Autonomous instrument system for monitoring radioactivity, underground gases and environmental parameters underground

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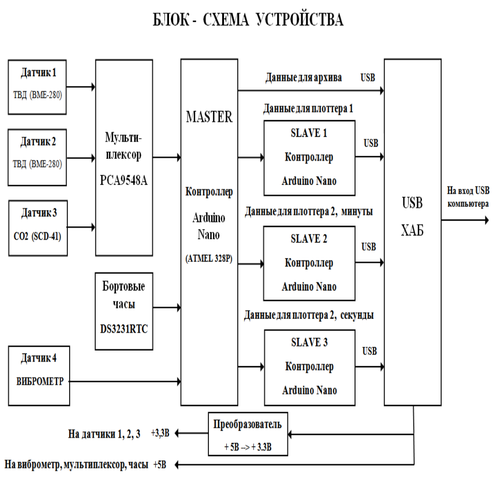
For experiments on searching for rare underground events, such as detection of solar neutrinos, neutrinos from supernovae, neutrinoless beta decay, the main problem is the background variation. Regardless of the detector power supply, two types of backgrounds can be specified: muons and natural radioactivity of construction materials, rock, as well as a variable component of radioactivity - underground gases. Emissions of radioactive gases can be a consequence of both impending earthquakes and changes in local humidity and pressure.

We have created an autonomous station capable of monitoring environmental parameters such as temperature, humidity, pressure, CO_2 concentration, radon, density of positive and negative air ions, and measuring vibration levels in different frequency ranges. The universal complex displays all parameters online on the monitor screen and saves them to a file for further processing. A diagram of the developed complex and the limits of the measured parameters are presented. The measurement results for the underground room of the experimental hall of 40 m^3 at a depth of 10 m are given.



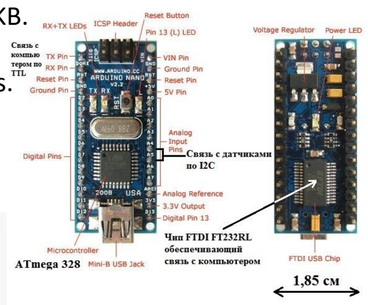
The hardware of the complex includes:

- Two temperature, humidity and pressure sensors (weather sensor) BME-280 by BOSH, Germany. One of them is built into the device case, the second is remote, on a 1.8 m long cable
- Multiplexer RCA9548A, designed to match two THP sensors with the same internal address with the microcontroller, as well as to match the logical levels of the sensors 0 ... 3.3 V with the logical levels of the microcontroller 0 ... 5 V.
- CO2 level sensor SCD-41 by Sensirion AG.
- Vibrometer sensor of our own design.- Voltage converter +5 V--> +3.3 V for powering the THP and CO2 sensors.
- On-board programmable real-time clock (RTC) DS3231, designed to link the received data to the time of their measurement.
- Master controller, built on the Arduino Nano microcontroller board, processes signals from sensors and outputs data to a registration text file and to additional controllers.
- Slave controllers for converting signals for output to graphs (Slave1 - Slave3), built on the Arduino Nano controller board.
- USB hub that combines signals from all controllers and outputs them to the computer.

Microcontroller made on the Arduino Nano platform

Main characteristics:

- Supply voltage +5 V.
- Logic levels 0 V, 5 V.
- Digital inputs/outputs: 14, of which 6 can be used for PWM with 8-bit resolution.
- Analog inputs: 8 10-bit DAC inputs.
- Max. input voltage +5 V
- Max. input/output current 40 mA
- Clock frequency 16 MHz.
- Flash memory 32 KB.
- RAM 2 KB.
- EEPROM 512 bytes.

