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DEVELOPMENT OF LOW-LOSS QUASI-SLANTED SPUDT FILTERS

V.B.Chvets, A.N. Rusakov, V.S.Orlov
Moscow Radiocommunication Research Institute,
Nizhegorodskaya str., 32, Moscow,109029, Russia

Abstract – The paper describes quasi-slanted SPUDTs with stepped electrodes. Using such transducers simplifies the fabrication of low-loss SAW filters for frequencies 400-600 MHz. To improve filter selectivity, two efficient simulation procedures have been developed, namely, the procedure of electrode withdrawal weighting of quasi-slanted SPUDTs and the procedure of simulating the effect of SAW diffraction on filter performance. The results of modeling and experiments for 385 MHz and 450 MHz WLAN filters are reported.

1. INTRODUCTION

Bi-directional interdigital transducers with slanted electrode, or slanted IDT, (the electrode period varies along the axis perpendicular to the SAW propagation direction) are utilized in SAW transversal filters having passbands BW3=$\Delta f_3 / f_0$=5-30%[1]. The implementation of various known single phase unidirectional transducers (SPUDTs) [2,3] with slanted electrodes (or slanted SPUDTs) allows the insertion loss reduction to IL=7-14 dB and triple transit signal (TTS) suppression to –(40-50) dB in a wide band BW3=(2-30)% [4].

In calculating frequency responses, slanted IDTs or SPUDTs filters are conventionally divided into 50-100 virtual acoustic channels parallel to the SAW propagation direction [1]. In each virtual channel, slanted electrodes are considered as parallel electrodes. In addition, it is assumed that these virtual acoustic channels, or sub-filters, operate independently of one another [1].

In practical situations, crosstalks affect strongly frequency characteristics of SAW filters using slanted IDTs or SPUDTs. These crosstalks appear because, first, an acoustic channel emits a portion of SAW energy in the direction of the adjacent channel and, second, the SAW bounded beam experiences diffraction divergence. Crosstalks increase with the broadening of the pass band, since the slope of electrodes then rises.

A SAW filter based on quasi-slanted transducers (or QST filter) is a set of M_C=10-30 real acoustic channels [5]. Each real acoustic channel in QST has parallel electrodes with uniform width, period and aperture A_i. These electrodes are perpendicular to the direction of SAW propagation. Stepped electrodes are formed because of connecting strips between channels (Fig.1).

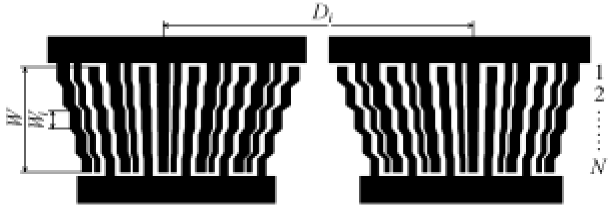


Fig.1. Configuration of filter based on quasi-slanted SPUDT

QST filters can be designed using withdrawal weighting for stop-band responses, channel weighting for pass-band amplitude responses, and distance weighting for phase responses [5]. One can use different weighting functions for exciting and reflecting electrodes in each channel of QST filters, if necessary. Additional weighting of the electrode length in the direction of SAW propagation can also be used. So, the ability of controlling the frequency responses is one of the main advantages of QST filters. SAW diffraction and crosstalks have a minor effect on the performance of QST filters, because acoustic channels use parallel electrodes. Moreover, the fabrication of photomasks for QST filters is substantially simpler than that for filters with slanted electrodes.

Due to the above-mentioned advantages QST filter is one of the most promising SAW filter types for pass bands in the range BW3=1.5-70 % [5]. However, the requirements of smaller chip size, higher selectivity and wider range of operating frequencies stimulates further development of new techniques for design and simulation of low-loss QST filters.

In this paper, we describe two quasi-slanted SPUDT structures with minimum electrode width $b = \lambda / 8$ and $b = \lambda / 6$, respectively. Such structures allow the application of low-loss QST filters at frequencies as high as 500-600 MHz. An efficient technique, based on selective withdrawal weighting (WW), has been developed to simulate short-length high-selective quasi-slanted SPUDTs. To improve the selectivity and phase response of small-size filters with quasi-slanted SPUDTs, SAW diffraction was taken into account using the Angular Spectrum Model [6].

