SURFACE ACOUSTIC WAVE SLANTED CORRELATORS FOR LINEAR FM PULSE-COMPRESSORS

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ABSTRACT

A surface acoustic wave slanted transducer pulse compressor with the power flat to within 1/2 dB over a 66% bandwidth is reported in this paper. It uses no matching networks and has -27 dB insertion loss with linear time delay over the band.

INTRODUCTION

One of the most important surface acoustic wave (SAW) devices in systems today is the linear FM chirp. This device is used in modern radar systems as a matched filter, so that the received energy is compressed to a time interval short enough to give the required resolution. This technique is known as pulse compression. Both frequency filtering and time sidelobe suppression can be performed at IF with SAW devices.

Improved radar performance necessarily relies on the compressed pulse from the pulse compressor SAW device to have narrow pulse width and very low sidelobes. Fresnel ripple in the time domain of the SAW devices will degrade the time sidelobes. An example of this ripple is shown in Figure 1. The plot is for a time bandwidth product of 100 for two identical chirp transducers on one substrate. If the ripple is reduced the time sidelobes may also be reduced. The best reported sidelobes for a SAW pulse compressor were reported by Armstrong and Butler (1). Using a computer aided design technique they compensated for time domain "Fresnel" ripples by finding the inverse Fourier transform of the desired transfer function. The inverse Fourier transform necessarily gives an infinitely long time domain function. This function must then be truncated in time and as a result there is a degradation of the time sidelobes. The theoretical sidelobes were -45 dB using a Taylor series approximation to the Dolph-Chebyshev function. After truncation the realized time sidelobes were -41 dB.

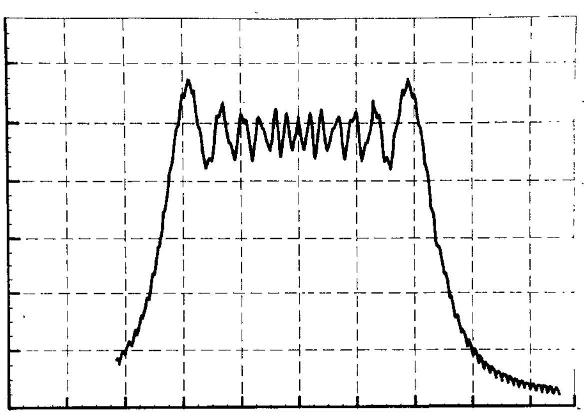


Figure 1. Fresnel Ripple in the Frequency Domain created by the In-Line Linear FM Chirp for a Time-Bandwidth Product of 100.

Other types of ripple in the passband of the device will also degrade the sidelobe levels. According to Klauder, et al. (2) amplitude ripple must be held to .2 dB and phase ripple to 1^{o} if sidelobes of -40 dB are to be achieved. This indicates that not only Fresnel ripple must be reduced but any distortion in the passband such as triple transit signals, bulk mode distortion and distortion due to transducer matching networks must be eliminated. This paper will discuss a technique for reducing Fresnel ripple and achieving flat frequency response for a linear FM down chirp SAW device.

THE SLANTED TRANSDUCER

The slanted transducer was first mentioned by Tancrell (3), and referred to by several authors (1,4) as an effective method of reducing Fresnel ripple and thereby reducing the time sidelobes. However, only Maines (4) discusses the slanted transducer in any detail. He reports the absence of sidelobe degradation due to Fresnel ripple but sees some degradation due to interelectrode reflections and triple transit signals.

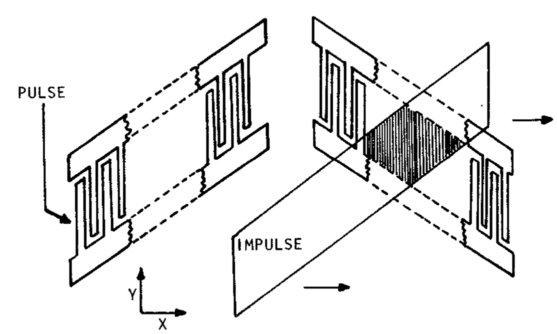


Figure 2. The Slanted Transducer Structure for Linear FM Pulse Compressors.

