Abstract – This paper is devoted to optimization of quasi-slanted interdigital transducers (IDT) [1] that have some advantages over classical fan-shaped IDTs [2] if few channels are used. Objects under optimization are electrode polarities, relative channel apertures, channel center frequencies and channel shifts. By varying the number of channels one can change the diffraction effect and transducer impedance at the same IDT aperture and length, which provides better matching with substrate features.

I. INTRODUCTION

Quasi-slanted transducer (QST) (Fig.1b) [1] ranks between IDT with parallel electrodes (Fig.1a) and fan-shaped IDT [2] (Fig.1c). Both utmost IDTs can be also considered as extreme examples of quasi-slanted transducers: with one channel and with a huge number of channels, correspondingly. Parallel-electrodes IDTs differ greatly in their features (impedance, sensitivity to diffraction, etc) from fan-shaped transducers with about the same length, bandwidth and frequency response (FR) shape factor. So, by enlarging the number of channels from 1 to 10-20, one can to change QST features in a wide range.

For most filter specifications, QST with 10 channels and more has about the same features as fan-shaped analog. From this point of view QSTs with less number of channels are of larger interest and provide really new possibilities. Some publications are devoted to design of quasi-slanted transducers [1,3] but only with large number of channels.

This paper is devoted mainly to design of quasi-slanted transducers with few channels, in most cases over the range of 4-11.

II. FR SHAPE FACTOR AND QST IMPEDANCE AS A FUNCTION OF THE NUMBER OF CHANNELS

Filter frequency response is the sum of individual channel responses (Fig.2). The more channels the smaller difference between center frequencies of adjacent channels and the larger their interference. That is why fan-shaped IDTs and QSTs with large number of channels have the transition band much wider compared with individual channel transition bands (Fig.2a). In contrast to this, in the case of 4
channels, for example, the total filter response in the transition band follows closely the outermost channel FR (Fig.2b), which provides better FR shape factor at the same IDT length. In Fig.2 both filters have the same FR shape factor despite IDTs in the second filter are shorter by 20%: 501*401 electrodes against 601*481 in the first filter.

The less number of channels the wider individual channel response (Fig.2), which means higher IDT impedance's and smaller capacities. I.e. by changing number of channels one can match filter layout to substrate features for reducing insertion losses.

III. SAW DIFFRACTION IN QST FILTERS

For accurate simulation of QST filter response, SAW diffraction was taken into account using Angular Spectrum Method [4] for computing all Y-parameters of filter. Transfer admittance $Y_{21} = Y_{12}$ between two quasi-slanted IDTs may be written as a double summation over channels of both transducers:

$$Y_{21} = \frac{\omega}{2\pi} \sum_{m=1}^{\infty} \sum_{p=1}^{q} A_{pq}(k_y) \exp\left[j D_{pq} k_m(k_y) + j(Y_p - Y_q)_{k_y} \right] d{k_y},$$

$$A_{pq}(k_y) = K(k_y) \sigma_p(k_y) \sigma_q^{-1}(k_y),$$

$$K(k_y) = \frac{1}{\varepsilon_{i,\sigma}^2} \frac{k_m^2(k_y) - k_n^2(k_y)}{2k_y(k_y) k_m(k_y)},$$

$$\sigma_p(k_y) = \iint \sigma_p(x,y) \exp[j k_p(x,y)] x+y dxdy,$$

$$\sigma_q^{-1}(k_y) = \iint \sigma_q(x,y) \exp[j k_q(x,y)] x+y dxdy,$$

where $k_m$ and $k_n$ are the wave vector components determined by the corresponding slowness curves in both transducer regions and the free surface region, respectively; $k_m$ and $k_n$ are the wave vectors on metallized (shorted) and free surface of substrate. Both quasi-slanted IDTs have $L$ channels. The distance between the nearest electrodes of channel $p$ of input IDT and channel $q$ of output IDT equals $D_{pq}$, $Y_p$ is the center of aperture $W_p$ of the channel $p$ of input IDT. Similarly, $Y_q$ is the center of aperture $W_q$ of the channel $q$ of output IDT. For rectangular source (neglecting the transversal end-effects) the excitation factors may be simplified and presented as:

$$\sigma_p(k_y) = \left(\frac{\sin(k_y W_p / 2)}{k_y / 2} \sum_{m=1}^{M} c_m \exp[j X_m^p k_{1x}(k_y)] \right),$$

where,

$$c_m = \int \sigma_p(x) \exp(j k_m x) dx,$$

$$c_n = \int \sigma_q(x) \exp(j k_n x) dx,$$

here $X_m^p$, $X_n^q$, $a_m$, $a_n$ are the center and half-width of $m$-th and $n$-th electrodes of channels $p$ and $q$, respectively.