2. SPUDT STRUCTURES FOR HIGH FREQUENCY QST LOW-LOSS FILTERS

The pass band of low-loss QST filters ranges from BW3=1.5% to BW3=40%. If the pass band is larger than 40%, the directivity of known SPUDTs tends to zero. As a result, the insertion loss is as high as it is in bi-directional IDTs. It is reasonable to choose SPUDT with different specific effectiveness of SAW excitation per wave length according to the specified values of filter bandwidth, insertion loss, and TTS suppression.

In the case of narrow passbands, excess effectiveness can be reduced if the number of reflecting electrodes in the SPUDT chosen is smaller than the number of exciting electrodes. Fig.2 shows the effectiveness of excitation for some SPUDTs.

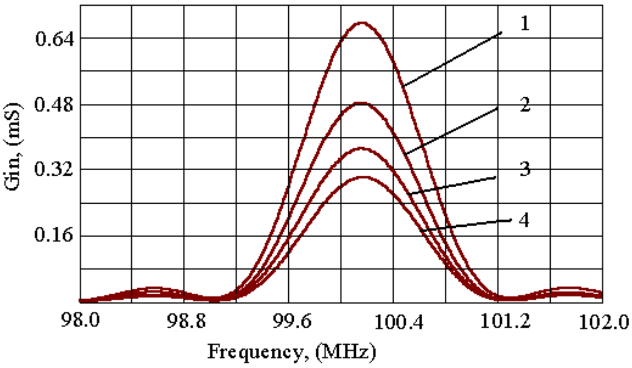
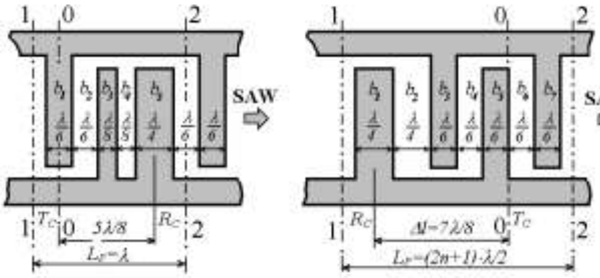


Fig. 2. Comparison of specific effectiveness of different SPUDT structures: 1 - NSF SPUDT; 2 – TES SPUDT; 3 - DART SPUDT and EWC SPUDT; 4 – HF SPUDT.

One sees that nonuniform split finger (NSF) SPUDT [3] has the maximum effectiveness. The effectiveness of DART SPUDT [2] is slightly inferior to that of NSF SPUDT. However, NSF SPUDT and DART SPUDT have narrow electrodes of width $b = \lambda / 16$ and $b = \lambda / 8$ respectively (λ is the wavelength), which makes difficult their application at frequencies higher than 200-400 MHz.

To broaden the range of operating frequencies, a number of structures of high-frequency SPUDTs with wider electrodes have been developed. For example, in a three-electrode section (TES) SPUDT [7], each periodic elementary section is $L_P = 1\lambda$ long and includes two exciting electrodes of width $b_1 = \lambda / 6$ and $b_3 = \lambda / 8$ and one reflecting electrode of width $b_5 = \lambda / 4$ (Fig.3a). TES SPUDT has specific effectiveness 1,47 times higher than that of DART SPUDT (Fig.2). Therefore TES SPUDT is recommended for wider filter bandwidths.

Fig. 3b illustrates a new structure of high-frequency (HF) SPUDT. Each periodic elementary section of HF SPUDT involves three exciting electrodes of width $b_3 = b_5 = b_7 = \lambda / 6$ and one reflecting electrode of width $b_1 = \lambda / 4$. The elementary section has the length $L_P = 1.5\lambda$ [8]. The specific effectiveness of HF SPUDT is slightly lower than that of DART (Fig.2). Therefore HF SPUDT can be implemented in SAW filters with narrower bandwidths.



a b

Fig.3. Elementary section of SPUDTs: a - TES SPUDT;
b - High Frequency SPUDT

Thus, application of TES SPUDT and HF SPUDT broadens the operating frequency range of low-loss QST filters up to 500-600 MHz due to wider electrodes. Moreover, high specific effectiveness of SAW excitation in TES SPUDT allows the reduction of insertion loss in the case of wide bandwidth.

