Surface acoustic wave low insertion loss delay line for applications in sensors

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Abstract: It was shown that low insertion loss of a surface acoustic wave (SAW) delay line could be achieved when strong triple transit signals (TTS) are present. As an example, low insertion loss delay line on YZ $LiNbO_3$, was developed. Double electrodes were used in interdigital transducers (IDTs) and in a screen. At a frequency of 62 MHz, insertion loss of about 8 dB, was obtained. Low insertion loss and narrow bandwidth make this SAW delay line attractive for applications in physical and gas sensors.

Key words: delay line, insertion loss, $LiNbO_3$, surface acoustic wave (SAW)

Linia opóźniająca z akustyczną falą powierzchniową o małej tłumienności wtrącenia do zastosowań w czujnikach

Streszczenie: Wykazano, że mała tłumienność wtrącenia linii opóźniającej z akustyczną falą powierzchniową (AFP) jest możliwa do uzyskania, gdy występuje silny sygnał trzeciego echa (STE). Jako przykład, opracowana została linia opóźniająca na podłożu YZ $LiNbO_3$. W przetwornikach międzypalczastych i w ekranie zastosowano podwójne elektrody. Na częstotliwości 62 MHz uzyskano tłumienność wtrącenia około 8 dB. Mała tłumienność wtrącenia i wąskie pasmo czynią tę linię atrakcyjną do zastosowań w czujnikach fizycznych i gazowych.

Słowa kluczowe: linia opóźniająca, tłumienność wtrącenia, $LiNbO_3$, akustyczna fala powierzchniowa (AFP)

1. Introduction

Minimum insertion loss of a typical SAW delay line should be about 15 dB [1]. This condition is a result of a requirement that distortions of the amplitude response caused by the triple transit signals (TTS) should be sufficiently small. Therefore, in the case of high electromechanical coupling substrates, it is necessary to use a special structure of the interdigital transducers (IDTs) to satisfy the above condition and to obtain sufficiently narrow bandwidth for operation in an oscillator circuit. The purpose of this paper is to present calculated and measured results of a low insertion loss delay line with simple double electrode IDTs on the YZ $LiNbO_3$ substrate.

2. Transfer function of the delay line

The investigated delay line (Fig. 1) consists of two identical double electrode IDTs and a screen (Fig. 1). It is assumed that widths of electrodes and gaps are equal. Here p, W, l, d and L are the period of electrodes, aperture, length of IDT, length of screen and inductance, respectively. Transfer function T_{12} of a symmetrical delay line can be written as [2]:

$$T_{12} = \frac{tS_{13}^2}{1 - t^2 S_{11}^2}, \quad (1)$$

$$t = T_i \exp(-j\omega\,(l + d) / v. \quad (2)$$

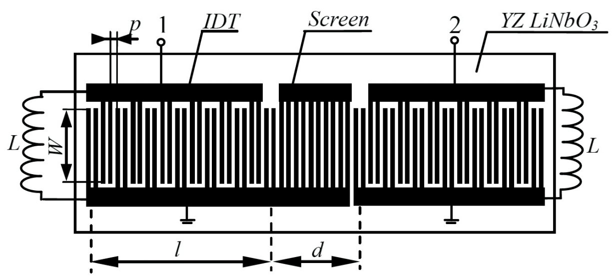

Fig. 1. Structure of SAW delay line.
Rys. 1. Struktura linii opóźniającej z AFP.

Here S_{11} and S_{13} are the scattering matrix coefficients of the IDT, T_i is the loss coefficient, ω is the angular frequency and v is the SAW velocity. S_{11} is the SAW reflection coefficient at the acoustic port, whereas S_{13} is the transfer coefficient between the acoustic and electrical ports of the IDT. These coefficients can be determined from the following expressions [3]:

$$S_{11} = \frac{G_t}{D}, \quad (3)$$

$$S_{13} = -j\,\frac{\sqrt{2G_l G_t}}{D}, \quad (4)$$

$$D = G_l + G_t + j(B_l + B_t + \omega C_0). \quad (5)$$

Here G_l, G_t and B_l, B_t are the real and imaginary parts of the load and IDT admittances, respectively, and C_0 is the static capacitance of the IDT [1, 4].

$$G_t = G_0 N_g^2 (\sin X / X)^2, \quad (6)$$

$$B_t = G_0 N_g^2 [\sin (2X) - 2X] / (2X^2), \quad (7)$$

$$G_0 = 2.443 f_0 W (\varepsilon_0 + \varepsilon_p) K^2, \quad (8)$$

$$C_0 = W (\varepsilon_0 + \varepsilon_p) / \sqrt{2}, \quad (9)$$

$$X = \pi N_g (f - f_0) / 2f_{0,} \quad (10)$$

$$\beta = \omega / v, \quad (11)$$

where N_g is the number of gaps with non-zero overlap in the IDT; l, d , and W are shown in Fig. 1, f_0 is the center frequency, ε_0 is the dielectric constant of the vacuum, ε_p is the effective dielectric constant of the piezoelectric substrate, K^2 is the square of the electromechanical coupling coefficient, ω is the angular frequency and v is the SAW velocity in the area of periodical electrodes.

Velocity v can be determined from the expression [1]:

$$v = v_f / [1 + 0.85 (v_f - v_m) / v_m], \quad (12)$$

where v_f and v_m are the SAW velocities for free and metalized surface, respectively.

Expression (1) can be written in the form:

$$T_{12} = |T_{12}| \exp (j\Phi), \quad (13)$$

where $|T_{12}|$ is the ratio of amplitudes and Φ is the phase angle.

