

REFLECTIVE ARRAY SAW NARROWBAND FILTERS

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Abstract

Experimental results are presented for a reflective-array SAW device that is optimized for narrowband filter applications. The filter consists of broadband input and output transducers with two weighted reflector arrays. Previous devices of this type have used reflective dot density and depth profile weighting for the reflective arrays. A unique implementation of this design technique for a 70 MHz narrowband filter is demonstrated, in which position-weighting of the reflector arrays is used. This filter has 0.2% fractional bandwidth and excellent amplitude and phase characteristics. A detailed analysis of the filter by use of a computer simulation and comparisons between the predicted and experimental responses will be discussed.

Introduction

Surface acoustic wave (SAW) bandpass filters have been widely used as the optimum filter solution for many applications in the VHF and UHF ranges. The typical fractional bandwidth of the conventional SAW filters varies from 0.25 to 30%. The lower limit of the fractional bandwidth is set by die size or overcoupling or other sources of distortion. For narrower fractional bandwidth requirements, surface acoustic wave resonators are normally coupled together to form low-loss narrowband filters. However, for fractional bandwidths that are greater than 0.1%, the in-line acoustically coupled resonator filter usually exhibits poor close-in rejection. In addition, SAW multipole resonator filters generally exhibit poor phase characteristics across the bandwidth. Thus, there is a need for a filter design technique that will cover the range from 0.1 to 0.25% fractional bandwidth with good amplitude and phase response.

The reflective-array SAW design approach provides a mean of implementing narrowband filters in the bandwidth region between SAW resonator filters and conventional SAW filters. This configuration results in a shorter die length compared to a conventional SAW filter, but with better filter characteristics than

either a SAW resonator filter or conventional filters at these fractional bandwidths.

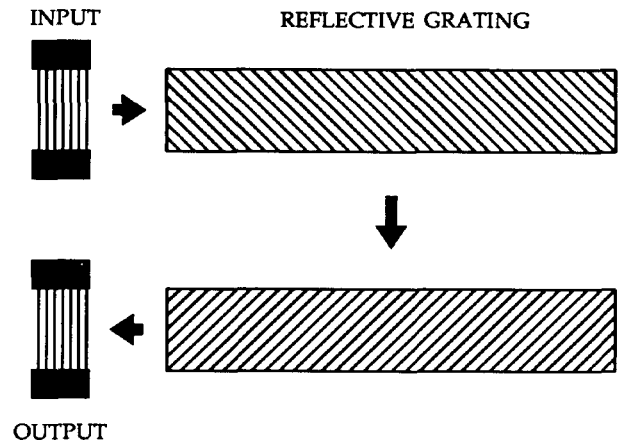


Figure 1 : SAW Reflective Array Filter (RAF)

Reflective Array Filter

Conventional narrowband SAW transversal filters generally require transducers that are very long and comprised of many electrodes. The acoustic overcoupling and other distortions that are caused by a large number of electrodes in the transducers can produce both amplitude and phase distortion in the filter passband response.

The reflective array filter (RAF) design can avoid the phase and amplitude distortion described above by separating the frequency selection and energy transduction process as shown in Figure 1. Since the launching and receiving transducers have relatively few fingers, acoustic overcoupling in the transducer is avoided. This design technique also provides more tolerance to fabrication defects since the filter characteristics are determined by the localized mechanical reflections in the array which are less sensitive to these defects than transducers. The filter frequency characteristics are determined by the reflective grating impulse response. This response can be computed by performing a modified spatial

convolution of the two reflective arrays. Since the two arrays fold the necessary acoustic path, the reflective array filter results in a shorter device than an equivalent conventional filter with the same bandwidth and shape factor. The concepts of weighting a reflective array by varying dot density or groove depth to realize bandpass filters are described in references 1 and 2. The groove depth weighting generally requires ion milling and is more complex to fabricate than a single level aluminium patterning process and the reflective dot array results in large photomask flash count and greater scattering loss. Position weighting of the reflector array, described herein, avoids these disadvantages.

