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OPTO-ULTRASONIC COMMUNICATION CHANNELS

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Introduction. Ultrasound is widely used in various applications, such as monitoring the state of structures, biomedical ultrasound imaging, and information (data) transmission. Ultrasonic transceivers are one of the modern communication systems, both for short-range and remote access. Indeed, the technology of the process of transmitting information using communication channels based on ultrasonic (US) vibrations and the physical implementation of transmission using optical fiber are widely used in conditions of confidentiality of data processing. At the same time, the needs of wireless and wired communication demanded the development of more advanced applications (software, hardware solutions). In particular, new challenges have arisen requiring transceivers to have high frequency, wide bandwidth and compact size. **Aim.** Consider the "technology – opto-ultrasonic" approach used in data transmission and reception channels. This technology involves the generation of ultrasound by a pulse using the optical-acoustic effect, followed by the reception and processing of ultrasonic vibrations. Optical ultrasonic transceivers based on the photo-acoustic (US) principle of operation have great potential, in particular, to obtain the necessary: (super high) frequency of the transmitted signal; wide bandwidth (speed); ease of use as transceivers; low manufacturing cost. **Materials and methods.** Various methods of spectral analysis (Fourier and Wavelet) have been investigated to ensure the achievement of the above goal. **Results.** Compared to traditional technologies of information reception and transmission, optical ultrasonic transceivers provide high-frequency communication, wide bandwidth and compact size. **Conclusion.** The paper investigates the methods of spectral analysis (Fourier and Wavelet) and proposes, based on these studies, possible options for the implementation of optical ultrasonic transceivers that can generate ultrasonic pulses with a duration on a nanosecond scale using an ultrafast laser and receive confidential data with a high degree of security. At the same time, by combining the principle of generating photo-acoustic ultrasound with the use of optical fiber, it is possible to obtain compact and inexpensive ultrasonic transceivers.

Keywords: ultrasound, receivers and transmitters (generation) of information, data, communication channels, fiber optic, bandwidth, technology, laser ultrasound, sensors, optical-acoustic effect.

Introduction

The development of wireless high-frequency communication technology has been going on for more than 10 years, but it has not received widespread use. The leaders of the mobile markets cannot agree on a single format for the near-field communication protocol: Apple ignores this direction, and manufacturers of phones with the Android platform, on the contrary, are promoting [1, 2]. Due to the fact that the emergence of a generally accepted standard for short-range communication is now questionable, data transmission via ultrasound could be a good alternative. The advantage of this method (method) is that, in contrast to NFC (near-field communication), data transmission via ultrasound can be carried out on almost any phone, since any phone is equipped with a speaker and a microphone [3, 4]. The only thing that is necessary is that the phone processor must be able to carry out the necessary calculations. This is due to the fact that the use of the proposed method does not impose specific requirements on the technical characteristics of the phone, but is implemented at the software level. Sound wave data can be used to exchange information between phones with a wide variety of operating systems, which is especially important in the current situation of increasing differentiation of mobile platforms. Ultrasound technology can be used not only for data transmission, but also for object recognition in space and suppression of physical carriers for undesirable information sources [5, 6]. The theory of wavelet transform is used to study the processes of processing an ultrasonic signal. Wavelet transform is a transform using functions localized both in real time and in Fourier frequency space. Basically, it is divided into two types. One type of wavelet transform is easily reversible. That is, the original signal can be recovered after being converted. For example, image compression and cleaning [7, 8]. The second type of wavelet transform is intended for signal analysis. For example, analysis and processing of ultrasonic signals. In this work, we propose a variant for implementing a communication channel with ultrasonic sensors, which combines the use of ultrasound and a method for creating optical pulses of a given duration. This improves the efficiency of information transfer compared to standard ultrasonic techniques, while providing reduced signal energy loss and maximum control over the waveforms of the ultrasonic transmitter and data receiver [9–12].

