



## Doppler Effect and Acoustic Trails of Neutrinos

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### Abstract

*In the monitoring mode, signals averaged over 1 minute were recorded in four one-third octave bands: 30, 160, 500 and 1200 Hz. Sometimes, audio signals were recorded using a computer sound card. These signals had varied and surprising forms, but there was no technical capability to record them in monitoring mode. This opportunity appeared in California in 2015. In the period from 2015 to 2017, in the SAFOD pilot well in California at a depth of 1000 m with coordinates 35.974257 N, -120.552076 W, seismological surveys were carried out for the first time using the innovative MIG-3V geophone with a wide band in the infrasonic and sound frequency ranges and in the amplitude range of more than 240 dB. In August 2016, a similar geophone for the same purpose was installed in the VGS well with coordinates 56.967017 N, 43.720605 E to a depth of 1400 m. Digital data in the automatic monitoring mode was recorded continuously every 0.1 ms. Analysis of the data obtained in the SAFOD well (more than 4 TB) showed that, along with seismic signals, there are acoustic traces in the data, which have never been observed in the wells before. Similar tracks were observed in the VGS well. Acoustic trails similar in shape and frequency are observed in the aquatic environment of lakes and Oceans when searching for acoustic trails from high-energy cosmic particles, in particular, with the help of acoustic neutrino detectors.*

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## Introduction

The main goal of the study is to show a wide range of specialists the possibility of studying high-energy cosmic particles not only in water or ice, but also in rocks, using the existing numerous wells. And to identify traces of cosmic particles against the background of seismic and electrical interference, the Doppler Effect can be used.

K. Doppler in 1842 discovered that the frequency of acoustic radiation observed by the receiver becomes higher when the source approaches the receiver and less when the source is removed from the receiver. If the source and receiver of the sound do not move relative to each other, then the Doppler Effect is not observed (Dingle, 1960). This means that it is possible to use the Doppler Effect to identify the acoustic traces of neutrinos, the "fragments" of which move at high speed relative to the receiver, in contrast to acoustic signals from biological sources or interference from electrical networks and devices. Both those and other sources of acoustic or electrical noise either do not move, or their speed is low for the Doppler effect to be noticeable (Vandenbroucke et al., 2005; Tingle et al., 2017).

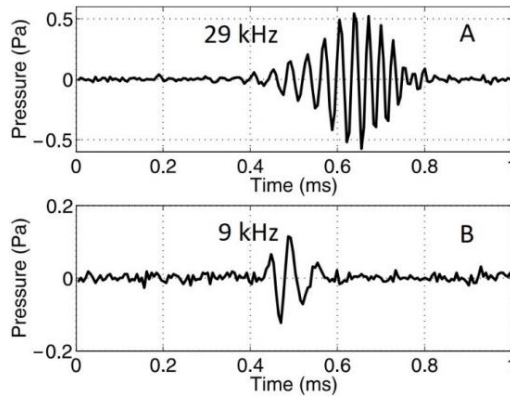


Figure 1. View of fragments (1 ms) of hydrophone tracks with acoustic events.

Figure 1 shows a diamond-like event “A” with an average frequency of about 29 kHz, which was recorded by an array of hydrophones located in a deep sea channel near the Bahamas at coordinates  $24^{\circ} 30' N$  and  $77^{\circ} 40' W$ . Frequency of the event from beginning to end, it increases markedly, which is typical for sounds of animal origin, but signs of the Doppler Effect are not observed. Therefore, it can be assumed that the frequency changes in the source itself, and the event is not associated with neutrinos. The second event “B” is multipolar with an average frequency of about 9 kHz and a noticeable decrease in frequency in the second half of the event has signs of the Doppler Effect (Wolf , 1990).

Figure 2 shows short (2 ms) fragments of three orthogonal components (X, Y, and Z) of the minute track of the device installed on the second floor of a wooden building in a dense urban environment. The event in Figure 2 has significant amplitudes in all three directions with an apparent frequency of 16.6 kHz. It is preceded and accompanied by oscillations with significantly lower amplitudes and an apparent frequency of 25 kHz. The waveform is similar to a "diamond", but the Doppler Effect is not observed. Most likely, this is a signal from a stationary electromagnetic source, especially since air and underground power networks and devices are located in the immediate vicinity of the receiver.

