Testing of New Seismic Sensors for Footstep Detection and Other Security Applications

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ABSTRACT

General Sensing Systems (GSS) has been successfully developing a new sensor for the past several years. Herein we describe the lab and field testing of this small size, extremely lost cost and high performance seismic sensor intended for up-to-date security and military systems. This article delivers the latest results of the wide-ranging laboratory and field tests of this new sensor. During the testing, GSS's new sensor was compared with the leading commercially available geophones, the GS-14-L3 and GS-20DX geophones produced by Geo Space Corporation. The obtained results confirm our pilot lab testing [1] in terms of the advantages of new sensor. The results show that the new GSS sensor has an expanding frequency response range in both the low and high frequency areas. The GSS sensor also has the highest sensitivity among all the compared geophones as well as a lower sensitivity threshold. This point is significant for real signal interpretation in heavy noise environments and is a significant advantage of the GSS sensor's performance in comparison to that of existing commercial geophones. The comparative field test results show that the GSS sensor allows to detect footstep signal by almost 3 times larger distance between the sensor and walking person. This is crucial for increased detection range of seismic-acoustic reconnaissance systems. In general, the results show it is possible to manufacture very small and inexpensive seismic sensors with significantly improved performance characteristics.

Keywords: Miniature seismic sensor.

1. INTRODUCTION

Seismic footstep detection-based systems are critical for various homeland security and military applications, and their performance depends on the characteristics of the seismic sensors. Unfortunately, currently available seismic sensors do not provide satisfactory results. According to our research [2], even the most popular commercially available seismic sensors/geophones for detection purposes have a number of key disadvantages.

In previous papers [1, 3], we reported the design and the pilot lab test results of the new GSS sensor (GSS-EBS). During the pilot lab testing we compared the new sensor with the most popular geophones (GS-14-L3 and GS-20DX) produced by Geo Space Corporation or by other companies that use GSC's patents.

In this paper, we report the broadband lab and field test results of the new GSS sensor in comparison with the same GS-14-L3 and GS-20DX geophones. Our results indicate that the GSS sensor is capable of satisfying requirements of many military applications. The key result of the field testing is that the GSS's sensor allows to detect footstep signal by almost three times larger distance between the sensor and walking person in comparison with the best existing commercial geophones.

2. RESULTS AND DISCUSSION

2.1 Micro-electromechanical (MEM) node and electronic circuit

GSS's proprietary micro-electromechanical (MEM) node of the sensor was described in full in [1, 3]. A picture of the GSS sensor with a middle replaceable mass, which was used during testing, is shown in Figure 1.

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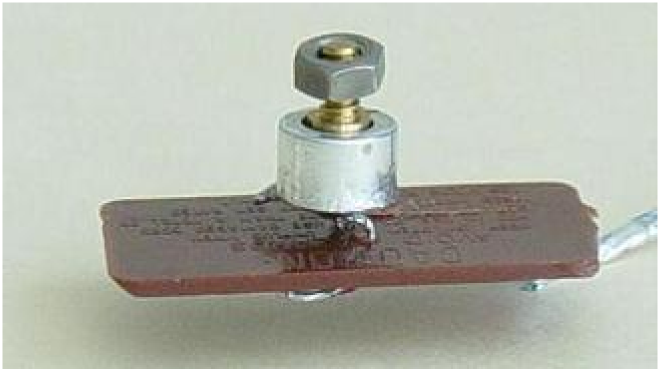

Figure 1. GSS sensor with middle replaceable mass on a board for secure attachment to a vibration stand (lab test) or to a land case of a standard geophone (field test).

The special board shown in Figure 1 was used for attaching the GSS-EBS to a vibration stand (lab test) or to a land case of a standard geophone (field test). For our final lab testing and for the all field testing, the GSS-EBS and both the GS-14-L3 and the GS-20DX geophones were installed in standard land cases (Figure 2).

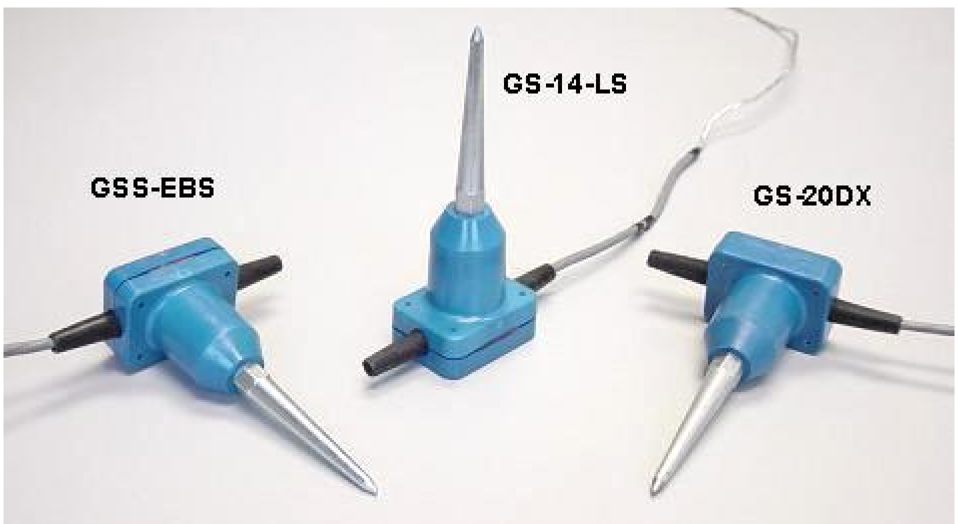

Figure 2. GSS-EBS and Geo Space's GS-14-L3 and GS-20DX in land cases.

