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Wireless Seismic Sensor for Monitoring a Geographical Region

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Abstract

This paper presents a method for real-time monitoring of seismic activity in the Vrancea epicenter. A robust sensor was developed, that detects small and large amplitude seismic movement. It is equipped with a radio broadcasting warning system and it signals into the 144MHz band available to authorized radio amateurs. Earlier experiments approached a development solution based on a digital 2-axis accelerometer. Because traces of radioactivity were present in the sensor placement area, the internal operations of the digital accelerometer were disrupted and the experiment failed from the beginning. A classical method was adopted using oscillating movements of magnets that generate a variable electrical current to the terminals of coils. To increase the sensitivity of the detection coils, a special method of construction was tested, which also allows detecting the direction of the seismic source.

Key words: *seismic movement, detection, earthquake, sensor.*

Introduction

Located in the central-eastern Romania, the Vrancea epicenter area is characterized by a moderate seismic activity, resulting in an average of 3 devastating earthquakes per century. Seismic movement consists of interacting activity between the tectonic plates due to horizontal flow and vertical ascending magma currents, or plate movement due to deep Earth cavities crashes. In both cases low frequency vibrations are generated and spread in all directions. Speed of propagation for vibration environment differs from the nature of propagation environment [1]. Depending on the nature of rock, speed of propagation can vary between 1 and 14km/s [2], which is considerably lower than the propagation of electromagnetic waves. This way an interval of several seconds is obtained, in which the warning signal transmission, reception and security measures can be fulfilled. Transmission of warning signal must be done quickly and should not be disturbed by any delay factors. According to [3], advanced predicting systems are developed but they are still unable to provide the exact time in seconds. Predicting systems lets scientists know the about time the earthquake will happen. The system presented in this paper can prevent a set of damages if a series of tasks are carried out shortly before disaster happens. A good example is remote powering some electro valves to block the flow of methane gas at the distributing company and also on all the pipelines network segments. In the moment the earthquake hits, any possible damage on some segments of the network will release only the remaining gas pressure stored in those segments, avoiding further gas supply from the source or from other undamaged sections. This way any possible fire damage in the area of gas pipelines will be more limited. The diagram of the proposed system is shown in Fig. 1.

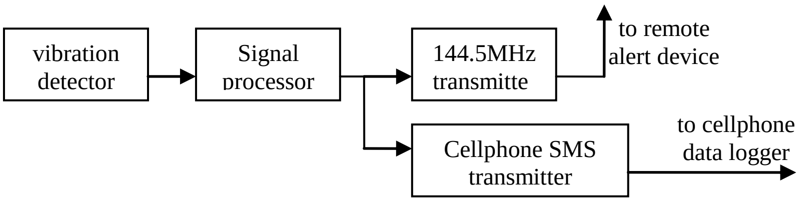

Fig. 1. Block diagram of the seismic sensor.

Digital vibration sensor

In order to carry out the experiment, a digital 2-axis micro-electro-mechanical system (MEMS) accelerometer was used, which is shown in Fig. 2.

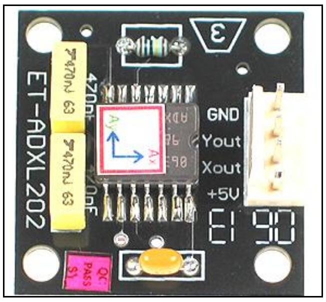

Fig. 2. MEMS ADXL202 accelerometer.

The sensor provides two digital (pulsing) signals (*Xout*, *Yout*) representing the mechanical vibrations detected on the corresponding two axis of coordinates. It also provides two analog (voltage) signals (*Xfilt*, *Yfilt*) marked as pin outs on the datasheet presented in [4] and proportional to the vibrations. An advantage of this sensor is the possibility of determining the direction of the detected mechanical vibration by vector-adding the information on the two axes. The sensor can detect acceleration from -2g and +2g at a minimum 1ms sampling rate. The detected frequencies are between 10 Hz and 5 kHz. Best resolution of detection is 0.4mg and corresponds, according to [4], to a 10ms sampling rate.

