Autonomous wireless sound gauge device for measuring liquid level in well

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Abstract. The paper describes an acoustic measurement and control method for remote monitoring of liquid level determination in wells and reservoirs. Before the paper, the task was to increase the depth of non-contact measurement of the liquid level in the well by measuring the time of direct propagation of ultrasound from the transmitter to the receiver, which, in contrast to the reflected sound, provides a much greater range of sound propagation and also the range of measurement and monitoring it using GSM networks. Data is returned to the main module via a USB channel or wireless radio transmitter 24 from the measurement channel. With the help of the first, ultrasound's propagation speed is determined, and the second time determines the distance from the installation site of the main module to the measuring part located on the surface of the well water in a floating position. In the main microcontroller, if the GSM network is available 16, the data is transmitted to the host server; otherwise, it is stored in the internal flash memory to wait for the availability of the GSM network, after which again, all micro-controllers of the device switch to energy-saving mode until the next measurement cycle.

1 Introduction

The article is devoted to acoustic methods of measurement or control, and the considered method can be used to determine the liquid level in wells, wells, and reservoirs.

Known methods and devices for measuring the water level in wells (or a vessel) according to patents in Europe [1], USA [2], and China [3] containing an ultrasonic emitter and a sensor, characterized in that the acoustic transducer is located in the upper [2] or lower part [1] of the pipe (or vessel) and is designed to emit a sound pulse, which is reflected from the surface of the liquid level, also to receive the reflected pulse.

Disadvantages: due to the echoscopic (using reflected signal) method, non-contact measurement of large depths of the water level is not provided, or it requires a large radiation power, which is not acceptable for autonomous battery-powered systems.

It is also known as a method for measuring [4] the level in hydrogeological wells using a non-contact sonic level gauge, including the supply of an audio signal through the open wellhead, receiving the reflected signal, and calculating the time of passage of the signal of the depth of the water surface, in that before using the sonic non-contact level gauge, it is

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calibrated with a high-precision a level gauge, for example, of a contact type, and correction is carried out by introducing a correction factor, and from the received reflected sound signal, a signal is selected that has the longest transit time with the highest amplitude, and the level depth is calculated using this signal.

The disadvantage of this method is the need to use the reflected echo signal, which greatly reduces the measurement distance [10-13].

Closest to the one under consideration is a method and device for the oil and gas industry in determining the liquid level in wells and in hydrodynamic studies of wells [5]. In the well, according to a given program, a sound, and electromagnetic wave are simultaneously created, which is the starting point for the time of passage of a sound wave from the liquid level to the wellhead, the time of passage of sound wave from the level to the wellhead and the speed of sound in a gaseous medium is measured, followed by determining the distance using the formula $H = t \times V$, where H is the distance from the mouth to the water level, a, t is the time of passage of a sound wave from the mouth to the level, and V is the speed of sound in a gaseous medium.

The disadvantage of this method is the complexity of the design of the floating part, and the catcher also does not provide high accuracy since the current temperature of the gas medium is not taken into account; where the sound wave propagates, the speed of which strongly depends on the temperature of the medium. The sound emitter is located in the floating part, which limits the measurement distance due to the limited self-contained power supply elements.

1.1 Ultrasonic method of direct measurement of water level in boreholes and wells

The objective of the invention is to create a non-contact, battery-powered wireless system for increasing the accuracy of measuring the water level in deep wells [6-10].

The task is achieved by the fact that the proposed device consists of three parts (Fig. 1) with an autonomous battery (accumulator) power supply, and the water level is measured by direct radiation of ultrasound with a frequency of 40 kHz from the sound generator located in the first part installed at the wellhead, and the reception of this ultrasound is carried out on the receiver installed in the second part, which floats freely on the surface of the well water. There is also a third calibration part, lowered into the well strictly 5 meters from the first part using an armored USB cable, which also has an ultrasonic receiver to determine the speed of sound propagation in the airspace of the well. To calculate the ultrasound propagation time from the generator to the receiver of the calibration part, a sync pulse is simultaneously generated via the USB cable. Also, at this time, the first part generates a synchronization radio signal at a frequency of 433 MHz to measure the propagation time of the ultrasound to the receiver located in the second part. Accordingly, the calibration part via the USB cable a, the second part through the radio channel returns the propagation time of the ultrasound back to the first part, where the water depth is calculated and transmitted to the server via the mobile network using a GSM modem.