1. Statement of the problem

It is required to research and develop a new approach "opto-ultrasound" effective for use in data transmission and reception channels. This technology involves the generation of ultrasound by a pulse due to the optical-acoustic effect. Optical ultrasonic transceivers based on the photo-acoustic principle of operation have a great potential for obtaining a high frequency of the transmitted signal, a wide bandwidth (speed), ease of use as transmitters and a relatively low cost of implementation.

2. Solution of the problem. Methods and Approaches

2.1. Digital signal processing

Continuous signals are described by continuous functions of time. The instantaneous values of such signals change in time smoothly, without abrupt jumps (breaks). Many real signals are continuous. These include, for example, electrical signals in the transmission of speech, music and images [1, 4]. All signals are divided into four groups according to the way of presentation: analog, discrete, quantized and digital.

In order to start transmitting useful information using signals, it is necessary to modify the carrier frequency so that it repeats the patterns of the useful signal. This transformation is called modulation. Vibrations of various shapes (rectangular, triangular, etc.) can be used as a carrier. However, harmonic oscillations are most often used [12–14]. Depending on which of the parameters of the carrier oscillation changes, the following types of modulation are distinguished: amplitude, frequency, phase, etc. [10, 11]. Modulation with a discrete signal is called digital modulation or keying. The following types of keying are available: frequency shift keying, phase shift keying, amplitude shift keying, and quadrature amplitude shift keying. Fig. 1 shows the main characteristics of signals, spectra of modulated signals depending on the modulation parameters [13–15].

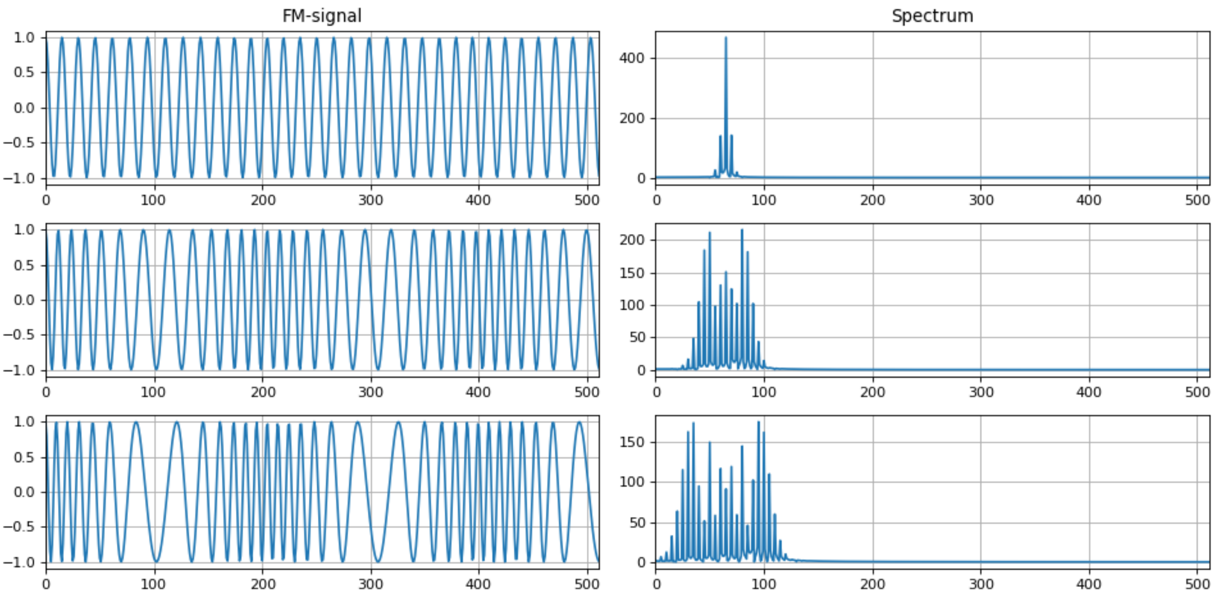

Fig. 1. Modulation of the signal and their spectrum

2.2. Wireless communication system using ultrasonic signals

This system includes a transmission module and a receiving module (Fig. 2). The transmission module receives input signals from the wireless device, modifies the received input signals so that it converts each received input signal into a corresponding ultrasonic signal, and wirelessly transmits each said ultrasonic signal through the ultrasonic channel [8, 9].