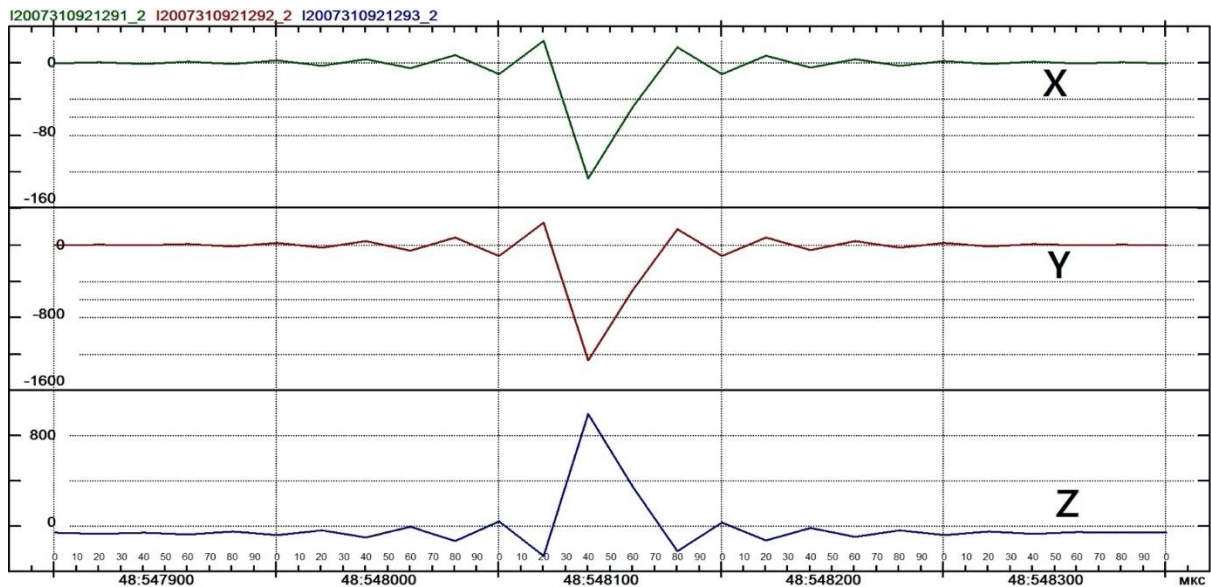


Figure 2. View of fragments (0.00202 s) of minute tracks of two horizontal (X, Y) and vertical (Z) channels (from top to bottom) with 100 kHz digitization

## Methods

Recently, the scientific community has been discussing the possibility of detecting neutrino traces not only in water or ice, but also in the solid medium of the earth's crust (Trzaska et al., 2019). Figure 3 shows the result of comparing bipolar pulses generated by ultra-high energy particles: in rock - A (red line) and in water - B (blue line). Judging by the figure, it can be seen that the signal amplitude in the rock is an order of magnitude higher than the signal amplitude in water, and the frequency is three times higher. Such a “gift of nature” must be used, especially since the innovative technology for measuring high-frequency acoustic signals in harsh environments with amplitudes of up to  $10^{-15}$  m and in less detail has been developed and passed long tests.

The proposed method for detecting and identifying acoustic traces in wells became possible only after the creation of an innovative Magnetoelastic Inertial Geophone (MIG-3W), which measures the amplitudes of the orthogonal components of the displacement acceleration velocity vector (“jerk of velocity”) in rigid media. The created geophone has an amplitude-frequency characteristic similar to an electrodynamic geophone, but differs from the latter in that its mechanical resonance can reach several thousand Hertz, up to which the sensitivity grows at a rate of 60 dB per decade of frequency increase.