The analog output signals were processed according to Fig. 3.

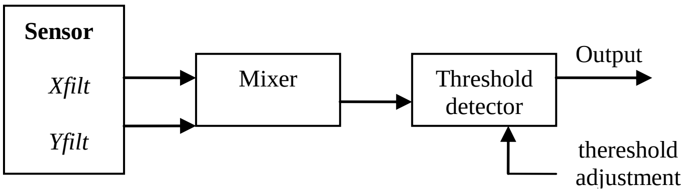

Fig. 3. Signal processing block diagram.

As the purpose of the experiment is to detect any vibration, the signals from both *x* and *y* axis are mixed and amplified in order to get the output signal. This process is ensured by the mixer block in Fig. 3. The threshold detector sets the lower limit of the detected signal for which the alarm state will be broadcasted.

The experiment for vibration detection took place in an isolated area. In the cities it is usually impossible to conduct measurements of the earth vibrations due to disturbances caused by traffic or by conflict with the law for the misuse of public gardens. A remote area outside the city was chosen because of its isolated location from urban traffic and factories noise. An important factor in choosing the area was its low exposure to weather phenomena such as storms or lightning.

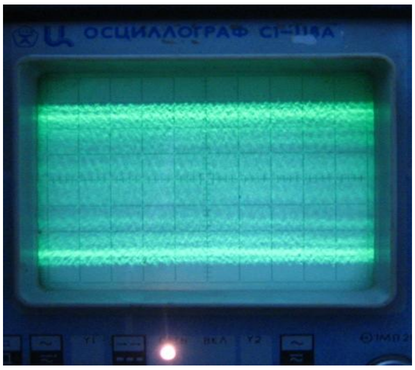

Fig. 4. Noise caused by soil radioactivity.

The sensor was tightly sealed in a metal box and buried at 50cm depth into the ground. The purpose of the experiment was recording on the oscilloscope the vibrations produced from a nearby stationing vehicle with the engine running. An unexplained phenomenon was noticed. The sensor indicated vibrations all the time it was outside of the ground, and then it refused to work inside the ground. Wave form inside the ground has been highlighted on the oscilloscope and is shown in Fig. 4. We can notice that no pulses occurred but a strong background noise. The phenomenon was explained using a Geiger-Muller counter which indicated almost the maximum allowed radiation at ground level and inside the soil.

Radiation damage is the general alteration of the operational and detection properties of any semiconductor detector. The main effects produced by high-energy particles are atoms displacements and long-term ionization, which are responsible for degradation and surface damages of the semiconductor [5], [6]. While the sensor is operating in these conditions, such effects also interfere in the output signals until the sensor will be irreversible damaged.

Classic vibration sensor

In the second part of the experiment, a classical electro-mechanic vibration sensor was developed which can also be used in determining the direction of the epicenter.

The classical model of the vibration sensor is presented in Figure 4.

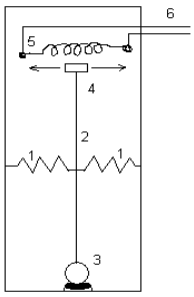

Fig. 4. Seismic sensor.

According to Fig. 4, the sensor components are as following:

1. Spring, small elastic constant;
2. Plastic rod with small metal sphere at its lower end;
3. Rounded half-sphere axle;
4. Magnet;
5. Coil;
6. Output electric terminals.

Two such devices were constructed and both placed in a single glass-fiber tubular cavity, which does not influence the magnets. The constructive difference between them is in the length of the pendulum rod. A device was fitted with a 1 meter length pendulum, the other with a 1 cm length. The springs were chosen to have the lowest elastic constant possible. The reason for using two detection sensors is given by the differences in amplitude and frequency between the two main types of seismic waves: pressure waves and transversal waves, which have different wavelengths, and the aim is to detect both types of wave.

