Lab Testing of New Seismic Sensor for Defense and Security Applications

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ABSTRACT

General Sensing Systems (GSS) has developed a sensor based on electret material. Herein we describe the creation and lab testing of this very small and high performance seismic sensor intended for up-to-date security and military systems. This article delivers the first results of laboratory tests of this small size and extremely low cost new sensor. This new sensor was compared with the most popular geophones, the GS-14-L3 and GS-20DX geophones produced by Geo Space Corporation. The results show that the new, GSS sensor has an expanding frequency response range in both the low and high frequency areas. This is crucial for increased detection range of seismic-acoustic and hydro acoustic reconnaissance systems. The new, GSS sensor also has the highest sensitivity among all the compared geophones as well as a lower sensitivity threshold. When the amplitude of vibrations is very small, the GS-14-L3 and GS-20DX geophones, for example, miss signals—whereas the new sensor has a good response. Specifically, this performance characteristic of the new GSS sensor also allows the development of reconnaissance systems with a high detection range. Test results also show that the new sensor demonstrates good signal discrimination, ensuring efficient signal interpretation. In general, the results reported here show that the use of electret materials enables the manufacture of very small and inexpensive seismic-acoustic and hydro acoustic sensors with improved performance characteristics.

Keywords: Seismic-acoustic sensors, electret-based devices.

1. INTRODUCTION

General Sensing Systems has developed two proprietary designs of the electret-based geophones/sensors, submitted for patents to the USPTO in 2003 [1]. During the past year of our research and development, we strove to create a sensor without the main disadvantages of current seismic sensors employed in defense and security applications. The main issues related to the current seismic sensors have been described [2]. They include:

- Poor response to low frequency signals, leading to decrease of the detection range of targets
- Unsatisfactory sensitivity threshold, causing missing of low level seismic signals from outlying targets
- Long damping signal time and corresponding low response accuracy, leading to problems with outlying target detection in high noise level environments
- Relatively bulky size and high price which prevents extensive use of seismic sensors

In this paper, we report the first lab test results of the new GSS electret-based sensor in comparison with the most popular geophones produced by Geo Space Corporation or by other companies, which use GSC's patents. We used the GS-14-L3 and GS-20DX geophones for comparison. Our results indicate that the use of an electret-based sensitive element is a promising approach for the development of sensors capable of fully satisfying military application requirements.

2. RESULTS AND DISCUSSION

2.1 Micro-electromechanical (MEM) node and electronic circuit

In order to investigate the qualitative parameters of the sensor we designed a test version of sensor, using a lug with a replaceable mass (see principles of operation of such type sensor [1]). Figure 1 shows a cross-section of the corresponding GSS electret-based sensor (GSS-EBS).

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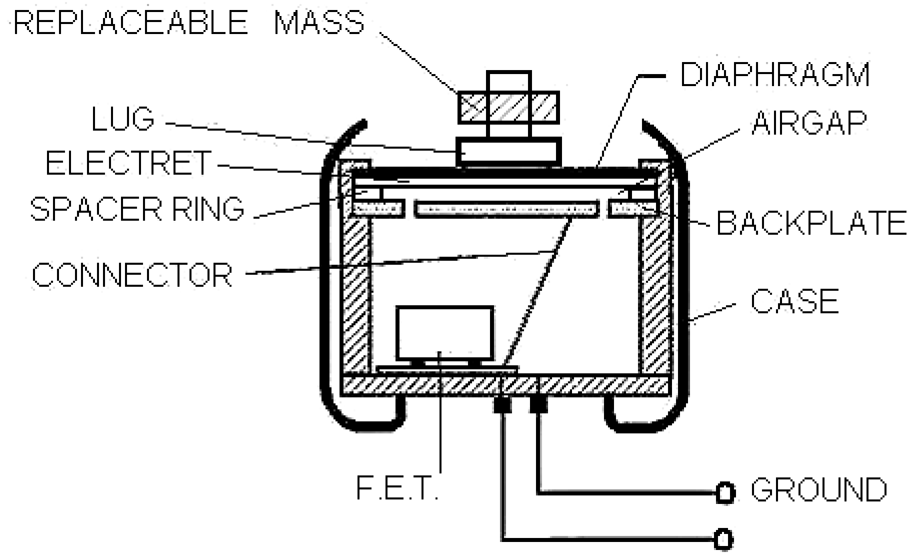

Figure 1. A cross-section of the proposed electret-based sensor (test version).