The receiving module (Fig. 2) receives the transmitted ultrasonic signals, reconstructs the corresponding input signals, and allows each corresponding input signal to be output through one or more output devices. Conversion of input signals can include compression, encoding, and modulation of input signals. The input signals can be voice audio signals allowing the use of a telephone call support system by proviлding ultrasonic communication capabilities. For example, communication between a wireless headset and a mobile phone. The transmit and receive modules can be linked to a wireless headset and a mobile phone to provide ultrasonic communication and, if necessary, radio frequency communication between them [2, 3].

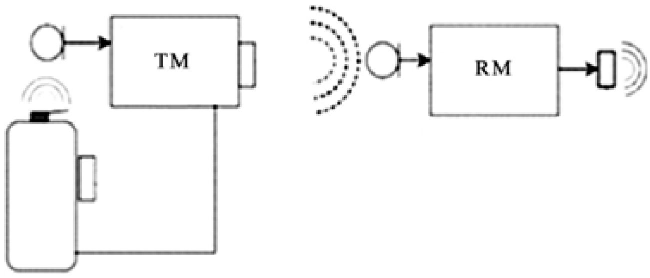

Fig. 2. Block diagram of a wireless communication system using ultrasonic signals: TM – transmission module, RM – receiving module

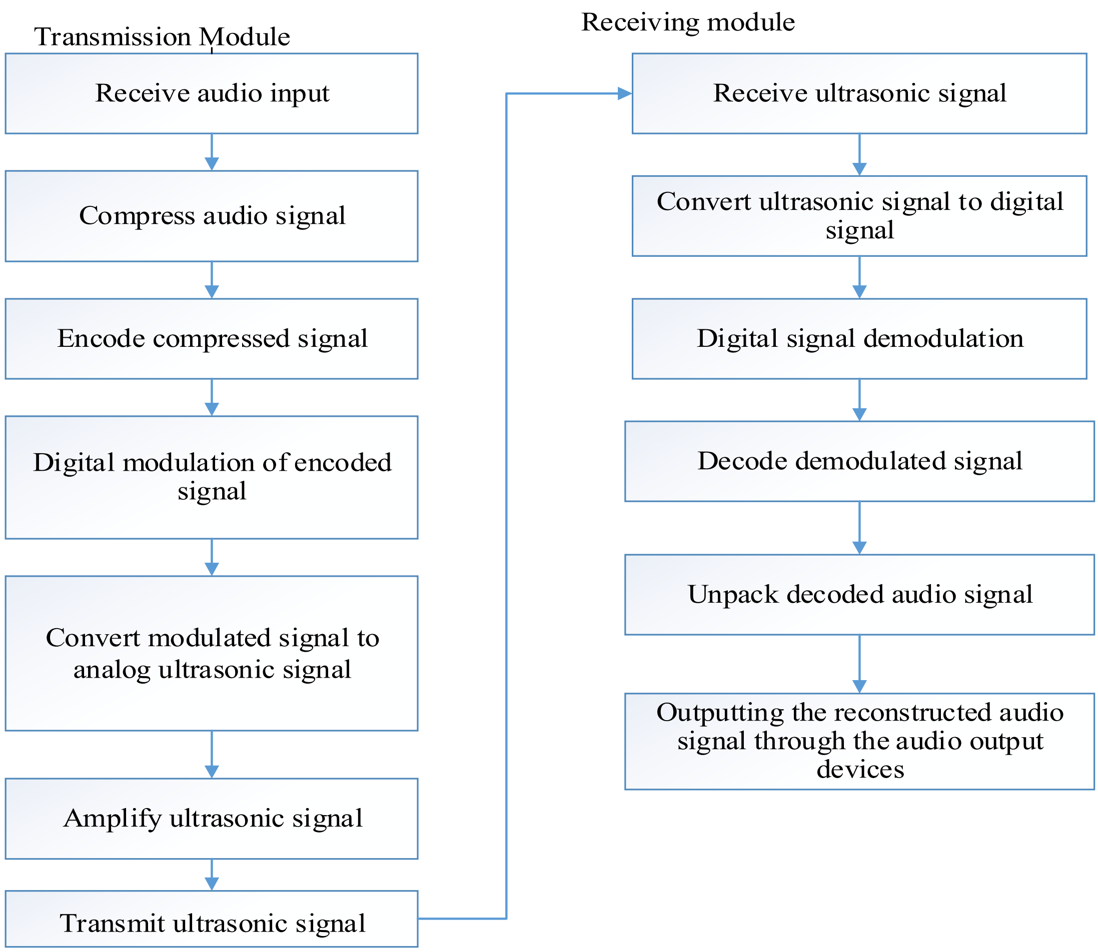

Fig. 3. Block diagram of the organization of the transmitting and receiving process of ultrasonic communication

In Fig. 3 is a block diagram based on ultrasonic communication (Fig. 2), schematically illustrating the process of ultrasonic communication between the transmitting module and the receiving module. According to this process, the transmitting module receives an input audio signal through one or more receivers, such as a microphone, and converts the received audio signal in accordance with one or more modification methods with different conditions, which ultimately result in a corresponding ultrasonic signal. As shown in Fig. 3, the modification can include: compressing the input audio signal, encoding the compressed signal, resulting in the encoded and compressed audio signal at this stage. The encoded audio signal can then be digitally modulated in accordance with one or more modulation techniques such as single-carrier and / or multi-carrier modulation, i.e. OFDMA or CDMA modulation. This stage will allow you to move on to the digital signal, which is the input audio signal. The digital signal can then be converted to an analog ultrasonic signal, which is fed to the transducer of the transmission module to enable the transmission of the ultrasonic signal. The transmission of ultrasonic signals may be accomplished, as indicated above, by one or more acoustic output devices that can output ultrasonic signals, such as speakers, piezoelectric devices, and the like. These devices can be included as part of the transmission module or be external to it (for example, a speaker of a wireless device associated with the transmission module). The ultrasonic analog signal can be amplified for transmission by the amplifier of the transmission module.