Similar land cases were applied to creating similar vibrational conditions for all geophones.

The electronic circuitry of the GSS-EBS has to provide the following properties: signal buffering, prefiltering, self-biasing, and external phantom biasing. The corresponding matching amplifier provides the necessary level of the output voltage. During our investigation, we used a simpler electronic circuit. This simple electronic circuit is comprised of three main parts: 1) a sensitive element/capacitor (described in [3]); 2) sensor powering circuit; and 3) a sensor amplifier.

For final lab tests and for the all field tests we used the powering circuit shown in Figure 3.

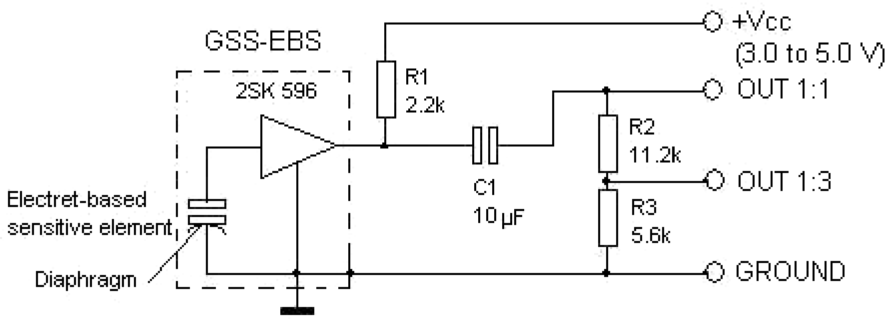

Figure 3. Sensor powering circuit.

This sensor powering circuit has an attenuator (1:3), which was used in lab and field tests for easier comparison of the different sensors signals. The value of elements R1, R2, R3 and C1 must provide lower cutoff frequency, which in our case was about 0.8 Hz. We used a field effect transistor (FET) type 2SK 596. This electronic circuit generally displays a relatively linear response curve, allowing us to closely investigate the dependence of the sensor's response to its MEM's characteristics.

The combination of a single FET and a low load resistor results in a low gain. We should therefore use significant pre-amplification to supply the signal to an analog-to-digital converter (ADC), especially by testing low amplitude seismic signals in real environment during field testing. A corresponding amplifier was created on an Analog Device operational amplifier OP295. This amplifier has a symmetrical input and variable gain in the range of $3x10^2$ to 10^4. We also used this amplifier for amplifying a signal from the GS-20DX and GS-14-L3 geophones. It allowed us to compare more accurately the characteristics of our seismic sensor and an existing seismic sensor.

2.2 Final lab testing of new sensor

During the lab and field testing we used the most obvious approach/methodology: a comparison of the new sensor with the existing, commercially available sensors under the same conditions during identical vibrational impacts of various amplitude. The displayed response differences clearly show all advantages and disadvantages of existing and proposed sensors.

Figure 4 below shows the simultaneous recordings of the same seismic signal using the GSS-EBS and the GS-14-L3 and GS-20DX commercial geophones.