Position Weighting Technique

The position weighting technique has been established as a practical means of implementing a weighting function for RAC devices [3]. This technique can also be applied to realize a narrowband reflective array filter that is simple in design and easily fabricated.

A description of the properties of a position-weighted array can be seen in Figure 2. If a surface wave is incident on the two edges of a reflective strip of width x as shown in Figure 2a, then the net finger reflection coefficient can be obtained by vector addition of the reflections from the front and the back edges of the strip. From Figure 2a, this result can be expressed as

$$A = 2r \sin\left(\frac{\pi x}{\lambda}\right). \quad (1)$$

where A = the amplitude of the net finger reflection coefficient
 r = the reflection coefficient of a finger edge.

To implement position weighting, a pair of reflectors is needed as shown in Figure 2b. From this figure, the effective reflector coefficient A' can be expressed as

$$A' = 2A \cos\left(\frac{\pi s}{\lambda}\right). \quad (2)$$

If the spacing s is equal to half the wavelength, then the reflected waves interfere destructively and the result is a null reflection coefficient irrespective of the strip width. If the spacing s is not equal to half the wavelength, then the strip width does affect the net finger reflection coefficient. Stronger reflection occurs as the strips in a reflector pair are moved closer together so that the center-to-center spacing is reduced. Thus, by varying the spacing s , a desired amplitude weighting function can be readily achieved.

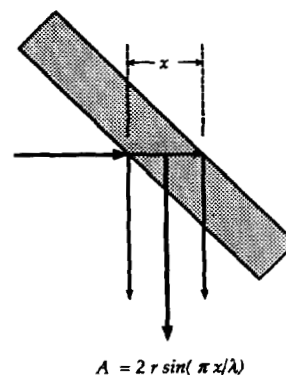


Figure 2a : Finger Reflection Coefficient

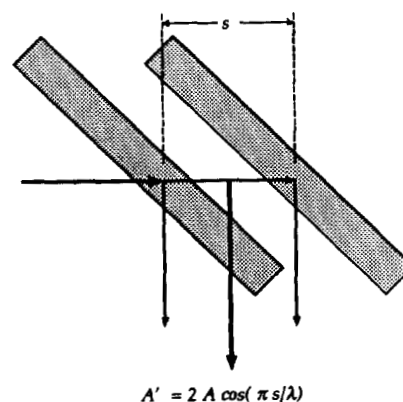


Figure 2b : Position Weighting of a RAF

Test Devices

A number of test devices were fabricated to evaluate the basic transmission and reflection of the wave propagating through the reflective array structure. These test devices were fabricated with different metal thicknesses to establish the constants that are needed for the development of an accurate computer model. All test devices had a center frequency of 70 MHz and were fabricated on ST-cut quartz.

The first test device used an unweighted reflective array 375 wavelengths long. The width of each strip was one-sixth wavelength with the center-to-center spacing between each strip in a reflector pair of 0.25 wavelength. The aluminum film thickness was 2500Å. The frequency response, as shown in Figure 3a, has a shape that closely follows a $\sin x/x$ response with a 3 dB bandwidth of approximately 75 KHz. The insertion loss is approximately 30.5 dB with a phase deviation across the passband of less than 0.5 degree.

The impulse response of this device, shown in Figure 3b, is a rectangle with a slope of $0.26 \text{ dB}/\mu\text{sec}$. This slope is attributed primarily to the bulk mode scattering within the array. The same device when fabricated with a metal film of $7800\text{\AA}$ exhibits a slope of $2.4 \text{ dB}/\mu\text{sec}$, which results in a significantly distorted $\sin x/x$ frequency response. However, the insertion loss of the filter is reduced to 17.2 dB . Thus, to obtain a good filter frequency characteristic with low insertion loss, compensation of the amplitude slope along the array is essential.

