Use of optical methods for detecting low frequency sounds

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Abstract – **This paper is a continuation of our studies related to the use of optical methods and optical communication fiber and wireless systems not only as a communication channel, but also as a network of sensors offering information. This type of information is generated by external influencing factors in the complex infrastructure of modern cities. One of these factors we have focused on is noise monitoring. This paper will consider an optical method based on wireless optical and fiber optic systems for monitoring and detecting low frequency sounds.**

Keywords – **optical, acoustic, sensor, smart cities, optical communications, LI Fi, audio, fibers.**

I. Introduction

Nowadays, the communication infrastructure of cities is becoming more and more complex, which gives rise to many applications of optical fiber networks, not only as a communication channel, but also applications as a sensor network. Through changes in the communication channel, it is possible to judge changes in temperature, humidity, vibration detection and more.

The focus of the research is on the detection of infra and low-frequency sounds, which are practically difficult to detect by standard microphones and sound pressure sensors. Especially in places where it is impossible to directly measure and deploy measuring equipment, such as shafts, tunnels under buildings, bridges, tall buildings and others. [1]

II. Theory

From our studies so far, we have seen that optical methods for collecting and transmitting audio information find wide application in various fields, and they offer very good performance where conventional methods are not applicable. [2,3] To date, we have built several systems for collecting and transmitting audio signals in the audible sound range, where even standard microphones perform well. In this study, however, we will focus on infra and low frequency sounds. They are difficult to read especially in an urban environment where we have many such low-frequency oscillations caused by micro and macro tremors. [4] Under this type of tremors are meant both natural anomalies and even the passage of large heavy machinery and trains.

The main problem we have focused on is the consideration of such infra and low frequency sounds in the infrastructure of cities. The detection of such sounds would be useful in monitoring the stability of tall buildings, as well as numerous applications in assessing the structural strength of buildings and facilities. [5-8] By infra and low-frequency sounds, to which the research is focused, we will understand the frequency ranges from 0 to 120 Hz. Covering, for example, the ranges of infrared emitters and subwoofer speakers.

Infra and low-frequency sounds have a long propagation wavelength, which also makes them more difficult to locate with standard measuring microphones, especially in places such as shafts, tunnels, bridges, etc. As we have discussed in previous studies, it is possible to probe the dynamic range of sounds using offsets of multimode optical fibers, and it is possible to implement this method in applications for measuring infra and low-frequency sound signals. Measuring these signals can be done in two ways. On the one hand, by a method of signal reflection by means of smooth reflective surfaces and laser beam reflection. On the other hand, by physically displacing optical fibers such that one of the optical fibers is stationary and the other is movable. Accordingly, by moving the movable fiber, it is possible to detect infra and low-frequency sound signals transmitted on the surfaces of buildings, bridges and other structures of the infrastructure of large cities. [9-11]

III. The Idea

The idea of the research is to construct an unconventional sensor system for reading low-frequency sound signals. Fig. 1 shows a block diagram of the experimental set-up including a source of low-frequency sounds, a medium for the propagation of sound waves and a receiver-sensor for reading low-frequency sounds.

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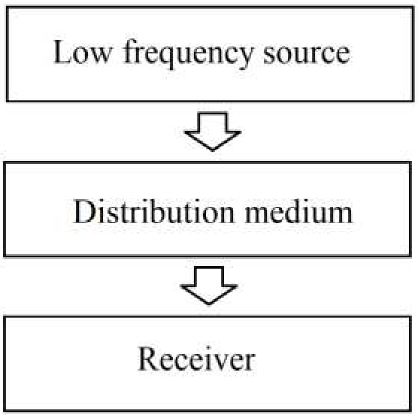


Fig.1. Block diagram of the experimental setup

For the generator of the low-frequency sounds in laboratory conditions, we will use a subwoofer speaker MTM Audio 3-Series W312D2-Plus designed by our partners from MTM audio and assembled by us in the laboratories of TU-Sofia. Fig. 2 shows the loudspeaker used as a generator of low-frequency sounds. The subwoofer speaker was powered with a suitable amplifier and frequency generator supplying the signal voltage.

a

b

Fig.2. Loudspeaker used for low frequency signal generator. Front view *a*, back view *b*

The medium for propagation of sound waves in the low frequencies could be both air and solid. For example, in an air environment, infra and low frequencies could be perceived as the displacement of an air mass and the formation of a thrust on that air mass. While in the propagation of infra and low-frequency sounds on solid surfaces, they are rather in the form of vibrations and physical displacement.

The designed receiver-sensor of sound waves is presented in Fig. 3, it is a 12 inch passive membrane with high sensitivity, on which a mirror with high reflectivity is mounted. The other part of the sensor is the optical transceiver link channel. The source of the optical radiation is a HeNe laser HNA188 with a wavelength of 632.8 nm. The receiver of the reflected laser radiation is an intensity (power) meter, and in initial research it is rather an experiment to see if the passive membrane can detect a low-frequency oscillation and, accordingly, obtain a change in the intensity of the optical radiation.

a

b

Fig.3. Receiver-sensor of low-frequency sound waves. Front view *a*, back view *b*.

