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Reflective Array Compressor With Etched Grooves

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ABSTRACT

Most surface wave filters use interdigital transducers on piezoelectric substates to produce chirp filters. Alternate type of filter use controlled reflection of surface waves from surface gratings. The second type (RAC - Reflective Array Compressor) are free of spurious signal and second order effects, and in large time-bandwith application are better than filter based on interdigital transduces. Designing method, technology and practical results of RAC filter with two 90 degree reflections are presented.

INTRODUCTION

Instead of well known dispersive delay lines (DDL) with interdigital transducer, reflective array compressors (RAC) can also be used. In comparison with DDL in RAC filters two times grater dispersion time can be achieved. The influence of spurious signals and second order effects is also significantly reduced. RAC filters are less sensitive to the fabrication errors. But because of more complicated two dimensional structure, designing of these filters is more difficult.

The delta function model was used to analyze the RAC filters. Despite its simplicity this model is very useful because of simple analogy between reflective structure geometry and impulse response of the device. This model can be used for filters with one 180° reflection or two 90° reflections. In delta function model it is assumed, that the surface acoustic wave propagating along the reflector is not attenuated, and the entire reflected signal is the sum of signals reflected from all grooves.

RAC ANALYSIS AND DESIGN

Reflection gratings plays main role in the shapening of RAC filter characteristic. The interdigital transducers are only necessary to convert the electric signal into acoustic wave and vice versa. The reflecting grating is usually made by plasma etching the large number of grooves. Instead of grooves metalized overlays can also be used. The reflecting structure properties depends on the grooves positions and reflecting coefficients.

The reflection coefficient r for the step of the groove or metalized strap is a function of h/λ and can be expanded in Taylor's series:

$$r\left(\frac{h}{\lambda}\right) = r_0 + C \cdot \left(\frac{h}{\lambda}\right) + \text{higher order terms}$$

where h is the groove depth or thickness of the metalized overlay, and λ is the SAW wavelength.

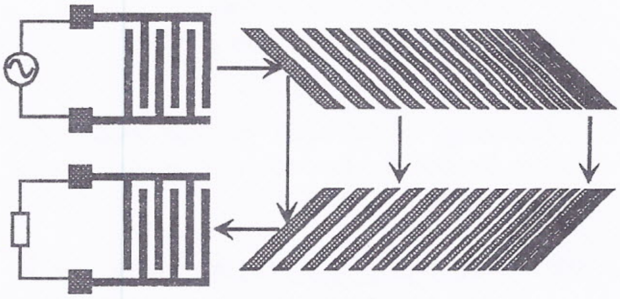

Fig. 1. RAC filter with two 90° reflections.

In a case of etched groove, the frequency independent term r_0 is equal to zero. On the other hand, if metalized straps are used and their thickness is negligible, the reflection factor is frequency independent. The higher order terms can be neglected if the h/λ is small enough (h/λ<0.03). The C constant depends on the substrate and overlay material and usually is evaluated experimentally. The material constants for the quartz substrate is presented in Table 1.

Table 1. Material constants for quartz substrate [2]

Reflector type	r_0	C
groove	0	0.23
aluminium strap	0.75	0.51

The reflection coefficient for a groove of the width a in the case of 90° reflection can be expressed by:

$$r_g(\omega) = 2jC\frac{h}{\lambda}\sin\left(\frac{1}{2}ak\right)$$

where $k = 2\pi/\lambda$ is a wavenumber.

For metalized structures the r_0 factor should be also taken into account:

$$r_g(\omega) = j\left[r_0 + C\frac{h}{\lambda}\right]\sin\left(\frac{1}{2}ak\right)$$

The grating transfer function for two grooves is described by [1,4]:

$$R(\omega) = r_{gm} r_{gn} \gamma_{mn} \exp\left[-j\left(k_x(x_m + x_n) + k_y y\right)\right]$$

$$\gamma_{m,n} = \frac{l_{m,n}\,\mathrm{ctg}\theta}{\left(l_{in} l_{out}\right)^{\frac{1}{2}}}$$

where

Θ - groove angle (for isotropic substrate Θ=45°),

l_{we} , l_{wy} - apertures of upper and lower gratings,

$l_{m,n}$ - physical length of the overlap,

y - distance between centers of the gratings.