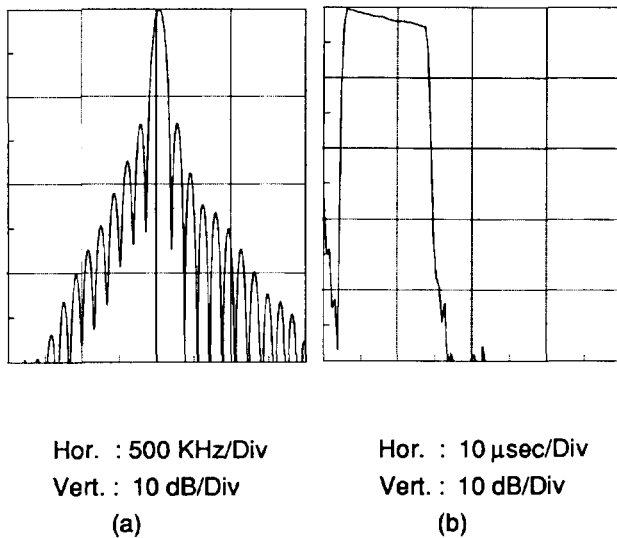


Figure 3 : (a) Measured Frequency and (b) Impulse Responses of an Unweighted RAF

RAF Theoretical Model

A computer aided model is used to simulate the filter characteristics as closely as possible. This gives a prediction of the filter performance prior to a commitment to a costly photomask and device fabrication. By entering the device material parameters and the transducer weighting characteristics, the input and the output transducer frequency responses are readily obtained by using the equivalent circuit model as developed by Krimholtz and Matthaei [4,5]. The frequency response of the reflective arrays is given by the Fourier transform of the total reflective grating impulse response [6]. The total grating impulse response is the convolution of the two gratings in time as illustrated in Figure 4. The interactive area of convolution in this case is generally a parallelogram, except at the tail ends of the array. The various sources of amplitude decay along the array such as propagation, diffraction and scattering losses also need to be included.

Figures 5a and 5b show the modeled frequency and time responses of the same filter shown in Figures 3a and 3b. Table 1 lists the theoretical results and actual measurements of the filter. They are in close agreement.

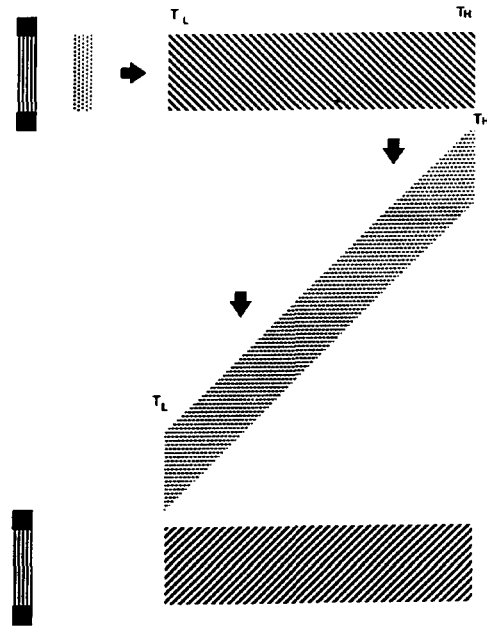


Figure 4 : Impulse Response Analysis of the Reflective Arrays

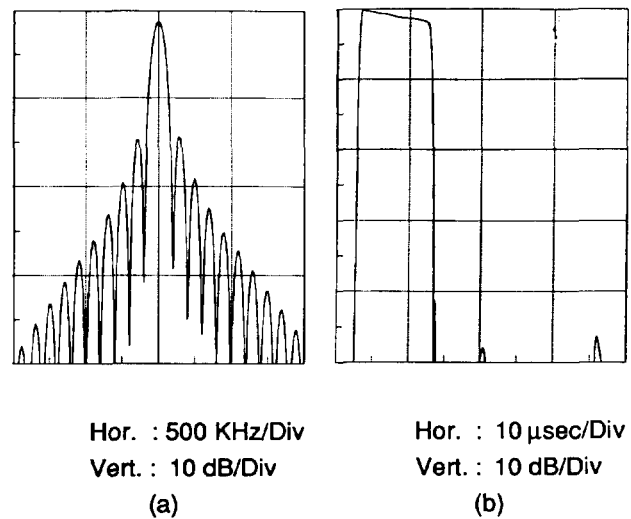


Figure 5 : (a) Modeled Frequency and (b) Impulse Responses of an Unweighted RAF

TABLE 1: A COMPARISON OF THEORY AND EXPERIMENT FOR AN UNWEIGHTED 70 MHz RAF

Parameters	Actual	Modeled
Insertion Loss (dB)	30.5	30.6
3 dB BW (KHz)	76	88
Phase Linearity (deg)	<0.5	<0.5
Slope in Impulse Response (dB/ μ sec)	0.26	0.21
Sidelobe Rejection (dB)	13.1	13.1

