New Seismic Sensors for Footstep Detection and Other Military Applications

Alex Pakhomov and Tim Goldburt*
General Sensing Systems LLC, 440 Saw Mill River Road, Ardsley, NY 10502

ABSTRACT

Performance of seismic security systems relies on the particular application of the characteristics of seismic sensors. Current seismic sensors do not yield best possible results. In addition to identifying the requirements for optimal seismic sensors, we have developed seismic sensors for defense and security applications. We show two different types of seismic sensors: a miniscule, extremely low cost sensor and a bulk sensor.

The miniscule, extremely low cost sensor is an electret-based geophone for both seismic and acoustic detection systems. This geophone detects a small size object—i.e. a walking/running/crawling person or a small underwater vehicle—that moves on the surface, underground, and/or in the water. It can also detect large size objects—i.e. heavy vehicles, trucks, tanks—as well as be used in littoral warfare. The electret-based design significantly improves technical characteristics achieving performance uniqueness: expanded frequency response range in the low frequency area, improved sensitivity threshold and accuracy response, and improved sensor's protection from electromagnetic interference.

The bulk sensor has an extremely large detection surface, a nanocomposite body in special form casing, and a special electronic circuit. These sensors allow detection of footstep signals in high ambient seismic noise levels. However, installation requires significant installation groundwork effort.

Keywords: Footstep detection, novel seismic sensors, homeland security, military seismic systems.

1. INTRODUCTION

We have succeeded in creating novel footstep detection systems and corresponding software [1]. The design and development of novel seismic sensors for footstep detection and homeland security applications is the next logical step in further significant improvement of footstep detection seismic systems.

We investigated the critical issues of current seismic sensors for defense and security applications [2]. As result, we have identified two types of new sensors and we have patents pending on seismic and acoustic vibration sensing based on electret seismic geophones and on large, extended nanocomposite sensors. Both types of sensors have a number of advantages over currently available sensors. The electret-based geophones are both extremely small and extremely low cost. On the other hand, the nanocomposite sensors have very large extended detection surface area and allow detection of footstep signals in very high ambient noise levels.

2. RESULTS AND DISCUSSION

2.1 Electret-based geophones

2.1.1 Technical approach

We present our prototypes of the electret-based geophones. These specific prototypes were developed in order to test the proposed technical approach.

The simpler design electret sensor is discussed first and shown in Figure 1. This Figure shows a cross-section of the proposed electret sensor.

* tgoldburt@aol.com; phone 1 914 674 8649; fax 1 914 674 8683

Sensors, and Command, Control, Communications, and Intelligence (C3I) Technologies for Homeland Security and Homeland Defense III, E. M. Carapezza, ed., Proc. of SPIE Vol. 5403 (SPIE, Bellingham, WA, 2004) · 0277-786X/04/$15 · doi: 10.1117/12.545293