The proposed design allows us to select the mass of the lug from 0.4 to 2.0g with an increment step of about 0.1 to 0.6g.

As a pilot electret material, we selected electret Teflon film. This electret material is commonly used in different acoustic applications and exhibits excellent mechanical properties. In terms of selecting a technology approach for potential manufacturing, we used an in-house technology for attaching the lug to the electret film. For potential manufacturing, we will investigate several bonding technologies that will allow to attach the lug in the in-line sensor manufacturing process.

Our electret-based sensitive element is comprised of a backplate, a spacer ring, an elastic diaphragm (which is an electret Teflon film with spray-coated metal surface), contact ring and the lug (with a possible replaceable mass)—see Figure 2 below.

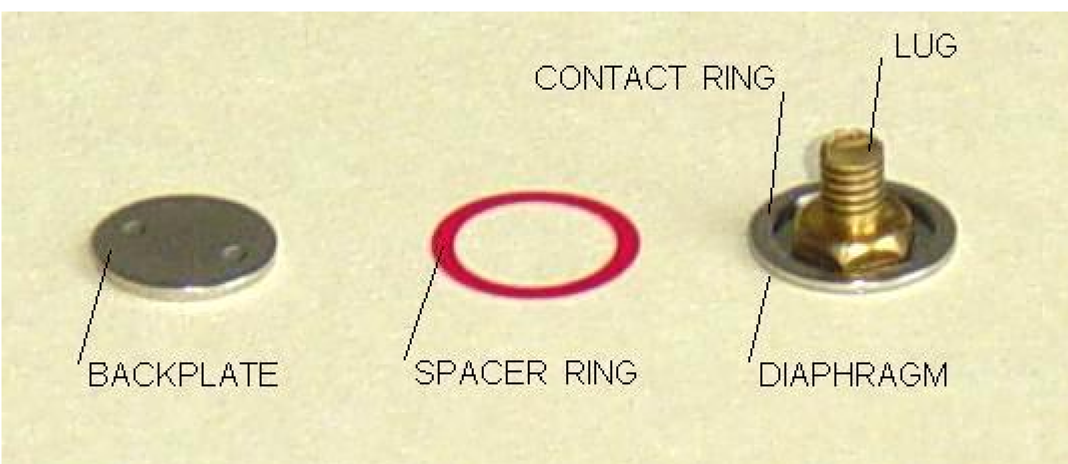

Figure 2. Electret-based sensitive element parts.

The diameter of the backplate, spacer, contact ring and diaphragm is about 9.0mm. The thickness of the backplate is about 0.5mm. The thickness of the spacer ring is subject to change during development (in the range of 0.03 to

0.06mm). The thickness of the contact ring is roughly 0.5mm. The full size of the test version sensor is about 9.7mm (diameter) by 13.0mm (height). The sensor mass is about 1.4 to 1.6g (without replaceable mass). Two examples of the test version of the GSS sensor are shown in Figure 3 in comparison with Geo Space's Commercial Geophones GS-14-L3 (in the middle) and GS-20DX (on the right).

Figure 3. Two examples of the test version of the GSS sensor in comparison with Geo Space's Commercial Geophones.

In the test version sensor, we used a standard electronic circuit. This type of circuit is usually used to provide a functioning electret capacitor. The possible sensor powering circuit is shown in Figures 4 below.

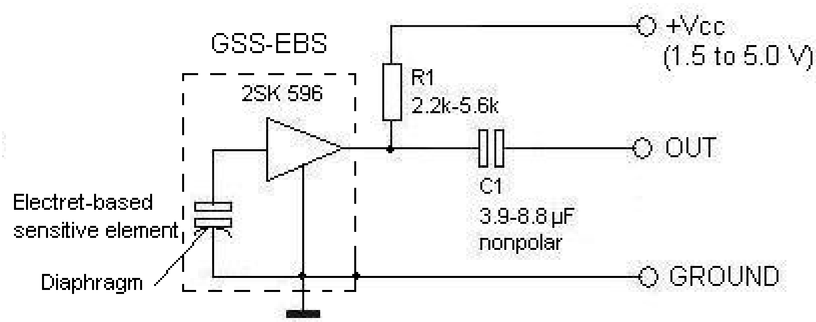

Figure 4. Electret-based sensor powering circuit.

