DESIGN AND PERFORMANCE OF WIDE–BAND IIDT–TYPE SAW FILTERS WITH LOW LOSS AND IMPROVED SIDELOBE SUPPRESSION

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ABSTRACT

Wide–band low–loss SAW filters employing interdigitated interdigital transducers (IIDT's) suitable for cellular radio systems are presented. The filters were fabricated on 36^0 YX–$LiTaO_3$ substrates. The sidelobe suppression has been improved by withdrawal weighting techniques. A design method which optimizes the weighting functions and number of fingers has been worked out. In the 500 MHz band, fractional bandwidths of up to 5.2 % with passband ripples smaller than 1 dB were attained. Insertion loss and sidelobe suppression were at 1.8 dB and 23 dB, respectively.

INTRODUCTION

With the increased market for cellular radio systems, much attention has been directed to the use of surface–acoustic–wave (SAW) low–loss filters. While early analog systems used RF frequencies of a few hundred MHz, there is now a clear tendency towards higher frequencies in digital systems. The GSM standard and the PCN system in Europe, for example, use RF frequencies in the 900 MHz and 1.8 GHz bands, respectively. To minimize degradation in system performance, the front–end filters must have both low insertion loss and high stopband rejection, and must also satisfy electrical requirements with regard to V.S.W.R. and return loss [1,2]. Traditional transversal SAW filters employing bidirectional interdigital transducers (IDT's) meet most of these requirements but suffer from too high losses [3]. However, two basically different technical approaches may be used to circumvent the inherent three–port nature of the IDT. The first approach is based upon the use of unidirectional transducers (UDT's) as is the case with single–phase [4] or two–phase excitation UDT's [5]. Being unidirectional, the SAW transducers can be matched at both the electric and the acoustic ports. This leads to a drastic reduction of spurious triple transit echo signals. However, the UDT approaches generally incur some penalties such as the need of narrow electrode widths or their requirement of additional phasing networks which is a clear drawback for low–cost mass production.

The second method to reduce insertion loss was proposed by *Lewis* in 1972 and employs bidirectional IDT's [6]. The structure is an interdigitated IDT (IIDT) configuration consisting of a series of IDT's alternately connected to the electrical input and output ports (Fig. 1). In this design, each output IDT receives acoustic energy from either side. Thus, the only inherent loss in the IIDT configuration is due to the end input transducers, each of which loses half its radiated energy unless additional reflectors are placed at the ends of the acoustic track. The minimum theoretical insertion loss IL_{min} of a perfectly matched structure consisting of N output IDT's interdigitated with (N+1) input IDT's is expressed as $IL_{min}(dB) = 10 \log [(N+1)/N]$. Thus, the ideally achievable loss falls below 1 dB for $(2N+1) \geq 9$. The maximum number of transducers, however, should be limited to about (2N+1) = 15 due to impedance matching and chip size requirements. From the fabrication point of view, the IIDT approach to low–loss SAW filters is simple, reliable and amenable to mass production. It has already been demonstrated that SAW filters employing IIDT's have low insertion loss [7–12]. Among the drawbacks of such filters reported up to the present are the somewhat poor sidelobe suppression and an inherent passband ripple being not acceptable in a number of applications. In principle, the sidelobe suppression can be improved by apodization weighting (overlap between adjacent fingers is not uniform) or by withdrawal weighting (certain selected fingers are omitted). However, apodization weighting involves the loss–enhancing influence of diffraction of surface acoustic waves. In what follows, we use withdrawal weighting for sidelobe suppression.

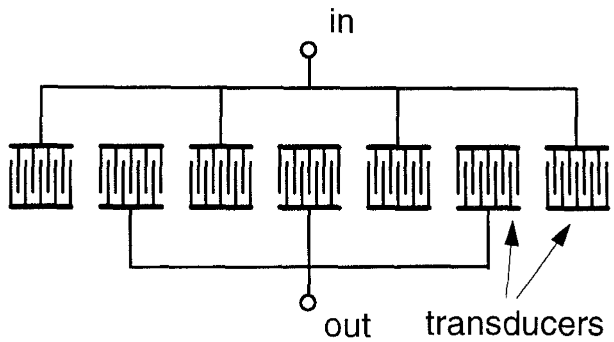

Fig. 1 Interdigitated interdigital transducer (IIDT) filter

DESIGN

Single–electrode ($\lambda/4$–width finger) transducers must be used at frequencies in the GHz band owing to the limited resolution of the photolithographic patterning process. As a