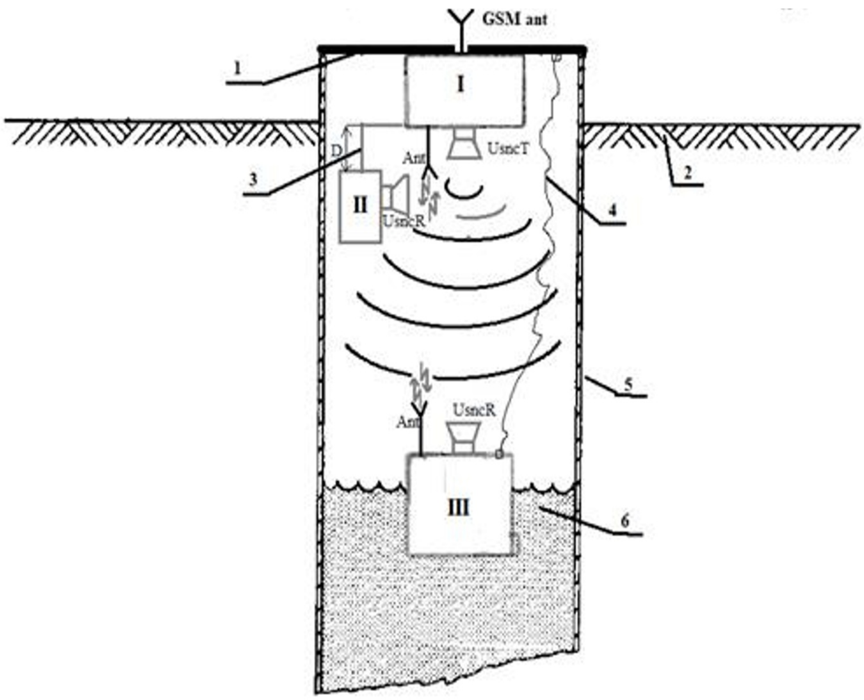

Fig. 1. The structure of the method and the device for measuring the water level in the well: 1 is well cover; 2 is soil (ground); 3 is armored USB cable D=5(3) meter; 4 is holding line; 5 is well wall; 6 is surface of water at the bottom of the well; I is the first - the main part of the sound level gauge; II is the second - the calibration part of the sound level gauge; III is the third - the floating part of the sound level gauge; Ant - 433 MHz transceiver antenna; UsincR - 40 kHz ultrasound receiver sensor; UsincT - 40 kHz ultrasound emitter; GSM ant is GSM modem antenna.

The identified distinguishing features in the proposed combination were not found in previously known technical solutions; therefore, they ensure the achievement of the goal and can be qualified as significant differences.

The device is illustrated by drawings: figure 1 shows a sound measuring device in installed parts inside a well; figures 2, 3, 4 show the internal structure of the three parts of the device for monitoring the level of liquids.

A non-contact, wireless sound measuring device with an autonomous battery (accumulator) supply (Fig.1) consists of the first main part I where there is a 32-bit XCPU RISC ARM core microcontroller whose structure is described in Figure 2, an eight-bit micro-consuming microcontroller for calibration of the second part II and floating on the surface of the water well micro-intake microcontroller third part III.