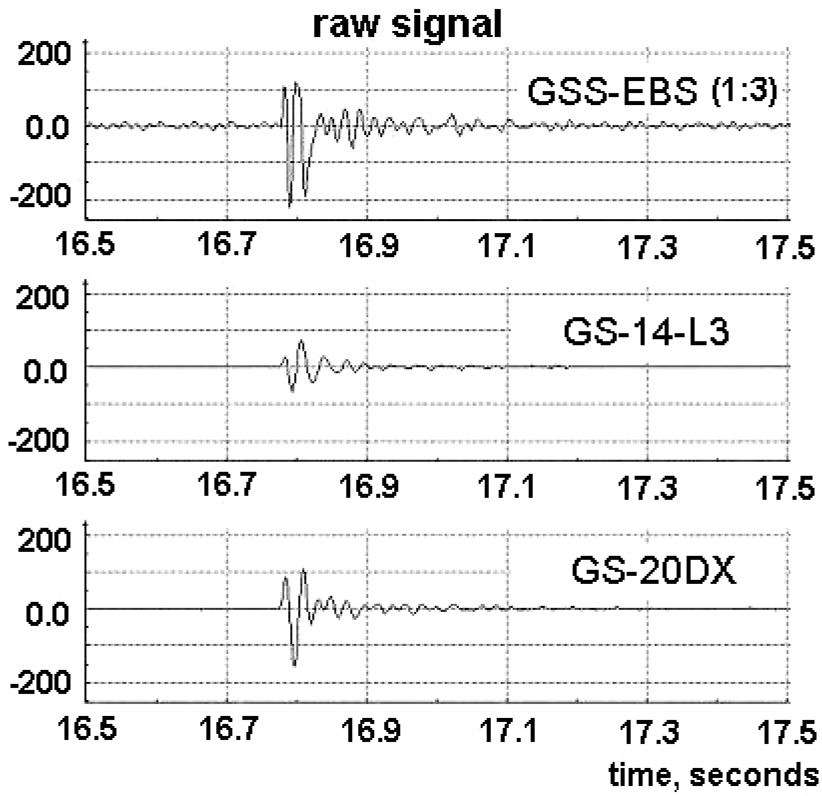

Figure 4. Records of the same seismic signal by the GSS-EBS and two different geophones GS-14-L3 and GS-20DX. Strong impact and using of an attenuator (1:3) for GSS-EBS.

The GSS sensor and both the GS-14-L3 and GS-20DX geophones were put in one place at the same position of the vibrating surface. Output of all sensors was connected to an analog-to-digital converter (ADC) without additional amplification. Equal strong impacts were exerted on all sensor land cases during these recordings. For more obvious comparison, the GSS-EBS signal was reduced by using an attenuator (1:3). All sensors show satisfactory signal level. The geophone GS-14-L3 shows a signal lower than that of the GS-20DX, which is in good accord with the manufacturer's data for these geophones [4]. The amplitude spectrum of these signals is shown in Figure 5 below.

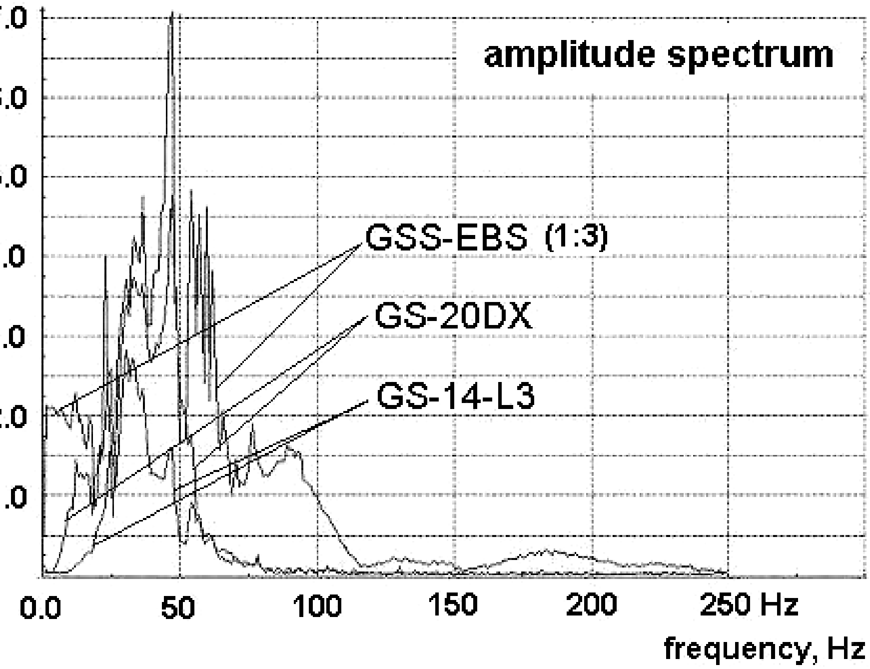

Figure 5. The amplitude spectrum of the seismic signals recorded by the GSS-EBS, GS-14-L3 and GS-20DX geophones and shown in Figure 4.

The land case installed GSS-EBS shows a much better response to low and high frequency signals than either the GS-14-L3 or GS-20DX geophones. As in the testing without land cases [1], the GSS-EBS 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. Note that the spectral responses of both the GS-14-L3 and GS-20DX geophones are in accordance with the manufacturer's data for these geophones [4]. It is interesting that at frequencies 25-50Hz, the amplitude spectrum of all sensors have the similar shape. Therefore, if we trust the manufacturer's data and suppose linear response curves for the GS-14-L3 and GS-20DX commercial geophones, these results confirm the linear response curve of the GSS-EBS at frequencies of 25-50Hz.

During the next series of lab tests, real environment conditions were simulated, wherein the footstep signal magnitude is very low. A weak impact was exerted on all sensor land cases and the amplifiers with a gain of about 10,000 were used for all geophones. Examples of such records and corresponding amplitude spectrum are shown in Figures 6 and 7 below.

