COM Parameters of STX Quartz and STX+25 Quartz

V.I. Cherednick
Chemical department
State University
Nizhny Novgorod, Russia
odissey@sandy.ru

M.Y. Dvoesherstov
Radio-physical department
State University
Nizhny Novgorod, Russia
dvoesh@rf.unn.ru

***Abstract*— Dispersion curves for STX Quartz and for STX+25 Quartz are calculated by modified FEMSDA program. All the basic COM parameters are extracted from calculated dispersion curves. In particular, the phase velocity in the center of the stopband, reflectivity, transduction coefficient per electrode and directionality are determined for 0.1 <= w/p <= 0.9 and 0 <= h/p <= 0.1, where w and h are width and thickness of electrodes respectively and p is the spatial period of the grating. It is shown, in particular, that the maximum of the transduction coefficient stays near w/p = 0.5 for all the h/p values, and the maximum of the reflectivity for short-circuited aluminum grating shifts from w/p = 0.3 to w/p = 0.9 when h/p changes from 0 to 0.1. Amplitude-frequency characteristics of some concrete devices are calculated.**

I. Introduction

COM parameters are needed for surface acoustic wave transducers calculations. Dispersion curves of propagation characteristics under periodic metallic grating are used for COM parameters extraction. The Hashimoto's FEMSDA method is the most widely used for dispersion curves obtaining [1]. The FEMSDA program allows to calculate propagation characteristics of any piezoelectric substrates. But the iterative procedure of solution searching, used in the FEMSDA program, can work properly only if the electromechanical coupling coefficient of the substrate is large enough. Such substrates as Lithium Niobate and Lithium Tantalate can be calculated by FEMSDA program rather easily. But calculation of dispersion curves for Quartz is very difficult and practically impossible in many cases because of its low electromechanical coupling coefficient. The iterative search procedure of the FEMSDA program cannot find solution in this case, even when the start point of searching is very close to the solution, especially near edges or (and) the center of the stopband.

We have translated the FEMSDA program from FORTAN to Borland C++ Builder language and made modifications to it. All its capabilities are reproduced and some more possibilities are added. In particular, the rather reliable procedure of searching for the global minimum of the multivariable function is included in this program [2]. This procedure allows to finding the solution for any existing piezoelectric substrate. Moreover an additional FEM subroutine is included, which allows to calculate electrodes with trapezoidal profile. Some more modifications are made too for expanding the possibilities of the program with added user friendliness.

II. Dispersion Curves for STX Quartz

Dispersion curves for STX Quartz with aluminum grating are calculated by this modified program (material constants of the original FEMSDA program are used). Fig. 1 shows an example of such dispersion curves. These curves are calculated for h/p = 0.04, w/p = 0.3, where p, w, and h are period of grating, width and thickness of electrode respectively. Dimensionless frequency F = fp/Vn, where f is a frequency, Vn = 3158.8 m/s – velocity for normalization (close to the velocity of the surface acoustic wave along a free surface).

III. COM Parameters for STX Quartz

Dispersion curves allow to extract such COM parameters:

1. Reflectivity per one electrode for short-circuited grating (analogously for open-circuited one):

$$r_s = \pi(F_{s2} - F_{s1})/(F_{s2} + F_{s1}). \qquad (1)$$

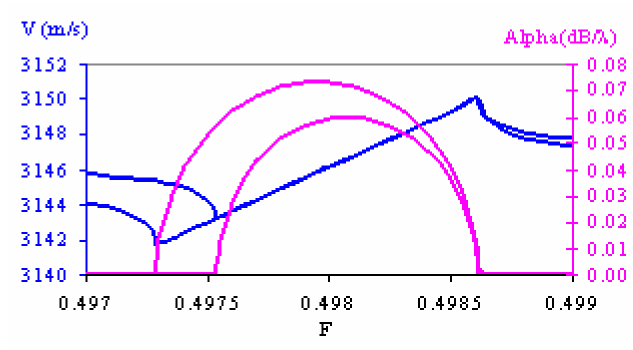

Figure 1. Dispersion curves of STX Quartz for short-circuited and open-circuited (correspond to higher frequencies) grating.