Weighted RAF

To realize a useful filter with lower sidelobes and shape factor, it is necessary to add weighting along the reflective array. By varying the spacing between a pair of reflectors, an amplitude weighted function can be implemented. An experimental device using position-weighted reflectors was designed and fabricated. The width of the reflecting strip of this device was one-sixth of a wavelength with a minimum center-to-center spacing of 0.25 wavelength. Both of the transducers have a length of 100 wavelengths and are unweighted. For wider fractional bandwidth requirements, the input and output transducers can be weighted to achieve additional sidelobe rejection.

Figures 6a and 6b show the measured and modeled filter impulse responses, respectively. Figures 7a and 7b show the measured frequency and phase responses of the same filter. Figures 8a and 8b show its modeled frequency and phase responses. Table 2 lists the predicted and actual measured parameters of the this filter. The 3 dB bandwidth of this filter was 142 KHz with a 40 dB bandwidth of 396 KHz and a near-in rejection better than 40 dB. The ultimate rejection is limited by electromagnetic feedthrough to 55 dB. This filter has an insertion loss of 20.1 dB with very little amplitude ripple. It was externally matched with a single inductor on each port. A two-element matching network could reduce the insertion loss of the filter to 18 dB at the expense of increasing the amplitude and phase ripple. The excellent phase characteristic of the filter makes the RAF design an optimum approach for narrowband filter applications where phase linearity and phase tracking are important. As can be seen, the theoretical response is in close agreement with the experimental results.