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substrate, we chose 36^0 YX–$LiTaO_3$ due to its rather large electromechanical coupling ($k^2 \doteq 0.07$) and good temperature coefficients ($\doteq -30$ ppm/K). To study the influences of the many design parameters on the frequency response of the IIDT structures, we investigated filters at a center frequency of 500 MHz. This frequency band is more convenient than higher frequency ranges where spurious second–order effects will come more severely into play. The acoustic wavelength was $\lambda = 8.263\ \mu m$ yielding electrode finger widths of about 2 μm. The metalization height (pure aluminum) was chosen to be 200 nm (2.5% of λ).

The development of a detailed design procedure is difficult because of the many design parameters which have to be taken into account. Our procedure is based on the P–matrix analysis [13] which includes the most pertinent physical effects such as propagation losses, distributed reflection phenomena, electrode resistance, and others. As a starting point, an approximate filter geometry was chosen by hand. Then, in an iteration loop, the geometry was modified and the P–matrix analysis tool was used to decide whether the modification resulted in better frequency characteristics (in which case it was retained and served as starting point for the next iteration cycle), or whether it could be discarded because the filter response did not improve. Fig. 2 shows the filter parameters which have been used to judge the quality of a device: minimum insertion loss IL_{min}, minimum sidelobe suppression A_{min}, passband ripple R, and relative bandwidth B. In order to be able to quantify the filter quality, we introduced a goal function W expressed as

$$W = a_1 IL_{min} [dB] + a_2 A_{min} [dB] + a_3 R [dB] + \frac{-b_3}{R [dB] + c_3} - 10^{-a_4(B-b_4)} ,$$

where a_i, b_i and c_3 are empirically scaled coefficients. The design goal is to optimize W; and this can be done automatically by the use of standard optimization algorithms.

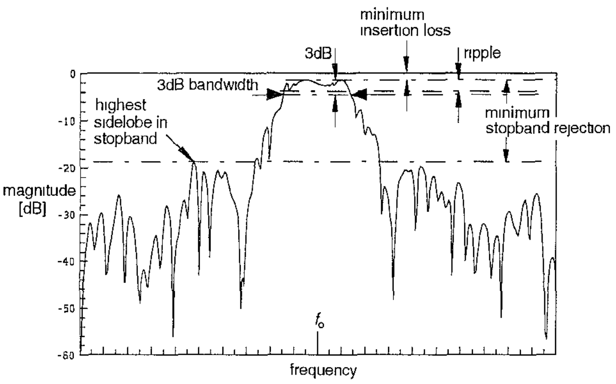

Fig. 2 Design criteria of a band–pass filter

As an example, let us now suppose a basic IIDT structure incorporating 15 IDT's. This structure is subdivided into three blocks as is depicted in Fig. 3. N_2 and N_1 are the IDT finger numbers in the outer blocks and the inner block, respectively. The number of IDT's of which the blocks are composed is called block size NA (outer blocks) or NI (inner block). Here, 2NA + NI = 15. We computed all the parameters IL_{min}, A_{min}, R and B defined above as functions of NA (Fig. 4). From these curves the optimum block sizes were found to be NA = NI = 5.

In the same manner, the optimum number of electrodes in each IDT and the distances between IDT's were determined.

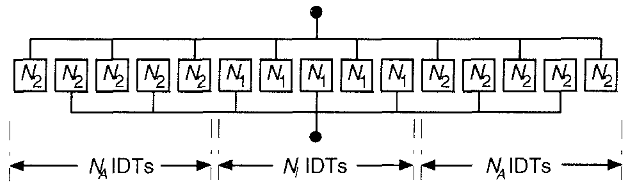

Fig. 3 Basic IIDT structure

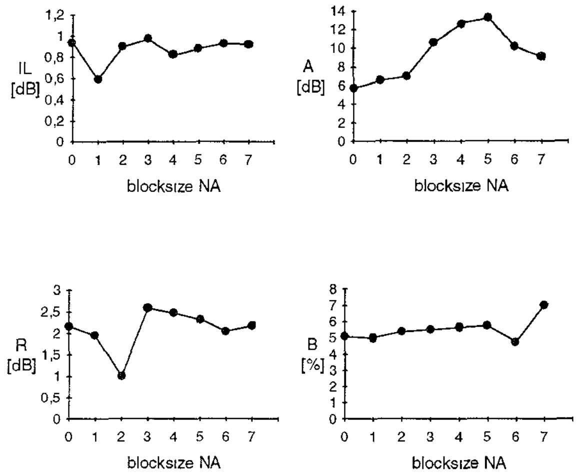

Fig. 4 Filter characteristics as a function of blocksize NA (2NA + NI = 15)

