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The theory of asymmetrical delay line with the surface acoustic wave for non-electric sensors

Abstract. *In the paper, which deals with the surface acoustic waves, is given the theory of synthesis of the asymmetrical delay line with the interdigital transducer with diluted electrodes. Based on derived theory, an experimentally verified delay line for use in the identification system, filters and resonators based on SAW for further specific applications has been designed.*

Streszczenie. *W niniejszej publikacji dotyczącej powierzchniowych fal akustycznych znajduje się opracowana teoria syntezy nieproporcjonalnej linii opóźniającej z przetwornikiem międzypalcowym z rozcieńczonymi elektrodami. W oparciu o teorię pochodną opracowano i przetestowano eksperymentalnie specyficzne elementy akustoelektroniczne do różnych zastosowań.* ***Teoria syntezy nieproporcjonalnej linii opóźniającej z przetwornikiem powierzchniowej fali akustycznej***

Keywords: delay line, diluted electrodes, surface acoustic wave, interdigital transducers, resonators.
Słowa kluczowe: opóźnienia, rozcieńczone elektrody, powierzchniowa fala akustyczna, przetworniki międzypaliczkowe, rezonatory.

Introduction

Among the perspective acoustoelectronic components with the surface acoustic waves (SAW) there are in addition to the bandpass filters also delay lines (DL) and resonators, which are used as selective elements of oscillators with harmonic oscillations. The main advantage is their small size and low weight, high mechanical strength, low sensitivity to vibration as well as the possibility to make the oscillators without the use of inductor. This is what guarantees their manufacturing perspective and wide range of use in measuring of electric and non-electric variables, in radio electronics, telecommunications, and introduces the necessity of elaboration of questions concerning to their theory and manufacturing.

In the present paper it is elaborated the theory of an asymmetrical delay line with interdigital transducer (IDT) with diluted electrodes.

Synthesis of Asymmetrical Delay Line

An asymmetrical delay line has input IDT with a small number of electrodes (i.e. broadband), and output IDT with a large number of electrodes (i.e. narrowband). Module characteristic can be close to the synchronous frequency sufficiently accurately approximated by the function of sinx/x where $x = N\pi(f-f_0)/f_0$ When increasing the number of electrodes IDT however, there is a strong signal caused by reflections from the edges of the electrodes, which substantially impairs the delay line properties and at the same time of the whole oscillator [1[. To suppress the signal we partly remove in the narrowband IDT the electrodes (i.e. "*diluted*" - divided into groups IDT). A similar problem arises in the synthesis of the filter with a narrow and very narrow pass band $\Delta f_3/f_0$ = 0,1 to 0,5 % (n. On the contrary, the methods of synthesis of filters with SAW are accurate at a relatively wide pass band f_3/f_0 = 1 to 30 %).

Frequency and Time Characteristics of the Individual Groups of Electrodes in IDT with Diluted Electrodes

The diluted IDT refers only to the periodic removal of the same groups of electrodes of IDT (Fig. 1a). If there is a change of the period or distance of groups and also the number, overlap, step, width or other parameter of electrodes of the retained groups according to a certain law, which differs from this accepted in the original IDT, then we are talking about so-called weighing of electrodes and it need to be examined separately.

In the general case, the impulse characteristic of diluted IDT, if we do not consider the discretization in the process of sampling time, can be expressed in the form of the sum of the impulse characteristics $h_m(t - t_m)$ shifted each other on the period of T_r (Fig.1b), i.e.

(1) $$h_r(t) = \sum_{m=1}^{M} h_m(t - t_m),$$

where $h_m(t - t_m)$ is a function, which describes the pulse characteristic of a group, consisting of N_i pairs of unsplit electrodes with the length T_i, m is a group number, M is the number of groups and $t_m = mT_r$.