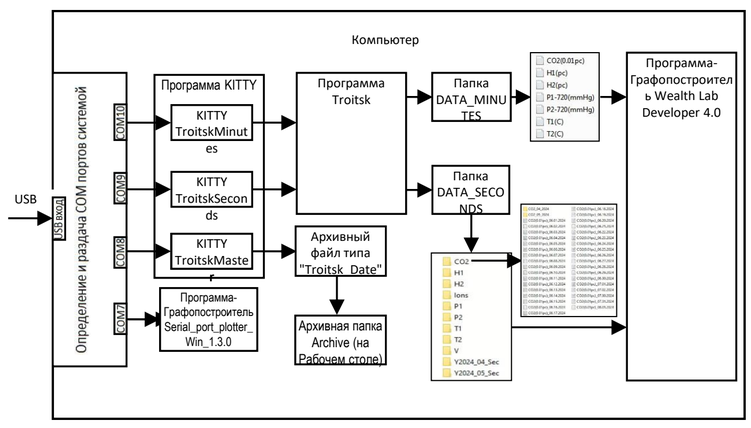


Temperature, humidity and pressure sensor (weather sensor) BME280

developed by BOSH has the following characteristics:

- Humidity: rise time constant up to 63% - 1 sec; absolute measurement error of relative humidity up to 3%, including hysteresis up to 1%.
- Pressure: temperature coefficient 1.5 Pa/˚C; absolute measurement error up to 1 hPa.
- Temperature: absolute measurement error 0.5˚C (25˚C) and 1.0˚C (-20...+60˚C). Operating range -40...+85˚C

Block diagram of the software package



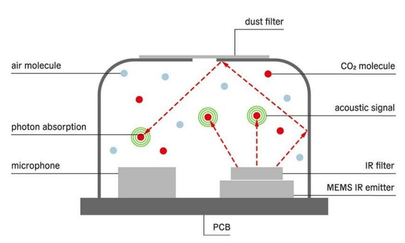
Modified negative and positive ion density recorder Sapphire-3M

It is designed to measure the concentration of light ions of positive and negative polarity in the air of premises.

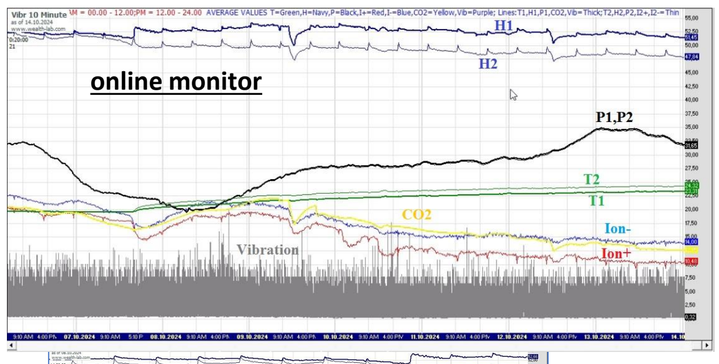
- Operating conditions: ambient temperature +22 (+/-5)˚C, relative humidity of ambient air: from 30% to 80%, ambient air pressure 760 +/-30 mm Hg.
- Measurement range of light ion concentration from $2x10^2$ to $1x10^6$ cm^{-3}.
- Ions are measured once every 4 seconds, the error of relative measurements is 3%.

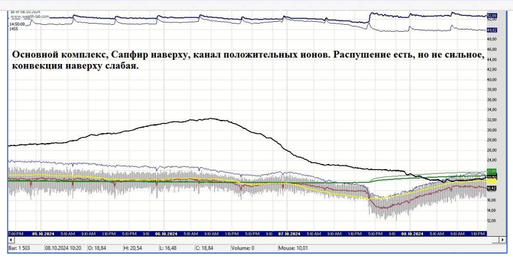
CO_2 level sensor:

- Measurement range 0 – 40000 ppm (0-4%) for SCD-41
- Absolute measurement error - 100 ppm (0.01%)
- Built-in self-calibration algorithm