According to the delta function model, the transfer function for two arrays of grooves can be described by the double sum:

$$R(\omega) = \exp(-jk_y y)\sum_{m,n} r_{g,m} r_{g,n} \gamma_{m,n} \exp\left(-jk_x(x_m + x_n)\right)$$

In the case of linear FM filter with initial frequency f_1 the grooves in the gratings must be spaced according to [4, 3]:

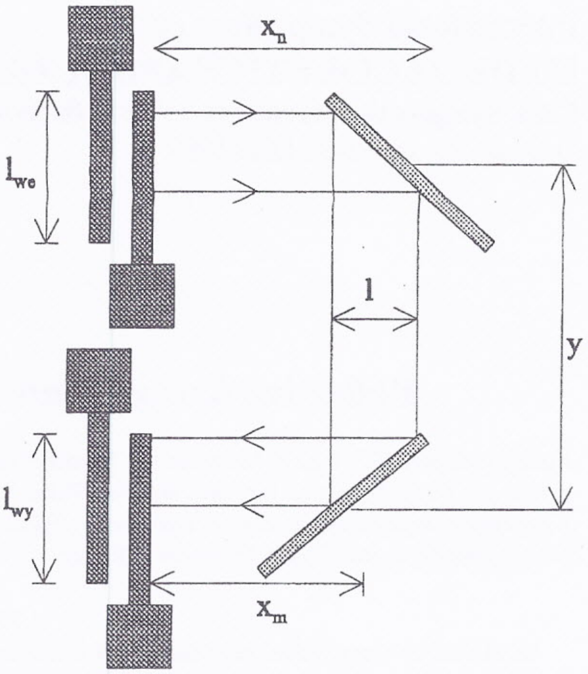

Fig. 2. Two 90° reflections from one pair of the grooves.

$$x_n - x_1 = \frac{\vartheta_x f_1}{2\mu}\left[-1 + \left(1 + \frac{4\mu}{f_2^{\,2}}(n-1)\right)^{\frac{1}{2}}\right]$$

$n = 1, 2, \ldots f_0 T/2 + 1,$

$\mu = B/T$.

where:

T - duration time,

B - signal bandwidth,

ϑ_x - SAW velocity,

The groove width is the half of the distance between neighboring grooves:

$$a_n = 1/2\,(x_n - x_{n-1})$$

Because the reflection coefficient is frequency dependent, in order to obtain flat impulse response a groove weighting must be used. The weighting may be incorporated by changing the grooves depths, lengths or widths. In a case of depth weighting the grooves depths can be described as [5]:

$$h_n = \frac{h_1}{\left(1 + \frac{2\mu}{\vartheta_x f_1} x_n\right)^2}$$

and for width weighting:

$$a_n' = a_n \frac{\pi}{2} \arcsin\left(\frac{1}{\left(1+\frac{2\mu}{\vartheta_x f_1} x_n\right)^2}\right)$$

Comparison of the frequency characteristics of reflecting gratings designed using various methods of weighting is presented in fig. 3. The results are comparable.