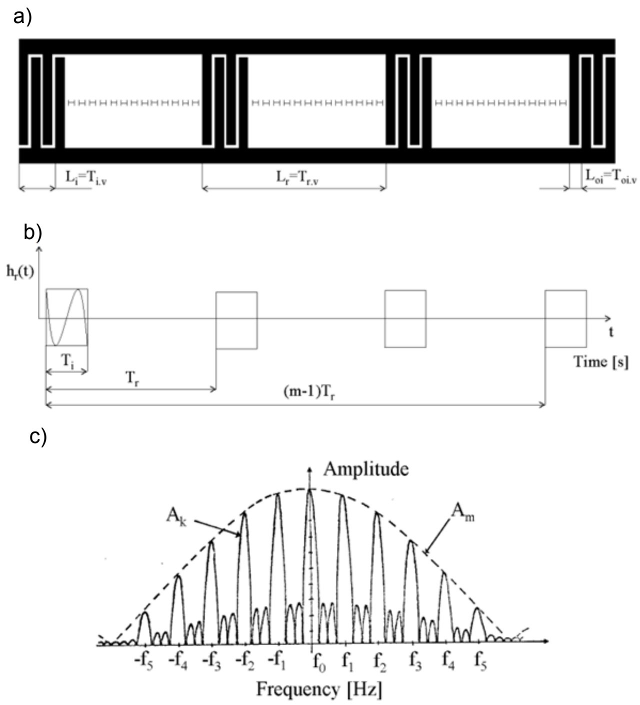


Fig.1. IDT with periodically diluted electrodes

In the periodic dilution by removing of electrodes within the length of the whole transducer, the phase shift of each group in the synchronous frequency is ωo times π and the initial phase of m - th group, $\Theta_{mn}(\omega_0) = \omega_0.T_m = \omega_0.(m-1).T_r = \pi.(m-1).N_r.N_i$, where $T_m = (m-1).T_{0i}.N_i.r$, is the time co-ordinate of the edge of m - th group with the respect to the edge of transducer, $N_r = N_i.r$ is the number of electrode pairs attributable to the spatial period L_r (Fig. 2a), $T_{oi} = 0.5\, f_{0i}$ is the period of location of the unsplit electrodes of i - th group.

Let us examine the characteristics of one of non - apodized group with equidistant distribution of electrodes (elaborated in ref. [2]).

Transmission Properties of Diluted IDT over a Wide Frequency Range

For the non - apodized equidistant IDT, which consists of M same groups symmetrical relative to the centre, is $\Theta_{mn}(\omega) = 2\pi$ and equation can be simplified to the form

$$H_{mr} = A_m(\Omega)\sin\left(\frac{\pi\omega}{2\omega_0}\right)\left[\begin{matrix}1+e^{-j\Omega T^r}+e^{-j2\Omega T^r}+... \\ +e^{-j(m-1)\Omega T_r}+e^{-j(M-1)\Omega T_r}\end{matrix}\right] = \tag{2}$$

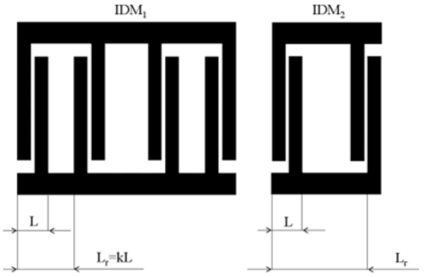
$$= A_m(\Omega)\sin\left(\frac{\pi\omega}{2\omega_0}\right)\sum_{m-1}^{M} e^{-j(m-1)\Omega T_r}$$

The analysis will come to a conclusion, the module characteristic of the diluted IDT (Fig. 1c) has in addition to a basic pass band at frequency f_0, partial pass - bands at frequencies $\pm f_k$, with “the step” f_r, which is inversely proportional to the spatial period L_r. The size of partial module characteristics $A_k(f)$ vary depending on the module characteristic of group $A_m(f)$.

The use of Diluted Interdigital Transducers

Diluted IDT can be used for the construction of narrow - band filters with comb - like frequency response. In that case it is advantageous to use narrowband IDT_1 with diluted electrodes and broadband IDT_2. In accordance with equation (1) the transfer function of the filter will have a range of narrowband partial passbands caused by dilution of electrodes of IDT_1]4], [5].

a)



b)

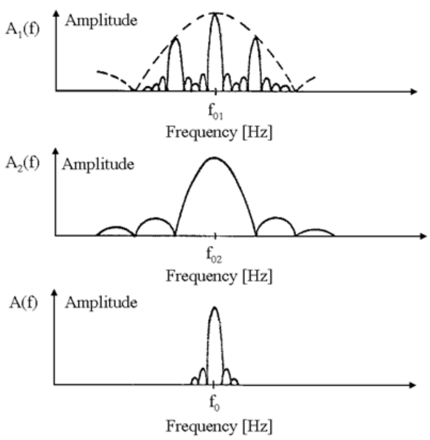
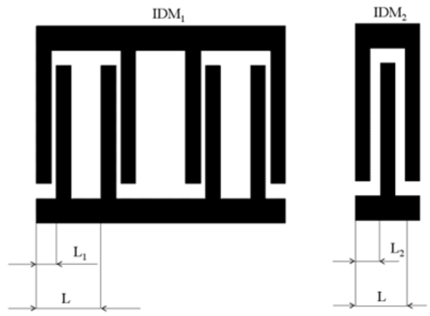