The transmitted ultrasonic signal can be received (detected) in the receiving module, which can then reconstruct the original input audio signal with an accuracy that depends on the quality and conditions of the communication, as well as on the components and configuration of the system. Reconstruction of the input audio signal can include as shown in Fig. 3, converting the ultrasonic analog signal to a digital signal, demodulating the digital signal according to the modulation techniques used to modulate the original input signal (for example, using FMDMA-reversed or CDMA-reversed). The resulting signal can be a recovered decoded and compressed audio signal, which can then be decoded and decompressed to thereby restore the original audio signal. The reconstructed audio signal can then be output using the built-in or separate audio output device such as speaker, headset, etc.

The article proposes a variant of the implementation of a communication channel with ultrasonic sensors, which combines the use of ultrasound and a method of creating optical pulses of a given duration. This improves communication efficiency over standard ultrasonic techniques, while providing reduced signal energy loss and maximum control over the waveforms of the ultrasonic transmitter and data receiver.

2.3. Description of the opto-ultrasonic transmitter and receiver system

The block diagram shown in Fig. 4 [16] illustrates the transmission of a stream of infrared and ultrasonic signals. Microcomputers control the operation of the system. Initially, an optical pulse is transmitted from an ultrasonic receiver. After receiving the optical pulse in another unit, the ultrasonic pulse is transmitted back to the receiver unit. The transmission time of the optical signal is negligible, so the microcontroller (on the receiving device) starts a timer when the optical signal is sent. Therefore, the timer value when the ultrasonic pulse is detected in the receiver is the transit time of the ultrasonic signal between the transducers. From this transmission time and speed of sound, the distance between the transducers can be calculated. This approach is limited to situations where transducers and associated electronics can be installed at both ends of the distance being measured [17–19].