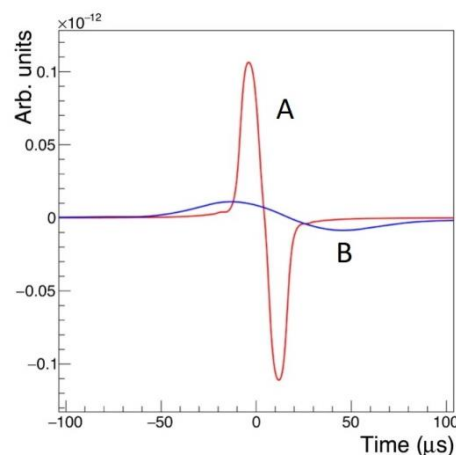


Figure 3. View of a track with a duration of 200  $\mu$ s, on which bipolar pulses are combined in rock A - (red line) and in water - B (blue line)

At the end of 2015, a MIG-3V geophone was placed in the SAFOD well with coordinates 35.974257 N and -120.552076 W at a depth of 1000 m and continuous monitoring of seismoacoustic emissions and earthquakes began. In August 2016, a similar geophone for the same purpose was installed in the VGS well with coordinates 56.967017 N, 43.720605 E to a depth of 1400 m. In the data from both wells, in addition to seismic signals as a "by-product", acoustic tracks similar to neutrino tracks were found, which are given in numerous publications on acoustic neutrino detectors (Belyakov, 2017). In boreholes, signals similar to “diamond” tracks have an apparent frequency of about 5 kHz. Basically, these are from 10 to 12 oscillations with smoothly increasing and smoothly decreasing amplitudes, which can be identified using the Doppler Effect as neutrino tracks

## Results and Discussion

Figure 4 shows two minute tracks recorded in the SAFOD well in California at a depth of 1000 m with a high-resolution vector geophone in amplitude and frequency and an analog-to-digital recording system with a sampling rate of 10 kHz. The top track is the horizontal direction, the bottom track is vertical. On both tracks, the maximum amplitudes of “diamond” events reach 150 mV horizontally and 300 mV vertically, with background amplitudes of 20 and 40 mV,

respectively. If we look at the given tracks in more detail, we can find other similar events with lower amplitudes.

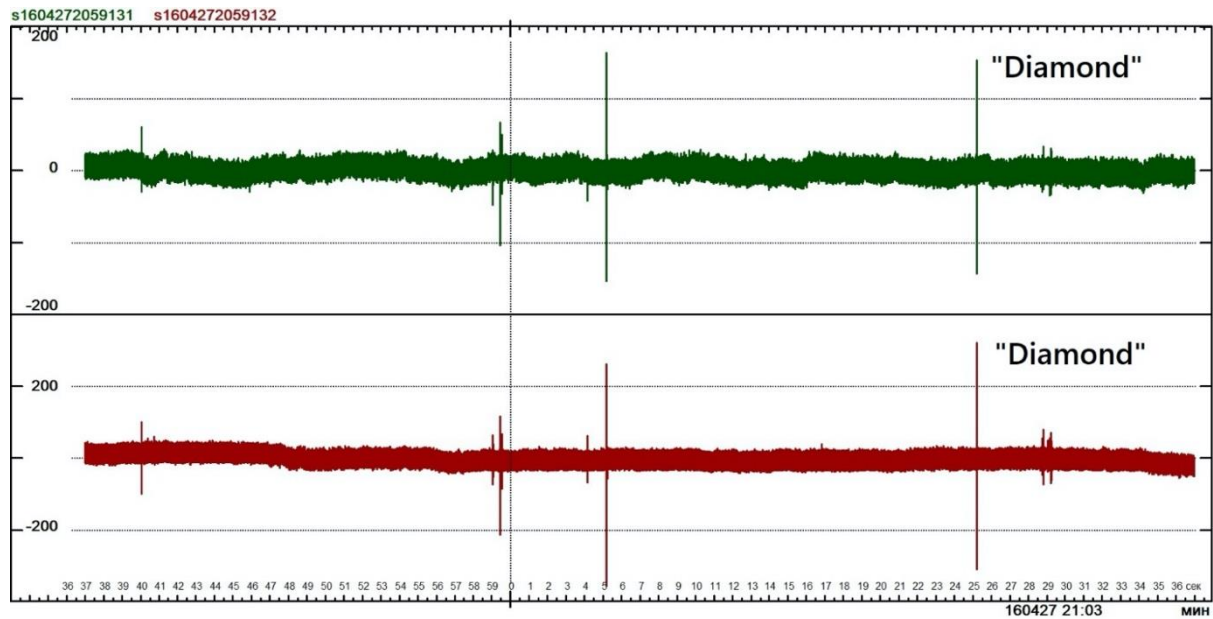


Figure 4. View of the minute track of the vertical and horizontal channels

In a more detailed time scale, a fragment of this picture is shown in Figure 5. In a detailed examination of short fragments of horizontal and vertical tracks, the amplitude in the horizontal track is close to 150 mV. In addition, in the vertical - up to 300 mV. In addition, the Doppler Effect is quite clearly observed: when approaching, the frequency is high, and when moving away, the frequency is low. Figure 5 shows this with the naked eye.

