Abstract – This paper is devoted to providing high frequency selectivity of interdigital transducers (IDT) with constant length of parallel electrodes. For realization of needed time response the proposed technique uses combined weighting of IDTs structure by optimal assignment of polarities of individual electrodes (polarity weighting) and by a voltage division between some parts of IDT (capacity weighting). The simulated and experimental characteristics are better than in case of using each of these weightings separately.

I. INTRODUCTION

IDTs with constant length of parallel electrodes are widely used in surface acoustic wave (SAW) filters in couple with apodized (overlap weighted) transducers. Usually unapodized IDTs play a minor role in filter selectivity. However, to reach extreme out-of-band rejection all filter components should have high selectivity. Moreover, in case of narrow aperture the use of apodization is undesirable at all because of diffraction effect. Withdrawal weighting (by removing selected electrodes from a regular structure [1-3]) and polarity weighting (by assignment of polarities of individual electrodes [4,5] Fig.1a) are good techniques for improvement of selectivity of narrow-band (≤1%) IDTs with constant length of electrodes. The wider IDT bandwidth the more difficult receiving of good selectivity. The algorithm developed before for optimization of wideband polarity weighted (PW) IDTs [5] provides frequency responses with good shape factor and close-in rejection, but at the price of large far-out sidelobes, which is the disadvantage especially for filters with both unapodized IDTs. The technique proposed here reduces this disadvantage by including a capacity weighting into PW IDTs.

II. IDT LAYOUT

At the stage of IDT synthesis we use simple and fast delta-function model, according which the frequency response (FR) of a symmetrical equidistant PW IDT with \( M \) (odd) electrodes is:

\[
H_{IDT}(f) = 2 \sum_{m=2}^{(M+1)/2} (P_m - P_{m+1}) \sin((m-1.5)\pi f / f_0),
\]

(1)

where \( P_m \) are electrode polarities (electric potentials), \( f_0 \) is the passband center frequency. PW IDT optimization means the choice of optimum set of polarities \( \{P_1, ..., P_{(M+1)/2}\} \). In “pure” PW IDTs (Fig.1a) \( P_m=1 \) for “hot” electrodes or 0 for grounded ones, so that the time response taps can have only values of 1, 0 or –1. Capacity weighting (or block weighting [6]) of IDTs (Fig.1b) gives better flexibility in realization of desired responses. Some electrodes are combined in “floating” sections that are not connected with any contact pad. Due to serial connection of some section capacities and voltage division between them, capacity weighting (CW) widens the set of tap weights in IDT time response.
As a rule, we use four floating sections in IDT, two sections at each side (Fig.1b). A scheme of IDT capacities is shown in Fig.2. To use the equation (1) for FR simulation one should define all potentials of electrodes. On the stage of IDT synthesis we assume that capacities between nearest sections are proportional to the number of active electrode envelopes but capacities between far-out regions are zero. So that, $P_m = V_1$ for “hot” electrodes; $P_m = V_0$ for grounded ones; $P_m = V_2$ and $P_m = V_3$ for the first and second floating sections (Fig.2), where

$$V_2 = \frac{(c_1c_2 + c_1c_3 + c_2c_3 + c_1c_2)}{(c_1c_2 + c_1c_3 + c_2c_3)};$$
$$V_3 = \frac{c_1c_2}{(c_1c_2 + c_1c_3 + c_2c_3)}.$$ (2)

Fig.2. Capacities and electric potentials in CW IDT

III. OPTIMIZATION PROCEDURE

The PW/CW optimization procedure is more complicated compared with the “pure” polarity weighting. Here the modification of any electrode polarity can change not only neighboring time response taps but, because of section capacity changing, also all taps in capacity weighted blocks (2).

As before [3,5], the key feature of our optimization algorithm is that the choice of the best IDT structure is based upon how well it meets the specifications not in the time domain but in the frequency domain directly.

Before the IDT synthesis process start, the software forms an initial time response, a cosine-squared-on-a-pedestal time function:

$$A(t) = k + (1-k) \cos^2(\pi/2 \tau) \sin(\pi \Delta f)/(\pi \Delta f), \quad (|t| \leq \tau),$$

where $\Delta f$ is the IDT bandwidth, $k = 0.5$. A time response synthesized by any apodized IDT optimization procedure also can be used.

The next stage includes a number of steps. On each step the algorithm analyzes all possible combinations of electrode polarities in some limited region of the IDT, 8-14 electrode positions, as a rule. This region scans step-by-step through the IDT. The purpose of the analysis is the choice of an electrode combination providing the best frequency response. During the first pass through the IDT the algorithm transforms step by step the initial time function into a real electrode structure and then improves it. The process continues until an improvement in the FR takes place. If during the full pass through the transducer there are no FR improvements, the process of optimization is finished.

Fig.3. Fourier transform of a desired FR (1); PW IDT (2) and PW/CW IDT (3) time responses.

Fig.3 compares envelopes of a desired time response (line 1), PW IDT time response (line 2) and PW/CW transducer (line 3). One can see that the last approximation is much better than for PW IDT. As a result, we have better IDT selectivity (Fig.4).

