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MONOLITHIC CRYSTAL FILTERS USING LITHIUM TANTALATE CRYSTAL

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The characteristics of lithium tantalate crystal filters and the method of their design are described. The experimental results are presented and discussed.

1. Characteristics of $LiTaO_3$ filters

The large electromechanical coupling coefficient of lithium tantalate allow for a much wider band of filters than that achieved with quartz. Traditionally used in resonators and monolithic filters with good results. *AT*-cut quartz posses a low electromechanical coupling coefficient ($\sim 9\%$), which restricts the maximum available filter bandwith to approximately 0.3% of the centre frequency for the fundamental mode of operation.

Lithium tantalate has a coupling coefficient about 40%, which makes possible the construction of filters with a bandwith of up to 6% at fundamental frequency ([1], [2]).

For monolithic filters the vibrational mode structure of the plate should be dominated by a single thickness shear mode with strong electromechanical coupling, low temperature coefficient of frequency, freedom from competing modes.

These conditions are satisfied in $LiTaO_3$ crystals by $Y\,163°$-cut. Having a strong shear mode with a good isolation from the competing mode, this cut has the disadvantage of having a poor temperature coefficient of resonance frequency. For *AT*-cut quartz it is ± 0.2 ppm/°C and for Y 163°-cut $LiTaO_3$, it is -22 ppm/°C ([3], [4]).

Figure 1 illustrates a $LiTaO_3$ Y-163° rotated Y-cut plate.

The direction of particle displacement lies within 3° of the Z' axis so that the mode is close to a pure shear mode. Because of this, the TS mode is along the Z'-axis for the lithium tantalate Y 163°-cut, but for AT-cut quartz the TS mode is along the axis.

Orientation precision of $LiTaO_3$ plates is less ($\pm 6'$) than for AT-cut quartz ($\pm 1'$).

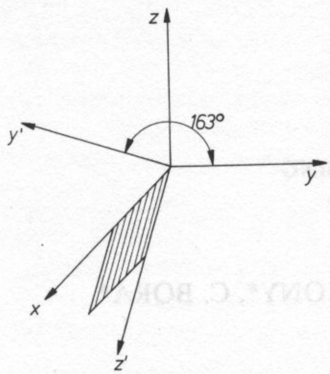

FIG. 1. The 163° rotated Y-cut $LiTaO_3$ plate

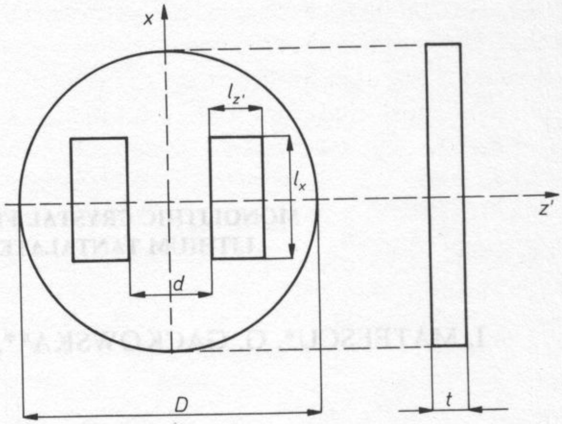

FIG. 2. Two-pole monolithic crystal filter

Lithium tantalate monolithic crystal filters provide a wide band of filters in the frequency range for centre frequency 10–100 MHz. $LiTaO_3$ plates require poling in a d.c. field. Lithium tantalate crystal is very sensitive to thermal shocks.

2. Design of monolithic $LiTaO_3$ crystal filters

The filtering operation is done on a single piezoelectric plate if a number of resonator pairs are deposited so that acoustic coupling can take place between them. Figure 2 presents a monolithic crystal filter with two resonators coupled in the Z′axis direction.

For lithium tantalate crystal in Z′ coupling direction (*TS* mode) bandwith is wider than for coupling direction(*TT* mode).