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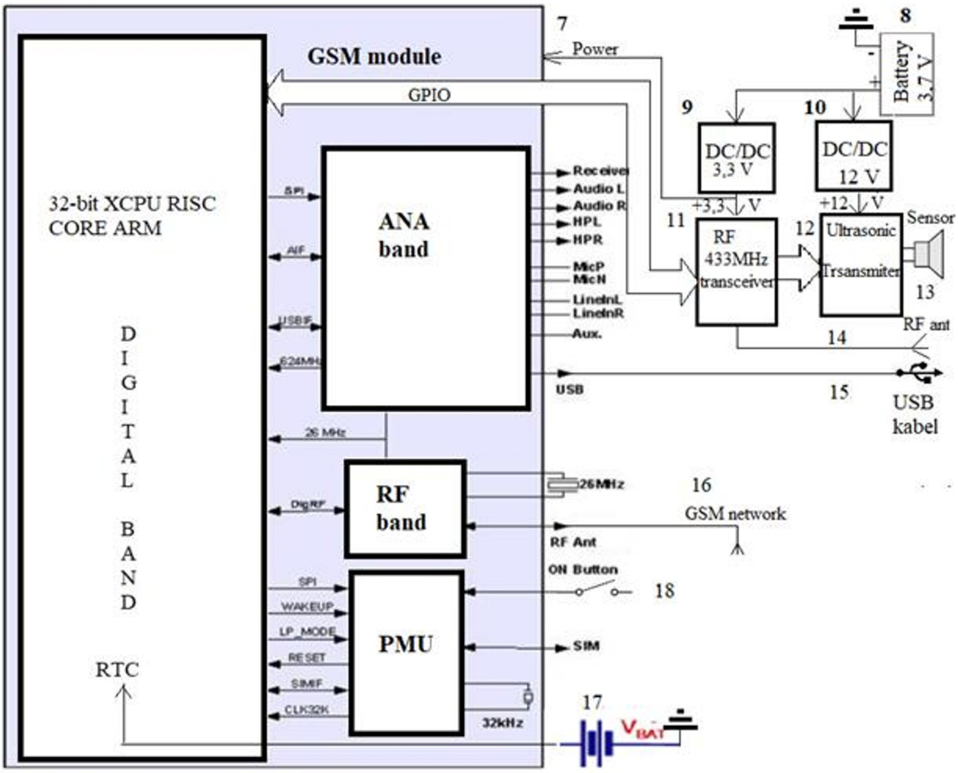

Fig. 2. Structure I of the first - the main part of the sound level gauge: 7 is GSM module based on SoC 32-bit XCPU RISC core ARM; 8 is battery (battery) supply 3.7 Volts; 9 is step-down/step-up converter with an output of 3.3 volts; 10 is step-up converter with an output of 12 volts; 11 is high-frequency transceiver module at 433 MHz; 12 is 40 kHz ultrasound generator module; 13 is ultrasound emitter at 40 kHz; 14 is transceiver antenna at 433 MHz; 15 is connecting USB armored cable for 5(3) meters; 16 is GSM modem antenna; 17 is battery powered real time clock (RTC).

The first main part I device (Fig. 2) is a master module. It consists of a GSM control module (Fig.2 -7) based on SoC 32-bit XCPU RISC with an ARM microcontroller core, a battery (accumulator) (Fig.2 -8) 3.7 volt power to power the entire module, buck/boost converter (Fig.2 -9) with 3.3-volt output to stabilize the overall power supply, boost converter (Fig.2 -10) with 12-volt output to power the ultrasonic amplifier, 433 MHz high-frequency transceiver module (Fig.2 -11) for radio signal conditioning and wireless communication with (Fig.2 -14) antenna 433 MHz, 40 kHz ultrasound generator module (Fig.2 -12) that generates measuring ultrasound with a 40 kHz ultrasound emitter (Fig.2 - 13) and is also equipped with an external GSM antenna (Fig.2 -16) for mobile communication. This module is connected via a USB cable to the calibration module II (Fig.3 - 20), which is also a power source and consists of an ultra-low-power microcontroller (Fig.3 - 19), a 40 kHz low-noise amplifier (Fig.3 - 21) for amplifying the ultrasound, and a 40 kHz ultrasound receiver sensor (Fig.3 - 22). The main part is also the initiator of the awakening from the energy-saving mode of the microcontroller; the third part III (Fig.4), located on the surface of the well water using wireless radio communication, consisting of a control ultra-low-power microcontroller (Fig.4 - 23), a radio module (Fig.4 - 24) at 433 MHz of a transceiver to wake up the module and wireless communication with the main module, a low-noise amplifier (Fig.4 - 25) to 40 kHz to amplify the signal received by the sensor of the ultrasound receiver (Fig.4 - 26), also a buck/boost converter (Fig.4 - 27) with a 3.3 Volt output and a 3.7 Volt battery (accumulator) (Fig.4 - 28) for autonomous power supply of this module.