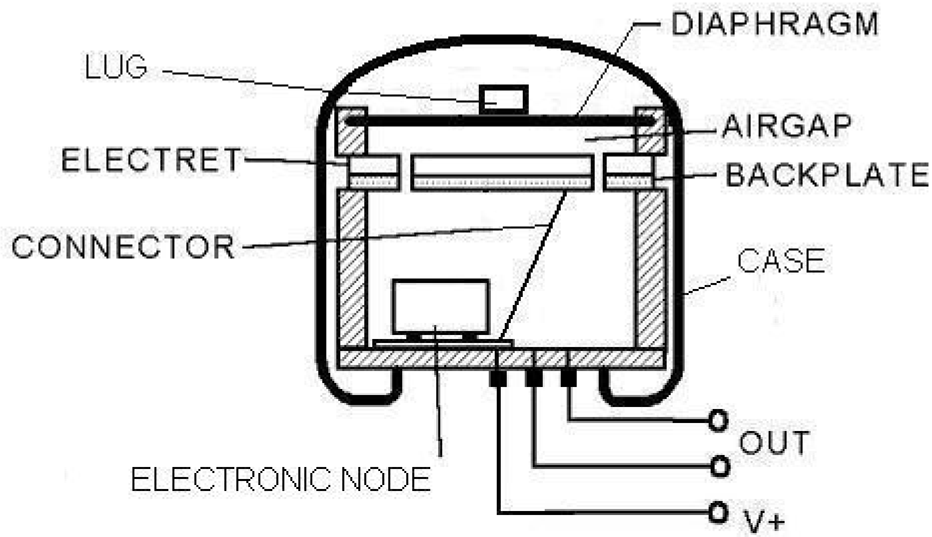

Figure 1. A cross-section of the proposed electret sensor (first design).

This design incorporates two nodes: the electret-based micro-electromechanical (MEM) node and the electronic circuitry (EC) node. The MEM node includes the electret sensitive element. This element is a flat capacitor with the electret film placed between the capacitor plates. The electret film is fabricated from pre-charged non-conductive material. One of these plates is a non-moving backplate and the other is a moving diaphragm. Diaphragm vibration causes the changes in the capacitance and therefore in the voltage of the capacitor. The corresponding EC node, the electronic node in Figure 1, converts the changes in capacitor voltage into the output voltage of the sensor.

The principal technical task in the first design of the proposed sensor is to accurately establish connectivity between the sensor vibrations and the vibrations of the moving diaphragm. In the simplest case this task is achieved by placing the lug in the center of the moving diaphragm. The lug and the diaphragm can be treated as the main oscillator. If the geophone vibrates, the main oscillator also vibrates. If the resonance frequency of the MEM oscillator is lower than the sensor vibration frequency, the vibrations of the main oscillator accurately reproduce the sensor vibrations. Thus, in order to create the geophone with satisfactory response in the low frequency range, the resonant frequency of the MEM oscillator should be 1 to 2 Hz. In addition, the MEM oscillator should inherently have a high damping factor. If the size of the oscillator is too small, for example 5 mm or less, the solution of the above task is not trivial.

The other vibration transmission method from the sensor to the moving diaphragm is illustrated in Figure 2. Figure 2 shows a cross-section of the proposed electret sensor based on the second design.

