A SYNTHESIS PROCEDURE FOR UNAPODIZED NONDISPERSIVE SURFACE WAVE FILTERS*

W. R. Smith

Hughes Aircraft Company, Fullerton, California 92634

Abstract

A synthesis procedure is presented for nondispersive surface acoustic wave filters having unapodized transducers. The simplest filter design utilizes flat-passband transducers whose uniform acoustic beam is useful in acoustic correlators and reflective array pulse compressors (RAC). Another device is a spectral weighting (e.g. Hamming) filter which may be a separate unit or an integral part of a RAC.

Introduction

Surface acoustic waves have previously been demonstrated as a convenient means of implementing nondispersive delay lines with fractional bandwidths exceeding an octave.[1,2] By using two identical interdigital transducers oriented as shown in Figure 1, a nondispersive filter can be obtained even though each transducer has a nonuniform electrode spacing.[3] The transducers operate over a band ranging from a low frequency f_1 (where the most widely spaced electrodes are one half acoustic wavelength apart) to a high frequency f_2, where the most closely spaced electrodes are synchronous. Previously reported transducer design procedures[1,3] are applicable to dispersive filters whose amplitude and phase are specified. In those designs, the desired amplitude response is achieved by apodization, i.e., assignment of a different amplitude weight to each electrode via its acoustic aperture (length of interdigitation with the adjacent electrodes in the interleaved comb).

Although apodization is the only means of implementing amplitude weighting in dispersive delay lines, it has two notable disadvantages. Lightly weighted electrodes with narrow apertures can lead to unwanted acoustic diffraction, and the analysis of apodized transducer pairs generally requires a complicated two-dimensional model.[3]

Design Procedure

The present nondispersive filter design approach can avoid these disadvantages by use of unapodized transducers, all of whose electrodes have the same aperture as illustrated in Figure 1. The two identical transducers produce a nondispersive filter regardless of the choice of electrode positions which determine the dispersion inherent in either transducer alone. Therefore, the desired amplitude weighting can be accomplished by spacing the electrodes in such a way that the larger amplitude responses occur at frequencies where more electrodes are synchronous (See also Ref. 4).

The design procedure is derived by comparing the transducer, at each frequency "f", to a periodic transducer which is synchronous at that frequency.[5] The effective number of electrodes in this periodic transducer is denoted by $N_a(f)$, a quantity originally introduced[6] in the analogous problem of acoustic scattering by dispersive gratings. Figure 2 illustrates the method of finding $N_a(f)$: when the driving frequency is f, we locate the positions t_- and $t+$ where the electrode pattern first incurs a 90^o phase error with respect to the sinusoidal surface wave. $N_a(f)$ is found by counting the electrodes between the positions t_- and $t+$.

Applying Ref. 5, Section III to the equivalent periodic transducer yields the following design procedure. To approximate a given amplitude transfer function e(f), $(f_1 < f < f_2)$ with an N-electrode transducer, solve the differential equation

$$g''(t) = k\,\frac{(g'(t))^3}{e(g'(t))}$$

with initial conditions $g(o) = o$, $g'(o) = f_1$, where

$$k = \frac{2(f_2-f_1)\ e(f_o)}{Nf_o^{\ 2}}$$

and f_o is a convenient reference at or near the center of the band. The electrode positions t_n are then found from

$$g(t_n) = \frac{n}{2}, \quad 1 \le n \le N.$$

In practice, the use of completely unapodized transducers, as shown in Figure 1, leads to a filter response which has undesirable ripple superimposed on the desired envelope e(f). It is therefore desirable to lengthen each transducer by applying the above procedure to a frequency interval (f_1', f_2') which extends somewhat beyond the design passband (f_1, f_2). Passband ripple may then be suppressed by tapering smoothly to zero the apertures of (only) the end electrodes whose synchronous frequencies lie outside the design passband (f_1, f_2). It is assumed that diffraction effects in these "tail" electrodes have no first-order importance.

Design Examples

The simplest and most important example obtains when e(t) = const, for $f_1 < f < f_2$ - the case of a uniform amplitude response over the desired bandwidth.[6] Using circuit model analysis[1] we have computed the response for a filter of this type having a 250 MHz bandwidth centered at 400 MHz, with 101 electrodes in each transducer. On each end of each transducer, approximately 20 electrodes have synchronous frequencies outside the design passband and are apodized in a smoothly tapered fashion in order to reduce ripple.

