A SAW PULSE COMPRESSION FILTER USING THE REFLECTIVE DOT ARRAY

H. van de Vaart and L. P. Solie
Sperry Research Center
Sudbury, Massachusetts 01776

Abstract

A new type of pulse compression filter is described using the Reflective Dot Array (RDA). The RDA is similar to the Reflective Array Compressor (RAC), except that the array of reflecting grooves is replaced by an array of reflecting metallic dots. The RDA has the principal advantage of being part of the same mask and metalization as the interdigital transducers, allowing single step fabrication. A linear FM filter was developed with a center frequency of 60 MHz, bandwidth of 20 MHz and differential time delay of 10 μs, with less than 4° of rms phase deviation from quadratic without phase compensating film, showing that high performance pulse compression filters can be produced at low cost.

Introduction

The reflection of surface acoustic waves by an array of grooves has been used for several years to fabricate high performance pulse expansion and compression filters, as well as bandpass filters.[1,2] The advantages are well known: 1) bulk modes and pseudo surface modes are not detected by the output transducers because they are reflected at a different angle, 2) the structure is defect tolerant, 3) there is no regeneration, 4) grooves are separated by $\lambda/\sqrt{2}$ whereas electrodes with split fingers are separated by $\lambda/4$, 5) the magnitude of the reflection is only dependent on the depth of the groove, and not on the piezoelectric coupling, thereby increasing the flexibility of achieving the desired tap weight, 6) the depth weighting provides true amplitude weighting over the full beam width, eliminating diffraction problems and 7) twice the differential time delay can be obtained for a given length substrate. The major disadvantages lie in the fabrication process: 1) a complex ion beam etching system is necessary to provide the variable depth grooves, 2) the process is serial so that devices can be fabricated only one at a time and 3) precise alignment is necessary between the metalized transducers (produced in one step) and the array of grooves (produced in another step).

In previous papers, it was shown that the reflections of surface waves can be accomplished by an array of metalized dots (RDA), where the number of dots in each row determines the strength of the reflection, i.e., provides amplitude weighting.[3,4] This principle was applied to the construction of a high performance bandpass filter. The advantages of using the RDA are that, in addition to all the advantages of the reflective array compressor as listed above, the amplitude weighting is built into the same mask that contains the transducers, both transducers and the array of dots are evaporated into the substrate at the same time, eliminating the critical alignment step, and this process allows fabrication of many devices in parallel.

In this paper, we report on the design of pulse compression filters using the RDA approach. The design procedure is in many respects identical to the RAC device. However, there is a difference in the manner in which the phase compensation due to the mass loading of the metal dots is calculated as compared to the grooved devices. The design of a pulse compression filter with a time-bandwidth product of 200 and the results obtained are described in the next sections.

RDA Design

In analogy to the transfer function for grooved devices,[1] the transfer function for an RDA can be written as

$$H(\omega) = \left(\frac{Ch\omega}{2\pi v}\right)^2 \sin^2\left(\frac{\omega d}{2v}\right) \sum_{m,n=1}^{N} a_m a_n \gamma_{mn} e^{-i\frac{\omega}{v}(x_m+x_n)} \tag{1}$$

where C is proportionality constant relating the reflectivity to the height of the discontinuity (here the thickness h of the metal dot), v is the surface wave velocity, d is the dimension of the dot in the direction of propagation (assumed constant over the array), a_m and a_n represent the normalized weighting for each row in the two arrays, γ_{mn} is the overlap function which measures the fraction of the n-th groove illuminated by the m-th groove, and x_m and x_n measure the distance from the first groove to the m-th and n-th groove, respectively. As will be shown in the following section, using Eq. (1) predicts the transfer characteristics of the RDA device with good accuracy.