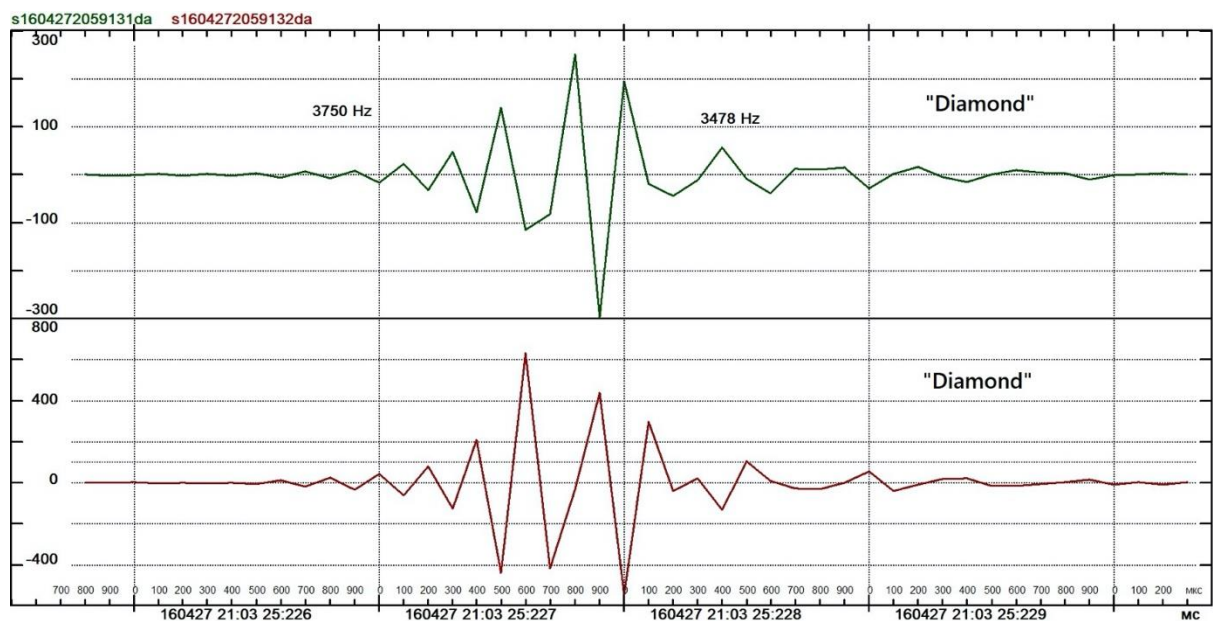


Figure 5. View of a fragment on a large scale (0.0047 s) of a minute track of the vertical (bottom) and horizontal (top) channels.

Traces of the same shape as in Figure 5 are called "diamond". In this case, they have a frequency of 3750 Hz when approaching the registration point, and a frequency of 3438 Hz when moving away from it. Everything is as with the Doppler Effect. Such traces in wells are common, but not massively. There are other similar traces, the frequency of which does not change. This is mainly electromagnetic interference and should be ignored.



Figure six shows a one-minute track of a vertical channel at a depth of 1000 m, where a lot of bipolar events are observed. Unfortunately, the instability of the zero level of the horizontal channel registration system did not allow showing it.