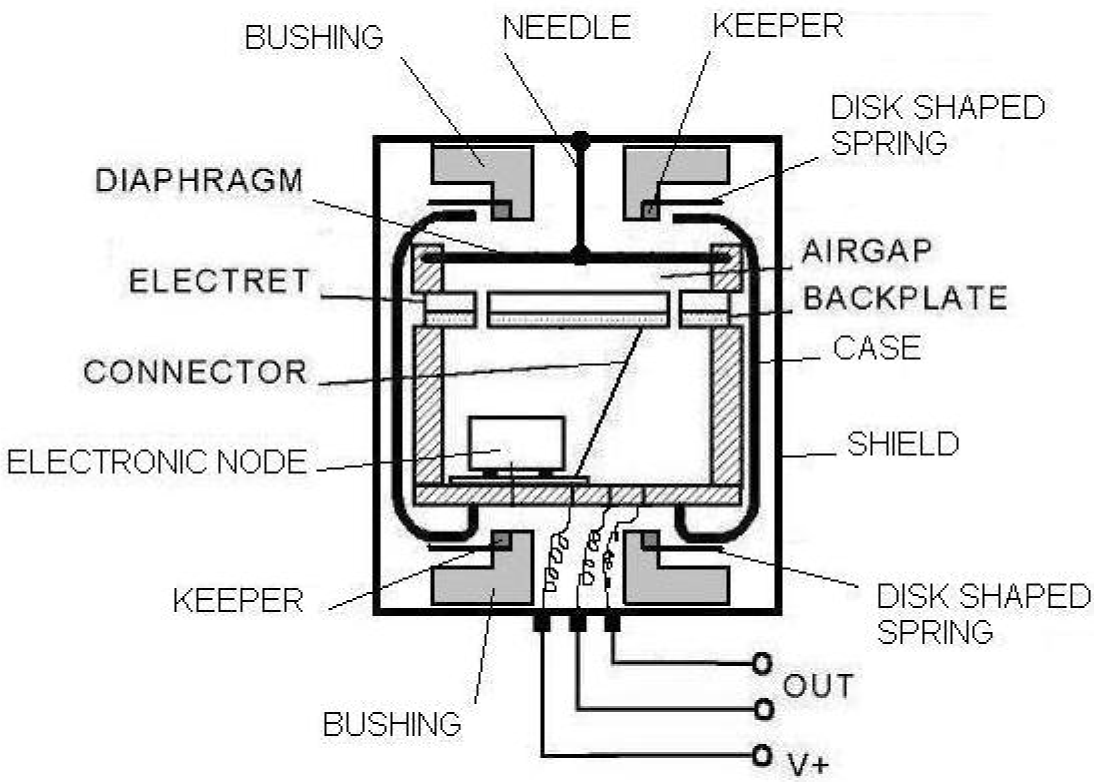

Figure 2. A cross-section of the proposed electret sensor (second design).

For this second design, the inner case of the sensor will vibrate with the sensor vibrations. The vibrations occur between the two disk shaped springs. The inner case and the two disc shaped springs are the MEM oscillator in this second design. The sensor vibrations will cause the diaphragm vibration because the center of the diaphragm is connected with the needle to the sensor outer shield (see Figure 2). The resonance frequency of the MEM oscillator should also be 1 to 2 Hz in this design. Achieving this resonance frequency requirement for the second design (Figure 2) is simpler than in the above-mentioned first design (Figure 1) if the diameter of the diaphragm is less than 5 mm.

The other important part of the proposed sensor is the electronic circuitry node. The design of this node is similar for both simple and modified sensor designs. The schematic block diagram of the electronic circuitry is shown in Figure 3.

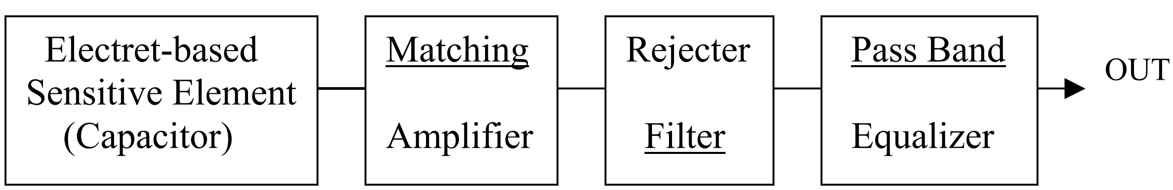

Figure 3. Schematic block diagram of the electronic circuitry for proposed sensors.

The proposed electronic circuitry consists of a matching amplifier, rejecter filter and pass band equalizer and has the following properties: signal buffering, filtering, self-biasing, and external phantom biasing. This electronic circuitry combined with the electret-based sensitive element allows one to address and solve the small sensor problem.
The response curve of the electret-based sensitive element is non-linear. However, its high dynamic range and use of a rejecter filter and pass band equalizer allow to achieve satisfactory response in the low frequency band, sufficiently linear response curve, and accurate response of a weak footstep signal. The matching amplifier provides the necessary level of the output voltage.

Although the linear response curve that we plan to obtain from our sensor represents a universal approach for sensor design—it allows one to utilize it in many various military applications—for many detection tasks it is also useful to create a special form response curve that deviates from the linear curve. The schematic shown in Figure 9 will allow us to create the necessary response curve by placing the pass band equalizer inside the sensor. Another advantage of our technical approach is that by placing the electronic circuitry inside the sensor results in optimal matching of the sensor output signal with different wire and wireless signal transmission devices, while permitting the signal summation from a number of the geophones [1-2]. This significantly broadens the range of the potential military applications such as mobile systems, long perimeter protection systems, and littoral warfare applications.

