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REGULAR ARTICLE

Frequency-Tunable Acousto-Electronic Devices

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The article describes an original design principle of a frequency-tunable acousto-electronic device based on Rayleigh surface acoustic waves (SAW). Basic information regarding the physical, structural, and technological features of surface acoustic wave devices underlying their construction principle is briefly present-ed. The paper demonstrates the broad application possibilities of acousto-electronic devices in various fields of science and engineering, primarily in instrument making, achieved due to high-performance parameters, stability, low weight and dimensions, high manufacturability, and ease of integration with microprocessor technology. The latter is crucial from the perspective of device intellectualization, which is particularly important for their implementation in high-level information technology systems. Recently, active acousto-electronics has seen significant growth, with considerable attention focused on frequency-tunable devices. This interest is driven, among other factors, by the need for rapid system reconfiguration in unmanned aerial vehicles (UAVs). The article examines several developments of SAW acousto-electronic devices within this category. Research results for an original frequency-tunable SAW device solution are presented and com-pared with existing analogs. A wide-range frequency tuning exceeding 10 % was achieved, which is unprece-dented compared to known solutions. Data on effective structural and technological design solutions of the device are provided. Opportunities for practical application in electronic systems, including special-purpose applications, are outlined.

Keywords: Acousto-electronics, Surface acoustic waves, Frequency tuning

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1. INTRODUCTION

The relevance of frequency-tunable electronic devices has consistently remained high. This issue has become particularly acute recently, driven by developments in various types of technical devices and systems required to enhance rapidly advancing modern weaponry—specifically regarding the prompt tuning of operating frequencies over the widest possible range.

This article presents microelectronic devices with tunable operating frequencies featuring different operating principles and structural-technological solutions (STS). The results achieved across various developments are compared based on their main characteristics and structural-technological designs.

2. BRIEF BACKGROUND ON ACOUSTO-ELECTRONIC DEVICES

The physics of acousto-electronic phenomena and effects, particularly those based on surface acoustic waves (SAW), is extensively documented in the literature [1-5]. The underlying principle involves the effects occurring during the excitation of SAWs by an interdigital transducer (IDT), their propagation through a piezoelectric acoustic substrate (acoustic waveguide), and their detection by an output IDT.

SAW devices are characterized by small dimensions, high precision and stability of parameters, low power consumption, and high manufacturability based on core technological operations well-established in microcircuit technology, as well as seamless interfacing with computers.

Such devices hold great promise for broad application in sensors for various functional purposes with static characteristics, including displacement, pressure and force, temperature, and gas sensors, among others [6]. Classified by the immutability of their functional characteristics, they all belong to the category of passive acousto-electronic devices.

Recent studies have shown that a fuller realization of the vast potential of acousto-electronics lies in the creation of devices with controllable characteristics. This constitutes a distinct category of active acousto-electronics.

To control the characteristics of an acousto-electronic device, effects resulting from the interaction of acoustic waves with various physical fields—such as electromagnetic, mechanical, thermal, and optical—can be utilized.

3. RESEARCH RESULTS AND DISCUSSION

We have proposed, investigated, and applied the angular dependence of the phase velocity of Rayleigh surface acoustic waves in anisotropic piezoelectrics to design SAW devices with controllable characteristics [7].

This paper presents the development and evaluation of a SAW device featuring an extended frequency tuning range. Such a device can serve as a building block for

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various functional units, including filters, oscillators, sensors, and related components. This approach is particularly relevant given the urgent requirement for operating frequency reconfiguration across diverse UAV systems. Compared to other existing developments [8-10], our solution offers significant advantages, primarily regarding the frequency tuning range.