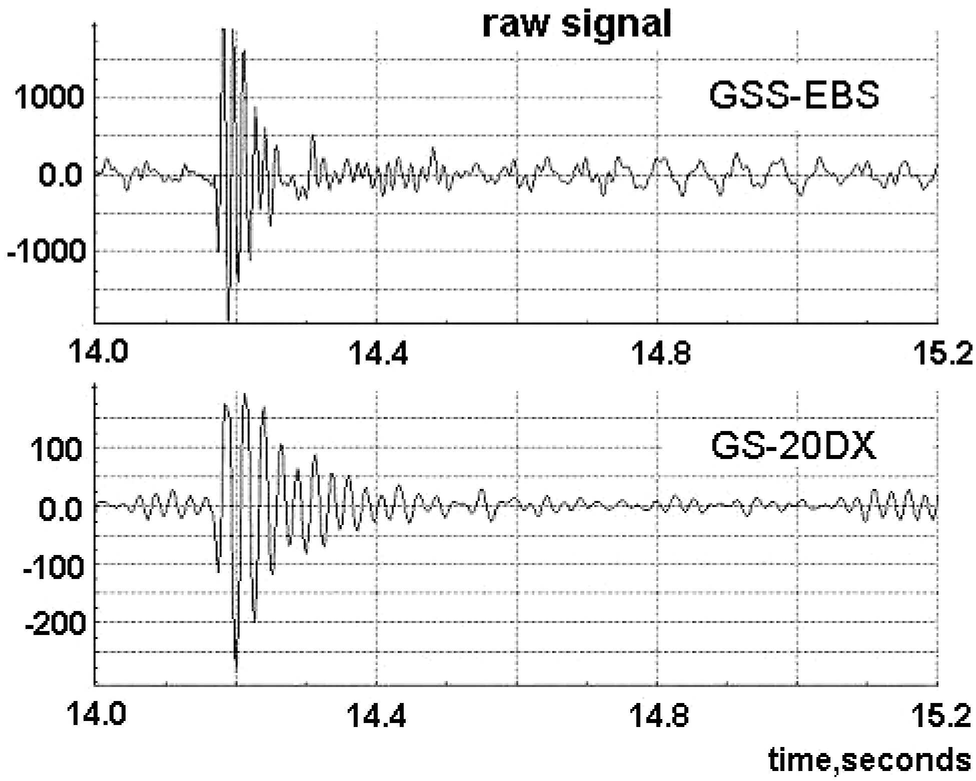

Figure 6. Records of the same seismic signal by the GSS-EBS and GS-20DX geophone. Weak impact and use of the amplifiers with gain of about 10,000 for all geophones.

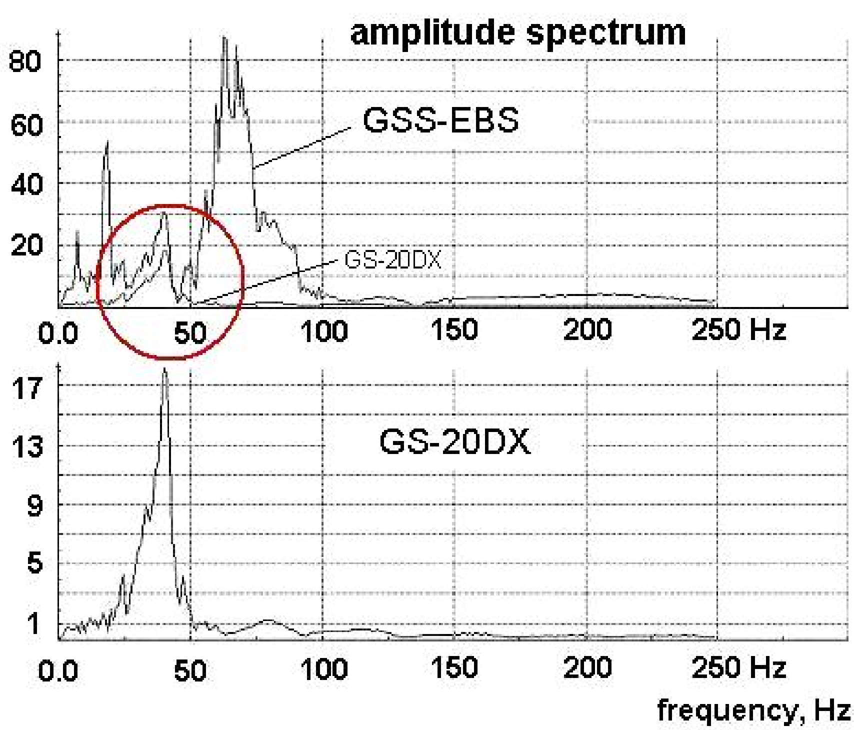

Figure 7. The amplitude spectrum of the seismic signals recorded by the GSS-EBS and GS-20DX geophone and shown in Figure 6.