An additional element in our sensor design technical approach is the use of a double shield. Combined with the electret-based sensor sensitive element, actually a capacitor in both designs, the double shield provides a reliable protection from electromagnetic interference. The double shield has a two-layer structure: the first layer fabricated from copper, and the second layer from nickel. This double shield is necessary only for high electromagnetic interference environments, such as Air Force radar installations. For lower interference, the single layer shielding fabricated from stainless steel is sufficient.

2.1.2 Main technical goals

The above technical approach allows one to achieve the following technical goals leading to a unique sensor with outstanding performance:

Reduced sensitivity threshold due to:

- Reduced mass and size of the sensor's mechanical oscillator;
- The use of a proprietary electret-based element allowing to amplify extremely small changes in the sensor's electret membrane electro-dynamic properties resulting in detectable signal generation in the sensor;
- Specially designed electronic circuitry.

Improved accuracy response due to:

- Proprietary micro-electromechanical (MEM) node through reduction in its resonance frequency and increased damping;
- Electronic circuitry using rejecter filter and pass band equalizer.

Expanded frequency response range, especially in the low frequency range, due to:

- Wide dynamic range response of the electret-based MEM node;
- Electronic circuitry using pass band equalizer for smoothing the amplitude versus frequency response curve.

Increased sensor's protection from electromagnetic interference by using:

- A double shield from two different materials. One shield will be fabricated from copper, and the other from nickel. This double shield is needed only in the case that the electromagnetic interference is very high;
- A single layer shield for other cases.

Our preliminary experiments showed that the proposed geophone has high response to frequencies in the 1-2 Hz and 4-6 KHz ranges. This is due to our proprietary mechanical architecture of the proposed geophones and electronic circuits.

2.1 Extended nanocomposite sensors

The sensing device in accordance with our design has a body that is composed of a particulate material including a plurality of particles. The body of the sensor is formed as a substantially flat, three dimensional object which can have significant horizontal sizes, i.e. from tens to hundred meters, and a relatively small vertical size, i.e. tens of centimeters. The body can have a rectangular shape, i.e. a rectangle with sizes of 7-15 by 35-75 meters. Such sensing devices can be used for guarding of perimeters of significant size. On the other hand, the shape on a horizontal plane can be arbitrary in correspondence with the shape of the guarded zone. If a guarded zone has a significant length and a complicated shape, the zone can be provided with a plurality of sensors of arbitrary shape adjacent to each other. If the surface of the guarded zone is not exactly horizontal, the sensing device can have a shape that corresponds to the shape of the guarded zone.

The particles of the particulate material can be composed of an electrically conductive material. For example, they can be formed from real carbon dust, etc. On the other hand, the particles can be composed of a non electrically conductive material, i.e. plastic, and then treated with an electrically conductive substance, i.e. an aqueous emulsion of fullerenes or nanotubes. It is also possible for the particles to be composed of an electrically conductive material and additionally be treated with electrically conductive substance, i.e. specified herein above, to enhance their electrically conductive properties. Thus, the carbon dust can be treated with the aqueous emulsion of fullerenes or nanotubes. When the particles contact with one another, they produce electrical contact and electrical conductivity of the whole body is provided.

The body is arranged in the ground, i.e. in a trench formed in the ground and having preferably a flat bottom and vertical walls. The particulate material is introduced into the trench and assumes the required shape so as to follow the shape of the trench. The upper surface of the body is then straightened. It is recommended that the upper surface of the body be arranged at a depth of approximately 0.2-0.3 meter, and its thickness be approximately 0.1-0.5 meter. The body of the material can be confined in a casing. It is used for maintaining the shape of the body of the particulate material after its introduction into the trench, or to prevent displacement of the particulate material in the ground during use. The casing can be composed of an environment resistant material, which is non electrically conductive, for example a plastic material. It can be provided with a plurality of perforations for ventilation purposes, located in the lower area of the casing. At the same time the upper part of the casing can be solid and water-impermeable so as to prevent excessive moisturizing of the particulate material from, for example, rain or melting snow.