2. Transduction coefficient:

$$m = \pi(F_{o2} - F_{s2} + F_{o1} - F_{s1}). \quad (2)$$

Here F_{s1}, F_{s2} – frequencies, corresponding to lower and upper edges of the stopband for short-circuited grating, F_{o1}, F_{o2} - for open-circuited one. Phase velocities Vs and Vo in the centers of stopbands can be determined from dispersion curves directly. Some COM parameters, obtained by such a manner, are shown in Figs. 2 and 3. Analogous dependences of transduction coefficient show that a maximum of this coefficient corresponds to $w/p \approx 0.5$ for all the h/p values.

IV. FREQUENCY RESPONSE FOR STX QUARTZ

Dependences of all the extracted COM parameters on the metallization ratio w/p are approximated by the 3rd power polynomials [3]. Dependences of these polynomials coefficients on the h/p value are approximated by such polynomials too. Obtained two-dimensional analytical dependences of COM parameters on w/p ($0.1 <= w/p <= 0.9$) and h/p ($0 <= h/p <= 0.1$) are used for calculation of amplitude-frequency characteristics of various SAW devices (filters, resonators, delay lines) by P-matrix technique [4].

A one-port synchronous SAW resonator on STX Quartz, described in [4], was calculated for demonstration of possibilities of the technique, described here. The spatial period of electrodes p = 3.932 μm, the aperture is 100*2p, the number of IDT electrodes is 50 (25 pairs), the number of reflecting electrodes is 300 on the each side, the aluminum electrode thickness is h = 160 nm (h/p = 0.0407) and the relative electrode width (metallization ratio) is w/p = 0.5.

Calculated admittance of this resonator is presented in Fig. 4 (real part – lower curve, and imaginary part – upper curve).

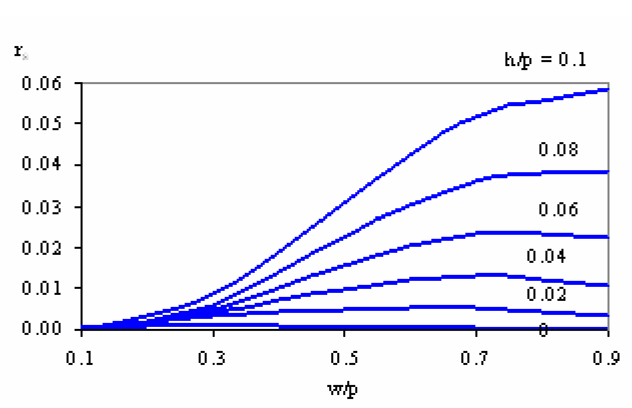

Figure 2. Dependences of reflectivity r_s on a relative electrode width w/p for various values of the relative thickness.

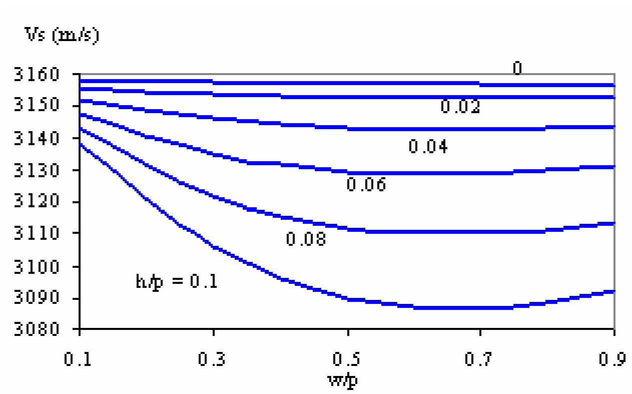

Figure 3. Dependences of phase velocity Vs on a relative electrode width w/p for various values of the relative thickness.

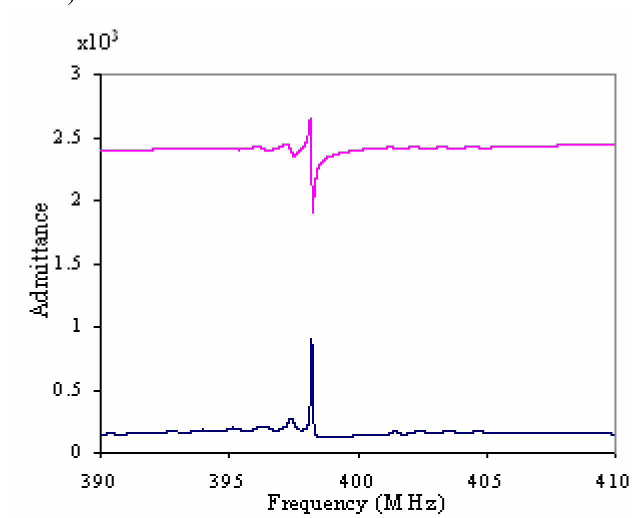

Figure 4. Amplitude-frequency characteristic of one port synchronous SAW resonator on STX Quartz, obtained by technique, described here.