Fig. 2. IDT with diluted electrodes

As in the first and in the second case, all the pass bands of the diluted IDT_1 (except the pass band at the frequency f_k) are considerably suppressed. Therefore, in the resulting module characteristic of the filter, there is only one pass band at the frequency $f_k = f_0 \pm k.f_0 = f_{02}$ (Fig. 3b).

a)



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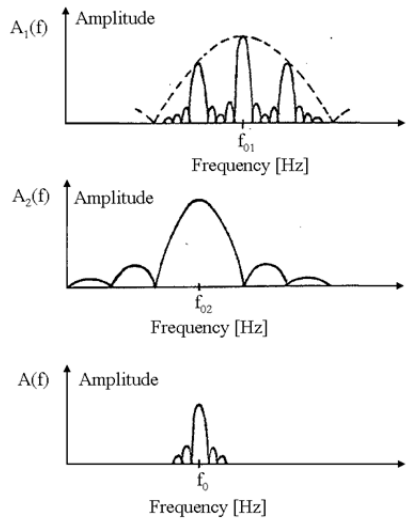
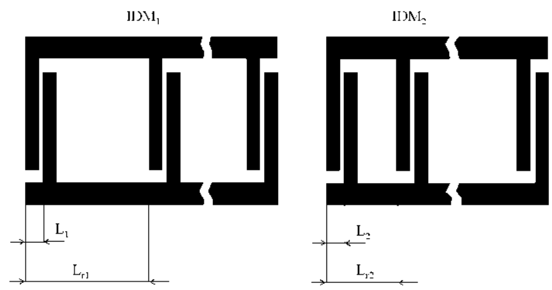


Fig.3. IDT with diluted electrodes

a)



b)

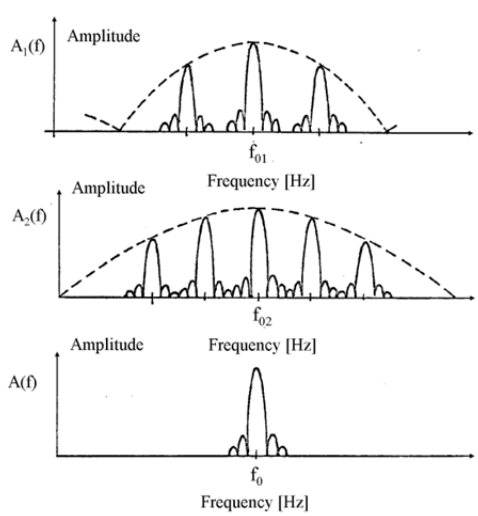


Fig. 4. IDT with diluted electrodes

Even narrower pass band $\Delta f_3/f_0$ = *0, 1 - 0, 2 %* can be realized using two diluted IDT (Fig. 4a). In this case are also possible two variants of the construction of narrow - band filters. In this case are also possible two variants of the construction of narrow - band filters. In the first variant are the synchronous frequencies of both diluted IDT (or spatial periods of electrodes) the same, i.e. $f_{01} = f_{02}$ a $L_1 = L_2$ and for the spatial periods of groups applies the relation

$$\frac{L_{ri}}{L_{r2}} = \frac{f_{r2}}{f_{r1}} = \frac{T_{r1}}{T_{r2}} = \frac{k}{l} \tag{3}$$

When this condition is met, partial pass bands of IDT_1 at the frequency $f_k = f_{01} \pm k.f_{r1}$ identify with partial pass bands of IDT_2 at the frequency $f_1 = f_{02} \pm l.f_{r2}$ and in the resulting module characteristic of filter there is only one pass band at the frequency $f_0 = f_k = f_1$ (Fig. 4b).

In the second variant, the spatial periods L_1 and L_2 are different (Fig. .5a), i.e. $L_1 > L_2$ or $L_1 < L_2$ and the spatial period of groups of the first L_{r1} and second L_{r2} of IDT are an integer multiple of the wavelengths λ_1 and λ_2, corresponding to the synchronous frequencies f_{01} and f_{02} of these transducers and they are determined from the relation

$$\frac{L_{ri}}{L_{r2}} = \frac{L_{r1}\left(1/L_1 - 1/L_2\right)}{2l + k/l} \tag{4}$$

where k and l are integers.

