A NEW LOW LOSS SAW FILTER STRUCTURE WITH EXTREMELY WIDE BANDWIDTH FOR MOBILE COMMUNICATION SYSTEMS

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ABSTRACT

We present a low loss surface acoustic wave (SAW) filter with a dual–track configuration which is characterized by a new arrangement of interdigital transducers (IDTs) and reflectors in each acoustic track as well as a special electrical connection of the IDTs. Broadband filter characteristics can easily be achieved by using chirped components. The inherently good stopband rejection of the new structure has been further improved by applying proper weighting techniques to the IDTs and reflectors. A filter with a relative bandwidth of 10 % and a center frequency of 200 MHz has been designed by means of a new synthesis method. The filter has been fabricated on 128° Y–X $LiNbO_3$. We measured a minimum insertion loss of 4 dB, a small passband ripple of about 1 dB, and a stopband rejection better than 35 dB. Excellent agreement between simulation and measurement has been found.

INTRODUCTION

The market for mobile communication systems is rapidly expanding. One of the major aims of modern cellular radio systems is to provide high-quality radio performance with low–power, small–size, small–weight mobile telephones. SAW filters offer the best possibility to fulfill these requirements. To avoid degradation of system performance, the RF filters must have both low insertion loss and high selectivity. Traditional transversal SAW filters satisfy the requirements of flat passband, sharp cutoff frequency response and high reliability. However, one major problem with these devices is that they generally have high insertion loss which is mainly due to the bidirectional nature of IDTs and the mismatch necessary to suppress the spurious triple transit echo. In order to overcome these flaws and to meet the design specifications for filters suitable to mobile radio applications, new design techniques must be used to reduce the insertion loss drastically. SAW filter designs leading to low insertion loss may be based on either unidirectional or symmetrically irradiated IDTs [1]. Up to now, several low loss filter techniques have been reported [2–8]. The relative bandwidths of these techniques are limited to below 5 %. However, to serve the increasing number of users within a given communication system one will finally have to supply more channels and therefore increase the bandwidths in both the transmitter and the receiver paths.

In what follows, we present a new structure to obtain simultaneously low loss, wide bandwidth, small passband ripple and high stopband rejection.

BASIC FILTER CONFIGURATION

The structure depicted schematically in Fig. 1 is a dual-track configuration incorporating IDTs and reflectors.

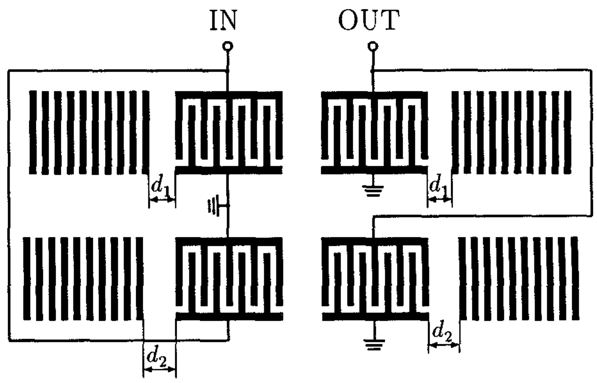

Figure 1: Dual-track reflector filter with mutually blind configuration of the IDTs

In each track two IDTs are arranged. The two input IDTs are electrically driven 180° out of phase, whereas the two output IDTs are in phase. Thus, if no reflectors were present, there would not be any transmission between the electrical ports. We therefore name this configuration "mutually blind". If reflectors are added on both sides of this configuration at a distance d_1 on the upper track and $d_2 = d_1 + \lambda/4$ on the lower track, the phase shift of 180° is canceled and transmission occurs. Note that the output IDTs are irradiated symmetrically yielding maximum acoustoelectric conversion towards the electrical output port. Only signals which have passed at least one reflector can be detected at the electrical output port. Therefore we call our new structure a "reflector filter". The dual-track filter configuration has several advantageous characteristics:

- low insertion loss
- wide bandwidth
- good stopband rejection
- no electromagnetic feedthrough when driven symmetrically
- independent design of reflectors and IDTs.