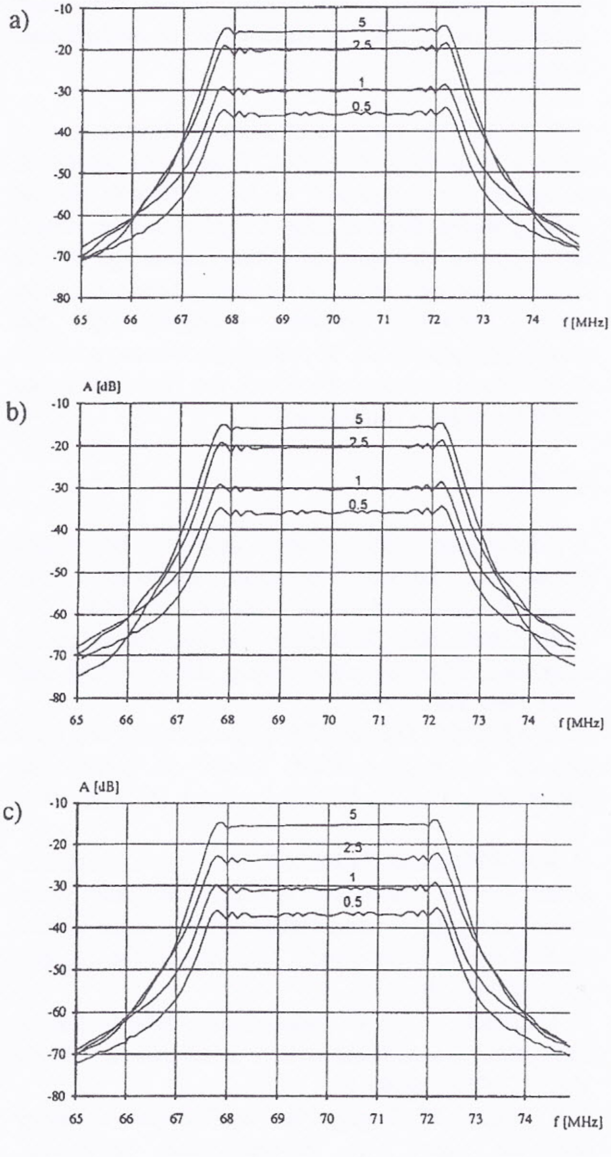

Fig. Frequency characteristics of the reflecting gratings designed using: a) length, b) depth and c) width weighting. Computations are made for apertures equal 0.5, 1, 2.5 and 5 mm.

RAC FILTERS TECHNOLOGY

One of the goals of this work was a commercial process development to obtain reflecting RA elements variable in depth. Therefore we had to do away with the commonly used method of etching "one-by-one" pair of reflecting elements though a mask transportable with respect to the substrate. That method being extremely complex, laborious and nonreproducible, is only applicable for making unique laboratory prototypes.

It should be also noted that the etching method with the use of a transportable mask becomes unsuitable with increasing operating frequency up to 1.0 ... 1.5 GHz because of the lack of the desired accuracy in micromovements. We have developed the reactor design, wherein samples are simultaneously transportable in opposite directions in front of an ion source. A carouse of the system accommodated 15 substrates at one time, whereas each of them (executing a rotary motion) was alternately subject to treatment by the ion beam. In addition, a linear motion was employed so that the substrate could be introduced into the treatment zone to produce the desired etch profile. A specified depth variation profile of reflecting elements was formed using a variable time of the ion-beam exposure for different areas of the substrate.

The system used an ion source with the cold cathode. A discharge was initiated in intercrossing magnetic and electric fields. A coil current variation allowed for forming the ion beam over wide limits. A vacuum chamber design made possible treatment of substrates, more than 200 mm in length.

Etching of plates of piezoquartz was done by a directed-beam of particles of tetrafluoromethane (CF_4). The usage of the reactive gas as a working substance allowed a corresponding increase in the etch rate, as compared with the processes using such inactive gases as argon, neon and xenon due availability if the chemical reactivity in addition to physical sputtering. The etch rate was as high as 0.7 μm/h for SiO_2. The current phototypesetting facilities make it possible to place those with the high positioning accuracy (0.1 μm). This eliminates the precision alignment step from the lithography process and improves reproducibility of the produced performance.

Our particular attention has been given to improving reproducibility in both the RA elements etching procedure and their cross-sections. The etch depth was tested by the interference method with the resolution 10 nm. Figure 4 presents the test data statistics in etch depths along the length of the RA (for 10 lots, 3 substrates in each). Measurements were taken at 10 different locations that were equally spaced along the RA length.

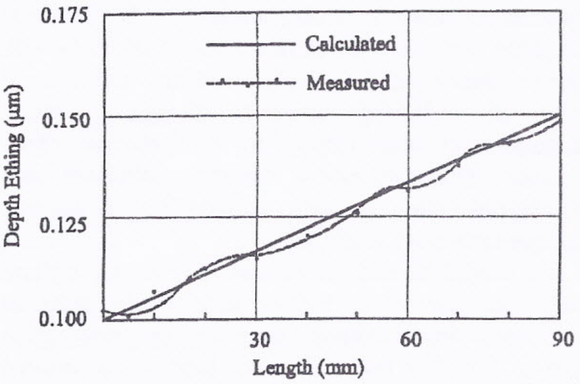

Fig. 4. Depth etching (calculated and measured) of the reflective array.