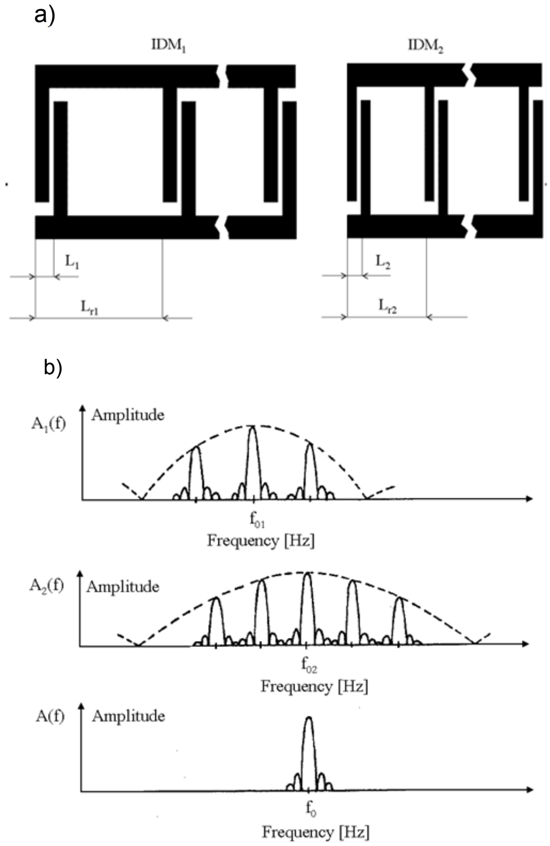


Fig. 5. The two diluted IDT

As in the first ($L_1 > L_2$) and in the second ($L_1 < L_2$) case, all the not identified partial pass bands are significantly suppressed and in the resulting module characteristic of the filter there is only one desired pass band for a synchronous frequency $f_0 = f_k = f_1$ (Fig. 5b).

In these constructions of narrow - band filters with two diluted IDT the working range of filters can be extended. In the lower part to the values of 0.5 to 1 MHz and less, by using "low - frequency" partial pass bands and in the upper area to the values of 500 to 600 MHz by using "high - frequency" partial pass bands, without increasing the dimensions of the filter and at the same time without increasing the requirements for the resolution of photolithography.

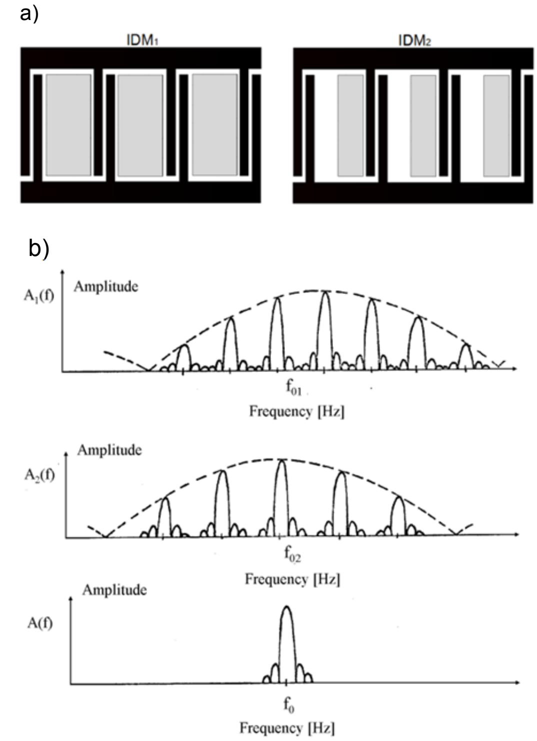


Fig.6. Diluted IDM with metal strip

Construction of diluted IDT´s enables in an easy way to retune the filter to a variety of synchronous frequencies. If into the gaps between individual groups of diluted IDT´s are placed the metal strips (Fig. 6a), by the change of the width of these strips we can change the speed of the propagation of SAW in IDT and thus move the partial pass band of one or other IDT, left or right. At a certain speed of SAW there will be identification of some partial pass bands so we can change synchronous frequency of the filter (Fig. 6b). The indicated design allows for example using one photomask make a variety of different filters with different synchronous frequencies. (Change of the width of the metal strip can be realized e.g. by the chemical etching, laser, etc.).

Experimental results

On the basis of previous theory have been designed, realized and experimentally verified a few filters and resonators for sensors of non - electrical quantities [5]. Here are example of realized filter (mentioned filter can be used e.g. for oscillator of common TV distribution, etc.).