A study of Figure 2 will indicate why the Fresnel ripple has been essentially eliminated in the slanted structure. The entire band of frequencies are not convolved with each other (5), rather only smaller areas shown shaded in Figure 2; so that the electrodes (or frequencies) involved in the convolution process are at approximately the same frequency. Obviously the Fresnel ripple will depend on the slant of the transducer.

A. Beamwidth Design. It is possible to create a constant power output versus frequency for the entire transducer by specifying the beamwidth of the transducer at each frequency of the linear chirp. This problem has been discussed by Smith, et al (6) using a different approach in which an expression for the beamwidths of the dispersive device were derived using the crossed field equivalent circuit model. The following approach will give the same result by assuming the simple equivalent circuit shown in Figure 3. Note that no matching network is included. There

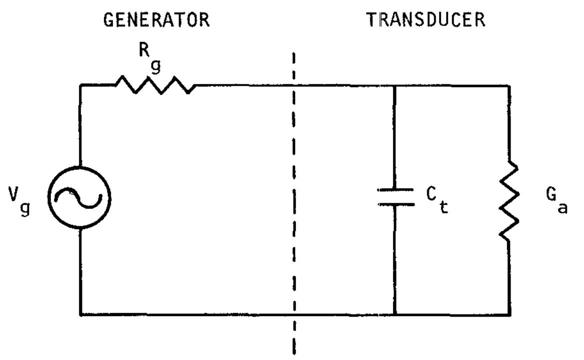


Figure 3. SAW Device Equivalent Circuit with No Matching Network.

are wideband devices on $LiNbO_3$ where the impedances are such that the minimum insertion loss may be achieved without a matching network. For the analysis here it will be assumed that the radiation conductance G_a is much smaller than the suceptance of the transducers static capacitance C_T, and that the magnitude of the generator resistance R_g is equal to the reactance of the transducer capacitance, X_C. Expressions will now be derived for the beamwidth of the transducer to produce constant power output and have the capacitive reactance $X_C = R_g$ at the center frequency f_o.

The voltage V across the radiation conductance G_a is given by

$$V = \frac{V_g X_C}{R_r^2 + X_C^2} \quad , \quad X_C << \frac{1}{G_a} \qquad (1)$$

Constant power output would dictate that

$$V^2 G_a = \text{Constant.}$$

Therefore

$$\frac{V_g^2 X_C^2 G_a}{R_g^2 + X_C^2} = K. \qquad (2)$$

Here all constants in V_g, X_C and G_a may be lumped into K so that the expression for the beamwidth becomes

$$W(f_i) = K_o \frac{R_g^2 + X_C^2}{f_i} \quad , \qquad (3)$$

where

$$G_a = Kf^3 W(f_i) \; . \qquad (4)$$

G_a is taken from Hartmann, et al (7). The value of K_o may be determined at the center frequency f_o by first assuming the value of a capacitor necessary to produce a reactance equal to the generator resistance at the center frequency. This value of capacitor will dictate a particular beamwidth of the transducer. G_o may then be calculated from equation (4) and K_o from equation (5). The beamwidths of the transducer may then be calculated by equation (3).

In the preceding paragraph, it was assumed that the generator resistance would be set equal to the reactance of the transducer capacitance. Such an assumption will lead to minimum-loss design only in the case of no matching networks with broad bandwidth transducers. When matching networks are present in narrowband devices, external resistance must be added to load the device until the loaded Q is at least equal to the reciprocal of the fractional bandwidth (7). This will give the minimum insertion loss for a given particular fractional bandwidth.

B. Unweighted Design Example. A set of transducers were designed using equation (3). Parasitic resistance was also added as a parameter because it may become large enough compared to the generator impedance to be significant. The parameters for the transducer are shown below.

o Bandwidth	100 MHz
o Center frequency	150 MHz
o BT product (two transducers)	80
o Material	$LiNbO_3$
o Transducer capacitance	22 pf
o Generator resistance	50 ohm

The beamwidth of the transducer varied from 50 mils at the low frequency end to 12 mils at the high frequency end.