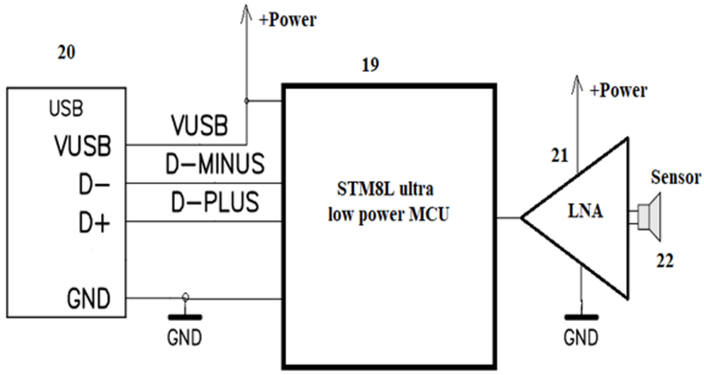

Fig. 3. Structure II of the second - calibration part of the sound level gauge: 19 is ultra-low-power microcontroller; 20 is USB bus for data exchange and power supply; 21 is Low noise amplifier at 40 kHz; 22 is 40 kHz ultrasound receiver sensor.

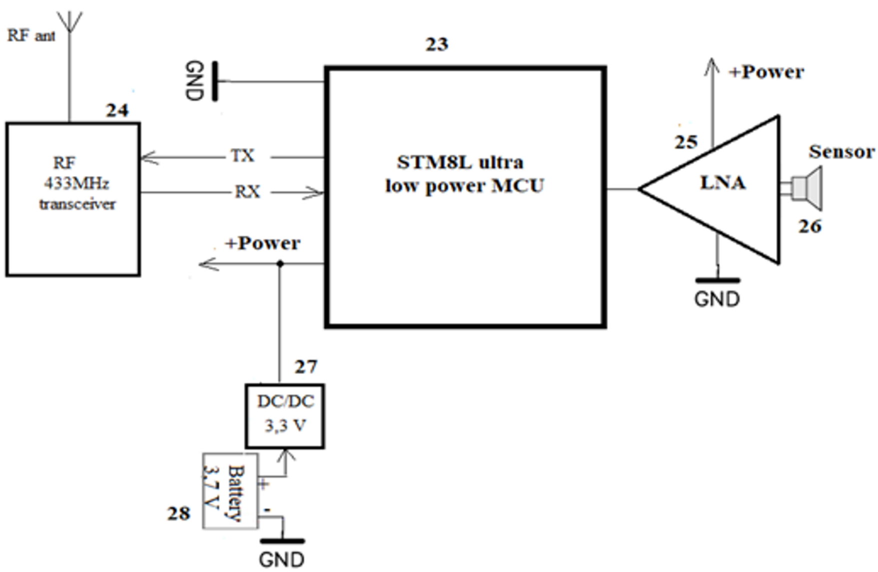

Fig. 4. Structure III The third is the floating part of the sonic level gauge: 23 is ultra-low-power microcontroller; 24 is high-frequency transceiver module at 433 MHz; 25 is low noise amplifier at 40 kHz; 26 is 40 kHz ultrasound receiver sensor; 27 is step-down/boost converter with an output of 3.3 volts; 28 is battery (battery) supply 3.7 Volts.

2 GSM module tester program for water level meter

A convenient test program for connecting, programming, and testing the A9 GSM module to a computer. The program has a clear and easy-to-use interface for quickly checking the GSM module using IT commands, SMS exchange, and Internet connection with GRPS [11-13].

1. Connecting and programming the GSM module A9 to a computer.

A9 is a compact, fully quad-band GSM/GPRS module. With stable performance, compact appearance, and cost-effectiveness, A9 is ideal for many customer needs, including smart home automation, wireless industrial control, and IoT applications in embedded wireless systems.

To program it or control it using "AT" commands, a special converter (adapter-converter) USB⇔USART (COM port-RS232) is required; for example, it can be a Silicon Labs CP210x USB - TTL module, as shown in the figure (Figure 5) [1, 2].