In calculating the position of each row, one has to consider the velocity reduction which is a function of the density and size of the dots, the metal thickness and the frequency. The fractional velocity reduction is assumed to take the form

$$\frac{\Delta v}{v} = -KA\left(\frac{h}{\lambda}\right)^2 \tag{2}$$

where K is a constant, A is the fractional area metalized and λ is the wavelength of the surface wave. This assumes that there is no continuous metalization, i.e., the dots are smaller than a wavelength so that there is no piezoelectric shorting. Equation (2) can be rewritten as

$$\frac{\Delta v_{ij}}{v_o} = \frac{-KNa_i}{16M}\left(\frac{h}{\lambda_o}\right)^2\left(\frac{f_j}{f_o}\right)^2\left(\frac{f_i}{f_o}\right) \tag{3}$$

where $\Delta v_{ij}/v$ is the fractional reduction of the phase velocity of a propagating wave of frequency f_j in the vicinity of a row at which frequency f_i is resonant, f_o is the center frequency and λ_o its corresponding wavelength, and $M\lambda_o$ is the width of the array. Equation (3) assumes the dots have an area of $(\lambda_o/4)^2$. For gold on $LiNbO_3$, K has been found empirically to be equal to 443.

The group velocity for a wave at frequency f_j is given by

$$v_g = 2\pi\left(\frac{dk'}{df_j}\right)^{-1} \tag{4}$$

where the wavevector $k' = k(1+\frac{\Delta v}{v})^{-1}$. The group delay for a surface wave at frequency f_j up to the row at which f_j is resonant (located at x_j) is then found to be

$$\tau_g(f_j) = \frac{x_j - x_1}{v_o} - 3\sum_{i=1}^{j-1} \frac{\lambda_i}{v_o}\frac{\Delta v_{ij}}{v_o} \tag{5}$$

By fitting this expression to the required chirp slope, the positions x_j (relative to the position of the first row x_1) can be determined. These equations can also be applied to the design of an RDA bandpass filter, for which case $f_i = f_o$.

Experimental Results

A linear FM filter was designed at a center frequency of 60 MHz, a bandwidth of 20 MHz and a differential time delay of 10 μs, for a time-bandwidth product of 200. The filter was overdesigned to 28 MHz bandwidth and 14 μs differential time delay in order to be able to gate out the ripple at the edges of the passband. Also, in order to prevent refraction of the surface wave as it enters the dot array, the edges of the array were cut off perpendicular to the propagation direction. This of course causes additional weighting at the edges of the passband, but helps to reduce the ripple. The input and output transducers were phase reversed transducers (9 fingers) with a measured insertion loss of 35 dB.

The computed passband response using Eq. (1), as well as the experimentally measured response, is shown in Fig. 1. Although the measured curve has a somewhat larger dip in the center of the band, the overall agreement is excellent. Gold dots were used with a thickness of 4400 Å; subtracting the transducer loss, the reflection loss is found to be ~10 dB per array.

The phase response was also measured, and fitted to a quadratic curve. The deviations from quadratic are shown in Fig. 2. The rms phase deviation is 3.8^o, an excellent result considering that no phase compensating film was used in between the two arrays. This response implies that, with appropriate weighting, pulse compressors with time sidelobes down 35 dB or better can easily be obtained using the RDA. Work on weighted RDA pulse compressors, as well as on devices with larger time-bandwidth products, is presently in progress.

Finally, two identical devices were used in a pulse compression loop. One device was impulsed to obtain the expanded signal, Fig. 3(a). After spectral inversion, this signal was gated and then compressed in the second RDA, Fig. 3(b). An expanded display of the compressed signal is shown in Fig. 3(c).

Conclusion

In this paper, we have reported the initial results obtained with a linear FM pulse expansion and compression filter with only a modest time-bandwidth product using the RDA approach. We believe that this approach will find wide application in the fabrication of high performance pulse compression filters, primarily because of the ease of fabrication while maintaining the excellent characteristics of the reflective array compressor. With the modern fast scanning pattern generators, mask fabrication has posed no problem. The somewhat higher cost of the mask (because of the many flashes) is more than offset by the elimination of the complex ion beam etching appratus. For very long time delay devices, it may prove advantageous to use etched holes (or posts) rather than metalized dots, but even in that case the etch depth is uniform and can be done in a simple sputter etch system, in parallel fashion rather than serial. For these reasons, the RDA approach shows promise to fabricate high performance filters at low cost.

