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Table of contents

Introduction 2
1. System structure 2
1.1. ZimaBase: USBL transmitting/direction finding antenna 2
1.1.1. General information 2
1.1.1. Operating with the remote software ZimaHost 5
1.1.1.1. System requirements 5
1.1.1.2. Description of the software interface 6
1.1.2. Maintenance and storage 9
1.2. Zima-R: beacon responder of USBL navigation system 9
1.2.1. General information 9
1.2.2. Versions 11
1.2.3. Operating with the device (standalone version) 11
1.2.4. Operating with the device (integrated version) 13
1.2.5. Maintenance and storage 14
2. Effective use of the Zima navigation system 14

Introduction

Underwater acoustic navigation system Zima is intended to determine in real time the horizontal angle and distance to underwater objects equipped with hydroacoustic responders Zima-R. Responders can be installed on remote-controlled underwater vehicles (ROV), manned submarines, autonomous uninhabited underwater vehicles (AUV), as well as divers and technical divers (in case of using an autonomous version of the beacon).

The Zima navigation system is an ultrashort baseline navigation system (USBL), with the principle of operation based on the use of a phased array antenna for determining the horizontal angle of arrival of a signal and determining the distance to the beacon by the "request-response" method. A distinctive feature of this system is the so-called two-way navigation, a patented solution that allows one to determine the distance both at the base station and at the beacon and also transmit to the beacon the azimuth angle to the base station.

The system also allows the transmission of telecontrol signals to beacons and receive telemetry data from beacons.

1. System structure

1.1. ZimaBase: USBL transmitting/direction finding antenna

1.1.1. General information

The base station of direction finding (hereinafter referred to as the base station) is intended for transmitting to the beacons control acoustic signals, determining the propagation time of the signal to beacons, determining the horizontal angle of arrival of the beacon responses, transmitting telecontrol commands and obtaining telemetry information from beacons by means of specialized acoustic signals.

The base station is made in the form of a maintenance-free monoblock on a cable filled in a high-strength polyurethane compound. The station has a phased array antenna, transmit antenna, built-in depth/temperature sensor. As an option, the base station is equipped with iMEMS AHRS . In general, the base station is mounted on a rigid vertical rod taking into account the directivity of the antenna - the determined angles of arrival are transmitted in the antenna coordinate system.

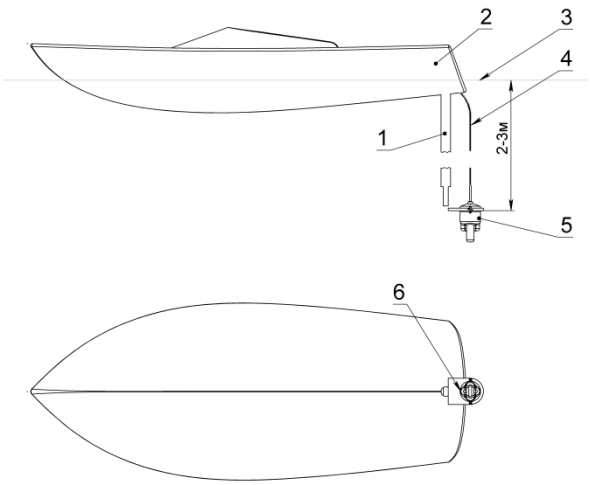

Figure 1 - Recommended installation scheme for the base station Zima-BASE.

In Figure 1, the numbers indicate: 1 - rod, 2 - watercraft, 3 - water level, 4 - base station cable, 5 - base station, 6 - zero direction of the direction-finding station.

Figure 2 shows the dimensional drawing of the base station Zima-BASE.

The base station has an input of an power/interface cable and a pressure/temperature sensor hole. Structurally, the base station is divided into the following parts: the cable entry (at the top of the station) and the mounting slot for fixing the station with a clamp. Below is the cylindrical surface of the transmitting piezo element, below which is a receiving phased array antenna. The surfaces of the transmitting element and the receiving array must not be covered or shielded during installation.