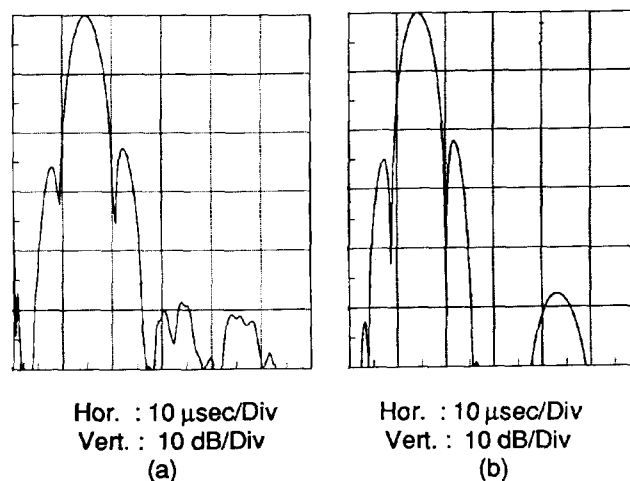


Figure 6 : (a) Measured and (b) Modeled Impulse Responses of a Weighted RAF

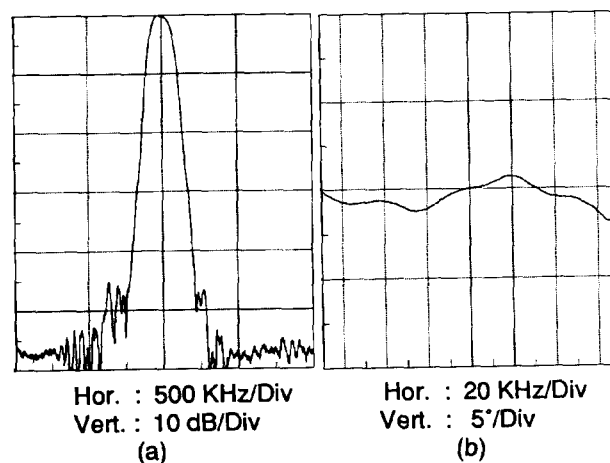


Figure 7 : Measured (a) Frequency and (b) Phase Responses of a Weighted RAF

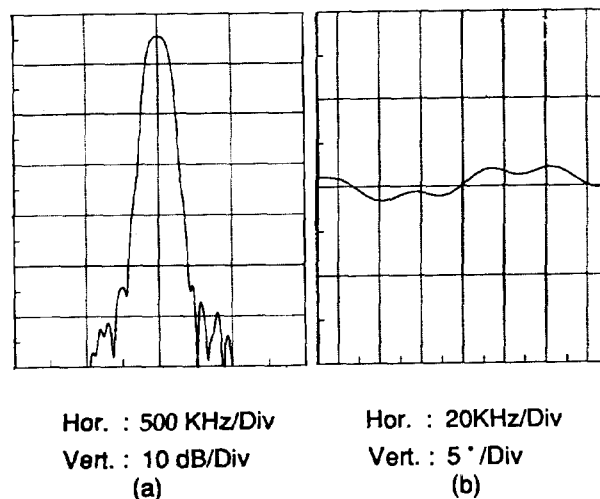


Figure 8 : Modeled (a) Frequency and (b) Phase Responses of a Weighted RAF

TABLE 2 : A COMPARISON OF THEORY AND EXPERIMENT FOR A WEIGHTED 70 MHz RAF

Parameters	Actual	Modeled
Insertion loss (dB)	20.1	19.5
1 dB BW (KHz)	96	101
3 dB BW (KHz)	142	142
40 db BW (KHz)	396	385
Phase linearity (deg)	+/- 1	+/- 1

Effects of Temperature on the RAF

Since the RAF uses a similar design to a RAC, it is important to measure the temperature effects, since ST-cut quartz exhibits a temperature-dependent anisotropy [7]. In order to observe the effects of temperature on the RAF, the filter insertion loss and center frequency were measured for various temperatures. From the results shown in Figure 9a, the total insertion loss variation is about 1 dB. Since most of the variation of insertion loss occurs at low temperatures, the reflective angle of the strips can be further optimized to reduce this variation. From Figure 9b, the second order temperature coefficient of frequency variation for the filter is found to be $-0.052 \text{ ppm}/^{\circ}\text{C}^2$, which is about 1.75 times worse than that of a conventional quartz device. The greater sensitivity of the RAF with temperature is attributed to the temperature dependent transverse velocity of ST-cut quartz with a metal film thickness of $9000\text{\AA}$.

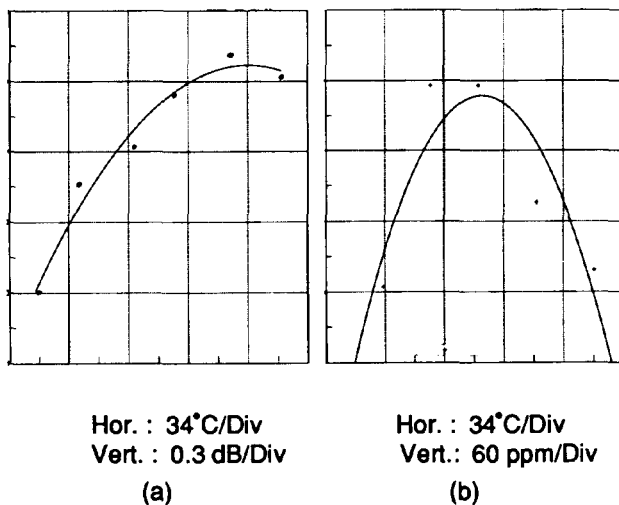


Figure 9 : (a) Insertion Loss Variation and (b) Frequency Drift versus Temperatures

Conclusions

In conclusion, a design technique for implementation of narrow fractional bandwidth filters with excellent amplitude and phase characteristics has been presented. This design approach results in a shorter die length as compared to conventional filter design and is more tolerant to fabrication defects such as shorts and opens. The reflective array filter design provides an optimum approach for applications where narrow bandwidth, phase linearity and phase tracking are important.

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