EXPERIMENTS

According to the model described above a RAC filter on quartz was designed. The assumed parameters of the filter are: center frequency 70 Mhz, frequency bandwidth 5 MHz, dispersion time 40µs. Comparison of calculated and measured frequency characteristics are presented in fig. 5. Interdigital transducers with 26 periodically spaced electrodes were used. The curvature of the characteristic is caused by large number of electrodes. The number of electrodes was increased in order to lower the insertion losses.

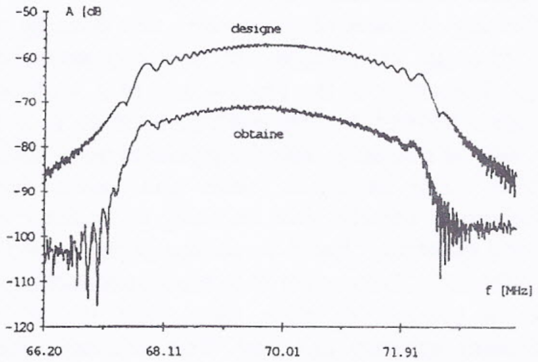

Fig. 5. Frequency characteristics of RAC filter.

This curvature can be eliminated if withdrawal weighted transducers are used fig. 6.

CONCLUSION

RAC filters are very useful, especially if large values of dispersion times are required. A sample RAC filter was designed with the use of the delta function models. The results are in good agreement with theory. The filters were fabricated using plasma etching technology. The RAC filters with metalized reflectors were presented in [6]. Although plasma etching process is more complicated, it enables depths weighting of the grooves. Main advantage of the depth weighting is that the weighting function can be easily changed without changing of the photolitographic mask. If etched grooves are used the direct signal is lower. To lower the insertion losses $LiNbO_3$ substrata can be used [7].

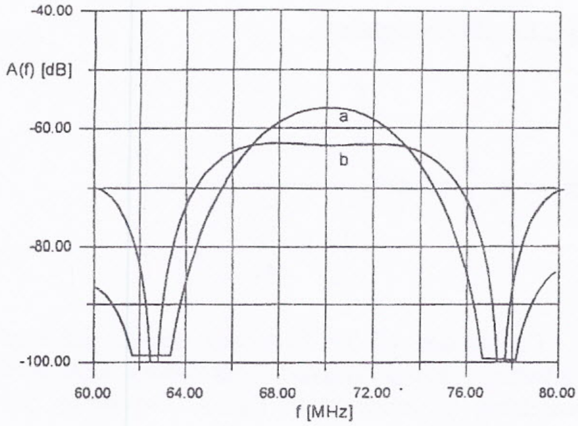

Fig. 6. Frequency characteristics of the transducers used in RAC filters: a) periodical, b) widthdrawal weighted.

REFERENCES

1. D.P.Morgan, Surface-wave devices for signal processing Elsevier Science Publisher B.V, Amsterdam - Oxford - New York - Tokyo 1991.

2. R.C.Willimson, Reflection grating filters in H. Matthews, "Surface wave filters, John Willey and Sons, New York 1977.

3. T.A.Martin, The IMCON pulse compression filter and its aplications, IEEE Trans. on Sonics and Ultrasonics, Vol. Su-20, No.2, April 1973, p. 104-112.

4. R.C.Williamson, H.I.Smith, The use of surface - elastic - wave reflection gratings in large time-bandwidth pulse - compression filters, IEEE Trans. on Sonics and Ultrasonics, Vol. Su-20, No.2, April 1973, p. 113-123.

5. C.Lardat, SAW Fused-silica reflective-array compressor Electronics Letter, 23rd January 1975, Vol.11, No.2, str.46-47.

6. K. Weiss, M. Tupaj, The RAC dispersive delay lines on quartz, 9th Piezoelectronic conference, Waplewo 1996.

7. V. F. Dmitriev, I. Mitrofanov, Design and fabrication of wide-band SAW DDL, 11th European Frequency and Time Forum, 1997.