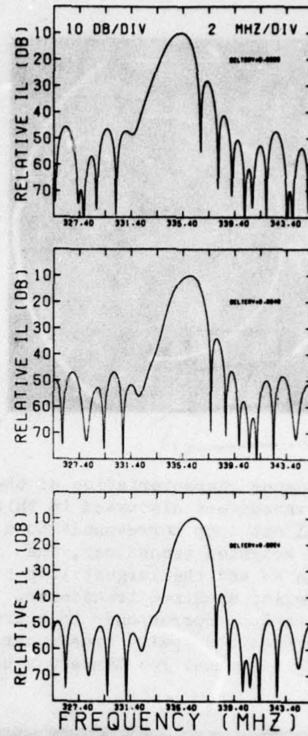

Figure 6. Theoretical frequency response curves corresponding to the experimental conditions of Fig. 5. *The mass loading parameter DELTERV is* varied for a best fit to the experimental results. In this case DELTERV = 0.0048.

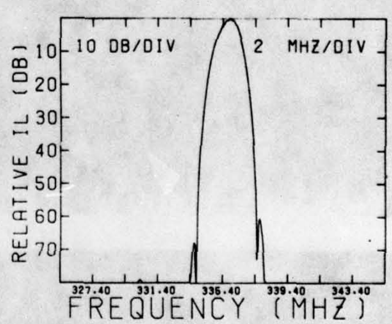

Figure 8. Theoretical frequency response corresponding to Fig. 7 (top).

Experimental results for a filter using two withdrawal weighted transducers are given in Fig. 10. While close-in sidelobe levels are comparable to those of the length apodized WW filter of Fig. 7, the rising far-out sidelobe characteristic of WW transducers are a disadvantage of this type filter. Also evident in Fig. 10 is a rather high "bulk" mode[14] spurious. This spurious is not a major function of the type of transducer chosen, but rather of the substrate geometry and preparation used for bulk mode suppression. This is illustrated in Fig. 11. Substrates having polished back

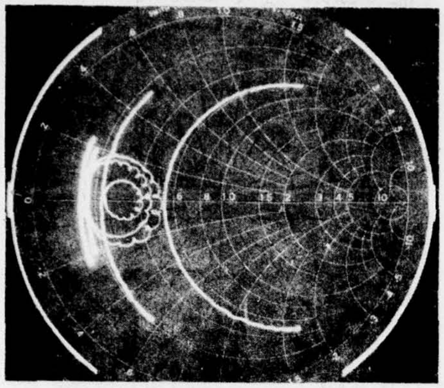

Figure 9. Impedance characteristics of the four types of transducers discussed in this paper. The smallest loop corresponds to a thinned overlap weighted transducer, the middle loop to a WW and the largest loop to an unthinned overlap apodized transducer. The curve with no loop corresponds to a broad-band (10 double electrode pair) transducer. Inductive tuning to cancel reactance was used in all cases.

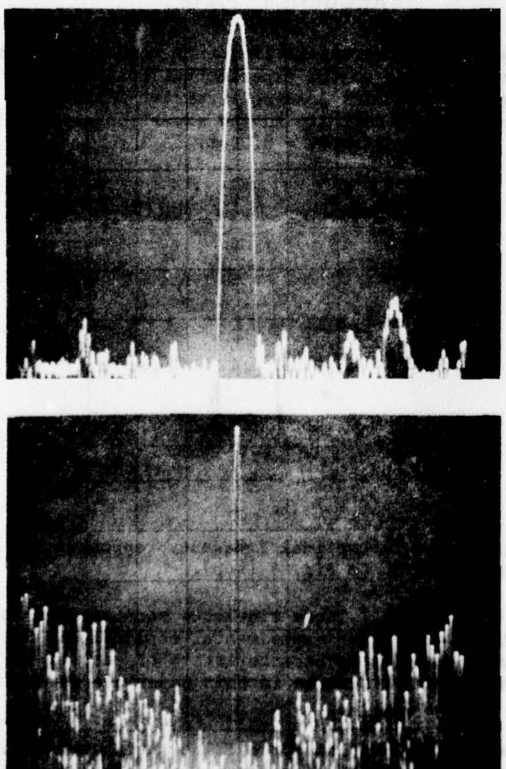

Figure 10. Frequency response curves of a SAW filter having both transducers withdrawal weighted. Vertical scale 10 dB/div. Actual insertion loss = 15dB. f_o = 335.4MHz. Top: 5MHz/div. Bottom: 20MHz/div.