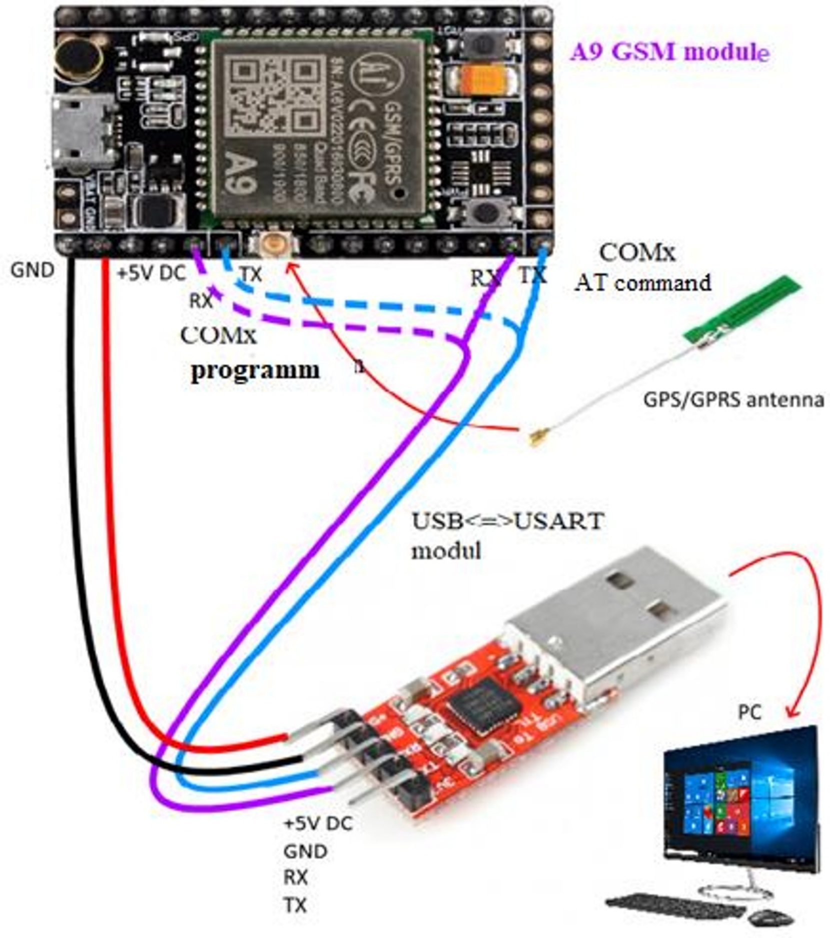

Fig. 5. Image of A9 GSM module connected to Silicon Labs CP210x USB⇔ USART module for operation (testing) (solid lines) or reprogramming (dashed lines).

First of all, it is checked whether the GSM module is working. To do this, create a "working connection," as shown in the figure (Figure 5), and determine the number of the Silicon Labs CP210x USB⇔ USART device (Figure 6) installed in the Windows Device Manager. For example, in the image in Fig. 6 is port 9 (COM9) [10, 12].

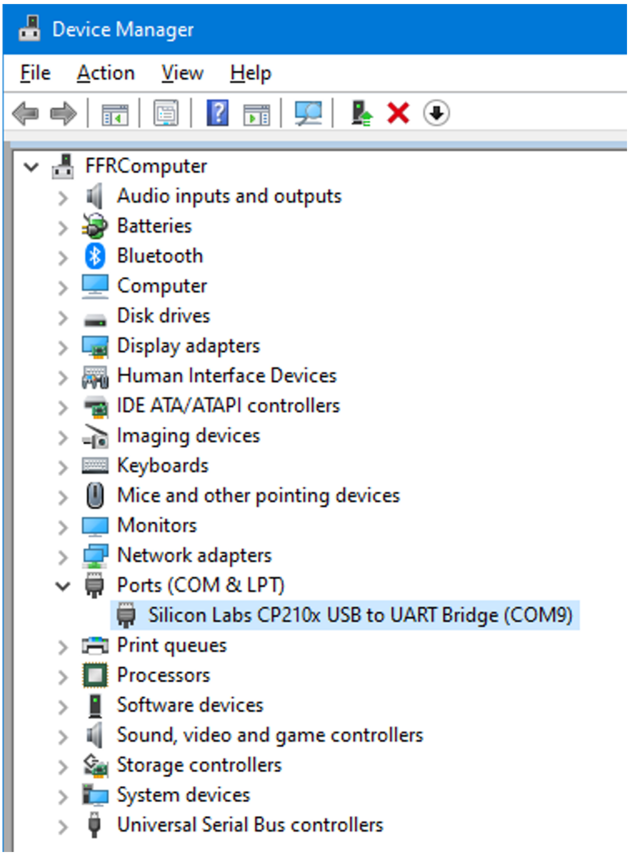

Fig. 6. Device Manager in Windows.

If it is not installed, you need to use the GSM module tester program that communicates through this port. At the top of this program, the number of the Silicon Labs CP210x USB⇔USART adapter installed in the previous step is selected from the "Port" "COM9" list (Fig.7).