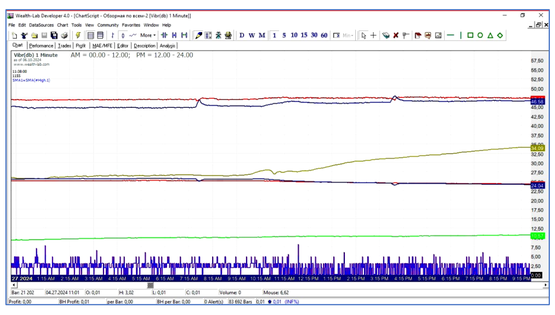


The sensor operates on the photoacoustic (optoacoustic) principle, with Sensirion's patented PASens and CMOSens technology.The effect consists of sound generation when gas is irradiated with IR rays. The absorption of radiation by gas molecules causes periodic local heating of the environment and an increase in pressure, leading to the occurrence of sound vibrations recorded by the microphone.The signal level from the microphone serves as a measure of the number of CO2 molecules in the measuring volume and is used to calculate the CO2 concentration. The use of PASens technology made it possible to create a miniature CO2 sensor, maintaining the main parameters at the level of the widely used NDIR (nondispersive infrared sensor) technology.





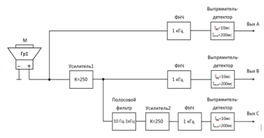
Moment of heating shutdown 04/27/2024At 10-15 cold water was supplied to the heating system, at 11-00 the water flow in the system was turned off



Vibrometer (our own design)

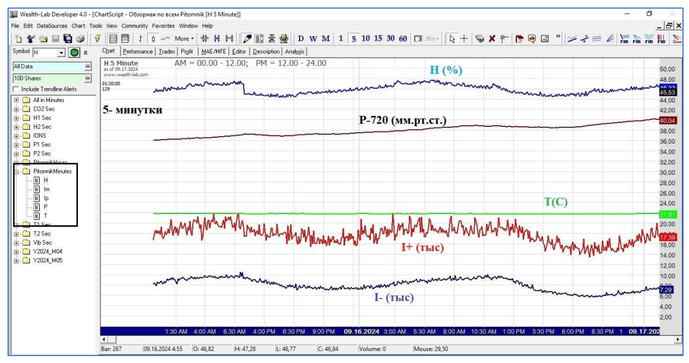
The sensitive element of the vibrometer is a speaker from headphones, sensitivity 100 dB/W, frequency range 20 Hz - 20 kHz, with a weight of 3.25 g glued to the diffuser (a coin with a nominal value of 1 ruble made of non-magnetic material, issued before 2012). The frequency of the system's own resonance is 32 Hz, due to which there is resonance at this frequency and an increase in sensitivity by 10 dB.

- The vibration level measurement range is about 75 dB with unevenness (range overlap) of 5 dB.
- It is made according to a sequential three-stage scheme.
- The role of the first stage is played by a broadband headphone speaker with a diameter of 50 mm, a sensitivity of 100 dB with an inertial load of 3.2 g glued to the diffuser.
- The natural resonant frequency of the system is 35 Hz.
- Max. output voltage from the head is 350 mV.
- The other two stages are amplifiers with a voltage gain of Ku = 300 each.
- From the output of each stage, the signal is fed to its own rectifier-detector, which generates signals for the ADC inputs of the microcontroller.



The complex allows:

1. *Measure physical parameters of the environment - ambient air temperature, humidity and pressure.*
2. *Measure vibration levels in different frequency ranges, which increases its sensitivity and allows monitoring crustal disturbances in the far and near zones and predicting possible earthquakes.*
3. *Measure the level of CO2, which, along with water vapor, is the main product of gas formation in seismically hazardous zones.*
4. *Read data on positive and negative ions from the Sapphire-3M ion recorder.*
5. *Output the obtained parameters to a single file and to graphs for monitoring and primary data processing.*



He –model collaboration: N.Yu. Agafonova[1], A.A. Afonin[6], V.V. Ashikhmin[1], L.B. Bezrukov[1], N.M. Budnev[5], R.I. Enikeev[1], E.A. Dobrynina[1], Yu.N. Eroshenko[1], S.V. Ingerman[1], I.S. Karpikov[1], V.V. Kazalov[1], V.M. Kolesnikov[1], A.K. Mezhokh[1], V.P. Morgalyuk[3], L.V. Pankov[4], V.B. Petkov[1], V.V. Sinev[1,2], I.R. Shakyrianova[1], V.F. Yakushev[1]

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The 7th International Conference on Particle Physics and Astrophysics (ICPPA-2024), 22-25 October 2024, MEPhI, Russia

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