3. OPTIMAL SIMULATION PROCEDURE FOR WITHDRAWAL WEIGHTED QST

The frequency response of a low-loss QST filter is simulated using a modified equivalent circuit model, with SAW reflection and charge distribution on the electrodes taken into account. An efficient technique based on selective withdrawal weighting (WW SPUDT) has been developed for the simulation of short-length high-selective quasi-slanted SPUDTs. At each iteration, the number of weighting coefficients is larger or smaller than the preceding number by only one coefficient. This additional, or withdrawn, weighting coefficient does not affect significantly the amplitude frequency response |S21| at the center frequency. Therefore it is possible to normalize this response prior to selecting variants. Thus, to analyze each new set of weighting coefficients at the fixed frequency, only one summation (deduction) and increment of four pointers are required. The computation time reduces substantially as a result. This method allows the synthesis of short weighting functions involving few hundred weighting coefficients.

As applied to longer weighting functions, the method proposed can be modified as follows. First, one of the conventional methods is used to obtain the initial set of weighting coefficients that includes, e.g., 500 coefficients. Further, one considers only the variants differing from the initial one by not more than 10 weighting coefficients, until the required frequency response |S21| is achieved. Such a method is especially efficient for the synthesis of filters with low shape factor.

To improve the selectivity of small-size filters with quasi-slanted SPUDTs, SAW diffraction was taken into account using the Angular Spectrum Model [6]. The complete wave spectrum was digitized and represented in the form of a finite set of separate modes. The Y_i-matrix of the filter was computed for each mode. Afterwards such one-mode Y_i-matrices were summed to obtain the resulting filter conductivity.

4. SIMULATION AND EXPERIMENTAL RESULTS

The quasi-slanted TES SPUDT and HF SPUDT proposed as well as the simulation techniques developed have been applied to design 385 MHz and 450 MHz WLAN filters in packages SMD 5.0x5.0x1.4 mm. The substrate was YZ-cut $LiNbO_3$.

The 385 MHz WLAN filter included two quasi-slanted TES SPUDT with lengths $L_1 = 116\lambda$ and $L_2 = 92\lambda$, aperture $W = 40\lambda$, where λ is a wavelength. First, each initial QST was divided into 23 acoustic channels. The distribution of channel apertures A_i over their mean frequencies (Fig. 4, line 1) has been found from the condition that the frequency response be flat within the pass band. The aperture distribution secured the 3 dB slop of peak of |S21| to compensate the effect of matching circuits. The distance between transducer centers in each sub-filters corresponded to the linear phase Θ of the filter as a whole and was 160λ.

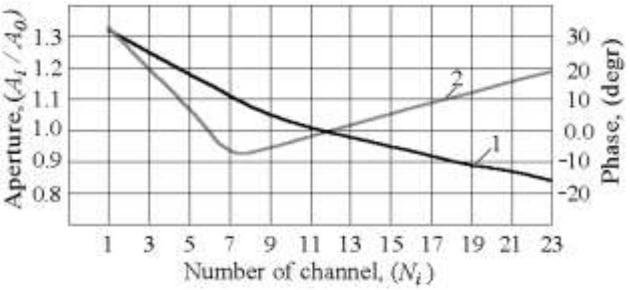


Fig.4. Dependence of channel aperture (1) and phase (2) on current number of channel

Next, weighting functions for input and output withdrawal weighted (WW) TES SPUDTs were found. The weighting functions differed from one another and secured the sub-filter selectivity greater than 52 dB (Fig.5). Amplitude- frequency |S21| and phase Θ characteristics of a filter were computed then. The SAW diffraction caused by variation of total aperture of TES SPUDTs in the range $22\lambda < W < 55\lambda$ (Fig.6) has been taken into account. The diffraction yielded the extra slope of amplitude response by 2.5 dB, the jump of phase response in the pass band by $\Delta\Theta = 40^o$, and the increase of sidelobe level at 406 MHz in the stopband by 8 dB. Due to the optimal choice of aperture $W = 40\lambda$ the distortions of |S21| decreased. However, the behavior of the phase Θ in the pass band was not improved.