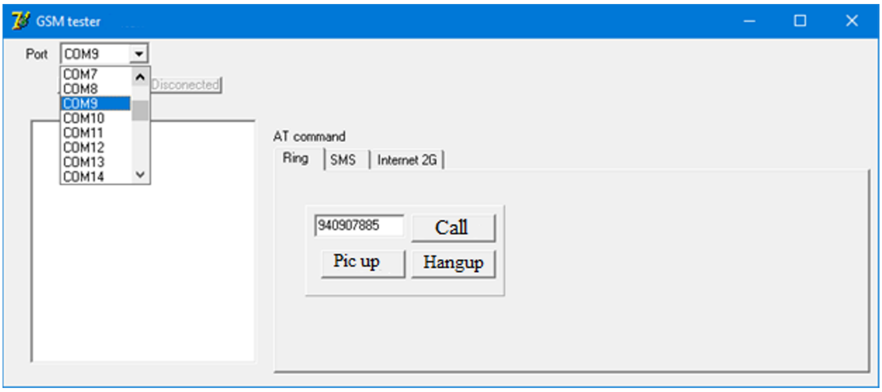

Fig. 7. Selecting the tester program for the GSM communication port module.

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As shown in Figure 7, the program interface has three tabular views called "AT Command".

The first one is called "Call" and is designed to test the ability of the GSM module to make calls. On this table page, there is 1 line for input and editing; in this line, the phone number is entered, which should be called via the GSM system, and the "Call" button is pressed (Fig. 7).

The progress of the call (including subsequent responses and events) is displayed in the notes editor area on the left side of the screen. This situation is shown in Figure 4. As you can see from the image, the module sends the strings "ATD994480155" and "OK" as a response, indicating that it understands the command. After that, if there is a client with a called number in the GSM system, the message "+CIEV: "CALL", 1" and then the message "+CIEV: "SOUNDER", 1" indicating that there is a call will be displayed repeatedly until will be pressed or rejected. If the call is rejected, the message "+CIEV: "CALL", 0" and "NO CARRIER" will be received; otherwise, the call will be accepted.

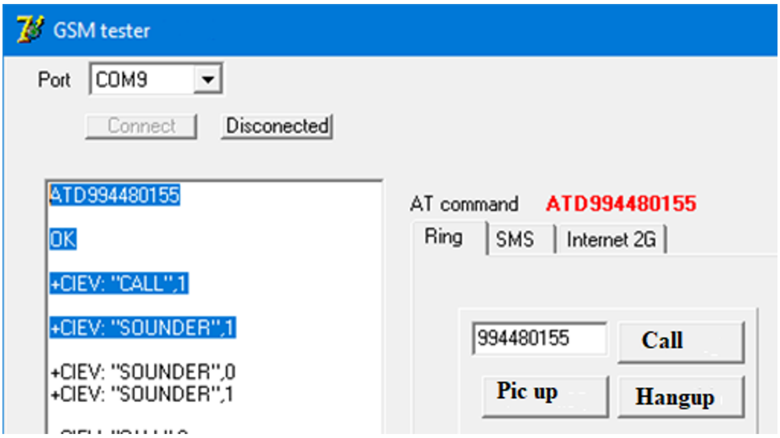

Fig. 8. Status of making a call through the GSM module tester program.

If you want to end the call, click the Reject button. The situation is shown in the following Figure 9. For example, if a client calls via GSM to the number of the SIM card installed in the modem, a line with the word "CALL" repeatedly appears in the note editor field. If the "Pick Up" button is pressed during this time, a voice connection with the client will be established, and when the " Hangup" button is pressed, information will be sent that the call was rejected, and the connection will be terminated.

The second page of the table named "AT command" is called "SMS", and its appearance is shown in Figure 10. This page has 2 lines for input and editing, and the first contains the phone number to which the SMS will be sent via the GSM system. If the SMS message to be sent is written in the line below, for example, "Command" and the "Send SMS" button is pressed (Fig. 10), then the program first selects the communication mode using ASCII codes (AT+CMGF). =1) and sends SMS to the entered number, will not. If everything goes well, the process ends with the phrase "OK" indicating the sent SMS, but if an error occurs, the phrase "Error" is included in the line.