After assembling the experimental setup, we have conducted an experiment in which, without changing the input power to the speaker, we will only change the frequency of the sound signals. The distance between the low frequency generator and the receiver is 1 meter. The environment is airy. Temperature in the laboratory was in the range 21-23 degrees of Celsius. Tests were conducted with frequencies varying from 10 to 120 Hz in 5 Hz increments. The graph of Fig.4 shows the change in intensity in %, considering 100% as the intensity of the laser beam in the absence of vibrations. The lower the %, the more deviation there is and accordingly it is possible to judge a better reading of the given low frequency. In fig.4 and Table 1. the obtained results of the experiment are presented graphically.

TABLE I
THE OBTAINED RESULTS FOR CHANGING THE INTENSITY OF LASER RADIATION WHEN CHANGING THE FREQUENCY FROM 10 TO 120 HZ.

F, Hz	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120
Int., %	33	31	27	23	26	34	60	62	67	71	74	76	81	84	83	86	87	87	89	91	93	94	94

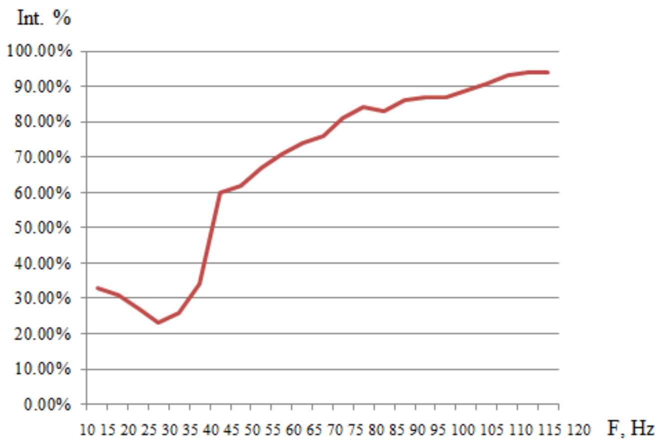
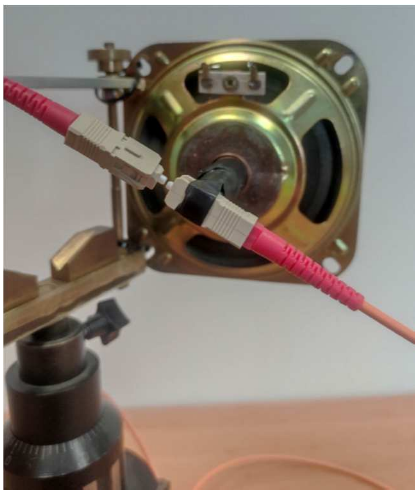


Fig.4. Graphic representation of the obtained results for changing the intensity of laser radiation when changing the frequency from 10 to 120 Hz.

As can be seen in the presented graph, at frequencies in the range from 10 to 35 Hz we have the largest intensity deviation, that is, in this frequency range this type of sensor is most sensitive. While at frequencies in the range of the audible spectrum – above 35 Hz, this type of system has relatively low sensitivity. This shows that the frequency ranges where standard microphones have poor sensitivity in the frequencies below 35 Hz, such type of sensors based on optical methods are also applicable with relatively high sensitivity.

The next system we constructed is via the multimode fiber switching method discussed in previous studies. In this case there is a stationary mounted optical fiber and a "floating" mounted optical fiber to a passive membrane representing the vibrating system for receiving the low frequency sounds. The principle of operation of this type of sensor is similar to the system discussed above with the main difference that multimode optical fibers are used here and the entire sensor system itself can be adjusted much more easily and once. Another advantage is the mobility and dimensions of the system offering positioning in many places where conventional sound pressure measurement systems are inapplicable. A prototype of the system is presented in fig. 5.

a



B

Fig.5. Prototype system for low frequency detection using multimode optical fibers and passive acoustic membrane. Front view *a*, back view *b*.

The experimental results of this prototype are still in the initial stage and will be addressed in future studies.

This type of system offers not only mobility and ease of setup, but also the ability to operate in locations where EMI/RFI interference could be affected, as well as locations where it is dangerous to use an electrically powered system. There, this system could be successfully implemented because of the all-optical transmission and reception of data without the need for electrical power.

IV. Conclusion

The proposed optical methods for detecting low frequency sounds have a great field for development in smart city infrastructures. As seen, this type of system can be relatively simple in design, but at the same time offering the possibility of receiving low frequencies, both from air and from solid media, which is difficult to achieve with conventional sound pressure measurement methods, especially at frequencies below 35 Hz.

Such type of systems can be applied both in the field of construction and road infrastructure. It is thus possible to use them to measure sound pressure at low frequencies in rooms, open spaces and vehicles.

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