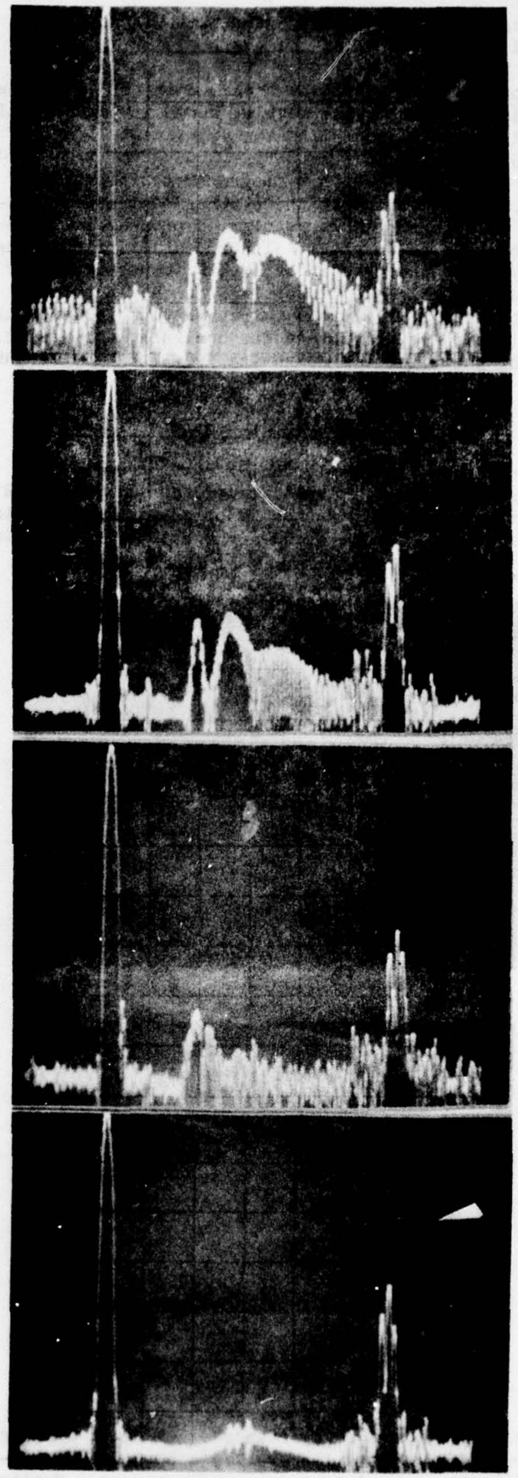

Figure 11. Illustration of the effect of SAW substrate back surface preparation on "bulk" mode spurious suppression. f_o= 365MHz with 10MHz/div horizontal scale, 10dB/div vertical scale. Top: polished bottom surface parallel to top surface. Upper middle: rough bottom, still parallel to top surface. Lower middle: rough bottom surface, canted at ~1° to top surface. Bottom: notched substrate as illustrated in Fig. 12. Note: the large response appearing at 395 MHz is a result of using a thinned transducer and is not a "bulk" spurious.

surfaces parallel to the propagation surface suffer from severe "bulk" mode problems. Roughening the back surface helps somewhat and canting the surface helps further. The final solution adopted for this paper (shown in Fig. 11 and also used for the filter of Fig. 7) utilizes a wedge or notch cut out of the substrate as shown in Fig. 12.

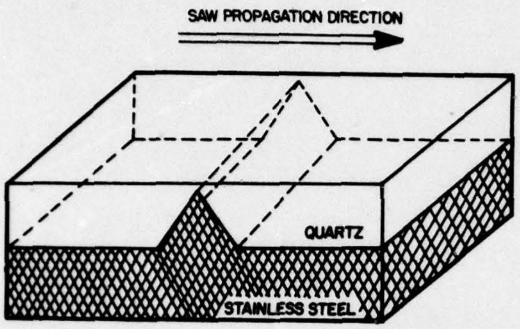

Figure 12. Illustration of the technique used to reduce "bulk" mode spurious.