In our algorithm, frequency specifications can be applied not only to a single transducer but also to a total filter frequency response, that is, selectivity of the second transducer can be taken into account as well as the influence of matching circuits.

IV. QUAZISTATIC CHARGE DISTRIBUTION MODEL

For posterior accurate simulation of synthesized IDT frequency response we need to know precise electric potentials of floating sections that can be obtained only by calculating the total charge.
distribution in the IDT structure. To reach sufficient accuracy, it is necessary to take into account influence at least 50 neighbors on each electrode.

We use an effective method based on Chebyshev polynomials as the expansion functions for charge distribution on electrodes [7]. The charge \( q_m(x) \) on the \( m \)-th electrode can be expressed by a series of generalized Chebyshev functions \( h_n(x) \), i.e.,

\[
q_m(x) = \sum_{n=0}^{N} \alpha_{mn} h_n \left( \frac{x-x_m}{w_m/2} \right),
\]

where \( x_m \) denotes the center of the \( m \)-th electrode and \( \alpha_{mn} \) are unknown coefficients, \( h_n(z) = T_{n+1}(z)/(1+z^2)^{1/2} \), \( z = (x-x_m)/(w_m/2) \), \(-1 < z < 1\). The charge \( q(x) \) on the surface is related to each other by [8]:

\[
P(x) = -\int_{-\infty}^{\infty} G(x-x') q(x') dx'.
\]

Taking into account only the electrostatic part of Green function \( G_E(x) = -\ln|x|/(\pi \epsilon(0)) \) [8], we have:

\[
P(x) = \sum_{m=1}^{M} \alpha_{mn} h_n \left( \frac{x-x_m}{w_m/2} \right) \int_{-\infty}^{\infty} G_E(x-x') q(x') dx', \tag{3}
\]

where \( M \) is the total number of electrodes. The advantage of this representation is that all integrals in (3) for electric potential \( P(x) \) are derived analytically.

Potential \( P(x) \), a constant value on electrode, dependents on the IDT-applied voltage \( V_1 \). Sampling \( P(x) \) at \( M*3 \) discrete points, \( N \) points on each electrode, and taking into account that total charge on every floating electrode group is zero, one can determine all unknown coefficients \( \alpha_{mn} \). The total charge \( Q_m \) on the \( m \)-th electrode (at \( x=x_m \)) is simply given by \( Q_m = \pi \alpha_{mn} w_m/2 \). Once unknown coefficients \( \alpha_{mn} \) are determined, potential \( P(x) \) is determined also.

Comparison of FRs simulated by delta-function and quazistatic charge distribution models demonstrates, in most cases, rather small derivation between them. However, sometimes delta-function model gives considerable error in PW/CW frequency response calculation (Fig.5). The filter presented in Fig.5 includes input PW/CW IDT and output PW transducer. This filter FR was later improved (Fig.6) by redesigning the output PW IDT with taking into account the precise input PW/CW IDT response. Comparing the dashed lines in Fig.5 and Fig.6 one can see the good coincidence the charge distribution model simulation with experiment.

V. EXPERIMENTAL RESULTS

A number of SAW filters with PW/CW IDTs was designed and manufactured on different substrates.

Fig.5. Filter FR simulated by delta-function (1) and quazistatic charge distribution (2) models

Fig.6. Measured FRs of a filter on LiTaO\(_3\) before (1) and after (2) correction; input PW/CW and output PW IDTs.

Fig.7. Measured FRs of filters on LiTaO\(_3\):
1 – input and output PW/CW IDTs;
2 – input apodized and output PW/CW IDTs.
Three modifications of a filter with the bandwidth of 3.3% have been prepared on 112-litum tantalite in the following configurations: input PW/CW IDT (395 electrodes) and output PW IDT (91 electrodes) (Fig.6); input (353) and output (201) PW/CW IDTs (Fig.7-1); input PW/CW IDT in the previous layout is replaced by apodized one of the same length (Fig.7-2). Fig.7 demonstrates that in case of narrow aperture (150 mcm, IDT aperture/length of 1/8), apodization provides worse FR shape factor than capacity weighting because of diffraction. An additional advantage of CW IDTs is their reduced capacity compared with analogous PW IDTs, which decreases unmatched insertion loss: 21 dB in these filters against 26 dB in an analog with both “pure” PW IDTs.

Fig.8. Frequency response of the filter on ST-quartz; input (501 electrodes) and output (401) PW/CW IDTs.

Fig.9. Measured FR of a single PW/CW IDT (65 electrodes) on LiNbO3

Fig.8 and Fig.9 demonstrate narrowband (1.5%) and wideband (10%) devices with PW/CW IDTs.

VI. CONCLUSION

On the base of combined polarity/capacity weighting technique an algorithm has been developed for optimization of SAW filters including unapodized IDTs with parallel electrodes. Effectiveness of the PW/CW technique is illustrated by experimental characteristics of SAW filters with bandwidths of 1.5-10% performed on different substrates. PW/CW IDTs provide good out-of-band rejection and frequency response shape factor in some cases better than apodized transducers.

REFERENCES


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