One more advantage of QST with few channels over fan-shaped IDTs (or QSTs with many channels) is lower level of diffraction due to comparatively large channel apertures. Fig.3 represents two QST filters with 11 and 4 channels and apertures of 44 and 88 wavelengths designed for ST-quartz. The total QST length is about 500 wavelengths. It is evident that the second structure is less sensitive to diffraction.

IV. OPTIMIZATION PROCEDURE

The main obstacle in use of QST with small number of channels for SAW filter design is considerable enlarging of passband ripple if the set of electrode polarities designed for fan-shaped IDTs is applied here. The synthesis technique should be
An outline flow chart of our optimization algorithm and MATLAB-based software is shown in Fig.4. The procedure consists of seven main stages.

1. The starting QST structure: constant difference between adjacent channel periods; equal channel apertures; no shift between channel centers. Algorithm optimizes length of unweighted channel electrode structures (i.e., channel bandwidths) to provide best FR shape factor at suitable in-band flatness.

2. “Natural” level of QST or fan-shaped filter bandwidth associated with channel periods is –6 dB. At the second stage the bandwidth is tuned to the specified level by scaling channel periods.

3. The third stage provides the specified form of in-band response, for correction of second-order effects, for example. Despite small number of channels, simultaneous optimization of their apertures and periods provides rather precise FR realization.

4. We use “stepped” functions [5] for initial weighting of QST electrode structures that are more convenient for their posterior approximation by electrode structures than smooth ones such as the Hamming or Kaiser functions. The fourth stage optimizes parameters of such functions to provide best out-of-band rejection at suitable in-band ripple.

5. The fifth step is most important for reaching of good filter selectivity. It performs optimization of electrode polarity distribution, i.e., polarity weighting (PW). The optimization technique is similar to the method described in [5] for fan-shaped IDTs and includes several steps. At each step the algorithm analyzes all possible combinations of electrode polarities in some limited region (“window”) of IDTs (8-12 electrode positions, as a rule). The “window” scans step by step through both IDTs many times. Our choice of the best PW structures is based on how large is the total filter out-of-band rejection. Bandwidth, in-band ripple and FR shape factor are controlled also.

6. Before IDTs had symmetrical structure, which meant constant group delay time (GDT). The sixth stage uses horizontal shifts between channel centers (distance weighting) for preparing desired GDT form. Unfortunately, the shifts disturb filter FR in some degree, especially in the bassband. One can show the same GDT form can be realized by various sets of shifts. Minimization of maximal shift is used in our algorithm to minimize FR disturbance. In addition, optimization of channel apertures and periods together with channel shifts compensates this disturbance and improves in-band flatness and out-of-band rejection at the same time.

7. Polarity weighting becomes not optimal after changing of channel apertures, periods and positions made on sixth stage. The 7-th stage tries to improve out-of-band rejection by new PW optimization.

Similarly to PW, optimization of channel apertures, periods and shifts also uses the “scanning window” method: algorithm analyzes possible combinations of small deviations of these parameters in few adjacent channels; the “window” scans through all channels many times until an improvement of FR takes place.

Note, at each stage the algorithm controls all parts of total filter response, but priorities in choice of the best structure are different for different stage.

Similar software was developed for optimization of quasi-rectangular slanted transducers [6] that can provide layout shortening compared with QSTs.

Fig.4. Flow-chart of QST filter design
Two examples of QST filter realization are presented in Fig.5. Filter with bandwidth of 6% includes QSTs with 161 * 129 electrodes, 7 channels. The filter shown in Fig.5a was designed for “stepped” in-band response and constant GDT. The second filter modification (Fig.5b) has flat in-band FR and sineshaped form of GDT.

Fig.5. Examples of realization of QST filter with: a) “stepped” in-band FR; b) specified GDT

A number of QST filters with bandwidth of 1.5-15% was designed with using the described technique. Fig.6 presents four modifications of the filter with bandwidth of 1.5% manufactured on ST-quartz. These experimental characteristics confirm better diffraction resistance of QSTs with few (four) channels and demonstrate good agreement with our diffraction simulation (compare with Fig.3).

VI. CONCLUSION

Quasi-slanted transducers with small number of electrodes (10 and less) rank between IDTs with constant length of parallel electrodes and fan-shaped IDTs. QSTs have better diffraction resistance compared with fan-shaped transducers and better flexibility in SAW filters realization than IDTs with straight electrodes.

A synthesis technique was developed to optimize electrode polarity distribution, channel apertures, periods and relative shifts for QST filter design.

REFERENCES


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