One linear FM down chirp was fabricated at 150 MHz and a similar device was constructed using electron beam technology at 750 MHz. Figure 4 shows a 10:1 version of the photomask used to fabricate the 150 MHz device. Both devices were identical and similar results were achieved for both. Figure 5(a) shows the frequency response of the 150 MHz down chirp. The X scale is 20 MHz per division centered at 150 MHz. The Y scale is 10 dB per division and shows an insertion loss of -27 dB. Bulk modes are evident on the high frequency side of the device and cause some ripple in the passband. Figure 5(b) shows the passband response on a Y scale of 2 dB per division. A reference line shows the deviation from flat to be about ½ dB. Ripple in the band is due to

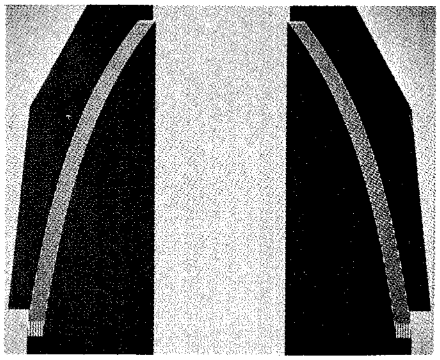
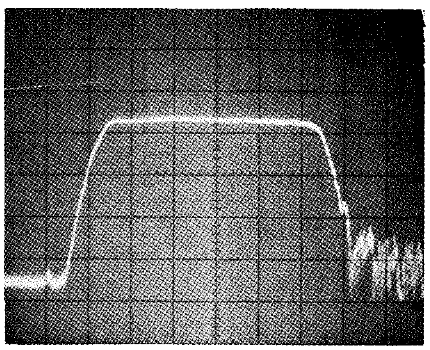


Figure 4. 10:1 mask for the 150 MHz Linear FM Down Chirp.

bulk modes, triple transit signals, and interelectrode reflections. Figure 6 is the frequency response of a 750 MHz down chirp of the same design as the 150 MHz pulse compressor. The X scale is 100 MHz per division and the Y scale is 10 dB per division. The insertion loss was -27 dB not the -20 dB shown in the figure. The ripple in the passband is due to cable reflections that occurred during the test. The bulk modes are not as significant for higher frequency devices.

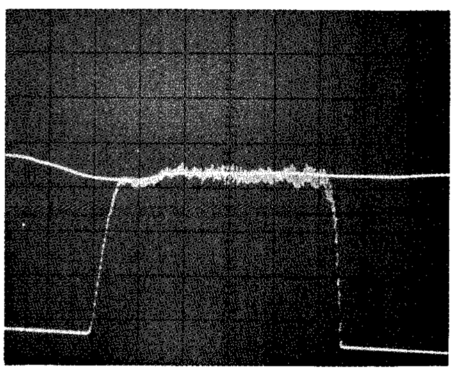
(a)



10 dB/div

150 MHz 20 MHz/div

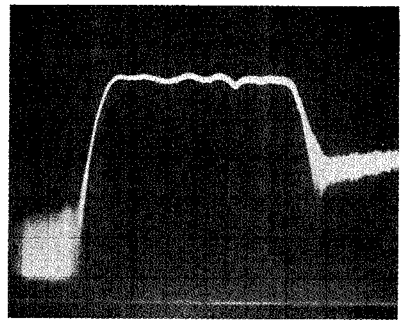
(b)



2 dB/div

150 MHz 20 MHz/div

Figure 5. Frequency Response of the 150 MHz Linear FM Down Chirp.



10 dB/div

750 MHz 100 MHz/div

Figure 6. Frequency Response of the 750 MHz Linear FM Down Chirp.

SUMMARY

It is evident that the slanted dispersive transducer can be effective in eliminating unwanted Fresnel ripple and producing a flat power response over wide bandwidths. Since Fresnel ripple is a major contributor to time sidelobe degradation in SAW pulse compressors, the slanted transducer looks promising for low time-sidelobe pulse compressors. Future work will include adding weighting to decrease sidelobes and extending the work to include quartz narrowband devices.

ACKNOWLEDGEMENT

The author gratefully acknowledges the many helpful discussions with Clinton Hartmann, Ron Hays, Don Mellon, and Doug MacDonald. The work of Lee Mrha in producing the photomask and testing the devices is also appreciated.

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