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COMMUNICATIONS

INTERDIGITAL TRANSDUCER WITH SLANTED FINGERS

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The use of interdigital transducers with slanted fingers for wideband linear phase surface acoustic wave filter is examined. The results of a theoretical and experimental study for 70 MHz and 25 percent bandwidth wideband linear phase surface acoustic wave filter on YZ-lithium niobate are given in this paper.

K e y w o r d s: surface acoustic wave, surface acoustic filter, interdigital transducer.

1 INTRODUCTION

The use of IDT with slanted fingers geometry for amplitude weighting of the SAW filters frequency response was reported a number years ago [1], [2] in an initial comparison of various IDT weighting schemes. Recently, the performance of SAW filters with up to 50 percent fractional bandwidth using such slanted fingers IDT geometries to reduce the adverse bulk wave interference effects in filters with fractional bandwidth greater than 20 percent has been examined.

Two sets of variables may be used to define the geometry of each interdigital transducer (IDT) for a surface acoustic wave (SAW) filter. These are the pure real weighting coefficients a_n, which determine the overlap of the individual IDT fingers, and the separation parameters d_n, which relate to the spacing between adjacent fingers. SAW bandpass filters with nominal linear phase response are realized by keeping distances d_n constant, while apodization coefficients a_n varying symmetrically about the center axis of the IDT [3], [4]. Filters with dispersive phase response have the IDT geometry arranged

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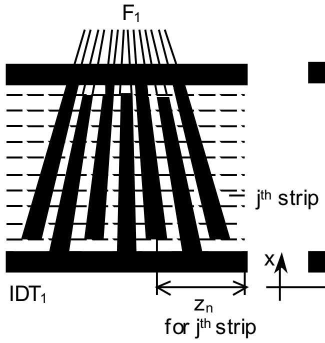

Fig. 1. Basic configuration of interdigital transducer with slanted transducer fingers.

non-symmetrically about that center axis. This is realized by the non- symmetric variation of a_n and/or d_n parameters about this axis. However, it may be noted that the nominal linear phase response can be realized with dispersive transducers too, if identical dispersive IDT's are employed at input and output ports [4].

A limitation of the employment of the above theory for geometrically sampled approximation of an actual smooth impulse response of the filter is the finite number of IDT fingers. In wideband SAW filters, in which a small number of IDT fingers are required, it affects the performance capability, and in addition, the idealized amplitude and phase response are degraded by various effects, such as the triple-transit interference, finger reflections, and/or bulk wave generation [5]. The experimental studies show that for YZ-lithium niobate these effects are significant in IDT's with 20 and more percent fractional bandwidth. Further, the input admittance of the standard IDT decreases with increasing fractional band width so that the impedance matching poses problem, when cable and packaging capacitance become comparable with the transducer capacitance. Thus, use of a special transducer is required to achieve the wide band pass of an IDT and at the same time avoiding the degradation effects.

2 THEORY

Figure 1 illustrates the basic pattern of the slanted finger IDT that is used as an input and output transducer. The geometric pattern of such a transducer is such that the fingers lie between lines drawn as rays from a focal point F. In this illustration, the rays have equal-angle separations, which leads to the metallization ratio of 0.5 in this case. The other values of metallization ratio could be obtained by appropriate selection of ray angles. In any event, one basic requirement of the IDT's pattern is that it must have a constant period along every axis parallel to the SAW propagation axis, shown here as the z-axis. Further, the filter bandwidth corresponding to a constant appodization structure is determined by the finger periods at the finger overlap extremities.

In order to calculate the transfer response of an IDT let divide the IDT into channels by horizontal lines, as sketched in Fig. 1. If the finger tilt angle is small, as is the case here, we can model each of these channels in terms of a standard uniform delay line, which fingers are normal to the SAW propagation axis. For the purpose of computation it is not necessary to consider channels with equal width as it is in the IDT pattern shown in Fig. 1, but if the center frequency and aperture width of the j-th channel are given by ω_j and $w_j(\omega)$, respectively, then the choice of equal aperture widths $w_j(\omega) = w(\omega)$ means that the channels have an unequal center frequency separation.