The seismic signals and corresponding amplitude spectrum shown in Figures 6 and 7 indicate that for low amplitude signals, the GSS-EBS has significant sensitivity advantages versus the GS-20DX, the best commercial geophone at present time (note the vertical scale in Figure 6). These sensitivity advantages are very clear, especially at frequencies below 24-25Hz, and are crucial at frequencies above 45-50Hz. As in the case of strong impact, Figure 7 shows that the GSS-EBS has a linear response curve from weak impact at frequencies 25-50Hz because the shapes of both amplitude spectrum are similar at their frequencies. However, Figure 7 shows that at frequencies above 50Hz, in weak impact, existing commercial sensors do not actually have a response and are not comparable to the new GSS-EBS which has much better response to very small amplitude signals at both high and low frequencies.

This point is significant for real signal interpretation in heavy noise environments and is a significant advantage of the GSS-EBS's performance in comparison to that of the GS-14-L3 and GS-20DX.

2.3 Pilot field testing of new sensor

All field tests were performed in Westchester County, NY in two different areas. This is one of the most difficult situations for seismic detection systems—rock mountains with grass surface (a high rock density reduces the seismic waves amplitude, whereas a soft ground surface reduces the footstep impact on the medium/earth). An example of the pilot field test's environmental conditions in area #1 is shown in Figure 8 below.

Figure 8. Pilot field test's environmental conditions in area #1.

All geophones were installed in both areas right on the ground surface. They were positioned in a triangle with distance between each of about 40cm. The start position of the human tester was about 4m from of the triangle. A person was walking away from the sensors (see Figure 9).

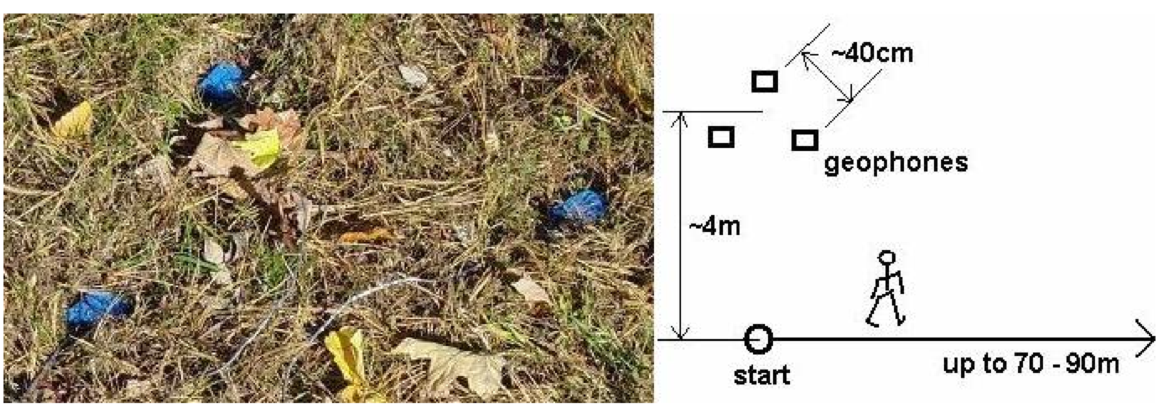

Figure 9. Test layout of geophones used to collect footstep data in both areas.

Recordings obtained in area #1 of the same seismic footstep signal and their envelopes are shown below in Figures 10 and 11. For convenience these figures show only the last 45 seconds of the recordings, where the seismic signal amplitude was low. Vertical scales are different for convenience.

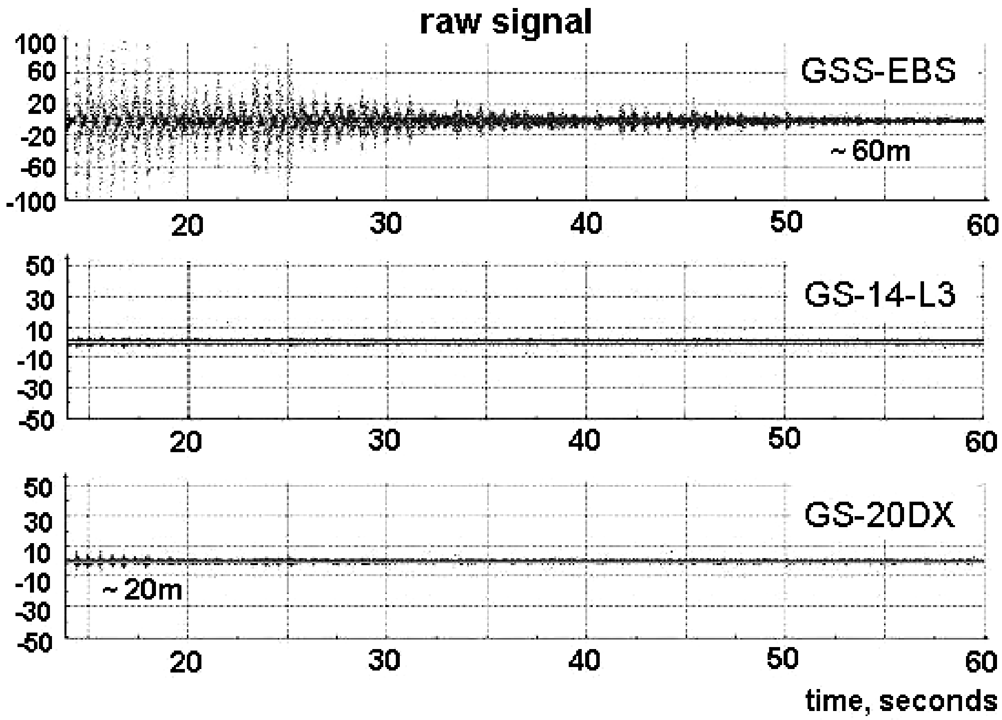

Figure 10. Recordings of the same seismic footstep signal (area #1). Last 45 seconds are shown.