In the first experiment each sensor was equipped with a circular coil with 100 turns and 8 ohms impedance. No metal core was used in manufacturing the coils in order not to influence the movement of magnets (Fig. 5). The two vibration signals from both detection coils were mixed and amplified. The vibration generator was a nearby stationed car with engine running. The resulting vibration signal picked from the input line of the threshold detector is shown in Fig. 6.

Fig. 5. Circular detection coil.

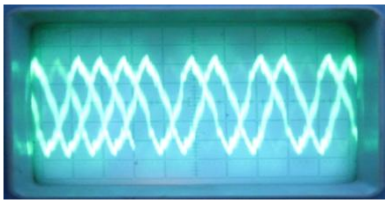

Fig. 6. Signal recorded from the circular detection coil.

In order to improve the sensor, a more complex structure was developed to increase the sensitivity but also for further development of the system to determine the direction of the seismic source. The schematics, the prototype and the construction concept are shown in Fig. 7.

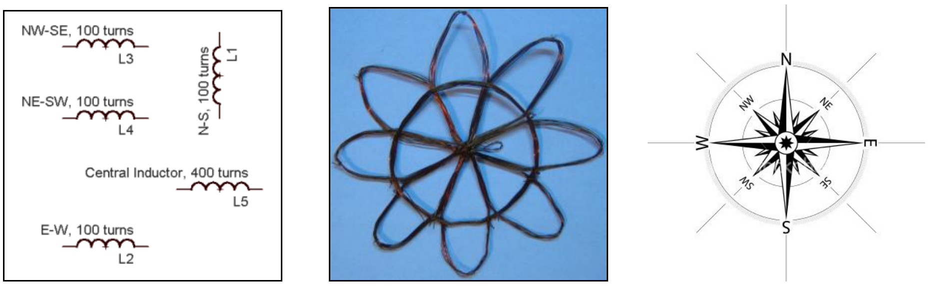

Fig. 7. Electric schematic, prototype and placements of the coils on cardinal points directions.

The circular coil shown in Fig. 5 is also present in the coil shown in Fig. 7. Its role is to detect the vibrations. To increase the sensitivity, the coil is winded with a greater number of turns than the first circular coil in Fig. 5 and the mixer stage was adapted for the new input impedance. Its aim is to detect the smallest vibrations. The three direction coils are able to detect signals coming from: north-south, east-west, north east – south west, north west – south east.

Kicking the sensor will trigger two signals as shown in Fig. 8. There are two sinusoidal signals of different amplitudes. The stronger signal is from the central coil and the weaker signal is from one of the direction coils. Because the vibrations caused by a kick are totally different from those produced by seismic movement, the sensor could not determine a precise direction. In this case, for any of the direction coils, the signal wave form is similar in form and size with sinusoidal upper half of Fig. 8.

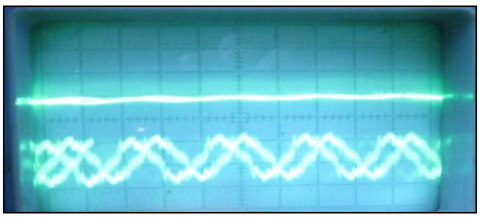

Fig. 8. Signal recorded from a direction coil (upper) and main coil (lower).

As the goal of this experiment is monitoring seismic vibrations, the 5 coils were inductively connected in series to an amplifier and a signal threshold detection module to determine the lower limit of the detected signal from that which the alarm signal will be broadcasted.

Remote transmitting system

Both the digital and the classic sensor that were presented in this paper have been connected to the radio transmitter and successfully tested in laboratory conditions. For a faster transmission of the alarm signal, a low latency transmission medium is required.

For finalizing the transmission module, three different possibilities were analyzed:

1. Internet connection - sometimes delayed due to extremely high traffic, because traffic flood generated by unprotected PC stations or unannounced interruption of service by the provider;

2. SMS alert – its delays are generated during authentication to cell relay, the processing time for the request, notice to receiver, the main transmission and the delay generated by internal functions of the recipient telephone;

3. Direct radio transmission system – the fastest method showing no latency.

There are networks of transceiver relays for radioamateurs frequency bands worldwide. A speciall HF-UFH third class transmission licence and at least 1W radio power are required in order to access the worldwide network of 144-146MHz radiorepeaters, which will carry this signal all over the world.