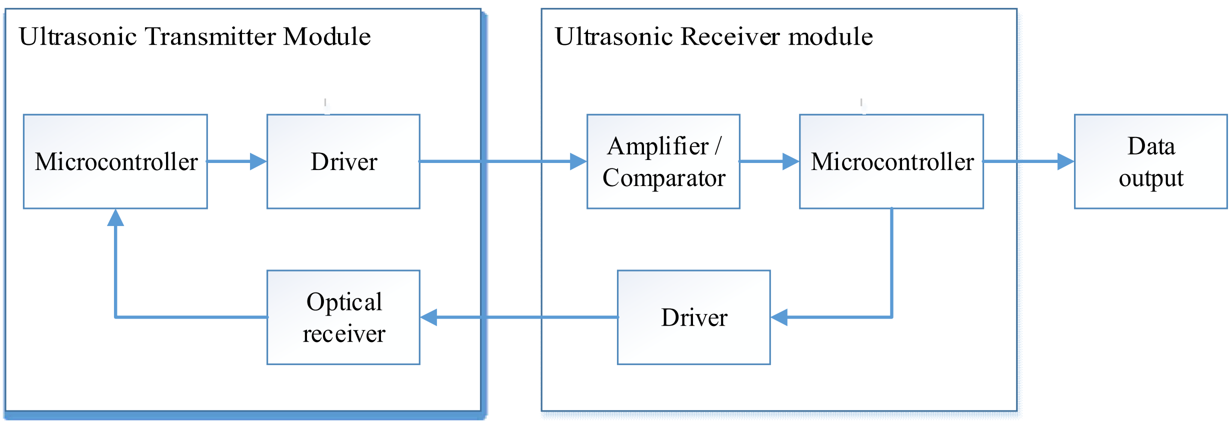

Fig. 4. Block diagram of the system

2.4. Optical description of the signal

An IR transmitter (infrared wavelength range of 870 nm) is an LED that is turned on (pulsed) by a transistor connected to a microcomputer [20, 21]. This pulse (0.5 ms) acts as a trigger signal. The lens built into the LED provides a 10 degree beam width.

The photodiode on the ultrasonic transmitter (IR receiver) is equipped with an IR cut filter to prevent accidental room illumination. Its current output is converted into a voltage pulse by an input amplifier. Subsequent amplifier stages increase the signal level and act as a high pass filter to further reduce low frequency noise. At the output of the comparator, the optical signal has the shape shown in Fig. 5 (the transmitted signal has a similar shape). The rising edge of the pulse is the synchronization signal.

Fig. 5. Received optical pulse

2.5. Transmission of an ultrasonic signal

Conventional ceramic piezoelectric transducers are used for both the transmitter and receiver. The tuned transducer rings (40 kHz) when excited by a single square-wave pulse (pulse). Due to the low damping, the transmitted wave sequence has a long exponential decay due to a single pulse or pulse. While the signal transmission rise time is different, there is no received signal.

The voltage waveform of the transmitter transmitter is shown in Fig. 6.

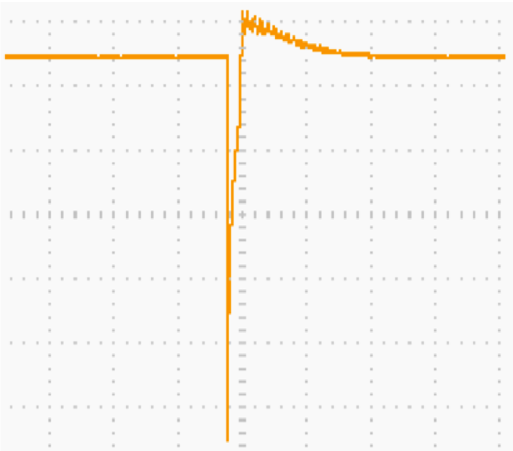

Fig. 6. Measuring form of the transmitter

2.6. Ultrasonic receiver (UR)

An UR with a high gain (×100) amplifies the signal from the receiving sensor, and the output is connected to a comparator, which, when the signal exceeds the threshold level, detects the received pulse (Fig. 7). The advantage is a faster rise time and a more accurate waveform, while the disadvantage is a much lower transmission amplitude than with conventional multi-cycle waveform excitation. This disadvantage is overcome here by using one-way transmission of the ultrasonic signal. If the transmitted waveform was not correctly formed by the second pulse, the transducer will ring excessively [14, 15].