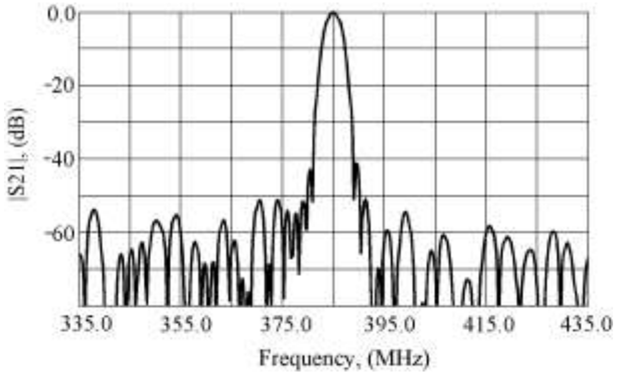


Fig.5.Simulated |S21| of sub-filter based on two WW TES SPUDT

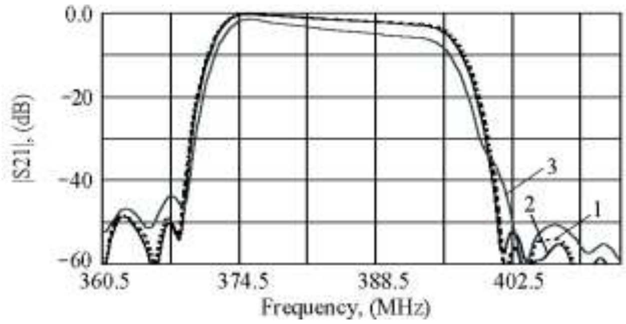


Fig.6. Simulated |S21| of filter with diffraction distortions:
1-W=55λ; 2- W=40λ; 3- W=22λ

To improve the phase Θ of the filter, we varied the distance D_0 between the centers of input and output QST within the range $110\lambda < D_0 < 330\lambda$. The slope of |S21| in the pass band was nearly constant. However, the level of the sidelobe at 403 MHz was found to change from –59 dB ($D_0 = 165\lambda$) to –46 dB ($D_0 = 110\lambda$ and 220λ). The optimal distance that provides minimum sidelobe level of |S21| was found to be $D_0 = 165\lambda$ which is close to the initial value $D_0 = 160\lambda$ at which the phase jump $\Delta\Theta = 40^o$ was observed.

Finally, in order to decrease distortions in the pass band, we refined the phases of individual sub-filters by changing the distance D_i between the centers of input and output TES SPUDT in these sub-filters (Fig.4, line 2). Due to refinement the phase ripples decreased to $\Delta\Theta = 4^o$ in the range $f_0 \pm 7$ MHz.

The simulation techniques have been verified experimentally. Fig.7 shows the measured |S21| and Θ of the above-described 385 MHz filter WLAN before and after phase refinement. Comparing Fig.7a and Fig.7b one sees that experimental and theoretical results are in good agreement. To summarize, the following experimental parameters were obtained in the matched 50 Ohm circuit: insertion loss IL=8.4 dB, band widths BW3=23.6 MHz and BW40=31.2 MHz, amplitude ripples Δa=0.5 dB, group delay ripples GDR=40 ns in f_0 ±7 MHz.