With the reference to Fig. 1, we may evaluate the transfer response $H_j(\omega)$ of j-th channel in one IDT, in terms of δ-function model.

If we take the reference axis of this response evaluation as being an off-center axis, as shown in Fig. 1, then the resultant response with $2N$ electrodes of alternating polarity may be expressed in the form [6]

$$\begin{aligned} H'_j(\omega) &= \sum_{n=1}^{2N} (-1)^n w_{jn}(\omega) f_j^{1/2} \exp(jkz_n) \\ &= \sum_{n=1}^{2N} (-1)^n w_{jn}(\omega) f_j^{1/2} \left[\cos(kz_n) + j\sin(kz_n)\right] , \end{aligned} \quad (1)$$

where $k = 2\pi/\lambda_j$ is the phase constant (the wave number) at frequency ω_j, $|(z_n - z_{n-1})| = \lambda_j/2 = v/2f_j$ for the uniform channel for which $w_{jn}(\omega) = w_j(\omega)$.

If we conveniently move the reference axis so that it coincides with the vertical center axis of the j-th channel, the sin term in (1) will drop out and $H_j(\omega)$ can be expressed as

$$\begin{aligned} H_j(\omega) = w_j(\omega) f_j^{1/2} \Big\{ 1 + 2\cos\frac{\pi(\omega-\omega_j)}{\omega_j}) \\ + 2\cos\frac{2\pi(\omega-\omega_j)}{\omega_j} + \cdots + 2\cos\frac{N\pi(\omega-\omega_j)}{\omega_j} \Big\}. \end{aligned} \quad (2)$$

We approximate equation (2) close to the center frequency ω_j by the sinc function

$$H_j(\omega) \cong w_j(\omega) f_j^{1/2} \frac{\sin\left[N\pi(\omega-\omega_j)/\omega_j\right]}{N\pi(\omega-\omega_j)/\omega_j} . \quad (3)$$

Since the center axis of the j-th channel is the center axis of all channels, the overall transfer response of one IDT will be a real function given by

$$H(\omega) = \sum_{j=1}^{S} H_j(\omega) \cong \sum_{j=1}^{S} w_j(\omega) f_j^{1/2} \frac{\sin\left[N\pi(\omega-\omega_j)/\omega_j\right]}{N\pi(\omega-\omega_j)/\omega_j} . \quad (4)$$

with S being the number of channels.

If a similar slanted finger, or uniform wideband IDT is used as the output transducer, the overall phase response will be nominally linear. It may be noted that this result for the slanted finger IDT is in accordance with the Tancrell theorem of transducers, that an IDT, which is symmetrical about the vertical axis has, in principle, a linear phase response [4].

When relation (2) or relation (4) are used to calculate the overall transfer response $H(\omega)$ of the model IDT, approximately equivalent mathematical results were obtained when the transducer is modelled

- either by the channels of equal aperture width w (and finger overlap) and unequal spacing of the center frequencies f_j,
- or by the channels of equal center frequency separations $\Delta f = f_j - f_{j+1}$ and resulting unequal aperture width w_j.

For the model using equal channel widths it is necessary to assume a sufficient number S of these channels, usually in the range $35 \le S \le 100$, so that the aperture width $w_j(\omega) = w(\omega) \ll w_0$, where w_0 is the actual IDT aperture width.

The length L_j of the jth channel was then approximated as

$$L_j = \frac{L_K + (L_D - L_K)j}{S}$$

where $j = 1, 2, \dots, S$, L_K and L_D, respectively, represented the lengths of the shortest and longest channel.

Setting the center frequency ω_j of the jth channel as $\omega_j = Nv/L_j$, where v is the SAW velocity, we obtain the approximation

$$f_j = \frac{S f_K f_D}{S f_D + j(BW_{KD})}, \ j = 1, 2, \dots, S, \tag{5}$$

where $f_K = Nv/L_K$, $f_D = Nv/L_D$ and $BW_{KD} = (f_K - f_D)$ is the "channel band width" parameter and we assume that $S f_D \gg f_K$.