This circuit allows to first provide a so-called phantom biased connection (interface) and second, an appropriate lower frequency response of our sensor. We use a field effect transistor (FET) type 2SK 596 in such a powering circuit. The current in this case must remain lower than 0.5mA over the power supply's voltage range. This electronic circuit generally displays a relatively linear response curve. This allows us to closely investigate the dependence of the sensor's response on its MEM's characteristics.

2.2 Better response to low and high frequencies signals

Figure 5 shows seismic signals, which were recorded during the laboratory fully controlled experiment.

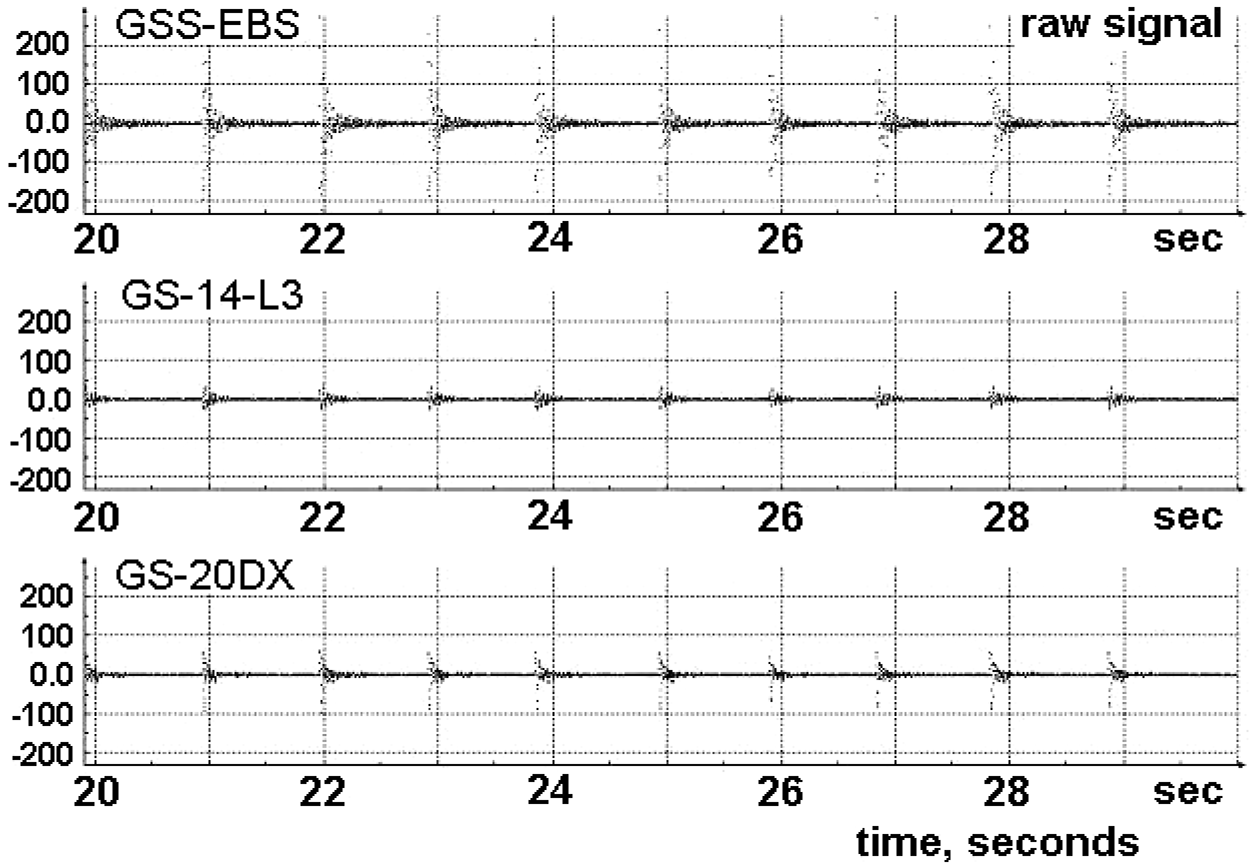

Figure 5. Records of the same seismic signal by the GSS electret-based sensor and two different geophones GS-14-L3 and GS-20DX (strong impacts).