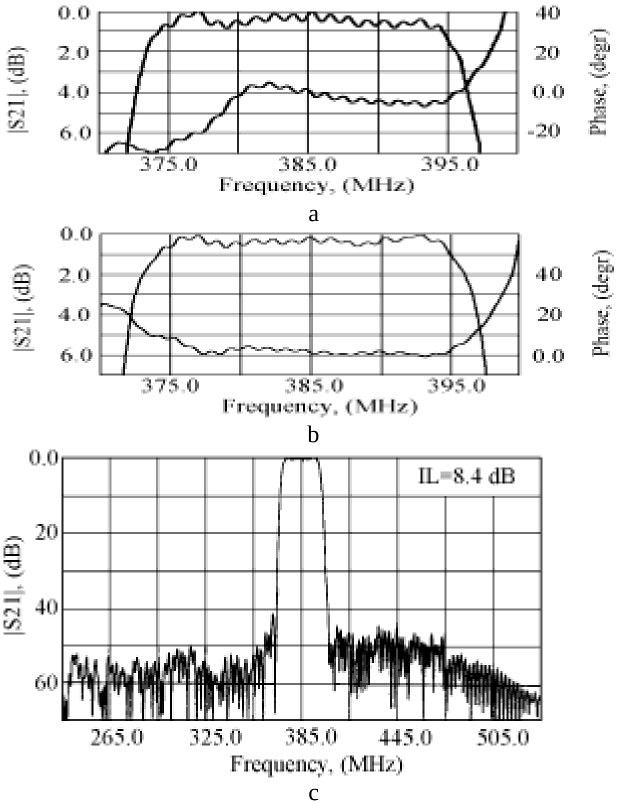


Fig.7. Measured responses of 385 MHz filter WLAN:
a – in pass band before correction; b, c – in pass band and wide band after correction.

The second 450 MHz WLAN filter used two quasi-slanted HF SPUDTs with apertures W =83 λ and lengths L_1=148 λ and L_2=116 λ. The input and output HF SPUDT were divided into 26 channels. The distance between the input and output HF SPUDT was D_0 =208 λ Fig. 8 shows the frequency response of the filter measured in the 50 Ohm matched circuit. The experimental parameters of the filter are as follows: BW3=21.9 MHz, BW40=32.3 MHz, IL=9.3 dB, AR=0.8 dB, $\Delta\Theta$=6°, GDT ripple 50 ns, UR=48 dB.

CONCLUSION

The TES SPUDT and HF SPUDT proposed distinguish from known SPUDT by wide electrodes and allow one to simplify the fabrication of 400-600 MHz quasi-slanted filters. We have shown that low-loss quasi-slanted filters can be designed using the following methods: effective withdrawal weighting for stop-band responses, channel aperture weighting for amplitude responses in the pass band, and distance weighting for compensation of diffraction distortions of phase or group delay responses. The results of measurements and simulation are in a good agreement.

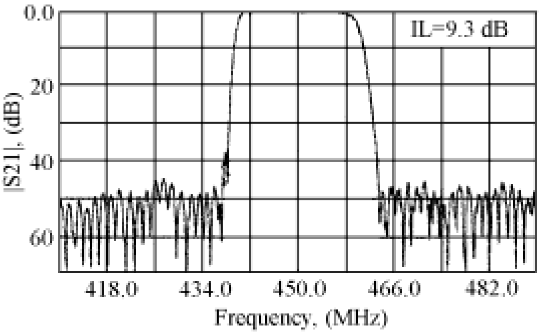


Fig.8. Measured response of 450 MHz filter WLAN

REFERENCES

[1] H.Yatsuda, K.Yamanouchi, "Automatic Computer-Aided Design of SAW Filters Using Slanted Finger Interdigital Transducers", IEEE Trans. Ultrason., Ferroelect., Freq. Contr., vol.47, No1, 2000, pp.140-146.

[2] T.Kodama et al., "Design of Low-Loss SAW Filters Employing Distributed Acoustic Reflection Transducers", IEEE 1986 Ultrason.Symp.Proc., pp.59-64.

[3] B.Hunsinger et al, "Surface Acoustic Wave Device with Reflection Suppression", US Patent, No 4162465, Int Cl^2 HO3H 9/04, July 24, 1979.

[4] L.Solie, "Tapered Transducers – Design and Application", IEEE 1998 Ultrason. Symp. Proc.,pp.27-37.

[5] V.B.Chvets, P.G.Ivanov, V.M.Makarov, V.S.Orlov, "Low-Loss Slanted SAW Filters with Low Shape Factors", IEEE 1999 Ultrason. Symp. Proc., pp.51-54.

[6] G.Farnell, in "Acoustic Surface Waves", Edited by A.Oliner, N-Y, 1978, pp.28-81.

[7] V.B.Chvets, V.S.Orlov, V.M.Makarov, “Unidirectional SAW Transducer". Patent of Russia No 2117383, Int. Cl^6 HO3H/00, September 24, 1997.

[8] Chvets V.B., Orlov V.S., "High Frequency SPUDT". Patent of Russia, No 99125446, Int.Cl^6 HO3H 9/145, December 3, 1999.