We designed and fabricated four series of filters (F1 to F4) composed of 15, 9 and 7 unweighted IDT's, respectively. The distance between the IDT's was 1.35 λ. The experimental insertion loss of filters F1 to F4 was below 2.7 dB. However, the stopband rejection was not better than 16.5 dB. To improve the sidelobe suppression, we now investigated the influence of withdrawal weighting techniques [14] on the filter response. In the same way as mentioned above, an optimization algorithm was used to select the best weighting functions for the IDT's. Fig. 5 demonstrates the improvement of the near–center–frequency sidelobe suppression by applying withdrawal weighting to a single IDT composed of 35 fingers.

EXPERIMENTAL RESULTS

In total, eight series (F1 to F8) of IIDT type SAW filters have been fabricated by a standard photolithographic process with 10:1 projection printing and lift–off technique. As mentioned above, filters F1 to F4 only contain uniform transducers whereas filters F5 to F8 employ withdrawal weighted IDT's. The filters were mounted into standard TO–39 packages with an organic adhesive and bonded with gold wires.

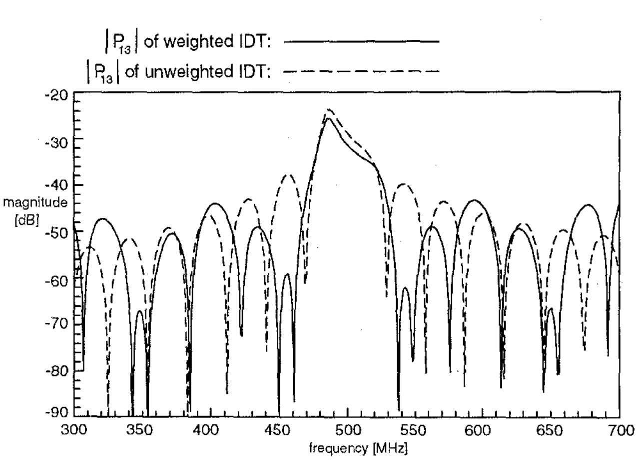

Fig. 5 Computed electroacoustic transfer function P_{13} of unweighted IDT and withdrawal weighted IDT (each IDT consists of 35 fingers)

In what follows, we will limit the discussion to series F7 and F8. The filters F7 are composed of 9 interdigitated IDT's of which six IDT's are symmetrically withdrawal weighted. The number of fingers varies between 29 and 45, and the distance between the transducers is 4.35 λ. The device is experimentally characterized by a bandwidth of 26 MHz (5.2 %), an insertion loss of 1.8 dB, a passband ripple of 1 dB, and a sidelobe suppression of 23 dB. Filters F8 are again composed of 9 interdigitated IDT's four of which are symmetrically withdrawal weighted. Here, the number of fingers varies between 49 and 71, and the distance between the transducers is again 4.35 λ. The measured filter data are as follows: the bandwidth is 17 MHz (3.4 %), the insertion loss is 1.7 dB, the passband ripple is 0.5 dB, and the sidelobe suppression is again 23 dB.

In both cases, we achieved a very good agreement between computed and experimental results as is seen in Figs. 6 and 7. The main deviations arise from the fact that some loss mechanisms (such as mode conversion into parasitic bulk waves) and electromagnetic feedthrough effects have not been included in the simulation model. The experimental minimum insertion loss could be reduced by increasing the metalization height since the leaky surface acoustic wave would then be bound closer to the surface by the energy trapping effect. However, such a measure would also increase reflections at the transducer electrodes and would be likely to lead to a greater passband ripple.