The GSS electret-based sensor and both the GS-14-L3 and GS-20DX geophones were placed in one place of vibrating surface. Output of all sensors was connected to an analog-to-digital converter (ADC) without additional amplification. Vibration signal amplitude was high enough. Periodical short-term impact on sensors was strong and had broadband spectrum. All sensors show satisfactory signal level. Geophone GS-14-L3 shows a signal lower than that of geophone GS-20DX, which is in good accord with the manufacturer's data for these geophones [3]. The GSS electret-based sensor shows significantly higher-level signal than both the GS-14-L3 and GS-20DX geophones. On these records, the signal amplitude of the GSS electret-based sensor is about three times higher than the signal amplitude of the GS-20DX geophone and about eight times higher than the signal amplitude of the GS-14-L3 geophone.

The corresponding amplitude spectrum of the above presented seismic signals is shown in Figure 6 below.

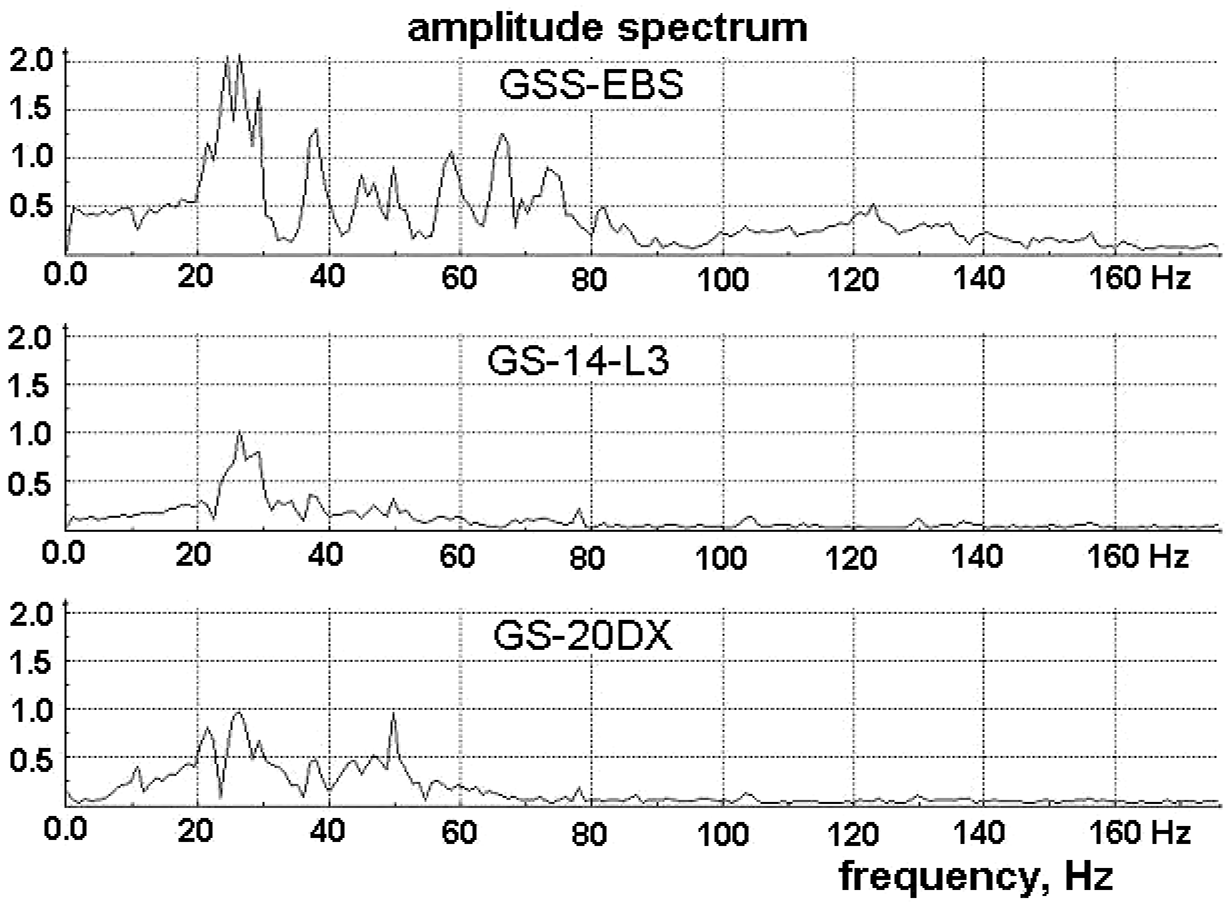

Figure 6. The amplitude spectrum of the seismic signals recorded by the GSS electret-based sensor, GS-14 and GS-20DX geophones and shown previously in Figure 5.

The GSS electret-based sensor shows a much better response to low and high frequency signals than either the GS-14-L3 or GS-20DX geophones. The GSS electret-based sensor performs better than the GS-14-L3 below 20-24Hz and above 40Hz frequencies and better than the GS-20DX geophone below 10-12Hz and above 50Hz frequencies. Frequencies below 10-20Hz are crucial for increased detection range of seismic detection systems. For example, in the footstep detection task, the majority of the seismic signal energy is found at less than 24Hz, at a distance between a walking person and the sensor of approximately 70m. Even at a smaller distance of 15m, a geophone without a response at lower than 24Hz loses at least 30% of the signal energy [4]. Therefore, the GSS electret-based sensor may provide a higher detection range of different targets. Frequencies higher than 40-50Hz may be very important for hydro acoustical applications, in which case the GSS electret-based sensor may also provide additional advantages.

2.3 Higher sensitivity plus lower sensitivity threshold and better signal separation

The amplitude spectrum of the seismic signals shown above in Figure 6 indicate that for all types of signal, the GSS electret-based sensor has significant sensitivity advantages among other sensors and these sensitivity advantages are crucial in many cases. An example of one of such cases is shown in Figure 7.