Using Fourier transformation and weighing functions, a PLF 13 filter has been designed and implemented.

Required parameters PLF 13:

the synchronous frequency is 143,5 MHz,
the bandwidth to 3 dB is ± 14 MHz,
the group delay is T < 10 ns.

Selected substrate:

Y - cut, Z - the direction of propagation $LiNbO_3$.
The gap between the upper and lower electrode is 20 µm.

The filter contains IDT_1 with diluted electrodes and broadband IDT_2 with the same spatial period ($L_1 = L_2$).

Diluted IDT_1 has: 42,5 groups made up of one pair of electrodes, i.e. 85 electrodes. Broadband IDT_2 has: 11 electrodes, i.e. 5,5 pairs. The spatial period: $L = \lambda/2 = 8$ µm, period of dilution: $L_r = 2500$ µm. Aperture*:* $w = 2300$ µm. Synchronous frequency of the filter $f_0 = 143{,}5$ MHz, the inserted damping: $b_d = 12$ dB, quality factor: $Q = 650$. The design drawing of realized filter is shown on the Fig. 7.

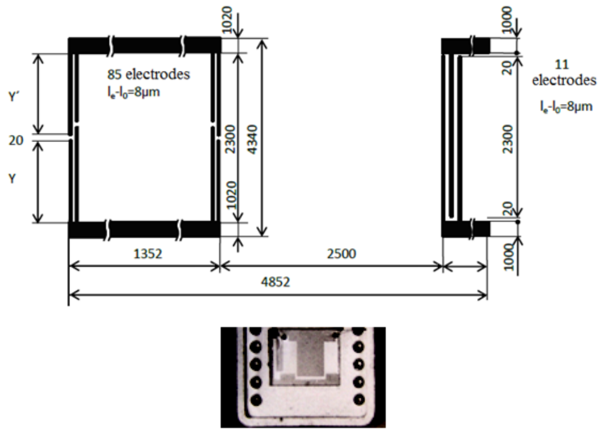


Fig.7. The desing drawing of realized filter

For a temperature sensor has been designed (Fig. 8a) and realized (Fig. 8b) one – port resonator with the electrically short – circuiting reflector system array.

Required parameters PLR 40:
IDM: N = 10 electrode, $l_e = l_0 = 11$ µm
Reflection system: N = 400 electrode, $l_e = l_0 = 6$ µm
Selected substrate:
Y – cut, Z – the direction of propagation $LiNbO_3$, thickness of the pad 0,5 mm.

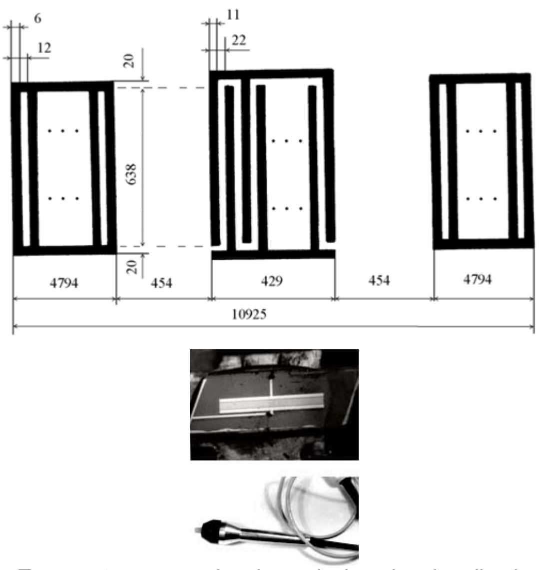


Fig.8. Temperature sensor has been designed and realized

Further applications of processed theory possibilities applications were in the case of design and realization of delaying lines in PAV also in the case of implementation other acoustoelectric components for non-electric quantities sensors that can be used in the diagnostics of electrical machines [3].

In the framework of the transformer status monitoring by using sensors technique and optimization of the transformer status it is concerned the proposed set of diagnostic procedures and measuring equipment for the effectively detection of the of transformers particular parts status (e.g. bushing, windings, insulators parts) using suitable sensors (e.g. temperature, humidity, piezoelectric, etc. but also in other application possibilities in automotive technology, etc.).

Conclusions

The aim of this publication is to design a procedure for the synthesis of IDT with diluted electrodes.

Based on the elaborated theory, design, implementation, measurements at the experimental samples and long term analysis of the obtained results may be stated that in this work are presented such applications, each of which is prospective and has potential use in practice.

Here are only some of the proposed and experimentally verified acoustoelectronic components with SAW.

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