Insertion loss IL is defined as:

$$IL = -20 \log |T_{12}|. \quad (14)$$

3. Calculation and measurement results

The following SAW data were used for the calculations [5]: $v_f \cong 3494$ m/s, $v_m \cong 3415$ m/s and $K^2 \cong 4.5\%$. It was found that $v \cong 3427$ m/s.

After preliminary calculations ($T_i = 1$), the following data were chosen for the delay line (Fig. 1): SAW wavelength $\lambda = 55.2$ μm, period of electrodes $p = 13.8$ μm, aperture $W = 1.5$ mm, number of the screen electrodes $N_S = 100$ and number of the IDT electrodes $N_T = 302$. It was found that to eliminate an asymmetry of the amplitude response, the static capacitance of the IDT should be compensated by using a parallel inductor coil of about 100 nH. Aluminum layer of about 0.25 μm thick was used for fabrication of the delay line electrodes.

The measured and calculated amplitude responses of the delay line, without inductors, are shown in Fig. 2.

Network Analyzer type 8753ET (Agilent Technologies Inc., Santa Clara, CA), was used for the measurements. The calculated response was obtained for the above SAW parameters of YZ $LiNbO_3$ and for the loss coefficient $T_i = 0.926$, determined by matching the measured and calculated insertion loss at the center frequency (Marker 1). Strong oscillations, caused by the SAW reflections from the IDTs, are seen inside the pass band of the delay line. The asymmetry of the transfer function is caused by the static capacitance and is removed when 100 nH inductors are connected in parallel to the IDTs (Fig. 3).

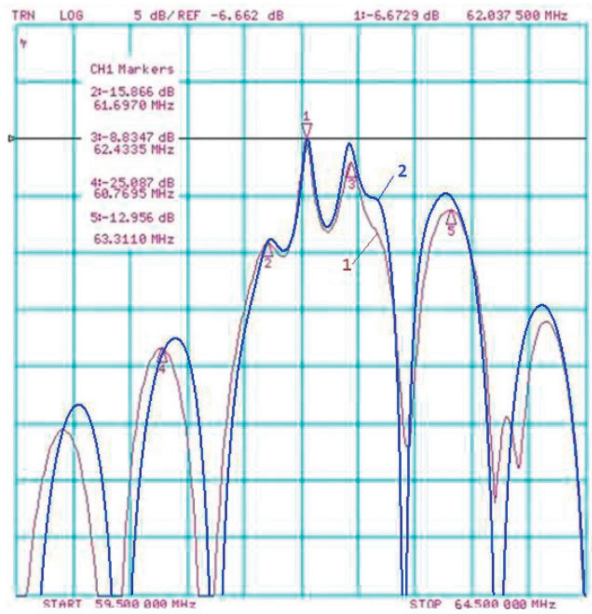

Fig. 2. Measured (1) and calculated (2) transfer functions of the delay line without inductors.

Rys. 2. Zmierzona (1) i obliczona (2) funkcja transmisji linii opóźniającej bez cewek.

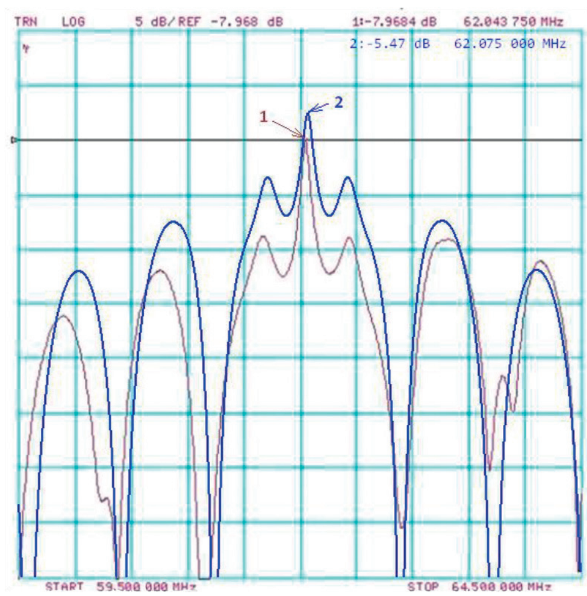

Fig. 3. Measured (1) and calculated (2) transfer functions with inductors.

Rys. 3. Zmierzona (1) i obliczona (2) funkcja transmisji linii opóźniającej z cewkami.

Differences between the measured and calculated amplitude responses without inductors (Fig. 2) are caused by such second order effects as ohmic losses and inductances of bonding wires used in the mounted device. These effects are especially important in the low loss delay lines because of high conductivity of the IDTs. However, because the main two peaks (markers 1 and 3) have opposite phases, this delay line can be used in an oscillator circuit without the inductors.

Difference of about 2.5 dB exists between the measured (1) and calculated (2) insertion loss with inductors (Fig. 3). This difference is probably caused by some additional second order effects introduced by the inductors. Nevertheless, an experimental insertion loss of about 8 dB was obtained.

4. Conclusions

SAW low insertion loss delay line on YZ $LiNbO_3$ was designed, fabricated and measured. It was shown that for high electromechanical coupling substrates and for sufficiently large number of the IDTs electrodes, strong resonances exist and low insertion loss of the delay line is possible. For low piezoelectric coupling substrates, additional LC circuit components should be used for matching the low conductance of the IDT to the high conductance of the load. Low insertion loss and narrow bandwidth make this SAW delay line attractive for applications in physical and gas sensors.

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