Abstract

This paper is devoted to providing high-frequency selectivity of interdigital transducers (IDTs) 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 combination 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 because of diffraction effects. Withdrawal weighting (by removing selected electrodes from a regular structure [1-3]) and polarity weighting (by assignment of polarities of individual electrodes [4,5]) 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.

Fig. 1. Topology of IDTs:
a – polarity weighted; b – polarity/capacity weighted

II. IDT LAYOUT

These weightings separately.

The combined polarity/capacity weighting of IDTs with constant length of parallel electrodes is achieved by combining some parts of IDTs (polarity weighting) and by a voltage division between some parts of IDTs (capacity weighting). The combined weighting is achieved by combining some parts of IDTs (polarity weighting) and by a voltage division between some parts of IDTs (capacity weighting). The combined weighting allows achieving the desired time response of IDTs with constant length of parallel electrodes for broadband SAW filters.
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.

\[ P_m = V_1 = 1 \text{ for "hot" electrodes; } \]
\[ P_m = V_0 = 0 \text{ for grounded ones; } \]
\[ P_m = V_2 \text{ and } P_m = V_3 \text{ for the first and second floating sections (Fig. 2), where} \]
\[ V_2 = \frac{c_1 \cdot c_2 + c_1 \cdot c_3}{c_1 \cdot c_2 + c_1 \cdot c_3 + c_2 \cdot c_3}; \]
\[ V_3 = \frac{c_1 \cdot c_2}{c_1 \cdot c_2 + c_1 \cdot c_3 + c_2 \cdot c_3}. \]

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 frequency domain 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:

\[ A(t) = k + (1+k) \cos^2 \left( \frac{\pi t}{2 \tau} \right) \sin \left( \frac{\pi t \Delta f}{\pi t \Delta f} \right), \text{ (|t|} \leq \tau), \]
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 result of optimization is much better then for PW IDT. As a PW/CW transducer (line 3), one can see that the last time response (line 2) and IDT time response (line 2) are much closer to the desired time response (line 1). As before [3,5], the key feature of our algorithm is that the choice of the best combination of electrode polarities can change not only neighboring time response taps but all taps in capacity weighted blocks of a received time function. During the first pass through the IDT the algorithm provides combination providing the best frequency response.

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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 of width $w_m$ can be expressed by a series of generalized Chebyshev functions $h_n(x)$, i.e.,

$$q_m(x) = \sum_{n=0}^{N} \alpha_{mn} h_n(x),$$

where $x_m$ denotes the center of the $m$-th electrode and $\alpha_{mn}$ are unknown coefficients, $h_n(z) = T_{n+1}(z)/(1+z^2)^{1/2}$, $z = (x+x_m)/(w_m/2), (-1 < z < 1)$, $T_n(z)$ are the Chebyshev polynomials. Usually, $N=3$ gives sufficient accuracy for IDTs with metallization ratio smaller than 0.9 [7].

The electric potential $P(x)$ and charge $q(x)$ on the surface are related to each other by [8]:

$$P(x) = \int_{-\infty}^{\infty} q(x') \delta(x-x') \, dx' = \int_{-\infty}^{\infty} q(x') \delta(x-x') \, dx',$$

$$\int_{-\infty}^{\infty} P(x) \, dx = 0,$$

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, depends on the IDT-applied voltage $V$. Sampling $P(x)$ at $N\times M$ points, $M$ points on each electrode, and taking into account that total charge on every floating electrode group is zero, one can determine all unknown coefficients. The total charge $Q_m$ on the $m$-th electrode (at $x=x_m$) is simply given by $Q_m = \pi \alpha_{m0} w_m/2$. 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 deviation between them. However, sometimes delta-function model gives considerable errors. The filter presented in Fig.5 includes input PW/CW IDT and output PW IDTs. The filter presented in Fig.5 was later improved (Fig.6) by redesigning the output PW IDT with taking into account the precise input PW/CW IDT response.

Experimental results

A number of SAW filters with PW/CW IDTs was designed and manufactured on different substrates. A comparison of FRs simulated by delta-function and quazistatic charge distribution models demonstrates, in most cases, rather small deviation between them. However, sometimes delta-function model gives considerable errors. The filter presented in Fig.5 includes input PW/CW IDT and output PW IDTs. This filter includes input PW/CW IDT and output PW IDTs. The filter presented in Fig.5 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.
Three modifications of a filter with the bandwidth of 3.3% have been prepared on 112-litium 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.

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 sharper frequency response and better out-of-band rejection in case of narrow aperture than PW IDTs. PW/CW technique is illustrated by experimental characteristics of PW IDTs with parallel electrodes. These modifications of a filter with the bandwidth

REFERENCES