In [8], frequency tuning is achieved by varying the DC voltage across the control electrodes of the SAW device within a few hundredths of a percent. Furthermore, the design of this device is quite complex: in addition to one input and two output IDTs, it incorporates a multistrip coupler with electrodes applied on both sides, requiring an additional power source for the high control voltage. Moreover, localizing the controlling electric field within an extremely small area of the acoustic waveguide poses a distinct, non-trivial engineering challenge. In [9], tuning is accomplished via an optical method; however, the tuning range remains too narrow for practical applications. Additionally, this device exhibits notable structural and technological drawbacks: the optically controlled design incorporates numerous precision elements, demands intricate assembly, and consumes considerable auxiliary electrical power.

A significantly better outcome compared to these and other counterparts is achieved by the method in [10], applied in a frequency-tunable SAW device. In this configuration, tuning is realized by altering the cut-plane orientation of a single-crystal piezoelectric acoustic waveguide (substrate) relative to the axis of an IDT system deposited on a dielectric plate. The resulting shift in operating frequency stems from the dependence of the SAW phase velocity on the angle between the IDT system axis and the crystallographic axis of the single-crystal piezoelectric waveguide.

This tuning method yields a substantially broader operating frequency adjustment range, reaching up to 5%. Importantly, this approach utilizes only one half of the SAW phase velocity angular dependence curve during tuning (Fig. 1, left portion of the characteristic curve—L).

To further expand the operating frequency tuning range, we proposed utilizing both portions of the dependence curve—the left and right sides (L and R) of the SAW angular characteristic [11].

In the proposed SAW device (Fig. 2)—comprising a single-crystal piezoelectric acoustic waveguide and a dielectric plate carrying a two-IDT system—the full angular dependence curve of the SAW phase velocity in the waveguide (Fig. 1, L+R) is utilized. This is implemented by altering the relative alignment (rotation) of the main device components and introducing an additional IDT system, an optoelectronic pair (LED–photodiode), and a switching opaque shutter attached to the piezoelectric waveguide to ensure a smooth transition from the left portion of the characteristic curve to the right. The optoelectronic pair is mounted on the same base as the dielectric plate carrying the IDT systems, aligned such that its optical center lies along the central axis of the second IDT system. The shutter is secured to the piezoelectric waveguide with its edge aligned with the waveguide's crystallographic axis (Fig. 2).

The device operates as follows: when an AC electrical signal is applied to the input IDT, an alternating electric field is generated across the air gap between the IDT and the waveguide, contactless-exciting a surface acoustic wave in the substrate. The wave propagates through the acoustic waveguide to the output IDT, where it is converted back into an electrical signal via the inverse piezoelectric effect.

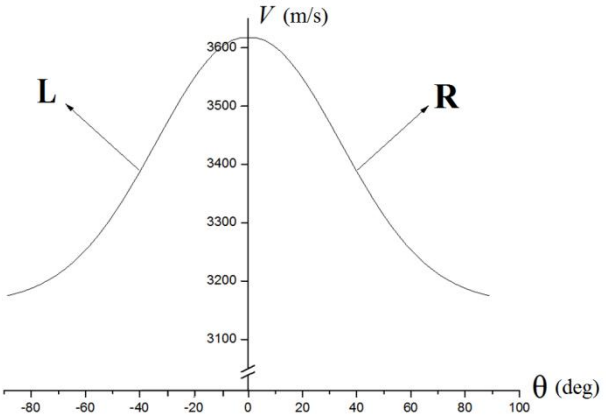


Fig. 1 – Plot of the Rayleigh SAW phase velocity as a function of the angle between the wave vector and the crystallographic axis for *ST*-cut SiO_2