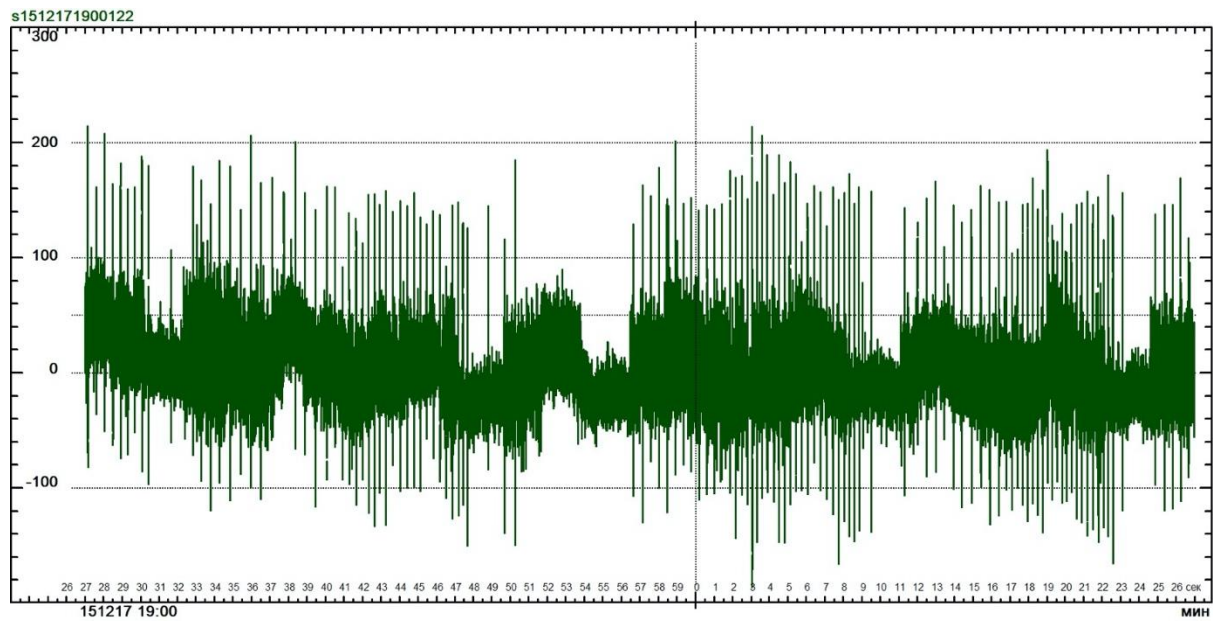


Figure 6. View of the minute track of the vertical channel with a mass of bipolar events

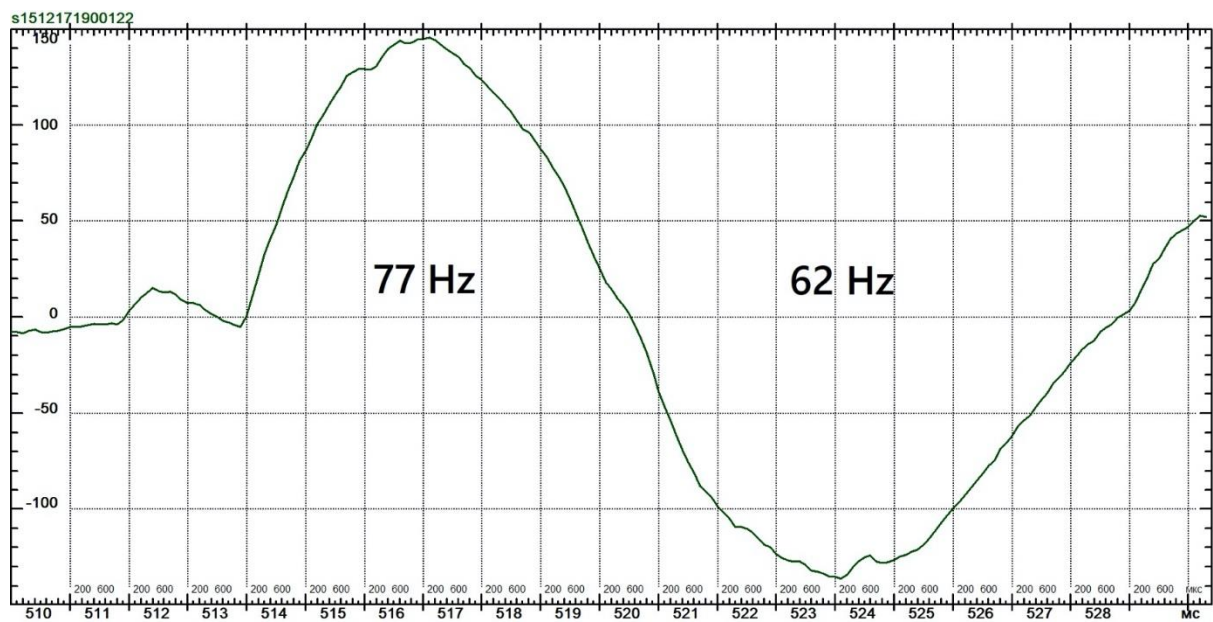


Figure 7. View of a fragment (0.019 s) of the minute track of the vertical channel.