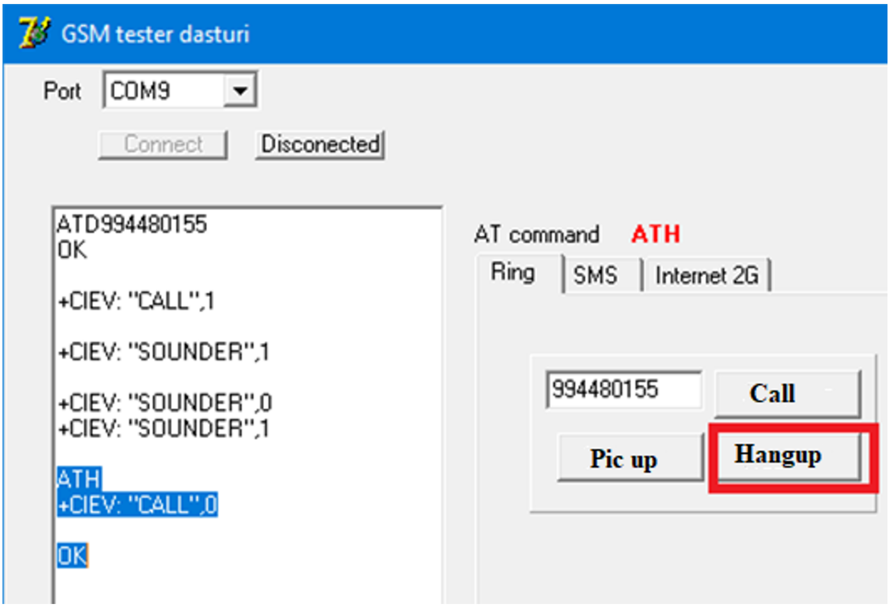

Fig. 9. Hangup status of the GSM module tester program after a call.

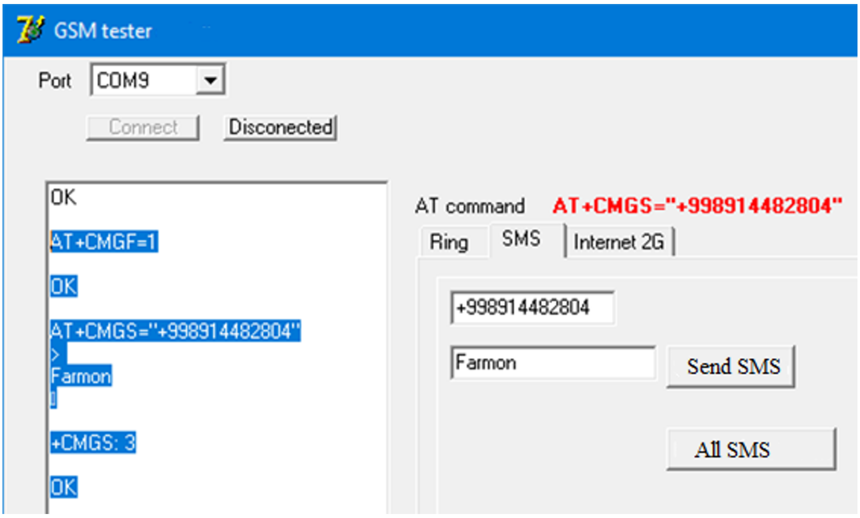

Fig. 10. The appearance of sending an SMS message to the client's number through the GSM module tester program.

If an SMS message is received from a client to the number of the SIM card installed in the GSM module, +CEIV:"MESSAGE", 1 line will appear before the message, as shown in Figure 11, and the full number of the client who sent the SMS and the time of arrival of the message will be returned on the next line. Only then will the sent SMS message itself be displayed (Fig. 11).

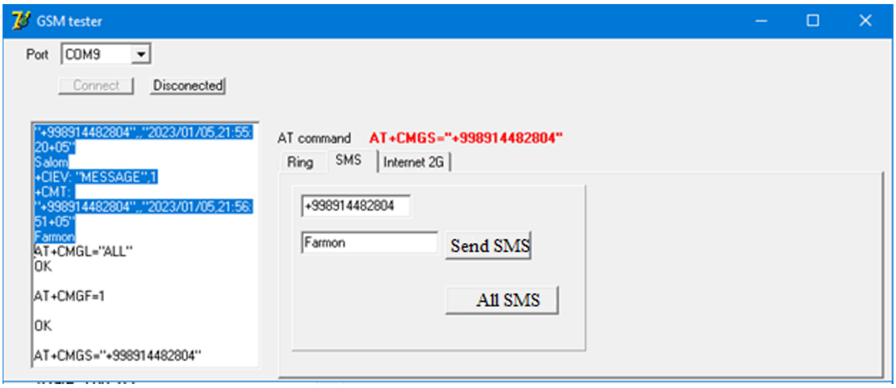

Fig. 11. Illustrated view of the SMS received from the subscriber's number through the GSM module tester program.