For alternative calculation involving equal frequency separations Δf of adjacent channels we used a value of $\Delta f = BW_{KD}/S$, with the number of channels S in the range $35 \le S \le 100$. If the slope m of the outside fingers for the overall IDT is expressed as

$$m = \frac{w_0}{L_D - L_K}$$

than the slope of the outside fingers for the jth channel is

$$m = \frac{w_0}{Nv\left(\frac{1}{f_D} - \frac{1}{f_K}\right)} = \frac{w_j(\omega)}{Nv\left(\frac{1}{f_j} - \frac{1}{f_j + \Delta f}\right)}$$

and the aperture $w_j(\omega)$ can be approximated as

$$w_j(\omega) = \frac{f_K f_D \Delta f}{(f_j^2 + f_j \Delta f) BW_{KD}}, \tag{6}$$

where $f_j = f_D + j\Delta f$ for $j = 0, 1, \dots, (S-1)$ and for the simplicity we normalize $w_0 = 1$.

These frequency response calculations do not include the effects of triple transits, finger reflections or circuit factor $C(\omega)$.

The IDT overall frequency response, calculated from relation (2) or (4) yields a phase response which is nominally linear if the second-order effects are neglected, but it will not yield an amplitude response which is flat across the whole desired pass band. With increasing frequency, the amplitude response in the pass bands is tilted downwards. This tilt may be explained in either of two ways. First, if the slanted finger IDT is modelled as a set of parallel channels with equal aperture w, then the separations of the composite sinc function terms will not remain constant in the frequency domain but will become larger with increasing frequency. This will result in an amplitude tilt when the sinc function terms are summed, despite the $f^{1/2}$ correction term in relations (2) and (4) associated with the transformer ratio in the crossed-field model. Second, if the finger IDT is modelled as a set of parallel channels with equal center frequency separations Δf, so that the composite sinc function terms will be equally spaced in the frequency domain, then the tilt can be explain by effects of aperture width terms $w_j(f)$ which decrease with increasing frequency, again despite the $f_j^{1/2}$ correction term.

To flatten this amplitude tilt various compensating techniques may be used.

3 EXPERIMENT

Based on the above theoretical analysis we developed, for the amplitude response calculation, a computer program called SLANT. Figure 2 shows the amplitude response for identical input and output IDT's, calculated for the SAW filter with slanted finger geometry IDT's. The calculation is made for $N = 30$ of finger pairs and the channel bandwidth W_{KD} of 25 percent [7]. The circuit factor or other corrections were neglected. The tilt of the amplitude response across the passband is evident from the figure.

We also designed and fabricated a wideband linear phase SAW filter — PLF 82 to verify experimentally the presented theory. This filter is made on an YZ-lithium niobate substrate of 1 mm thickness. It has identical input and output slanted finger IDT's with $N = 30$ of finger pairs made as aluminum thin film electrodes of 100 nm. The tilt angles of transducer fingers are restricted to a maximum of ± 6.7 degrees about the normal to the Z-axis, and the separation between the input and output IDT's was ~ 4.5 mm. The fractional bandwidth of the filter was 25 % with the central frequency of $f_0 = 71.4$ MHz, the group delay of $\tau = 1.3\,\mu$s, and insertion loss $b_v = 24$ dB. For attaining a flat amplitude response over the pass band, external compensation in the form of a shunt inductor was applied to the input IDT circuit. Figure 3 shows the measured amplitude response of the PLF 82 filter.

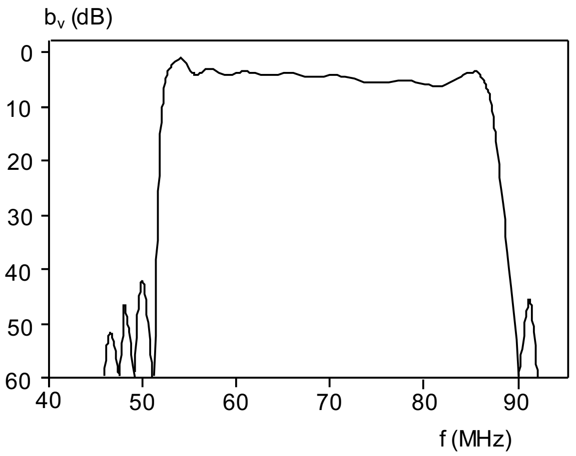

Fig. 2. Calculated amplitude response of the PLF 82 SAW filter with slanted finger IDT's.