The low loss filter characteristic is achieved by the mentioned symmetrical irradiation of the output IDTs in connection with the acoustic cavity formed by the reflectors. The use of chirped IDTs and reflectors leads to a wide bandwidth as is shown in the next section. The good stopband rejection is a consequence of the fact that three filtering elements are cascaded (two IDTs, one reflector). The possibility of electromagnetic feedthrough cancellation further improves the stopband behavior. Finally, the independent design of the components considerably simplifies the design of the complete filter and allows the synthesis of a given transfer function.

MODULAR SYNTHESIS OF FILTER COMPONENTS

At first some fundamental design parameters have to be fixed. As a substrate, 128° Y–X $LiNbO_3$ was chosen because of its high piezoelectric coupling coefficient which is absolutely necessary to achieve broadband matching at the electrical ports. The desired relative bandwidth was fixed to 10 %.

The next step is the design of the IDTs. An essential parameter is the input admittance because a low loss characteristic over the entire passband is only possible if broadband matching at both electrical ports can be achieved. A linear chirp law for the IDTs leads to proper matching conditions and therefore to negligible mismatch losses. The bandwidth of the (unweighted) IDTs was chosen about twice as large as the desired filter bandwidth so that apodization-weighting could be applied to improve Fresnel ripple behavior without increasing losses at passband frequencies. Moreover, IDTs of the multielectrode type were used to reduce reflections at the electrodes [9]. This results in further reduction of the passband ripple.

Next the reflectors have to be designed. In the filter passband they should reflect as much acoustic energy as possible whereas in the stopband almost the entire energy should pass the reflectors. Even on high coupling substrates only chirped reflectors can be used to achieve the desired broadband filter characteristics. Fig. 2 schematically shows a dual-track reflector filter with chirped components. It should be noted that the structure is completely symmetrical with respect to the dashed line. This configuration ensures that at all frequencies within the passband the output IDTs are irradiated symmetrically. Finger width-weighting was applied to the end fingers to reduce Fresnel ripple. A high reflection factor for all frequencies within the stopband of a chirped reflector can only be obtained if a sufficient number of strips reflect in phase at each stopband frequency. Consequently, the reflectors become relatively long (about 150 strips even on high coupling substrates) and the propagation loss of the incident acoustic wave becomes frequency dependent due to the dispersive filter characteristics. Without taking any compensating measure the frequency response of the complete filter would have an unacceptably tilted passband. Thus nonlinear chirp laws had to be found to obtain a stronger reflection of such signal parts which have a larger group delay time. Therefore we developed an iterative synthesis procedure based on the stationary phase method and the relations between the moduli and phases of two complex functions related by the Fourier transformation [10]. Input data are the center frequency, bandwidth, reflector time length, and some material parameters of the substrate. Our procedure converges after 3–4 iterations yielding acceptable computing times.

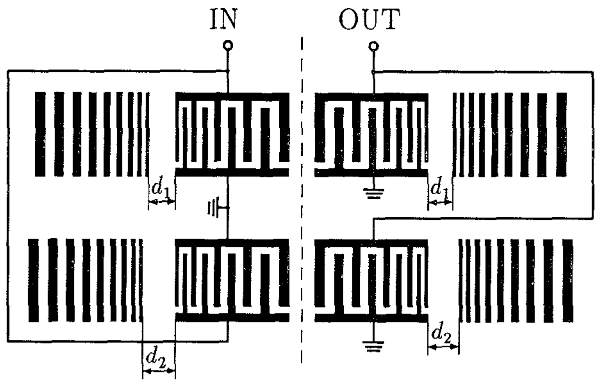

Figure 2: Dual-track reflector filter with chirped components for broadband operation

NUMERICAL ANALYSIS

After the geometry of all basic filter components had been synthesized, we analyzed them with an accurate model. Our simulation software is based on a one-dimensional P-matrix model [11,12]. At first the filter components such as IDTs and reflectors are simulated separately. Then the filter characteristics are computed by a network analyzing program which connects the electroacoustic components in the required manner. Finally the matching circuits at the electrical ports are calculated to achieve the complete transfer function. Figs. 3 and 4 show the simulated scattering

