SYNTHESIS OF PERIODIC APODIZED SAW FILTERS IN THE PRESENCE OF DIFFRACTION

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Abstract

Straightforward analytic synthesis techniques are derived for correcting for diffraction in periodic acoustic surface wave filters having one apodized transducer. Quantitative experimental verification of the procedure is provided for a $LiTaO_3$ filter operating at 340 MHz.

I. Introduction

Surface acoustic wave bandpass filters offer the advantages of small size and weight together with low cost and high reproducibility. Since an interdigital transducer can be made to be an excellent transversal filter, Fourier-transform-pair and digital filter [1,2] design procedures can be used to synthesize frequency responses. This is true in theory, at least. Unfortunately a problem arises from the manner in which weighting is applied to each interdigital gap. Finger overlap apodization results in diffraction variations which destroy the Fourier transform relation between the envelope of the finger overlap function and the device frequency response.

A direct synthesis method for correcting for these diffraction effects by modification of the original apodization is presented here for periodic (as opposed to dispersive [3]) transducers. Experimental confirmation of this technique is shown for a UHF filter fabricated on YZ $LiTaO_3$.

II. Basic Theory

The signal amplitude transferred to an electrical load from an acoustic aperture of width $\hat{L}$ ("hatted" quantities are wavelength scaled) irradiated by an acoustic beam of complex amplitude $A(x)$ has been given by Waldron [4] as

$$S = \frac{T(\hat{L})}{\sqrt{\hat{L}}} \int_{-\hat{L}/2}^{\hat{L}/2} A(x)\, dx \,. \qquad (1)$$

Here x is the direction perpendicular to the acoustic beam and $T(\hat{L})$ is defined in the following manner [4]. The amplitude of the electrical signal delivered to the load is $T(\hat{L})$ times the amplitude of an acoustic beam $\hat{L}$ wide and of constant amplitude and phase centered on the transducer at normal incidence.

Under the conditions for which an interdigital transducer can be directly represented as a transversal filter, it has been shown [5] that $T(\hat{L})$ is directly proportional to $\sqrt{\hat{L}}$. In other words

$$T(\hat{L}) = C\sqrt{\hat{L}} \qquad (2)$$

where C depends on other physical and geometrical parameters of the delay line [5] but is independent of $\hat{L}$. This is an important result as it means that the C associated with a given individual finger pair in an apodized transducer is independent of the finger overlap $\hat{L}_N$ and thus is the same for all gaps (for periodic transducers).
Equation (1) can thus be rewritten as

$$S = C \int_{-\hat{L}/2}^{\hat{L}/2} A(x)\, dx \qquad (3)$$

which forms the basis of the following development.

III. Correction for Diffraction

Consider an acoustic surface wave delay line having one apodized transducer and one uniform launching aperture as illustrated in Fig. 1. Under the condition of no diffraction, the voltage across the load due to the Nth finger pair having overlap $\hat{L}_N$, with respect to the voltage across the load due to the widest finger pair having overlap $\hat{L}_0$ is, from equation (3)

$$\frac{\int_{-\hat{L}_N/2}^{\hat{L}_N/2} A(0)\, dx}{\int_{-\hat{L}_0/2}^{\hat{L}_0/2} A(0)\, dx} = \frac{\hat{L}_N}{\hat{L}_0} \equiv R_{NOD} \quad \text{(ideal case - no diffraction)} \qquad (4)$$

Note that each finger pair is treated separately and superposition used to generate the total result.

In order to synthesize the desired frequency response in the presence of diffraction it is necessary to achieve this same ratio. That is,

$$R_D \equiv \frac{\int_{-\hat{L}'_N/2}^{\hat{L}'_N/2} A(x, \hat{Z}_N)\, dx}{\int_{-\hat{L}_0/2}^{\hat{L}_0/2} A(x, \hat{Z}_0)\, dx} \quad \text{(diffraction present)} \qquad (5)$$

must be set equal to R_{NOD}. Or combining equations (4) and (5)

$$\frac{\int_{-\hat{L}'_N/2}^{\hat{L}'_N/2} A(x, \hat{Z}_N)\, dx}{\int_{-\hat{L}_0/2}^{\hat{L}_0/2} A(x, \hat{Z}_0)\, dx} = \frac{\hat{L}_N}{\hat{L}_0} \qquad (6)$$

In these equations $\hat{L}'_N$ is the unknown aperture in the presence of diffraction of the Nth finger pair. It is located a distance of $\hat{Z}_N$ from the launching aperture as indicated in Fig. 1. For the present analysis we have arbitrarily set the widest overlap ($\hat{L}_0$) in the presence of diffraction to be equal to the widest overlap if no diffraction were present and in addition have taken it to be located a distance of $\hat{Z}_0$ from the launching transducer.