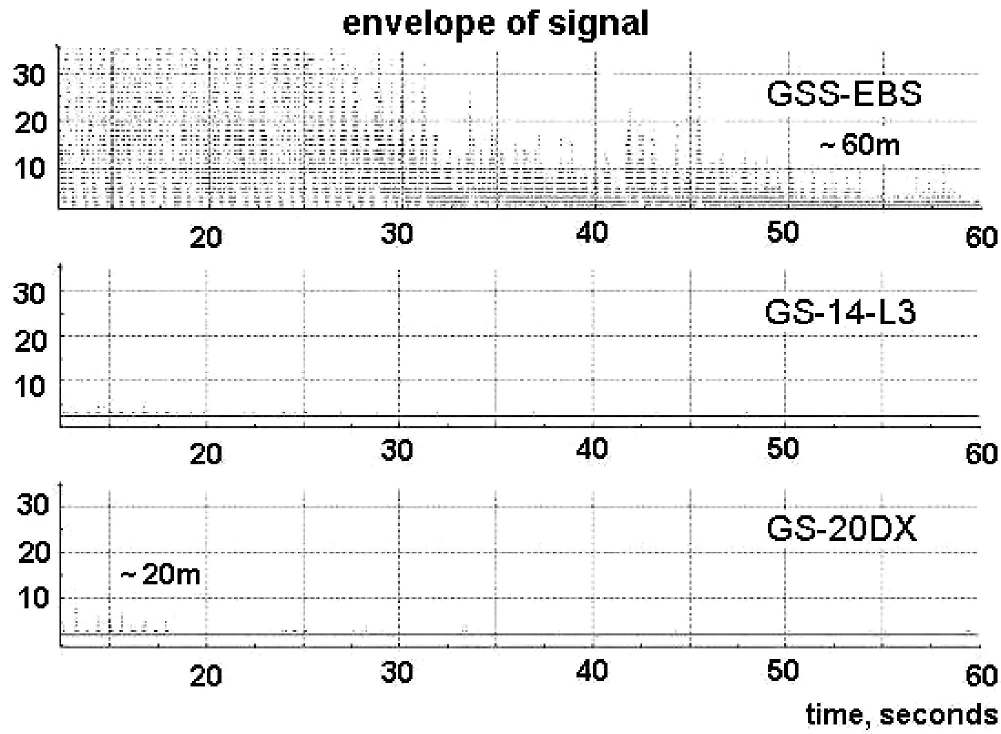

Figure 11. Envelopes of the signals shown in the Figure 10.

The data in Figures 10 and 11 clearly show that the GSS-EBS detects footstep signal by almost three times larger distance between the sensor and person—60 meters for the GSS-EBS versus 20 meters for the GS-20DX (the best geophone among the compared existing commercial geophones).

To better understand the advantages of the GSS-EBS, a highlight from Figure 10 of an area with one foot step signal is shown in Figure 12. The corresponding amplitude spectrum of the seismic signals is shown in Figure 13.