The predicted response of this filter is shown in Figure 3, where a YZ lithium niobate substrate is assumed. Not only does the filter exhibit a very flat response over a large fractional bandwidth; it is also the only known means of achieving this response in a surface wave device having a transversely uniform acoustic beam. Transducers with this property are valuable for use in a wideband surface wave reflective array pulse compressor[7] for radar pulse compression applications, or in a nonlinear correlator with two acoustic inputs.[8]

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A second example is a Hamming spectral weighting filter whose amplitude transfer function is

$$e(f) = 0.08 + 0.92 \cos^2 \left(\pi \frac{f-f_o}{B}\right)$$

where f_o (= 400 MHz) is the center frequency and B (= 250 MHz) is the bandwidth. Note that this expression is the power transfer function of each of the two identical transducers. Each transducer contains 300 electrodes and is unapodized except for a few "tail" electrodes on each end, again for suppressing ripple.

Figure 4 (solid curve) shows the calculated filter response, which is nearly identical to the desired Hamming weighting function (dashed curve). Inasmuch as there are small, ripple-like deviations between the desired and actual curves, we have taken the Fourier transform of the transfer function to determine whether these "error" ripples are large enough to cause serious degradation of the recompressed pulse time sidelobes when the filter is used in a pulse compression loop. The result is shown in Figure 5, where again the solid curve is the response of the new transducer design and the dashed curve represents the response of an ideal Hamming filter. The highest time sidelobe is at a level of -37 dB, which is less severe than the sidelobes typically caused by errors in the dispersive filter elements of a pulse compression system.

Conclusions

The transducer design procedure reported here has the merit that it can be used to synthesize any reasonably smooth transfer function e(f). In addition to the flat-passband and Hamming responses discussed above, a transducer response can also be synthesized to compensate for frequency-dependent acoustic propagation loss or any other source of amplitude error in an acoustic device.

Circuit model analysis[1] of the above types of filters has already demonstrated that the desired response is in fact obtained. Prototype filters will soon be fabricated and tested so that experimental confirmation can also be presented.

References

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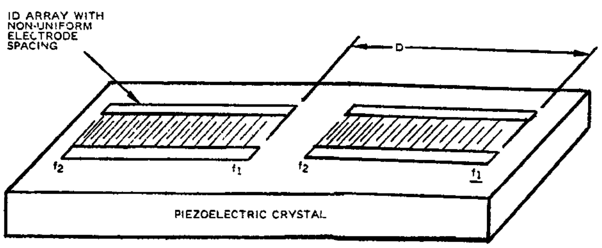