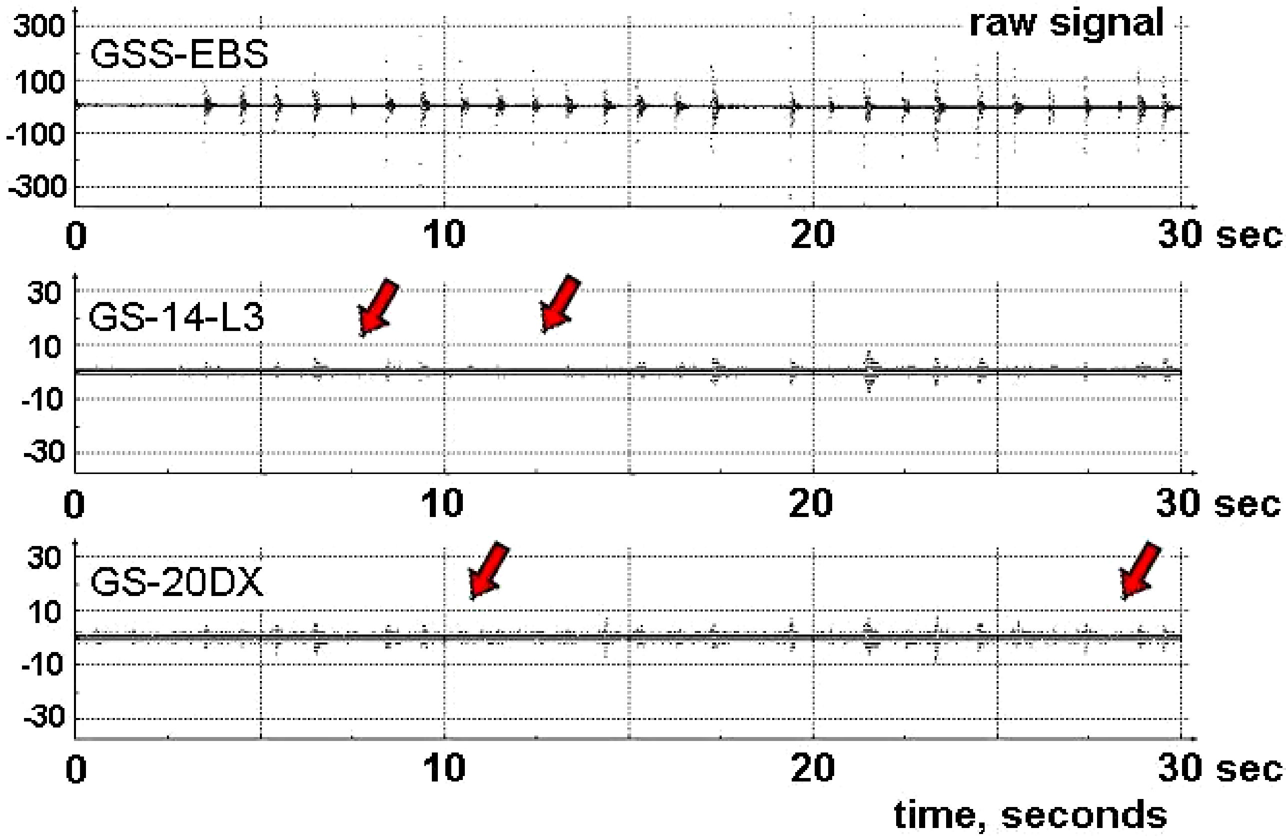

Figure 7. Records of the same seismic signal by the GSS electret-based sensor and two different geophones GS-14-L3 and GS-20DX (weak impacts).

All sensors were placed in one area of vibrating surface as before. Impacts on sensors were weak. While the GSS electret-based sensor has high response signal, both the GS-14-L3 (especially) and the GS-20DX geophones have very poor or even no response signals. The red arrows in Figure 7 point to such areas. Figure 8 shows one of these areas from Figure 7.