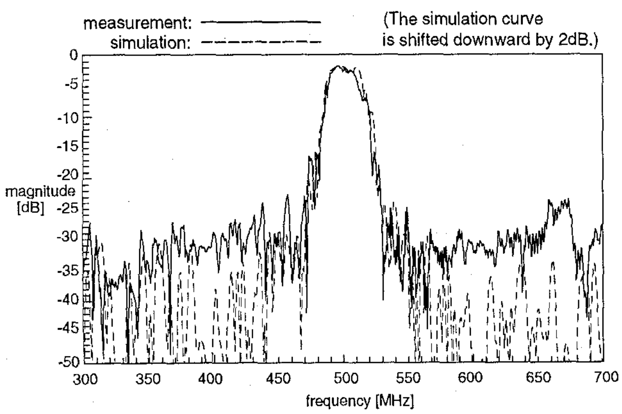

Fig. 6 Computed and experimental frequency response of filter F7 (ideally matched)

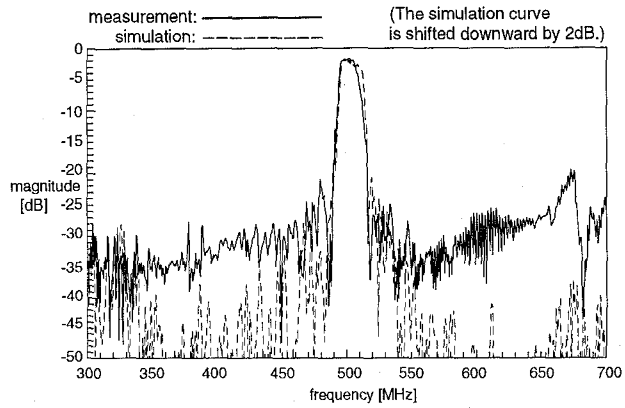

Fig. 7 Computed and experimental frequency response of filter F8 (ideally matched)

We have found that the filter characteristics are sensitive to the chip layout. Fig. 8 shows a typical chip layout.

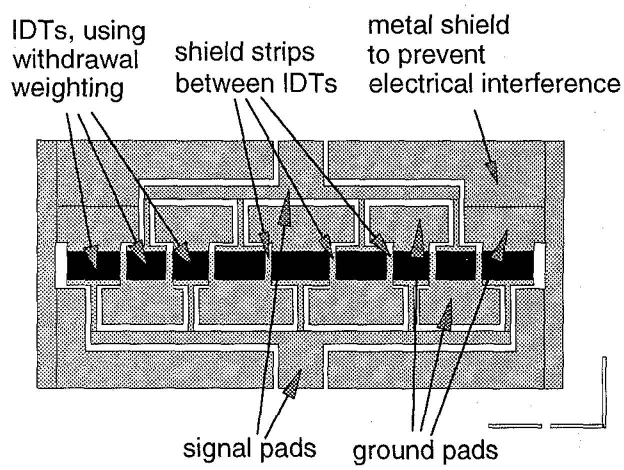

Fig. 8 Chip layout

For a closer agreement between measured and computed results such layout–dependent factors as coupling capacitances between pads or electromagnetic feedthrough would have to be taken into account. Considering the number of IDT's and the complex layout necessary to feed all the IDT's, this is no easy undertaking. In our design, we have included the ohmic losses of the signal pads. This is illustrated in Fig. 9 which shows – as an example for a fifteen–transducer IIDT device – the resistances representing the ohmic losses.

CONCLUSION

This work demonstrates the design of wide–band IIDT type SAW filters with relatively high stopband attenuation. Only $\lambda/4$–width electrodes were used so that these devices

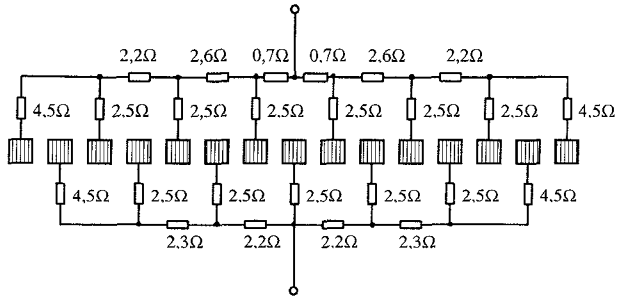

Fig. 9 Representation of ohmic losses of the signal pads

can also be fabricated for higher center frequencies. IIDT type SAW filters have higher power handling capabilities than other SAW approaches due to the fact that the acoustic energy is split up between many transducers; they also show less sensitivity to the ohmic finger resistance. This work arose from a requirement of wide–band low–loss filters in mobile communication systems in the 0.9 and 1.8 GHz bands. However, to study the basic influences of the many design parameters on the frequency response of the IIDT structures, we chose a center frequency of 500 MHz.

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