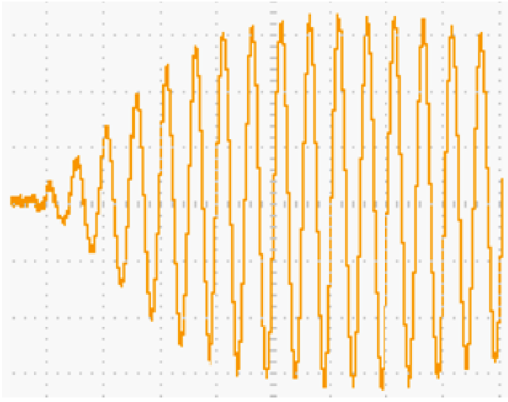

Fig. 7. Received ultrasonic signal

2.7. Microcomputer signal processing

The microcontroller (Fig. 8) detects the signal from the comparator and records the arrival time, which allows you to measure the time between the transmission of the optical pulse and the reception of the ultrasonic pulse. Knowing the speed of sound, the microcontroller converts this information into the distance between the ultrasonic transducers.

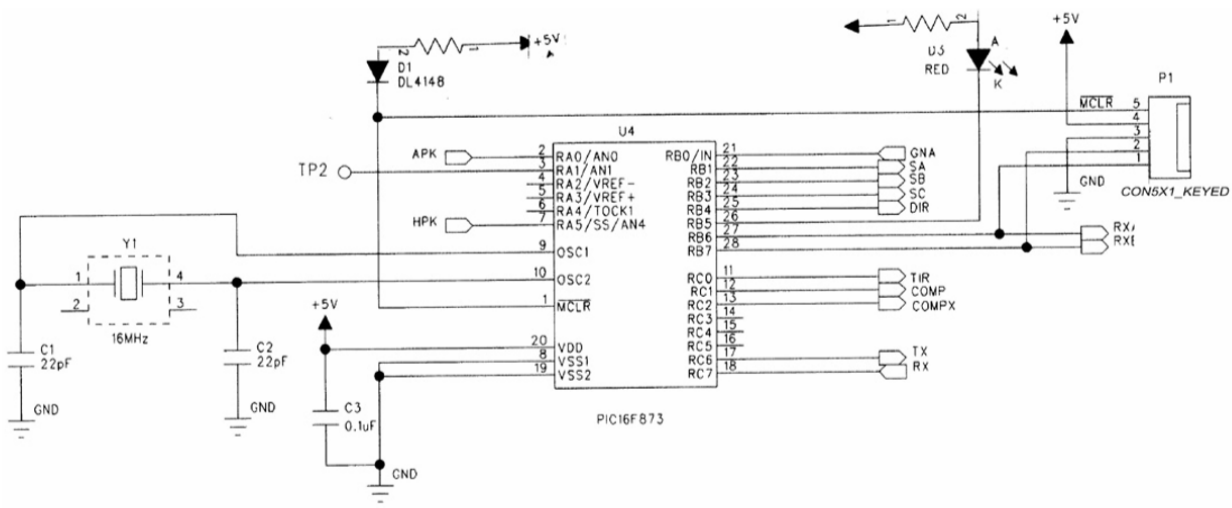

Fig. 8. Microcontroller circuit

Data is transferred to an external computer using the RS485 serial data bus.

Conclusion

In this work, optical ultrasonic transceivers have been investigated and developed, which can receive and generate ultrasonic pulses with a duration in the nanosecond range when using an ultrafast laser. As a result of the development of the opto-ultrasound technology, it can be noted that it is more efficient than the standard ultrasonic signal, providing with less signal loss and more accurate location of the reference points of the sensor, in particular, the transmitting and receiving transducers (sensors). In addition, by combining the principle of generating photo-acoustic ultrasound with optical fibers, compact ultrasonic transmitters can be obtained.