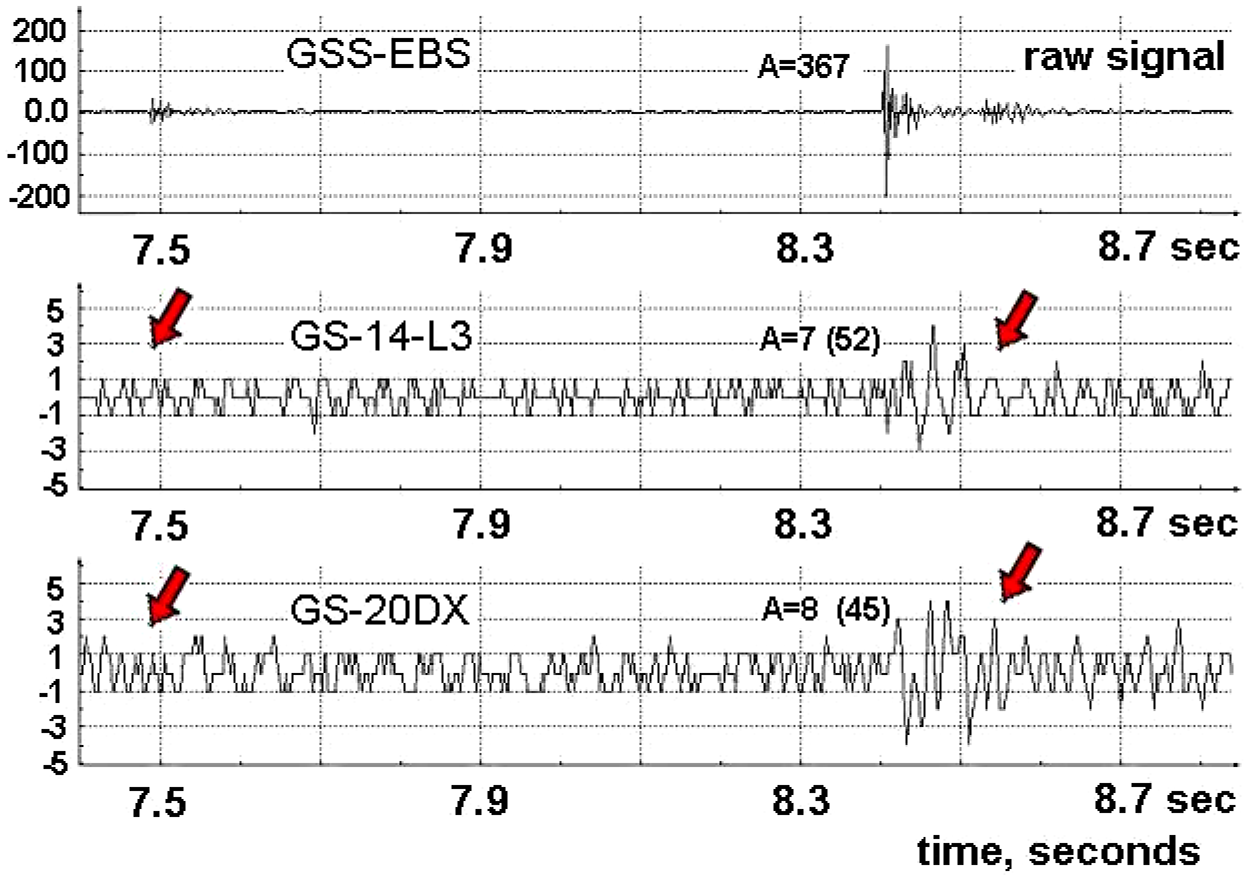

Figure 8. Highlight from Figure 7 of an area with weak GS-14-L3 and GS-20DX response.

The GS-14-L3 and GS-20DX geophones in this record do not show a response at time 7.5sec, while the GSS electret-based sensor has a good response with an amplitude of about 60. At 8.4sec, all sensors have a response, but the amplitude of the GS-14-L3 signal is about 52 times less and the amplitude of GS-20DX signal is about 45 times less than the amplitude of the GSS electret-based sensor. These results together with the Figure 5 data show that the GSS electret-based sensor has a sensitivity threshold lower than that of the GS-14-L3 and GS-20DX. Therefore the GSS electret-based sensor can pick up a signal in low level signal situations, where the GS-14-L3 and GS-20DX geophones do not have a response.

At the time 8.55sec, the GSS electret-based sensor shows a very clear third signal. However, the GS-14-L3 does not have a response at that time, and the GS-20DX does not show a third signal but shows only a long extended second signal without signal separation. This point is significant for real signal interpretation in heavy noise environments and is a big advantage of the GSS electret-based sensor's performance in comparison to the GS-14-L3 and GS-20DX.

Figure 9 below shows the records in different time and different cases, while the response signal amplitudes of all sensors were approximately equal.