For broadcasting and receiving, two portable romanian military-type RTP-4MF transceivers were modified to work in 144.900MHz.

Fig. 9. RTP-4MF-S military-type radio transmitters.

Conclusions

During the experiments, two sensors with different manufacturing technologies were used, the system successfully passing laboratory tests in both cases. Shortly before triggering an earthquake, there are often high concentrations of radioactive element radon 222 in groundwater aquifers, almost to the upper natural limit. Digital sensor testing took place the morning of 21st March 2009, with the result already presented. Geiger meter showed a concentration of radiation in the soil higher than the natural environment and in the evening of the same day a small magnitude earthquake was reported by the sensor-based coils, and also the next day in the newspapers. The classic seismic sensor is operational 24 hours per day and is installed in the city of Focşani in a relatively quiet area at 3 meters depth into the ground. It must not be influenced by road traffic or maintenance activities issued by the municipal council. The sensor containing the two high and small amplitude detection devices is sealed and isolated against humidity, and it is shown in Fig. 11.

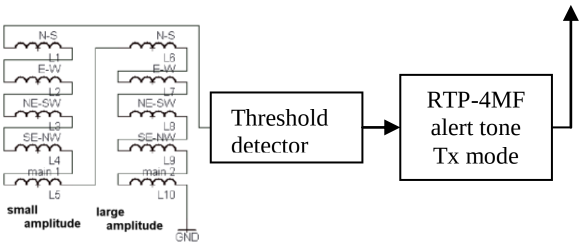

Fig. 10. Sensor schematic.

Fig. 11. Seismic sensor.

Some comparisons were made between the transmissions speeds via RTP-4MF and SMS service. A cell phone has been used to transmit the preprogrammed message consisting of the word *„earthquake”* at the time the sensor was triggered by a stroke. The distance between the city of Focşani and the city of Ploieşti is approximately 130km. Propagation time from the warning time until earthquake occurrence in Ploieşti is about 7 seconds. The minimum signal propagation of the warning SMS is also approximately 7 seconds and it was determined through a series of tests consisted in kicking the sensor and measuring the timing until the phone started the SMS warning signal. In other words the message reaches at the same time with the seismic waves. The biggest interval of time to receive the SMS during the whole test was 40 minutes. This means the transmission via SMS can only be used for information purposes, having no relevance for warning. The sensor can successfully detect any seismic activity and it warns when the magnitude exceeds 3 degrees on the Richter scale, as it is set into the threshold detector. Last four earthquakes with magnitude over 3.5 degrees were indicated at October 15th 2008, December 17th 2008, March 2nd 2009, March 21st 2009. This system can be successfully implemented in the field of industry and civil protection by interfacing it to different objectives that require special attention during seismic movements, such as methane gas pipes network.

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Senzor seismic cu radiotransmisie pentru monitorizarea unei regiuni geografice

Rezumat

Lucrarea prezintă o metodă de monitorizare în timp real a activităţii seismice în zona de epicentru Vrancea. A fost dezvoltat un senzor robust ce detectează mişcările seismice de amplitudini mici şi mari şi dotat cu un sistem de radiotransmisie a semnalului de avertizare în banda de 144 MHz disponibilă radioamatorilor autorizaţi. La începutul experimentelor a fost abordată soluţia dezvoltării pe baza unui accelerometru digital cu detecţie pe 2 axe. Datorită urmelor de radioactivitate prezente în zona de amplasare a senzorului, operaţiile interne ale accelerometrului digital au fost perturbate iar experimentul a eşuat chiar de la început. A fost abordată o metodă clasică folosind mişcări oscilatorii ale unor magneţi ce generează un curent electric variabil la bornele unor bobine. Pentru mărirea sensibilităţii detecţiei, a fost testată o metodă specială de construcţie ce permite şi detectarea direcţiei epicentrului.