In practice, then, a set of $\hat{L}_N$ is generated using ideal Fourier transform or digital design techniques [1,2]. The actual delay line is, however, fabricated using values of $\hat{L}'_N$ determined according to a modified version of equation (6) as described below. This form is more convenient for synthesis calculations and is obtained by first taking the magnitude squared of both side of equation (6), dividing both numerator and denominator of the right hand side by $\hat{L}_0^2|A(0)|^2$, rearranging terms and multiplying numerator and denominator by $\hat{L}_0\hat{L}'_N$, and finally by taking logarithms and recognizing that one term represents diffraction loss between two equal transducers [6] of width $\hat{L}_0$ and separated by a distance of $\hat{Z}_0$.

$$-10\log_{10}\frac{\left|\int_{-\tilde{L}_N/2}^{\tilde{L}_N/2} A(x,\hat{Z}_N)\,dx\right|^2}{\hat{L}_0\,\tilde{L}_N\left|A\,(0)\right|^2} - 10\log_{10}\left(\frac{\tilde{L}_N\,\hat{L}_0}{\hat{L}_N^2}\right) = \left\{\begin{matrix}\text{Diffraction loss in dB for two}\\ \text{equal } \hat{L}_0 \text{ transducers}\end{matrix}\right\} \qquad (7)$$

Computer iterative solution [7] of equation (7) provides the corrected overlap values, $\tilde{L}_N$.

IV. Experimental Verification

The design to be tested consists of an unapodized transducer having 69 fingers and an apodized transducer having 137. The particular set of $\hat{L}_N$ chosen for this example has the desired (no diffraction) frequency response shown in Fig. 2 (upper). The apodization used, although similar in appearance to cosine-squared-on-a-pedestal characteristics [8], followed no analytic function and was specified individually for each finger. The computer program [9] used to generate this plot accounts for electrical loading and back voltages as well as the use of double electrodes. Apodization is treated using the segmented approach [9] which, although costly in computer time, produces highly accurate results.

Correction for diffraction, that is determination of $\tilde{L}_N$, requires specification of the following parameters:

Material: YZ $LiTaO_3$

$\hat{L}_0 = 23.33$

$\hat{Z}_0 = 577.69$

$\lambda = v_s/f_o = \frac{3230 \text{ m/sec}}{340 \text{ MHz}} = 9.5\ \mu m$

(Here λ is the acoustic wavelength at center frequency f_o and v_s is the surface wave velocity).

Using these parameters in equation (7), a corrected set of $\tilde{L}_N$ was determined and an actual delay line fabricated on YZ $LiTaO_3$. Photographs of both transducers are presented in Fig. 3. Since split electrodes were used to minimize electrical and mass loading, electron beam photolithographic techniques [10] were used in order to obtain the 1.188 μm line widths and gap spacings.

The experimental insertion loss versus frequency response of the actual delay line is illustrated in Fig.2 (lower). Except for a small difference in insertion loss of 3 dB and a slight shift in overall center frequency of 1.4% as well as a minor shift between the center frequencies of the two experimental transducers, due probably to variations in electron beam fabrication technique, agreement with the desired response is excellent.

This agreement can be confirmed quantitatively in a manner independent of the slight differences observed above. The first two nulls on either side of the central resonance are due to the particular apodization present in the long transducer [8]. Since these nulls can be measured very accurately (3 parts in 10^4), a very sensitive measure of apodization is available. For the experimental case

$$2\,\frac{f_u - f_L}{f_u + f_L} = 0.04274 \text{ (experimental)} \qquad (8)$$

where f_u represents the frequency of the upper null and f_L the lower. This figure is in excellent agreement with that for the theoretical case.

$$2\,\frac{f_u - f_L}{f_u + f_L} = 0.04288 \quad \text{(theory)}. \qquad (9)$$

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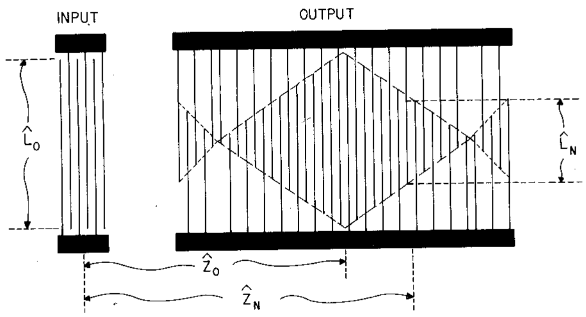

Figure 1 - Illustration of interdigital transducers with definition of terms used in diffraction correction derivations.