For the correct operation of the station, a direct visibility is required between the working surfaces of the station and the antenna of the responder.

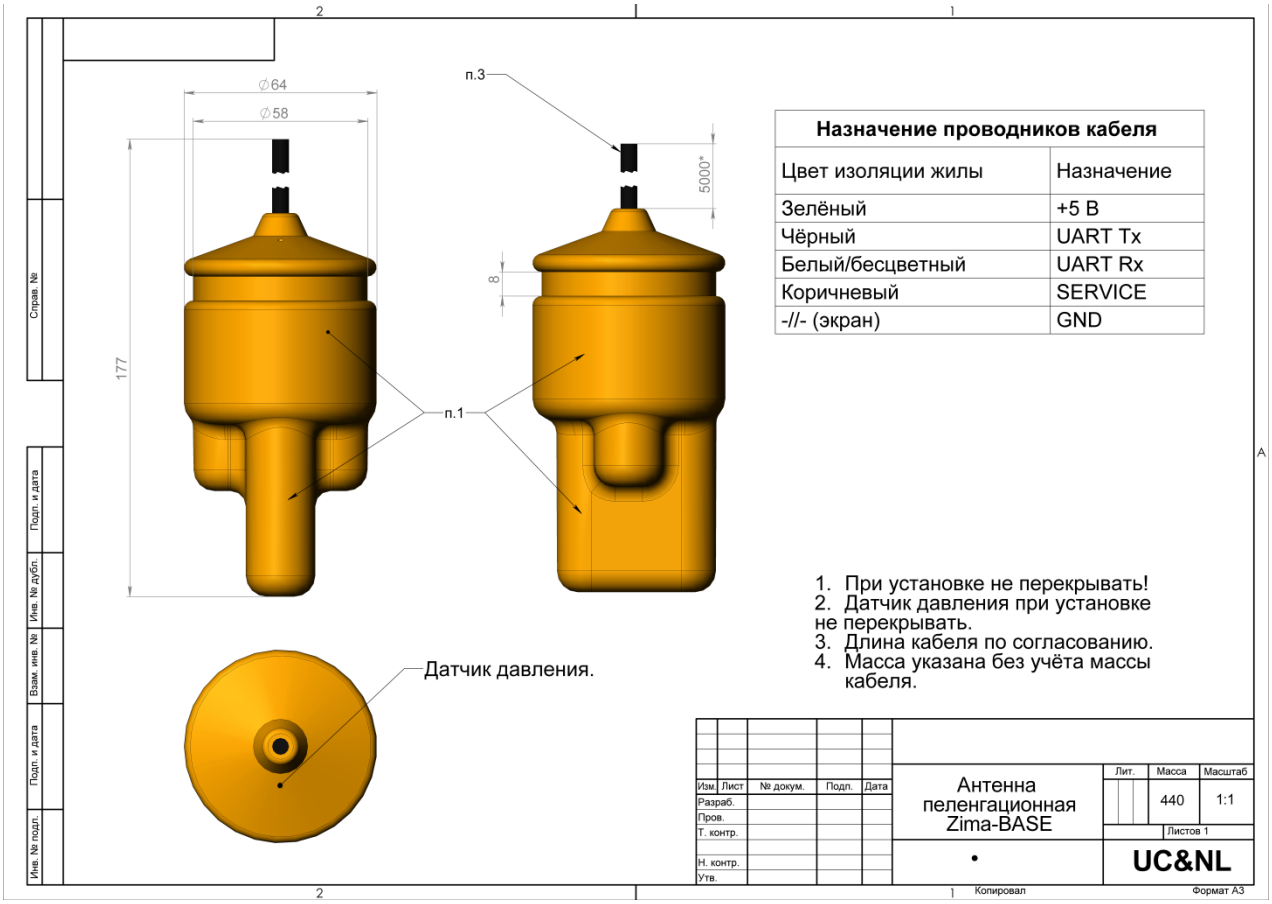

Figure 2 - The base station.