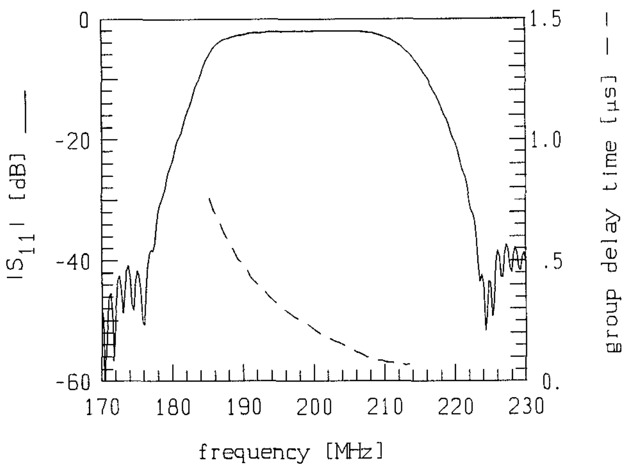

Figure 3: Simulated reflection factor S_{11} and group delay time of the reflector

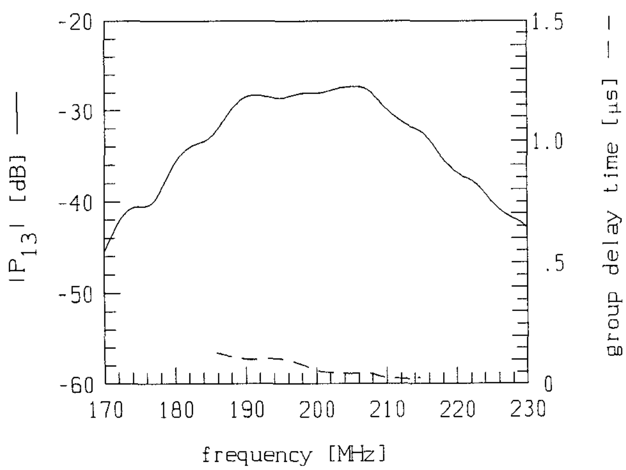

Figure 4: Simulated electroacoustic transfer function P_{13} and group delay time of the IDT

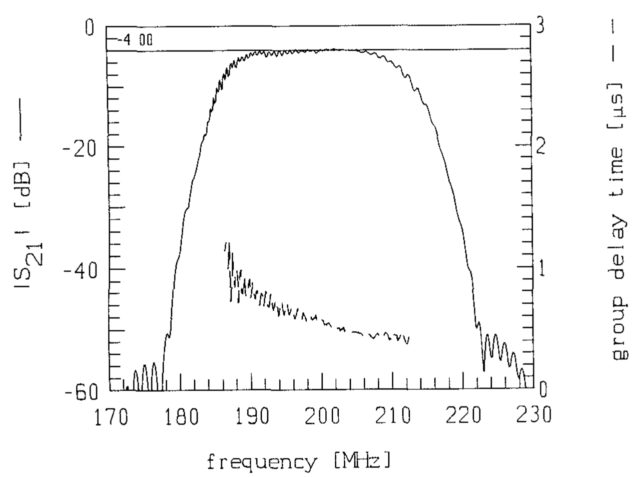

Figure 5: Simulated frequency response and group delay time of the complete filter

parameter S_{11} of the reflector and the electroacoustic transfer function P_{13} of the transducer, respectively. One can see that in both cases the Fresnel ripple is sufficiently reduced. Finally, Fig. 5 shows the simulated frequency response of the complete filter.

EXPERIMENTAL RESULTS

To demonstrate our new filter structure and to verify our design procedure, we have fabricated a dual-track reflector filter at a center frequency of 200 MHz with a designed bandwidth of 10 %. The metalization height is 400 nm. The finger width varies from 2 μm to 7 μm. A photolithographic process with 10:1 projection printing and lift-off technique has been used for device fabrication. For measurements with a network analyzer the filters were mounted into standard TO-8 packages by means of an organic adhesive and bonded with gold wires. The filter was not measured symmetrically. Therefore, electromagnetic feedthrough did not cancel. We removed it by time domain windowing. In Fig. 6 both the computed and experimental frequency response of the filter are shown. A minimum insertion loss of 4 dB and a small passband ripple of about 1 dB has been measured. The sidelobe suppression was better than 35 dB. As is seen, excellent agreement has been obtained between simulated and measured results.