FIG. 1

NONDISPERSIVE DELAY LINE CONFIGURATION USING IDENTICAL DISPERSIVE TRANSDUCERS

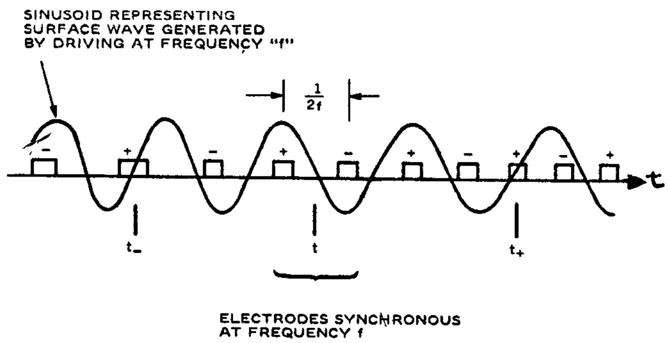

FIG. 2

DIAGRAM DEFINING THE "ACTIVE" REGION OF A DISPERSIVE TRANSDUCER

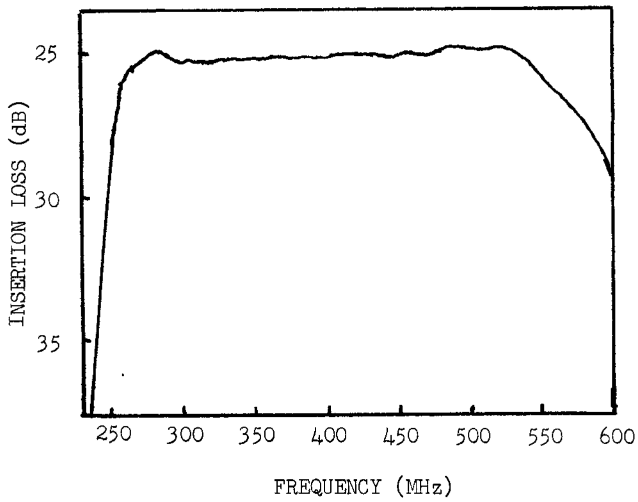

FIG. 3

PREDICTED PERFORMANCE OF A PAIR
OF UNAPODIZED TRANSDUCERS DESIGNED FOR
A FLAT, 62% BANDWIDTH

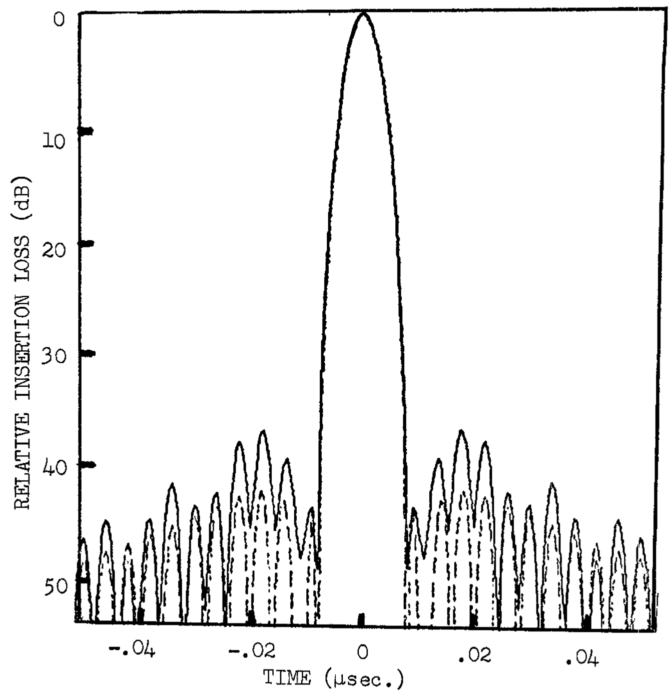

FIG. 5

RECOMPRESSED PULSE OBTAINED WHEN THE
ACOUSTIC HAMMING FILTER IS USED WITH PERFECT
LINEAR FM FILTERS. SOLID CURVE - PREDICTED RESPONSE;
DASHED CURVE - IDEAL RESPONSE

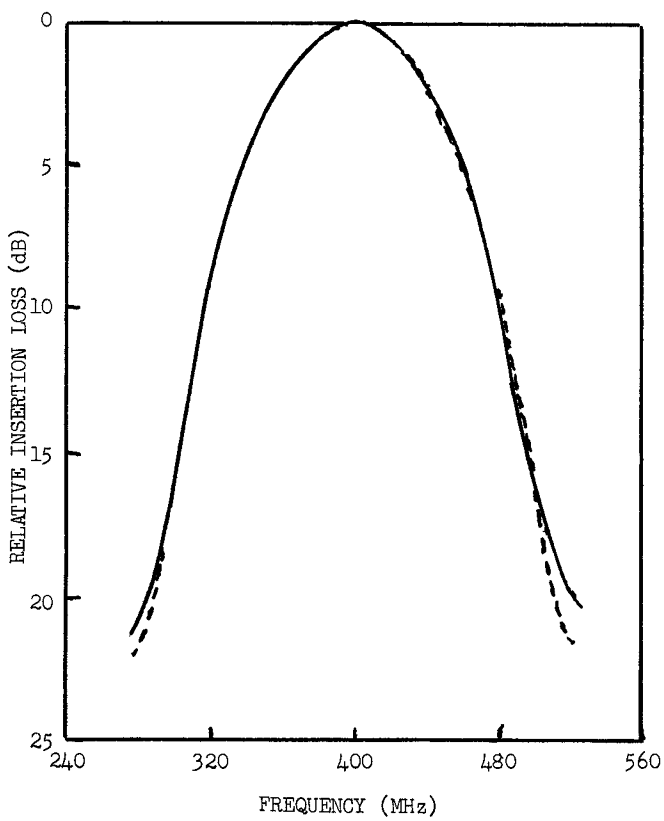

FIG. 4

CALCULATED FREQUENCY RESPONSE OF NEW HAMMING
WEIGHTING FILTER (SOLID CURVE) COMPARED TO IDEAL
HAMMING FUNCTION (DASHED CURVE)