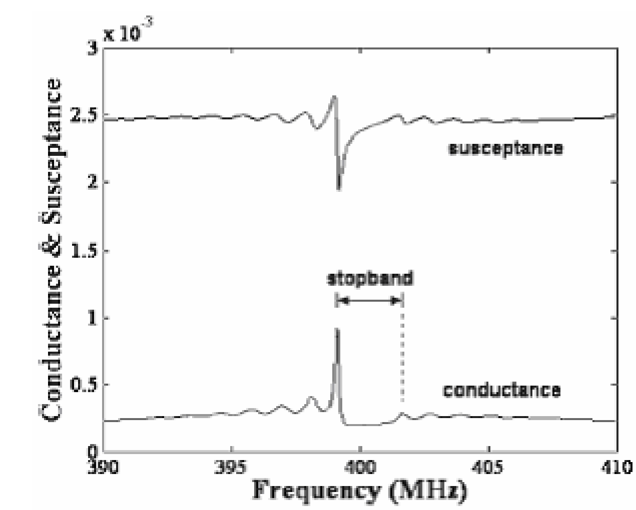

Figure 5. Amplitude-frequency characteristic of one port synchronous SAW resonator on STX Quartz, taken from [4] .

Fig. 5 shows results, taken from [4]. Results in Figs. 4 and 5 are very close to each other, although quite different method of COM parameter calculation is used in [4].

V. Dispersion Curves for STX+25 Quartz

An example of dispersion curves for STX+25 Quartz is presented in Fig. 6 for w/p = 0.7 and h/p = 0.04. Curves of attenuation in Fig. 6 intersect each other. This means, that opposite propagation directions are not equivalent (NSPUDT orientation).

VI. COM Parameters for STX+25 Quartz

Expressions (1) and (2) are used for reflectivity and transduction coefficient calculation and additionally directionality is calculated:

$$\theta = \frac{1}{2}\arccos\left(\frac{\Delta F_c^2 + \Delta F_s^2 - \Delta F_o^2}{2\Delta F_c \Delta F_s}\right) \qquad (3)$$

Here ΔF_s and ΔF_o – half-width of the stopband for short-circuited and open-circuited gratings respectively, ΔF_c – distance between centers of stopbands for short-circuited and open-circuited gratings.

In particular, $\theta = 45.45^o$ for curves, shown in Fig. 6. View of dependences of reflectivity, velocity and transduction coefficient on the electrode width for STX+25 Quartz is the same as for STX Quartz (see Figs. 2 and 3), only values of the velocity and transduction coefficient are somewhat larger and the value of the reflectivity is somewhat less than for STX Quartz. Typical view of dependence of directionality on the electrode width is shown in Fig. 7. Directionality approaches its optimal value 45^o near w/p = 0.5 for any relative thickness h/p > ≈ 0.04.

Dependences of directionality on w/p and h/p also are approximated with polynomials and this approximation is used for IDT characteristics calculation by P matrix technique.

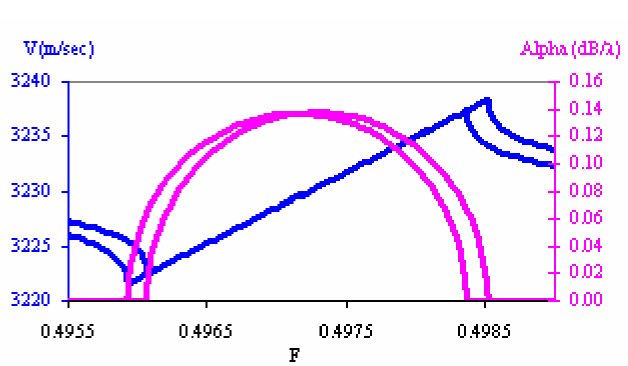

Figure 6. Dispersion curves of STX+25 Quartz..