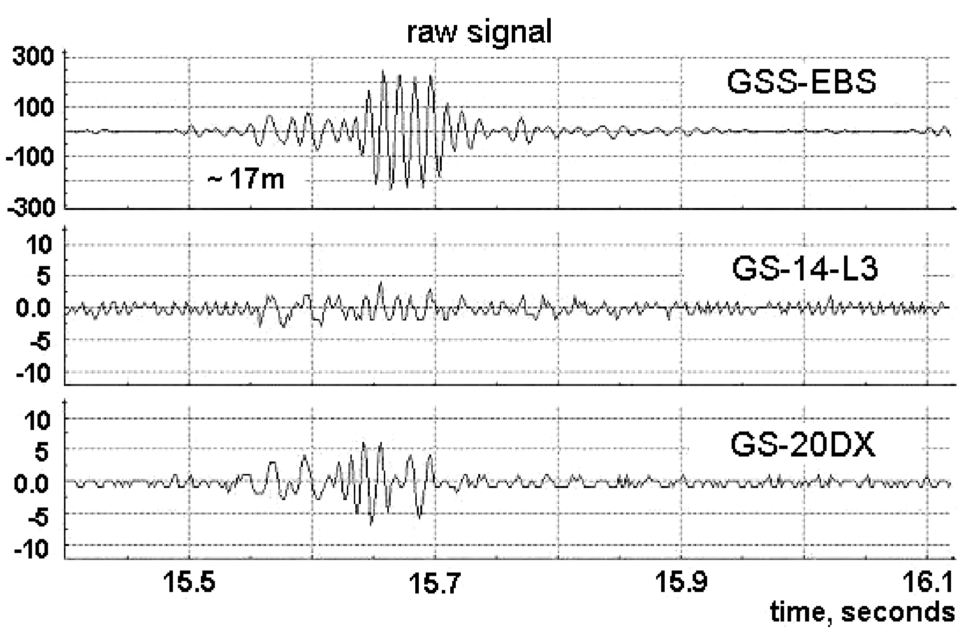

Figure 12. Highlight from Figure 10 of an area with a one step signal (Distance is about 17 m).

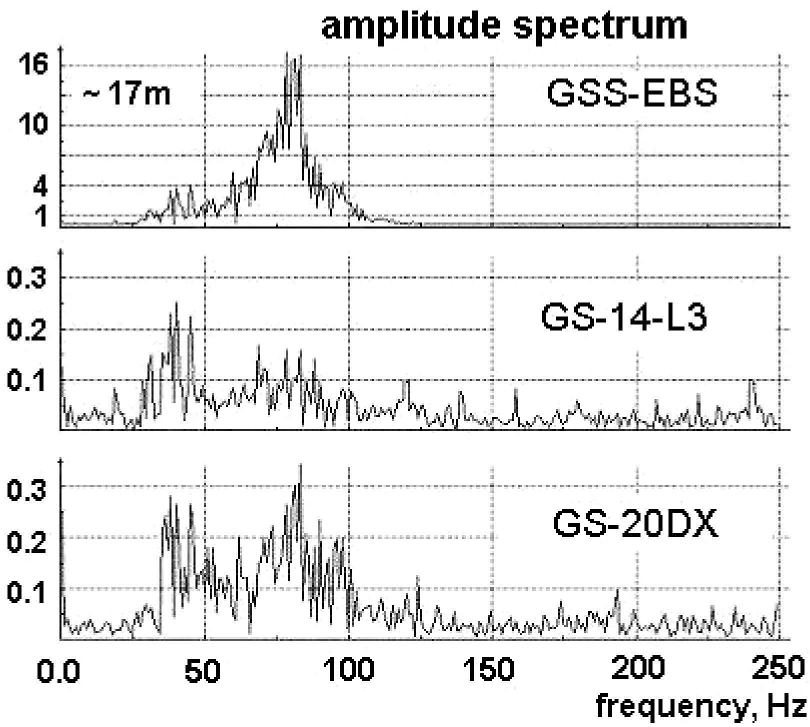

Figure 13. The amplitude spectrum of the seismic signals shown in Figure 12.

The selected area at the distance about 17 m is very close to maximal detection range of the GS-14-L3 and GS-20DX geophones. At this distance between the sensor and person the GS-14-L3 and GS-20DX geophones have very weak response at frequencies 50 to 100 Hz in comparison with the GSS-EBS. This allows to draw the conclusion that the GSS-EBS shows an increase in detection range due to better high frequency sensitivity that is in good accordance with our lab test data.

The same conclusion can be drawn from analysis of the amplitude spectrum of the footstep signals for different time marks (for different distances between sensors and walking person, see Figure 14 below).

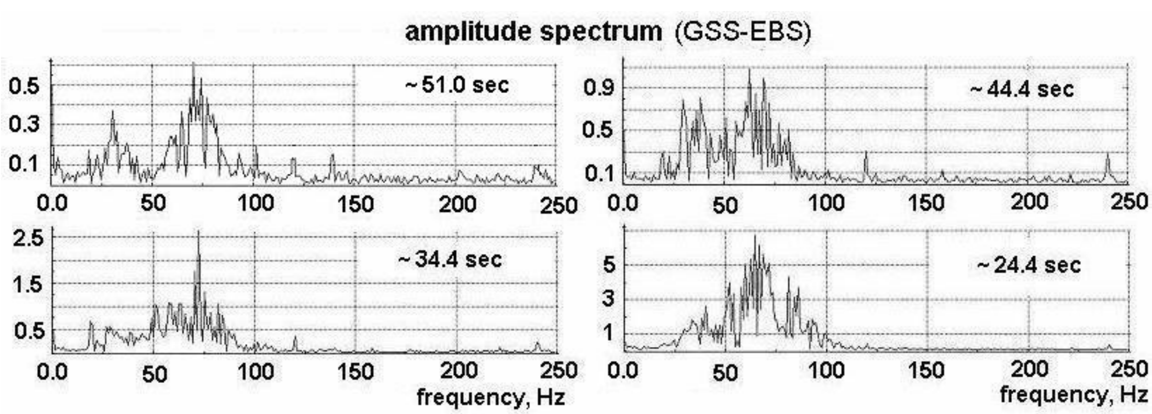

Figure 14. Amplitude spectrum of the footstep signals for different time marks (GSS-EBS).