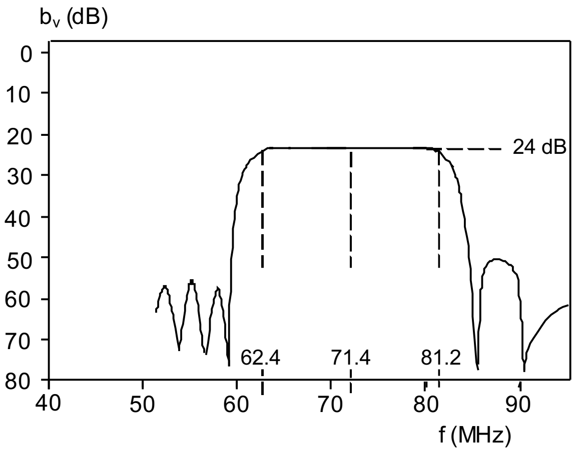

Fig. 3. Measured amplitude response of the PLF 82 filter.

4 DISCUSSION

SAW filters employing IDT's with slanted fingers would appear favorably in comparison with those using "conventional" geometries in attainment of the low slope factors and rejection bandwidths [1].

The observed amplitude response of the PLF 82 filter, using slanted fingers IDT's to obtain the required linear phase response over the filter fractional bandwidths of up to 50 percent, is in general agreement with that predicted by the δ-function model. To attain the flat amplitude response over the pass band, external compensation in the form of a shunt inductor was applied to the input IDT circuit. Other methods for compensating the amplitude tilt across the pass band can also be used.

Another method for amplitude response tilt compensation is the application of IDT with curved fingers. The observed amplitude response behavior is attributed to the characteristic response of the slanted finger IDT, rather than to circuit factor $C(\omega)$ loading in the δ-model function analysis. The analysis of this response by the generalized impulse response model leads the authors [8] to the conclusion that this type of filter has no inherent amplitude tilt across the pass band, so that the observed amplitude response tilt is primarily due to circuit factor loading and the use of an appropriate curved finger can give automatic compensation against the circuit factor $C(\omega)$ loading of wide band SAW filters and thereby eliminate the use of external compensating networks.

References

[1] VAN DEN HEUVEL, A. P.: Use of Rotated Electrodes for Amplitude Weighting in Interdigital Surface-Wave Transducers, Appl. Phys. Lett. vol. 21, Sept. 1972, pp. 280–282.

[2] DIEULESAINT, E.—ROYER, D.: Elastic Waves in Solids — Applications to Signal Processing, Wiley, New York, 1980.

[3] NEVESELÝ, M.: Akustoelektronika.

[4] TANCREL, R. H.: Principles of Surface Wave Design. Surface Wave Filters, M. Matthews, New York, Willey, 1997, ch. 3.

[5] SMITH, W. R.: Basics of the SAW interdigital transducers, Computer-Aided Design of Surface Acoustic Wave Devices, J.H. Collins and I. Masotti, New York, Elsevier, 1976, pp. 25–63.

[6] DANIEL, M. R.—DE KLERK, J.: Acoustic Radiation Measurements and Calculations for Three Surface Wave Filters Designs, IEEE Ultrasonics Symp. Proc., 1973, pp. 449–455.

[7] SPALDONOVÁ, D.: Contribution to the Analysis and Synthesis of Some Special Surface Acoustic Wave Transducers, Košice, 1993.

[8] SLATER, N. J.—CAMPBELL, C. K.: Improved Modelling of Wide-Band Linear Phase SAW Filters Using Transducer Witr Curved Finger, IEEE Trans. Son. and Ultrason., Vol. SU-31, No. 1, Jan. 1984.

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