An example of results of such calculations is shown in Fig. 8. These amplitude-frequency characteristics are obtained for w/p = 0.5 and h/p = 0.077 (p = 2 mm, aperture 185 μm). Directionality $\theta = 44.77^o$ for these values of w/p and h/p.

Difference of the signal levels on the resonance frequency for two opposite propagation directions is visible distinctly in Fig. 8.

So, the software, described here, allows calculation of dispersion curves, COM parameters, and IDT characteristics for various substrates, including ones with low electromechanical coupling coefficients, which are very hard to calculate by Hashimoto's original FEMSDA program. Parameters for substrates with rather large electromechanical coupling coefficients can be calculated quickly.

Substrates, such as STX Quartz, STX+25 Quartz, ATX Quartz, $42LiTaO_3$, $128LiNbO_3$, $YZLiNbO_3$, LGS are already calculated and any other substrate may be used for this type of calculation.

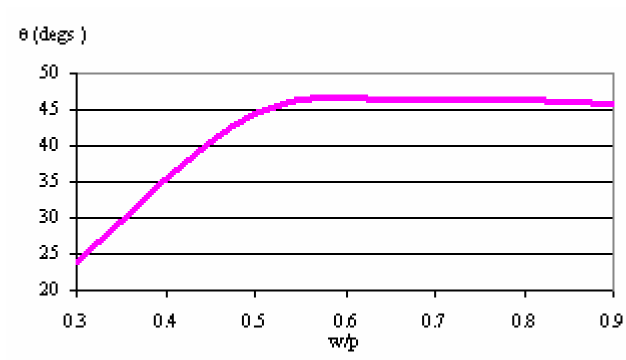

Figure 7. Dependence of directionality on the electrode width for h/p = 0.06 on STX+25 Quartz.

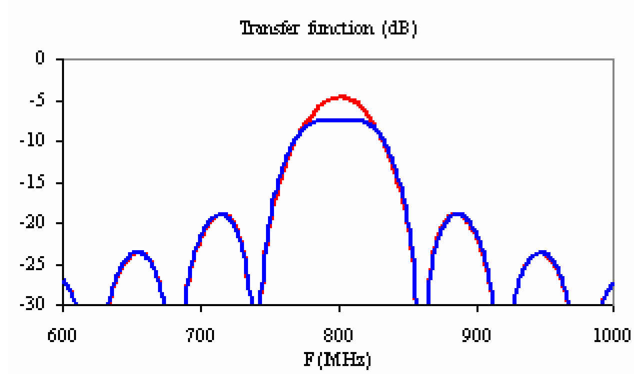

Figure 8. Amplitude-frequency characteristics of 27 electrode single IDT on STX+25 Quartz (red – forward propagation direction, blue – opposite direction).

VII. CONCLUSION

Calculation of dispersion curves for any substrate is possible with modified software described here. COM parameters are extracted from calculated dispersion curves, approximated with polynomials and IDTs characteristics are calculated by P matrix technique. For example, all the calculations are performed for STX Quartz and STX+25 Quartz – substrate, a difficult task for other known tools because of low electromechanical coupling coefficient of this crystal.

REFERENCES

[1] G. Endoh, K. Hashimoto and M. Yamaguchi, "Surface acoustic wave propagation characterization by finite-element method and spectral domain analysis", Jpn. J. Appl. Phys., Vol. 34 (1995), pp. 2638-2641.

[2] M.Yu. Dvoesherstov, V.I. Cherednick, A.P. Chirimanov, S.G. Petrov, "A method of search for SAW and leaky waves based on numerical global multi-variable procedures", SPIE, Vol. 3900, 0277-786X/99, pp. 290-296.

[3] K. Ibata, T. Omori, K. Hashimoto and M. Yamaguchi, "Polynomial approximation of SAW reflection characteristics for fast device simulation tools", Jpn. J. Appl. Phys., Vol. 38 (1999), pp. 3293-3296.

[4] T.-T. Wu, S.-M. Wang, Y.-Y. Chen, T.-Y. Wu, P.-Z. Chang, L.-S. Huang, C.-L. Wang, C.-W. Wu and C.-K. Lee, "Inverse determination of coupling of modes parameters of surface acoustic wave resonators", Jpn. J. Appl. *Phys*. Vol. 41 (2002), pp. 6610-6615.