The standard interface for connecting the base station is the UART with 3.3V data lines. The station is equipped with a cable, up to 5 meters long, using longer cables (using only twisted pair cables as an extension) requires the use of UART-> RS-422 interface converters with separate power supply.

Table 1 shows the technical characteristics of the base station.

Table 1 - Specifications of the base station Zima BASE

№	Parameter	Value	Note
1	Dimensions, mm	Φ64x128	Without cable
2	Weight, kg	0.44	Dry, excluding cable
3	Energy range, m	8000	
4	Maximum relative speed (Tx / Rx), m / s	+/-2	
5	Operating temperature range, ˚C	-5..50	
6	Power consumption (Rx / Tx), W	0.3/25	
7	Supply voltage, V	4-12	
8	Maximum depth, m	300	
9	Depth nominal accuracy, m	0.1	With the correct setting of salinity
10	Interface	UART 9600	+ NMEA0183 PZMA
11	data line voltage, V	0..3	
12	Bit Error Rate (BER)	10-6	
13	Start time, msec	100	
14	Signal to noise ratio in the band, dB	-4	Without considering multipath propagation and the Doppler effect
15	Nominal accuracy of the built-in temperature sensor, ˚C	0.1	
16	Cable length, m	1.5	
17	Code separation scheme (commands / subscribers)	32/23	
18	Nominal accuracy of determining the horizontal angle of arrival of the signal, ˚	1	
19	Nominal accuracy of distance measurement, m	0.3	
20	Frequency band, kHz	6-18	

1.1.1. Operating with the remote software ZimaHost

1.1.1.1. System requirements

Specialized software ZimaHost (further software) is running under MS Windows operating systems version 7, 8 and 10. We recommend a monitor with a size of at least 1024x768 pixels and a mouse or touchpad.

The software is portable and does not require any installation. However, since connecting to the base station is carried out via UART / RS-232 / RS-422 interface converters to USB, additional drivers for a particular converter may be required.

1.1.1.2. Description of the software interface

The general view of the main software window is shown in Figure 3. The window is divided into functional elements: the main menu, the "Radar" panel on which the position of the beacons is displayed relative to the base station, the status of the base station: AHRS (gyro azimuth), TRX (transceiver), DPT (depth) and TMP (temperature) of the built-in sensor of the base station and the status of the current transaction ("Action").