Figure 3 shows the electrical equivalent circuit of a symmetric two-pole filter. It is compatible with that used for quartz filters. Filter network design with lithium tantalate crystal follows a similar procedure to the quartz approach.

There are three steps of monolithic filter design: synthesis, analysis and calculation of geometrical dimensions. For all steps we used the method and computing programme for quartz monolithic filters [5] adapted to $LiTaO_3$ crystals.

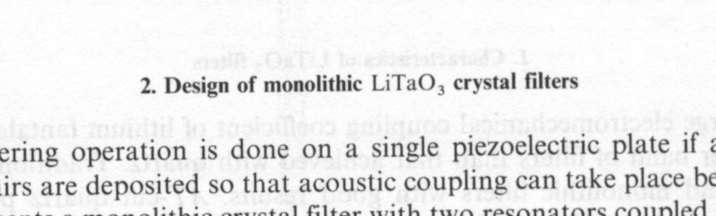

Fig. 3. Equivalent network for a high-coupling dual resonator

Specific piezoelectric, elastic and dielectric constants and relation between the electrical parameters of the network (Fig. 3) and the physical characteristics of the dual resonator are used in this programme.

The most important and useful relations are [6], [7]

$$L = \frac{0.154 N_m^2}{A f_m^3}\left[1 - \frac{0.224 m^2}{N_m^2}\right] \tag{1}$$

where A – area of electrode (mm^2), f_m – m^{th} order of frequency resonance (MHz), m – order resonance, N_m – frequency constant (MHz mm), L-inductance (H).

$$f_m = \frac{N_m}{t} \tag{2}$$

where t – thickness of the plate (mm).

The values of N_m for $LiTaO_3$ $Y163°$-cut are

$N_1 = 1.845$ MHz mm for fundamental frequency operation

$N_3 = 5.922$ MHz mm for third overtone frequency operation

$$A = l_x l_{z'} \tag{3}$$

where l_x and $l_{z'}$ are the dimensions of the electrodes. For fundamental frequency operation

$$\frac{l_{z'}}{t} \leq 9; \quad \frac{l_x}{t} \leq 5 \tag{4}$$

and for third overtone frequency operation:

$$\frac{l_{z'}}{t} \leq 8; \quad \frac{l_x}{t} \leq 4.5 \tag{5}$$

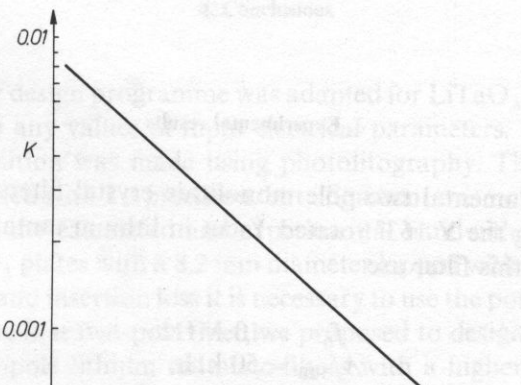

FIG. 4. Thickness shear inter-resonator coupling against electrode spacing

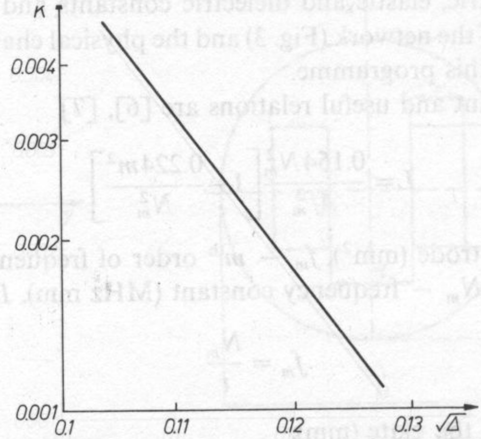

FIG. 5. Thickness shear inter-resonator coupling against square of plate back

The expression of inter-resonator coupling K has the form ([1], [8])

$$K = A\exp[-B(1-2\Delta^{1/2})\Delta^{1/2}d/t] \tag{6}$$

where A – function of electrode dimensions, d – inter-resonator spacing, A, B – functions of the coupling direction (TT or TS mode), Δ – plate back fractional frequency lowering produced by plating.