It is very important for similar results to be obtained in the littoral region on soggy ground.

2.4 Final field testing of new sensor

Final field tests were performed in area #2. Area #2 consisted of a grass surface (meadow) on rock bottom. A person was walking away from the sensors. Envelopes of the same seismic footstep signal recordings for the maximal detection range are shown below in Figure 15.

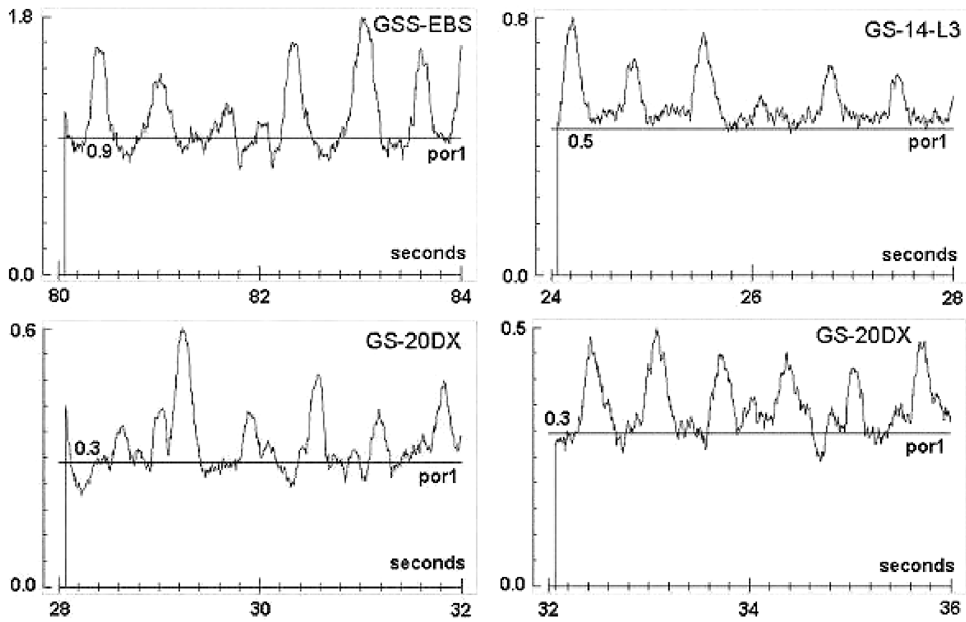

Figure 15. Envelopes of the same seismic footstep signal recordings with the time frames corresponding to the maximum of the footstep detection range. The level “por1” shows the value of the raw signal root-mean-square.

According to data from Figure 15, up to 84 second detection is allowed by the GSS-EBS and only up to 28-30 second detection is allowed by the GS-20DX and GS-14-L3 geophones. Therefore triple increase in footstep detection range is confirmed by area #2 testing.

3. CONCLUSIONS

In the previous paper [1], we presented the advantages of the new sensor in term of the basic volume-mass-price characteristics in comparison with the GS-14-L3 and GS-20DX geophones (according to manufacturer’s data [4]). All the above mentioned characteristics of the GSS sensor are significantly better than those of the GS-14-L3 and GS-20DX geophones.

In addition, the GSS-EBS shows higher sensitivity and lower sensitivity threshold especially in low and high frequency bands. Figure 16 shows in correct comparison qualitative scale advantages of GSS-EBS in terms of the sensitivity and sensitivity threshold.

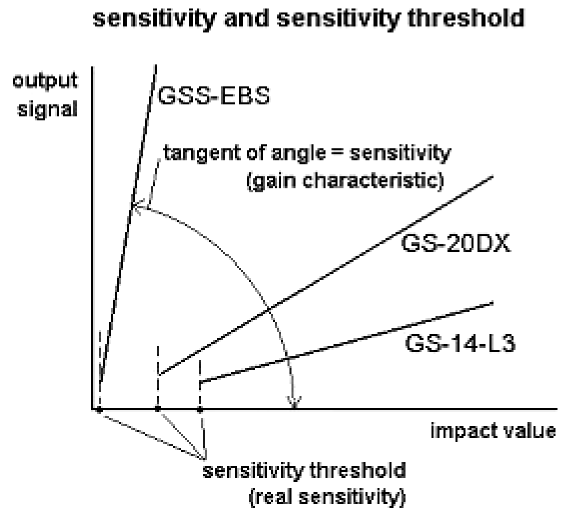

Figure 16. Higher sensitivity and lower sensitivity threshold of the GSS-EBS in comparison with commercial geophones.

Ultimately, the results of our lab and field testing of the new GSS sensor in comparison with the most popular commercial geophones demonstrated that in all the main characteristics, the GSS-EBS performs significantly better than the GS-14-L3 and GS-20DX geophones. For tactical applications, the most important characteristic is the GSS-EBS's triple increase in footstep detection range in real environment conditions.

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