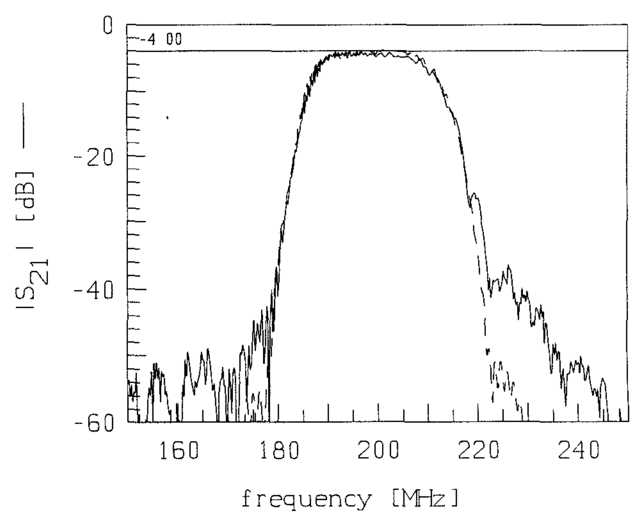

Figure 6: Comparison between simulated (- - -) and measured (——) frequency response

CONCLUSION

We have presented a new SAW structure which we call reflector filter because the frequency characteristic is mainly determined by reflectors. The special arrangement of IDTs and reflectors in two acoustic tracks enables the design of filters in the UHF/VHF range with simultaneously low insertion loss and wide bandwidth. In order to meet the requirements for RF filters in mobile communication systems a reflector filter with chirped components was developed. Using a combination of finger width–weighting and phase-weighting for the reflectors we could synthesize the complete filter geometry. The frequency response of our fabricated filter agrees very well with the simulated filter characteristics based on a P–matrix model. We measured a fractional bandwidth of 10 %, a minimum insertion loss of only 4 dB, and a small passband ripple. The present work demonstrates the feasibility of our new SAW filter structure for broadband mobile radio applications.

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REFERENCES

[1] R. B. Brown, "Low–loss device using multistrip coupler ring configuration with ripple cancellation", Proc. 1986 IEEE Ultrason. Symp., pp. 71–76

[2] M. Hikita, T. Tabuchi, H. Kojima, A. Sumioka, A. Nakagoshi, Y. Kinoshita, "High performance SAW filters with several new technologies for cellular radio", Proc. 1984 IEEE Ultrason. Symp., pp. 82–92

[3] K. Yamanouchi, Z. Chen, T. Meguro, "New low–loss surface acoustic wave transducers in the UHF range", IEEE Trans. Ultrason. Ferroelec. Freq. Contr., vol. UFFC-34, pp. 531–539, 1987

[4] K. Anemogiannis, F. Müller, W. Ruile, G. Riha, "High performance low–loss SAW filters for mobile radio with improved stopband rejection", Proc. 1988 IEEE Ultrason. Symp., pp. 77–82

[5] P. M. Smith, C. K. Campbell, "A theoretical and experimental study of low–loss SAW filters with interdigitated interdigital transducers", IEEE Trans. Ultrason. Ferroelec. Freq. Contr., vol. UFFC-36, pp. 10–15, 1989

[6] G. Fischerauer, I. Schropp, K. Anemogiannis, R. Dill, "IF and RF filters for mobile telephone systems", Proc. 1991 IEEE Ultrason. Symp., pp. 235–239

[7] C. Kappacher, O. Männer, W. Ruile, R. Dill, "Design and analysis of single phase unidirectional transducers", Proc. 1991 IEEE Ultrason. Symp., pp. 1–4

[8] M. Hikita, T. Tabuchi, T. Akagi, Y. Ishida, "New high–performance and low–loss SAW filters used in ultra–wideband cellular radio systems", Proc. 1991 IEEE Ultrason. Symp., pp. 225–229

[9] H. Engan, "Surface acoustic wave multielectrode transducers", IEEE Trans. Sonics Ultrason., vol. SU–22, pp. 395–401, 1975

[10] E. N. Fowle, "The design of FM pulse compression signals", IEEE Trans. Inform. Theory, vol. IT–10, pp. 61–67, 1964

[11] G. Tobolka, "Mixed matrix representation of SAW transducers", IEEE Trans. Sonics Ultrason., vol. SU–26, pp. 426–428, 1979

[12] G. Scholl, A. Christ, W. Ruile, P. Russer, R. Weigel, "Efficient analysis tool for coupled–SAW–resonator filters", IEEE Trans. Ultrason. Ferroelec. Freq. Contr., vol. UFFC-38, pp. 243-251, 1991