Acknowledgment

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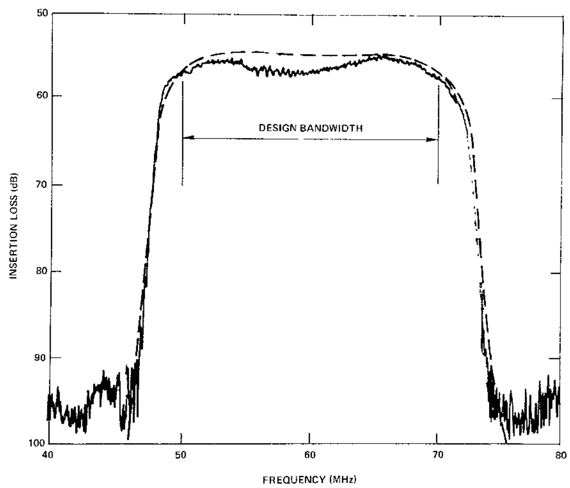

FIG. 1. Measured (solid line) and computed (dotted line) passband response of an RDA linear FM filter with F_c = 60 MHz, ΔF = 28 MHz and ΔT = 14 μs.

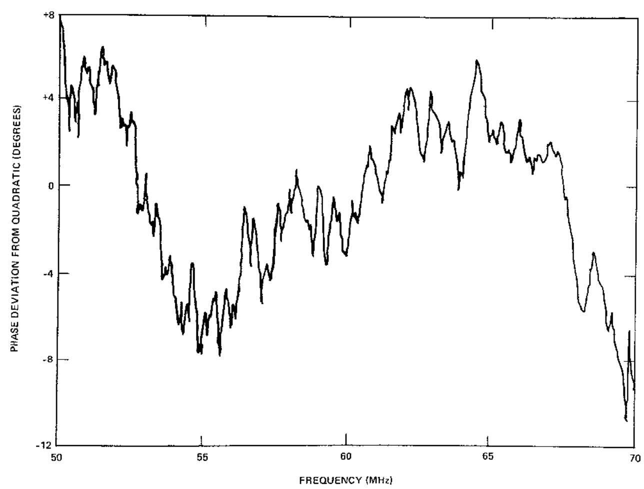

FIG. 2. Deviations of the measured phase from a quadratic fit vs frequency over the design bandwidth of 20 MHz. The rms phase deviation is 3.8^o.

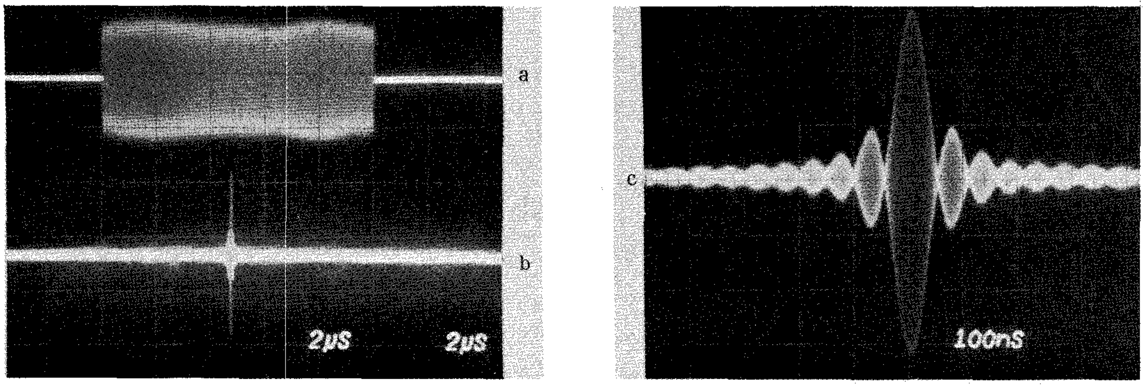

FIG. 3. Pulse compression test with two identical RDA devices. (a) expanded signal (2 μs/div), (b) compressed signal (2 μs/div), (c) expanded display of compressed signal (0.1 μs/div).