Figures 4 and 5 illustrate the dependence between the coupling coefficient and the distance d of the electrodes and plate back. From these curves we deduced the values for A and B.

3. Experimental results

Prototype fundamental two-pole monolithic crystal filters have been designed and fabricated using the Y 163° rotated Y-cut in lithium tantalate crystal.

Input data for this filter are:

$$f_0 = 10 \text{ MHz}$$
$$\Delta f_{3dB} = 50 \text{ kHz}$$
$$Z_0 = 400$$
$$A_{max} = 0.5 \text{ dB}$$
$$A_{min} = 18 \text{ dB}.$$

The frequency response of this filter is shown in Fig. 6, the measuring specification being:

$$f_0 = 9{,}998 \text{ MHz}$$
$$f_{3\text{dB}} = 48 \text{ kHz}$$
$$A_{\max} = 0.8 \text{ dB}$$
$$A_{\min} = 20 \text{ dB}$$

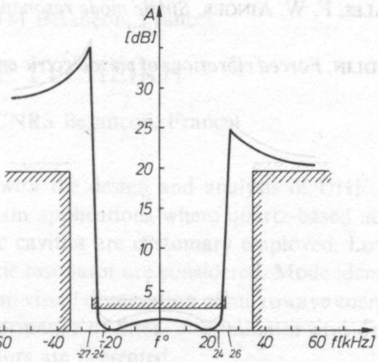

FIG. 6. Response of two-pole $LiTaO_3$ filter

4. Conclusions

The quartz filter design programme was adapted for $LiTaO_3$ $Y163°$-cut; it is good to design filters with any values of input electrical parameters.

Electrode deposition was made using photolitography. The dimensions of the electrode were obtained with 2 μ precision, but alignment was not too good; there was a difference between the calculated and experimental bandwith.

We used $LiTaO_3$ plates with a 8.2 mm diameter lapped with 3 μ abrasive powder, but to reduce the inband insertion loss it is necessary to use the polished crystal blanks.

Starting from the first two-pole filter, we proposed to design design and to make experimentally eight-pole lithium tantalate filters with a higher frequency overtone function and a wider bandwith.

We hope to obtain better agreement between theoretical and experimental resultas.

References

[1] M. C. HALES, T. W. BURGESS, *Design and construction of monolithic crystal filters using lithium tantalate*, Proc. of IEE, **123**, p. 657 (1976).

[2] B. GNIEWIŃSKA, CZ. KLIMEK, W. SOLUCH, *Rezonatory i generatory kwarcowe.*

[3] T. W. BURGESS, M. C. HALES, *Temperature coefficient of frequency in* $LiNbO_3$ *and* $LiTAO_3$ *plate resonators*, Proc. of IEE, **123**, p. 499 (1976).

[4] R. T. SMITH, F. S. WELSH, *Temperature dependence of the elastic, piezoelectric and dielectric constants of lithium tantalate and lithium niobate*, J. Appl. Phys., p. 2219 (1976).

[5] I. MATEESCU, *Filtre monolit cu cuart*, Teza de doctorat (1987).

[6] T. W. BURGESS, M. C. HALES, R. T. PORTER, *Equivalent circuit parameters for* $LiTaO_3$ *plate resonators*, Electr. Lett., **11**, p. 449, (1975).

[7] T. W. BURGESS, M. C. HALES, F. W. AINGER, *Single mode resonance in* $LiNbO_3$ *for filter design*, Electr. Lett., **9**, 251 (1973).

[8] H. F. TIERSTEN, R. D. MINDLIN, *Forced vibrations of piezoelectric crystal plates*, Q. Appl. Math., **20**, p. 107 (1962).