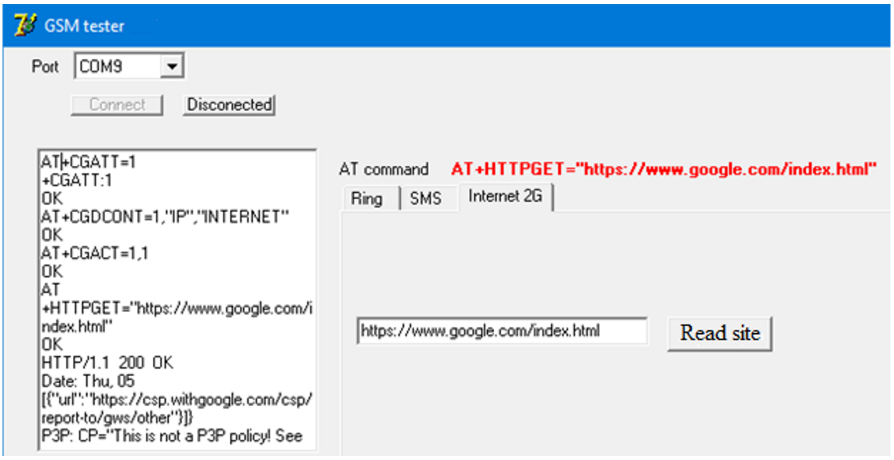

Fig. 12. An example of the result of rebooting the GSM module by pressing the reset button.

The table "AT command" is named the third page of the "2G Internet" page, and its appearance is shown in Figure 12. You can read the html file using the GPRS service on this page. It is enough to enter the full URL of the html file you want to read into the edit line on this page and click the "Read site" button (Fig. 12). After that, the program activates the GPRS service of the module, creates an access point and tries to read the html file via the GET command.

As you can see from the communication interface of this program, the A9 GSM module can be easily tested to check that it can perform many activities, such as making calls, sending SMS, connecting to the Internet, GPRS functions, etc., through the program. This allows it to be quickly used in IoT related applications. Since the program is managed by IT teams, it is very easy to manage the modules, and it is useful to create a good and compact tool for projects.

3 Results and discussion

The device operates in the following way, periodically based on the setpoint through the GSM module (Fig.2 -7) based on the RTC (real-time clock), which is powered by an autonomous battery (Fig.2 -17), the main part I wakes up. In turn, this module wakes up the calibration second part II (Fig. 3) from the power saving mode by a signal via the USB cable (Fig.3 – 15) and the microcontroller third part III (Fig. 4) via the 433 MHz radio signal of the radio frequency transceiver module (Fig.2 – 11) emitted by the antenna (Fig.2 – 14). When all three parts of the device are active simultaneously with the generation of an ultrasonic signal by the generator (Fig.2 – 12), signals are sent to start the timing via the USB cable (Fig.3 – 20) and via the radio transmitter (Fig.2 – 14) corresponding to the microcontrollers (Fig.3 – 19) or (Fig.4 – 23). And then receiver (Fig.3 – 21(22)) of the calibration ultrasound is also the receiver (amplifier 25 and sensor 26)(Fig.4) of the measuring ultrasound; the module, having received a signal from the generator, stops the countdown time, thereby obtaining the time for passing 5 (3) meters of calibration and the time to reach the water level in the wells

Data is returned to the main module via a USB channel (Fig.3 – 20) or wireless radio transmitter 24 from the measurement channel. With the help of the first, ultrasound's propagation speed is determined, and the second time determines the distance from the installation site of the main module to the measuring part located on the surface of the well water in a floating position. In the main microcontroller, if the GSM network is available 16, the data is transmitted to the host server; otherwise, it is stored in the internal flash memory to wait for the availability of the GSM network, after which again, all micro-controllers of the device switch to energy-saving mode until the next measurement cycle.

4 Conclusion

Compared with the known ones, the proposed method has a higher accuracy of determination since the float is located directly at the liquid level, and the distance is measured taking into account the temperature twice, which increases reliability.

The proposed method will find application in the operation of hydrostatic wells and used in water wells.

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