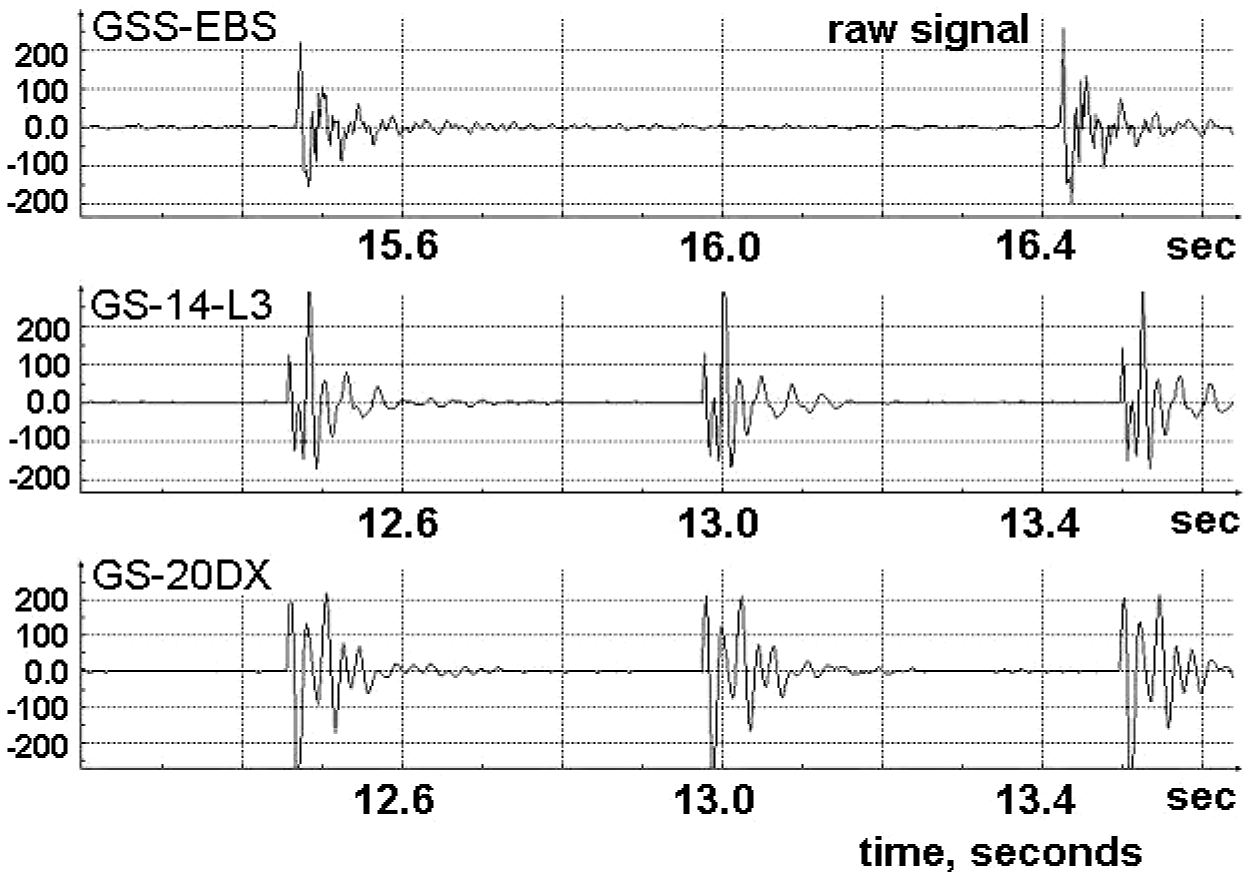

Figure 9. Damping time, signal maximum and pulse time of arrival.

Together with Figure 8, Figure 9 shows qualitative differences of sensor response signal characteristics. All the sensors have a time lag of signal maximum from pulse time of arrival, but the GSS electret-based sensor has the least time lag and the GS-14-L3 has the greatest time lag. Since all sensors have approximately equal damping time, the GSS electret-based sensor produces signals which can be separated more efficiently in difficult noise situations.

2.4 Smaller size, lower mass/weight, potentially lower price

Table 1 presents the basic characteristics of the tested GSS electret-based sensor and the GS-14-L3 and GS-20DX geophones (according to manufacturer's data [3]).

Table 1. Basic characteristics of the sensors

	GSS-EBS	GS-14-L3	GS-20DX
Volume, cm^3	~1.33	3.77	16.72
Mass, g	2.2 g	20-27 g	87 g
Price, $	~ $3-5	~ $45	~ $25

The Comparison of that data shows that:

- The GSS electret-based sensor has a volume about 3 times less than that of GS-14-L3 and 12 times less than that of GS-20DX
- The GSS electret-based sensor has a mass about 9-12 times less than that of GS-14-L3 and 40 times less than that of GS-20DX

- The GSS electret-based sensor may potentially have a price 9-15 times less than that of GS-14-L3 and 5-8 times less than that of GS-20DX

Therefore, all the above mentioned characteristics of the GSS electret-based sensor are actually about 10 times better than that of the GS-14-L3 and GS-20DX geophones.

3. CONCLUSIONS

All of the most popular commercial seismic sensors/geophones have a number of main disadvantages. These disadvantages prevent the development of new useful detection, reconnaissance, and surveillance systems for various homeland security and military applications. We designed and developed a novel electret-based sensor. The results of our lab testing of the sensor pilot version in comparison with the most popular commercial geophones demonstrate that the GSS electret-based sensor has:

- Better response to both low and high frequency signals
- Higher sensitivity, a lower sensitivity threshold, and better signal separation
- Smaller size, lower mass/weight, and potentially lower price

We plan further testing, including field-testing in a real environment. Next steps also include developing the technology for manufacturing electret-based sensors for different applications, as well as an upgrading of the electronic circuit.

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