In Figure 7, for the example of two half-waves of a bipolar pulse, the amplitudes of which are about 150 mV, it can be seen that the Doppler Effect for this case is expressed as a decrease in the apparent frequency at the receiver by 15 Hz after the source has passed through the receiver and moved away from it.

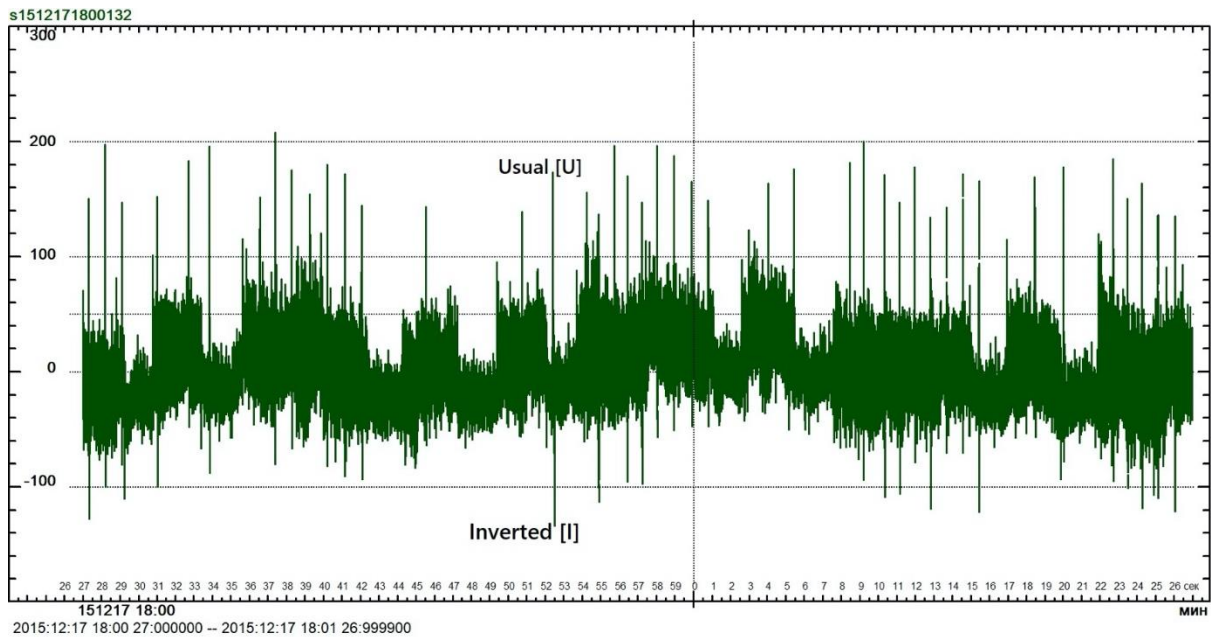


Figure 8. View of the minute track of the vertical channel with a series of unipolar impulses.

In Figure 8, at a distance of 25.5 s from the origin, two pulses were detected side by side: normal and inverse, which are shown on a larger scale in Figure 9. An inverted bipolar pulse is rare. It is very difficult to search for it in a large mass of ordinary events in manual mode.