An optical pulse is used to synchronize the transmitter and receiver. In the block diagram shown in Fig. 4, an optical pulse is transmitted from the ultrasonic receiver unit, initiated by its microcontroller, to the ultrasonic transmitter unit. Thus, the proposed approach based on ultrasound signal transmission and reception using optics (fiber optics) allows obtaining the following advantages:

– the loss of an ultrasonic signal is much less than with traditional reception and transmission;
– the location of the transducers is clearly defined;
– the phase and shape of the pulses are controllable and reproducible.

References

1. Filonenko V., Cullen C., Carswell J. Investigating Ultrasonic Positioning on Mobile Phones. *International Conference on Indoor Positioning and Indoor Navigation (IPIN)*, 2010, pp. 15–17.

2. Marina M.D., Norziana J., Jacentha M. Indoor positioning: technology comparison analysis. *International Journal of Engineering & Technology*, 2018, no. 7, pp. 133–137.

3. Rosenthal A., Razansky D., Ntziachristos V. High-Sensitivity Compact Ultrasonic Detector Based on a Pi-Phase-Shifted Fiber Bragg Grating. *Opt. Lett*, 2011, no. 36, pp. 1833–1835.

4. Keda Y.K., Yoshihiro O., Hiroshi U. International standard of infrared data communication, IrDA. *Shapu Giho/Sharp Technical Journal*, 1997, no. 68, pp. 11–17.

5. Saidov B.B., Tambovtsev V.I., Prokopov I.I. Spectrum Transformation of an Amplitude-Modulated Signal on an Ohmic Nonlinear Element. *Bulletin of the South Ural State University. Ser. Computer Technologies, Automatic Control, Radio Electronics*, 2020, vol. 20, no. 1, pp. 71–78. DOI: 10.14529/ctcr200107

6. Brodie G., Qiu Y., Cochran S., Spalding G., MacDonald M. Optically Transparent Piezoelectric Transducer for Ultrasonic Particle Manipulation. *IEEE Trans. Ultrason. Ferroelectr. Freq. Control*, 2014, no. 61, pp. 389–391.

7. Qiu Y. Piezoelectric Micromachined Ultrasound Transducer (PMUT) Arrays for Integrated Sensing, Actuation and Imaging. *Sensors*, 2015, no. 15, pp. 8020–8041.

8. Nakrop J., Sodsai W., Prasit N., Atipong S. Security System against Asset Theft by Using Radio Frequency Identification Technology. *5Th International Conference on Electrical Engineering / Electronics, Computer, Telecommunications and Information Technology*, 2008, pp. 761–764.

9. Elfes A. Sonar-Based Real-World Mapping and Navigation. *IEEE J. Robot. Automat*, 1987, vol. 3, pp. 249–265.

10. Jarvis R.A. A Perspective on Range finding Techniques for Computer Vision. *IEEE Trans. Pattern Anal. Mach. Intell*, 1983, vol. 2, pp. 122–139.

11. Saad M.M., Bleakley C.J,. Dobson S. Robust High-Accuracy Ultrasonic Range Measurement System. *IEEE Trans. Instrum. Meas*, 2011, vol. 60, pp. 3334–3341.

12. Zhou Q., Lau S., Wu D., Shung K.K. Piezoelectric Films for High Frequency Ultrasonic Transducers in Biomedical Applications. *Prog. Mater Sci.*, 2011, no. 56, pp. 139–174.

13. Biagi E., Margheri F., Menichelli D. Efficient Laser Ultrasound Generation by Using Heavily Absorbing Films as Targets. *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control*, 2001, vol. 48, no. 6, pp. 1669–1680.

14. Wissmeyer G., Soliman D., Shnaiderman R., Rosenthal A., Ntziachristos V. All-Optical Optoacoustic Microscope Based on Wideband Pulse Interferometry. *Opt. Lett*, 2016, no. 41, pp. 1953–1956.