The sensing device contains electrodes that are formed as electrode plates for connecting corresponding electronic devices to the body so as to monitor an electrical resistance of the body of the particulate material and process the monitoring results. The electrodes can be formed as thin metallic, non-corrosive plates having for example a rectangular shape, and can be isolated with screened wires to be connected to the electrodes. The electrodes are located at both sides of the body of the material. They are introduced into the body over its whole depth. The vertical size of the electrode plates substantially corresponds to the thickness of the body. The horizontal size of the electrode plates corresponds to an average width of the body in a horizontal plane. The electrodes can be also formed not as uninterrupted plate parts, but instead they can be composed of a plurality of plates, which are electrically connected with one another and can be curved. The plate parts which form a single electrode are arranged along the edge of the body one after the other, as shown for example in Figure 4.

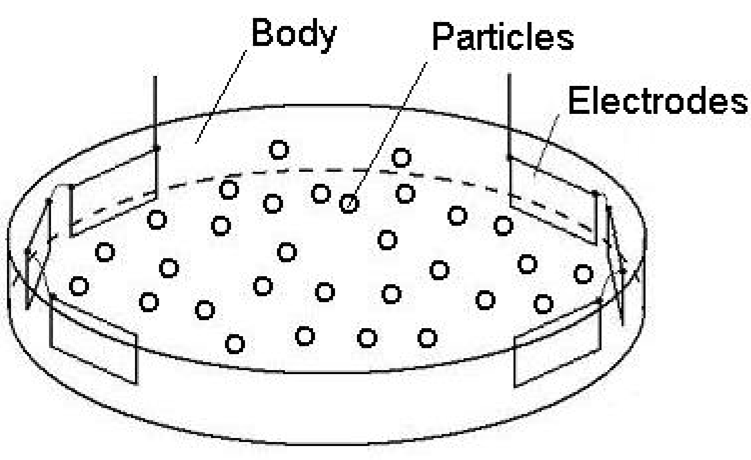

Figure 4. Cross section of the extended nanocomposite sensor.

When an intruder moves over the ground surface with the sensing device located underneath, micro displacements and micro vibrations of the body of the material occur. As a result, density and electrical conductivity of the body are changed, and electrical resistance of the body of the material is changed, which is measured between the electrodes. These changes in the resistance caused by the intruder represent information or a signal that is used for analysis and making decisions about the presence or absence of an intruder.

Figure 5 shows an electronic circuit of an information channel for the sensing device. It includes a voltage source, for example 3-30 Volt, and an amplifier. The changes of electrical resistance of the voltage supplied by the source are amplified by the amplifier.

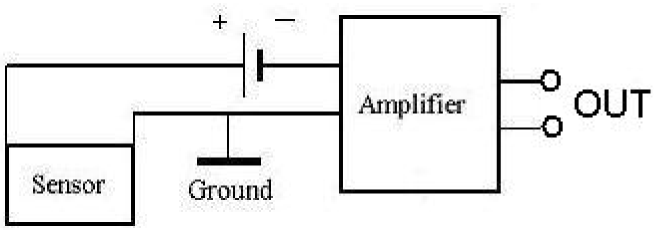

Figure 5. Schematic block diagram of the electronic circuitry for the extended nanocomposite sensors.

3. CONCLUSIONS

In our opinion, geophones based on electret materials provide the best results for various defense and security applications. Like the well-known electret microphones, electret-based geophones have greater accuracy of response, higher stability, linear frequency characteristics, higher dynamic range, and improved phase characteristics. Electret materials enable the manufacturing of miniscule, inexpensive geophones with superior performance characteristics.

Additionally, electret-based geophones provide very high noise immunity from electromagnetic interference which is very useful for tasks requiring small seismic signals in difficult ambient noise situations. The expected small size and low price enables manufacturers to implement technology for tasks that require simultaneous employment of a very high number of sensors. Finally, this development can be used for littoral warfare applications.

ACKNOWLEDGEMENTS

Dr. Ed Carapezza is acknowledged for technical discussions.

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