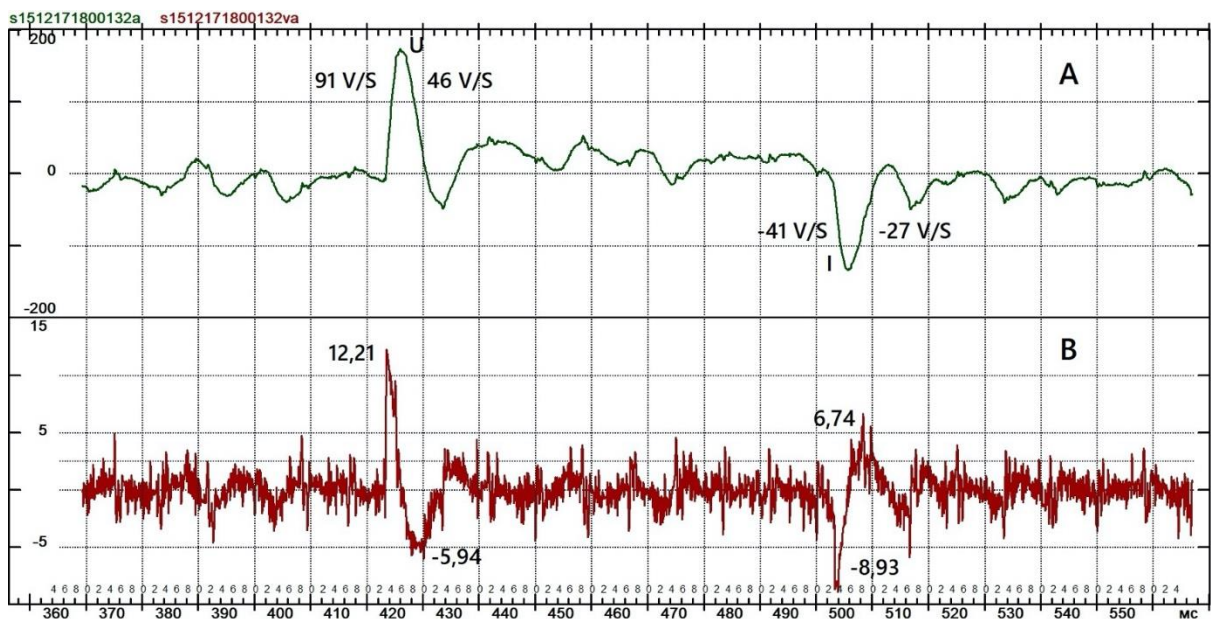


Figure 9. View of a fragment (0.2088 s) of the minute track of the amplitudes of the vertical channel - A and the rate of change of the amplitudes - B.

Track A shows the amplitude values of the pulses: about 170 mV for the positive pulse U and about 130 mV for the negative (inverted) - I. In addition, the rate of rise and fall of the amplitudes in physical units is shown. Track B shows the rate of rise and fall of the pulse amplitudes, calculated programmatically in arbitrary units. As you can see, both normal and inverted pulses have slew rates significantly higher than the fall rates, which can be caused by the movement of the signal source.

The original results shown in the previous chapter were obtained for the first time in world practice. This is due to the fact that these results were obtained by an innovative device, the characteristics of which are unknown to a wide range of scientists studying the flows of high-

energy cosmic particles. The fact is that the innovative fourth-generation MIG-3V geophones were manufactured in a pilot batch in small quantities in 1989-1990 and sold to Japan, Italy, Greece and the former Yugoslavia, but nothing is known about the fate of these devices. It is only known that in New Delhi, Republic of India, a geophone was installed at the Kamla Nehru Ridge observatory in a specially drilled well with a depth of 100 m and was continuously monitored from 2007 to 2010. Unique results were obtained on fluctuations of acoustic noise, synchronized with the rising and setting of the Sun (Belyakov, 2019). To our great regret, the signal registration system was focused on recording slow processes and could not record the flux of cosmic particles, although very large resources are spent on such studies in many countries (Landgrebe, 2003). For this, underwater and underground structures of a huge scale have already been built and are continuing to be built, which indicates the great importance of research carried out in this direction

## Conclusion

Alternative studies in shallow and deep wells will significantly expand the possibilities of studying cosmic particles. This is facilitated by the fact that a huge number of wells have already been drilled on all the Continents and many islands of the Earth, most of which are not used for their intended purpose. If desired, some of them can be used to create "neutrino" observatories, the cost of which will be incomparably less than the cost of marine and mainland observatories. Experiences of creating such observatories that have been operating in an autonomous mode for years have already been taken on the example of the SAFOD well in California, USA, in which more than four TB of digital information has already been received from a depth of 1000 m and which is waiting for its researcher. The second well is VGS in the Russian Federation. Its depth is more than 5000 m, and the geophone is installed at a depth of 1400 m in open space (without a casing). At a distance of 60 m to the South in a satellite borehole (SS), a similar geophone is installed at a depth of 553 m, also in an open rock space. On the basis of these two wells, the Institute of Physics of the Earth and the Institute of Applied Physics of the Academy of Sciences of the Russian Federation created a Geoacoustic Observatory with an equipped infrastructure.

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