Electromagnetic leakage or direct feedthru is suppressed by separating transducers by 9 mm, using a metal isolator bar placed 5×10^{-6} m over the surface and finally by sliding a part-metal and part-dielectric coverplate over the complete package to "tune out" residual leakage.

5. Single Electrode Complete Filters

Higher frequency single electrode bandpass filters can also be realized with techniques similar to those just described. At higher frequencies mass loading effects increase in severity, particularly since single electrodes must usually be used to avoid fabrication difficulties associated with the finer linewidth double electrodes. A reduction in the number of electrodes usually provides an excellent solution to this problem except when the reduced number of sampling units (electrodes or electrode pairs) degrades the filter shape. Thinning of apodized transducers is well-known,[9] but thinning of WW transducers is a more recent development.[6,7]

In the latter case the WW design algorithm is modified to automatically reduce the number of electrodes by a desired factor. In Fig. 13 the response of two normal WW transducers is shown at the top, and at the bottom, the improved response of two WW thinned transducers having half as many electrodes. Finally, in Fig. 14 the combined response of a thinned overlap apodized diffraction amplitude and phase corrected and thinned WW transducer filter demonstrates how these techniques can be employed to achieve excellent filter characteristics at high frequencies.

6. Summary and Conclusions

In this paper we have demonstrated the realization of low-out-of-band sidelobe, low spurious SAW bandpass filters. Keys to obtaining high performance were seen to be the use of combination length apodized and withdrawal weighted transducer filters plus a careful control of second order and spurious effects.

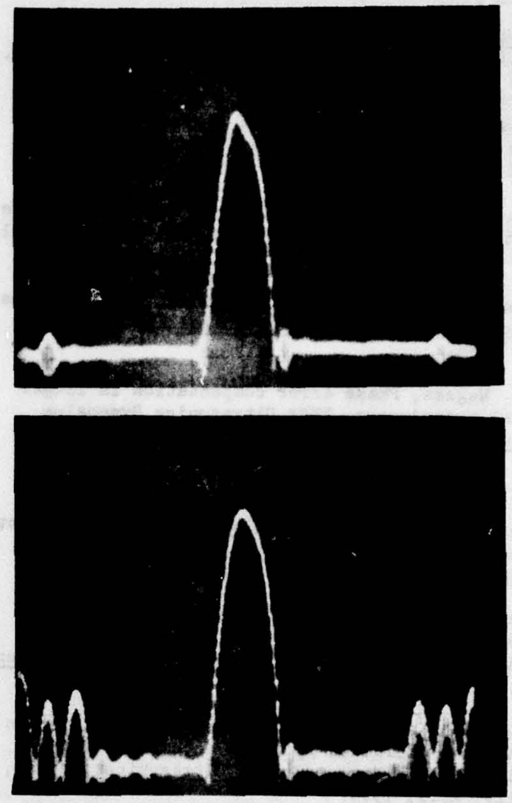

Figure 13. Frequency response curves of SAW filters using withdrawal weighted transducers for both input and output. f_o= 955.8MHz with 20MHz/div. 10dB/div vertical scale with center horizontal cross-hatched line = 40dB. Top: both transducers unthinned. Bottom: both transducers thinned.

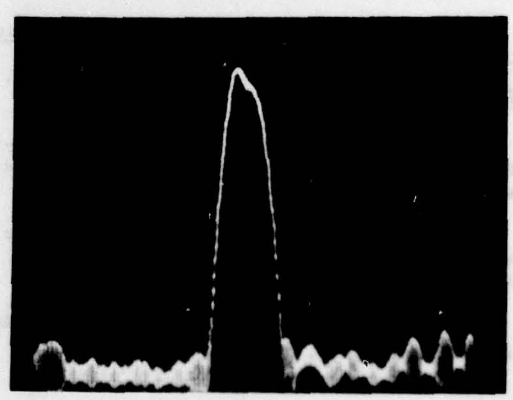

Figure 14. Frequency response of a thinned overlap apodized, thinned withdrawal weighted SAW filter on YZ lithium tantalate. f_o= 957 MHz with 20MHz/div, 10dB/div vertical scale with actual filter insertion loss = 19dB.

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