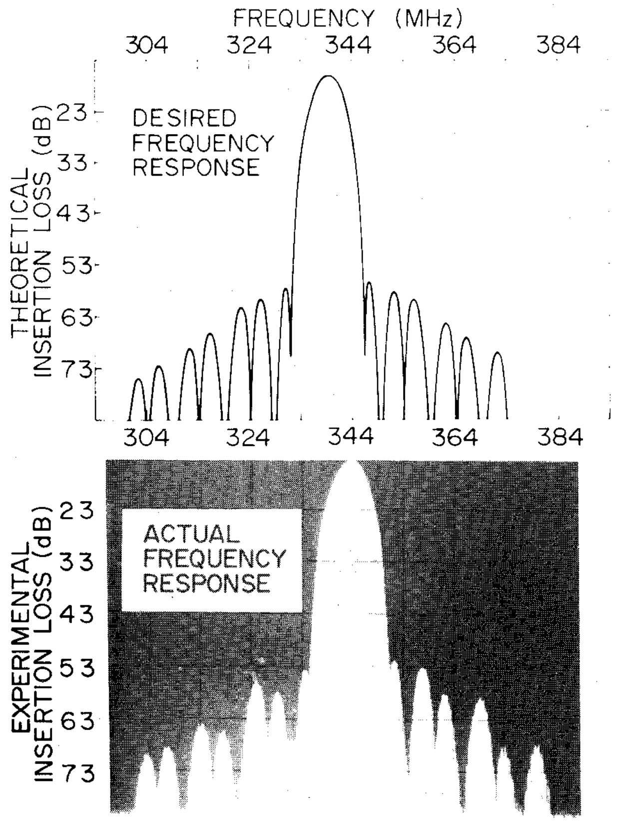

Figure 2 - (upper) Computer generated frequency response including second order transducer effects in the absence of diffraction. That is, using L_N. It is desired to synthesize this ideal response in the presence of diffraction.
(lower) Experimental frequency response of actual $LiTaO_3$ surface wave filter.
Scales: 10 dB/division on the vertical axis with the top line representing 13 dB and 10 MHz/division on the horizontal axis with the center cross-hatched line equaling 344 MHz.

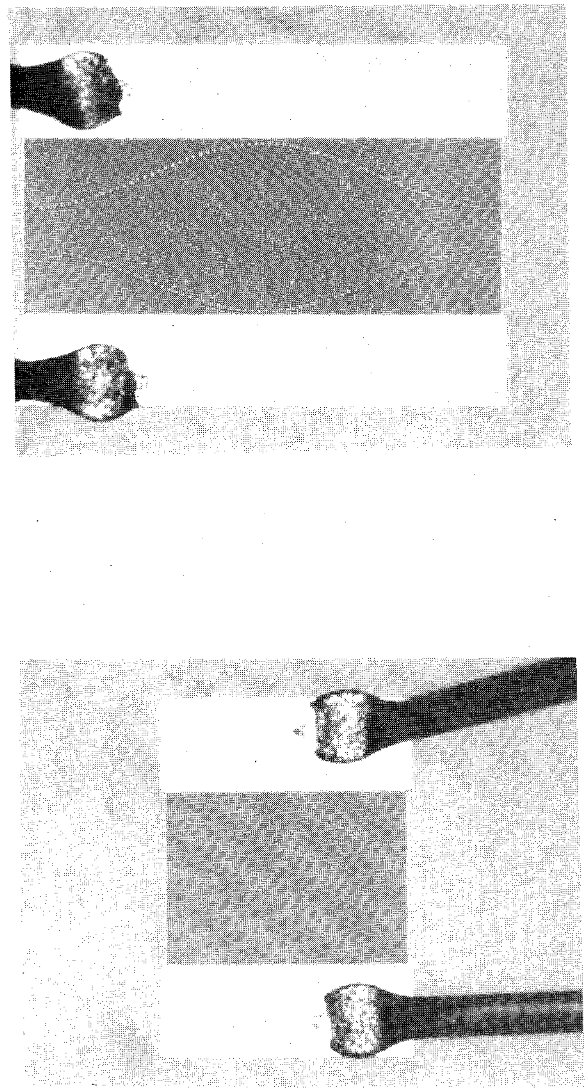

Figure 3 - Photographs of actual transducers fabricated on YZ $LiTaO_3$ using electron beam techniques [10]. The finger overlap values for the double electrode pairs were specified by the calculated values of L'_N.