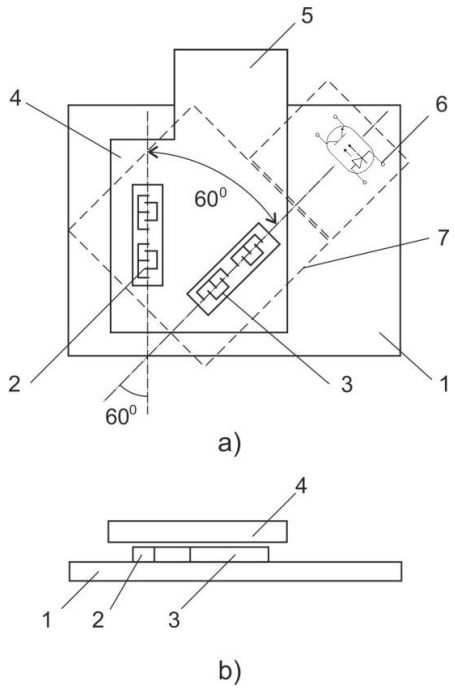


Fig. 2 – Block diagram of the device: 1 – board (substrate); 2 – IDT 1; 3 – IDT 2; 4 – piezoelectric acoustic waveguide; 5 – shutter; 6 – optocoupler; 7 – position of the acoustic waveguide after rotation

When rotating the piezoelectric waveguide, the resonant frequency of IDT 1 changes from f_{min1} to f_{max1}, and at a rotation angle matching the central axis of IDT 2, the resonant frequency of the IDT changes from f_{min2} to f_{max2}. Thus, frequency tuning is performed across the range from f_{min1} to f_{max2}.

The optoelectronic pair and the shutter serve to switch the signal received from IDT 1 to IDT 2 upon reaching the alignment along the piezoelectric waveguide axis, thereby ensuring continuous frequency

variation during the transition from the left portion of the angular dependence curve (Fig. 1L) to the right portion (Fig. 1R), which significantly expands the tuning range of the SAW device.

The operating frequency tuning range of this device exceeds 10%, which is significantly wider (~2 times) than that of the best known counterpart.

It should be noted that using *ST*-cut piezo-quartz as the piezoelectric acoustic waveguide also achieves high stability of the primary parameter, owing to the zero-temperature coefficient of frequency (TCF) of this material.

Such a frequency-tunable acousto-electronic device can be utilized in various radio frequency and electronic systems, including [12-13].

4. CONCLUSIONS

1. Rayleigh surface acoustic wave (SAW) acousto-electronic devices allow for a significant expansion of the frequency tuning range.

2. Such devices can serve as foundational building blocks for application in radio electronic devices and systems with diverse functional purposes.

3. Using *ST*-cut piezo-quartz SiO_2 as the piezoelectric acoustic waveguide in this device ensures high stability of the primary characteristic due to its zero TCF.

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Акустоелектронні пристрої з переналагоджуваною частотою

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У статті описано оригінальний принцип побудови електронного пристрою на поверхневих акустичних хвилях (ПАХ) Релея з переналагоджуваною робочою частотою. Коротко наведено основні відомості про фізичні і конструктивно-технологічні особливості акустоелектронних пристроїв на поверхневих акустичних хвилях, на яких базується принцип їх побудови. Показано широкі можливості застосування акустоелектронних пристроїв у різних галузях науки и техніки, в першу чергу в приладобудуванні, що базується на досягнутих високих параметрах основних характеристик, їх стабільності, малих масогабаритних параметрах, високій технологічності, легкості спряження з мікропроцесорною технікою. Останнє важливе з позицій інтелектуалізації пристроїв, що важливо при їх застосуванні в системах інформаційних технологій високого рівня. Особливого розвитку останнім часом набуває активна акустоелектроніка, в числі якої значна увага приділяється пристроям з переналагоджуваною частотою. Такий інтерес пов'язаний, зокрема, з необхідністю оперативно переналагоджувати відповідні системи в безпілотних літаючих апаратах. В статті розглянуті окремі розробки акустоелектронних пристроїв на ПАХ цього класу. Наведено результати досліджень оригінального рішення пристрою на ПАХ з переналагоджуваною робочою частотою, порівнюються з відомими аналогами. Досягнуто переналагоджування частоти в широкому діапазоні (понад 10%), що немає аналогів. Наводяться дані ефективних конструктивно-технологічних рішень пристрою. Вказані можливості практичного застосування в електронних системах, в тому числі спеціального призначення.

Keywords: Акустоелектроніка, Поверхневі акустичні хвилі, Переналагоджування частоти.