15. Taruttis A., Ntziachristos V. Advances in Real-Time Multispectral Optoacoustic Imaging and Its Applications. *Nat. Phot*, 2015, no. 9, pp. 219–227.

16. Ntziachristos V. Going Deeper than Microscopy: the Optical Imaging Frontier in Biology. *Nat. Methods*, 2010, no. 7, pp. 603–614.

17. Beard P. Biomedical Photo Acoustic Imaging. *Interface Focus*, 2011, no. 1, pp. 602–631.

18. Strohm E.M., Moore M.J., Kolios M.C. High Resolution Ultrasound and Photo Acoustic Imaging of Single Cells. *Photo Acoustics*, 2016, no. 4, pp. 36–42.

19. Darold W., Ming Z., Bhooma S. An Ultrasonic. *Optical Pulse Sensor for Precise Distance Measurements. Conference Paper*, 2005. pp. 1–5.

20. Hamilton J.D. High Frequency Optoacoustic Arrays Using Etalon Detection. *IEEE Trans. Ultrason. Ferroelectr. Freq. Control*, 2000, no. 47, pp. 160–169.

21. Aggelis D., Barkoula N., Matikas M., Paipetis, T.A. Acoustic Structural Health Monitoring of Composite Materials: Damage Identification and Evaluation in Cross Ply Laminates Using Acoustic Emission and Ultrasonics. *Compos. Sci. Technol*, 2012, no. 72, pp. 1127–1133.

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ОПТОУЛЬТРАЗВУКОВЫЕ КАНАЛЫ СВЯЗИ

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Введение. Ультразвук широко используется в различных приложениях, таких как мониторинг состояния конструкций, биомедицинская ультразвуковая визуализация, приемо-передача информации (данных). Ультразвуковые приемо-передатчики являются одной из современных систем коммуникации как на ближнем, так и удаленном доступе. Действительно, технология процесса передачи информации с помощью каналов связи на основе ультразвуковых (УЗ) колебаний и физической реализации передачи с помощью оптоволокна находят большое применение в условиях конфиденциальности обработки данных. При этом потребности беспроводной и проводной коммуникации потребовали разработку более совершенных приложений (программ, аппаратных решений). В частности, возникли новые проблемные вызовы, требующие, чтобы приемо-передатчики имели высокую частоту, широкую полосу пропускания и компактные размеры. **Цель исследования.** Рассмотреть подход «технология – оптоультразвук», применяемый в каналах приемо-передачи данных. Эта технология предполагает генерацию ультразвука импульсом с помощью оптико-акустического эффекта, с последующим приемом и обработкой УЗ-колебаний. Оптические ультразвуковые приемо-передатчики, основанные на фотоакустическом (УЗ) принципе действия, имеют большой потенциал, в частности, для получения необходимой (супервысокой) частоты передаваемого сигнала; широкой полосы пропускания (быстродействие); простоты использования в качестве приемо-передатчиков; не высокую стоимость изготовления. **Материалы и методы.** Были исследованы различные методы спектрального анализа (Фурье и Вейвлет), позволяющие обеспечить достижения поставленной выше цели. **Результаты.** По сравнению с традиционными технологиями приемо-передачи информации оптические ультразвуковые приемо-передатчики обеспечивают высокочастотную связь, широкую полосу пропускания и компактные размеры. **Заключение.** В работе исследованы методы спектрального анализа (Фурье и Вейвлет) и предложены на их основе возможные варианты реализации оптических ультразвуковых приемо-передатчиков, которые могут генерировать ультразвуковые импульсы с длительностью в масштабе наносекунд с помощью сверхбыстрого лазера и принимать с высокой степенью защищенности конфиденциальные данные. При этом комбинируя принцип генерации фотоакустического ультразвука с применением оптоволокна, можно получить компактные и недорогие ультразвуковые приемо-передатчики.

Ключевые слова: ультразвук, приемники и передатчики (генерация) информации, данные, каналы связи, оптоволокно, полоса пропускания, технология, лазерный ультразвук, датчики, оптико-акустический эффект.

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