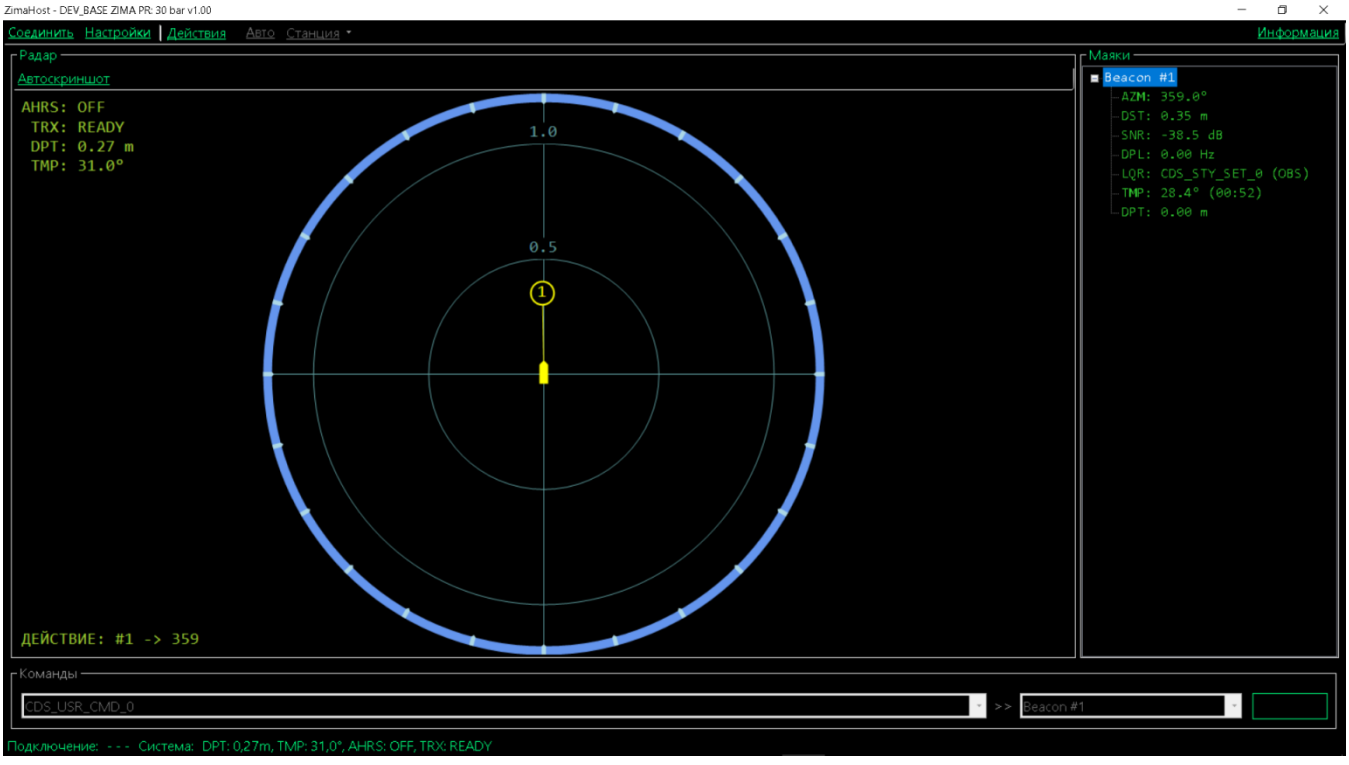

Figure 3 - General view of the main window of the ZimaHost software

The "Beacon" panel contains detailed information on the beacons with which work is being done. For each beacon, the following information can be displayed:

- AZM - azimuth - horizontal angle with respect to the antenna zero,
- DST - slant range,
- SNR - signal-to-noise ratio at the base station receiver,
- LQR - result of the last request,
- TMP - readings of the built-in temperature sensor on the beacon,
- DPT - readings of the built-in depth sensor on the beacon.

In addition, the status "TIMEOUT" may be displayed if, for some reason, the base station has not received the beacon response.

The "Commands" panel contains elements for selecting a user command, a beacon address and a button for sending the selected command to the selected beacon.

The item of the main menu "Settings" (it becomes available only when there is no software connection to the base station) brings up a configuration dialog box, which looks like in Figure 4.

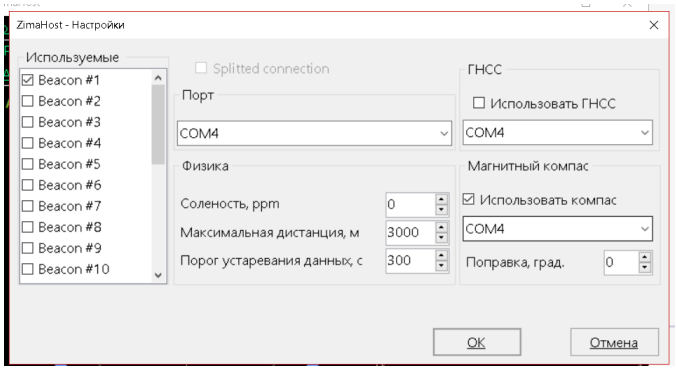

Figure 4 - General view of the settings dialog box

The Settings dialog box contains the "Port" drop-down list for selecting the interface port with the base station; The "Used" list allows you to select the addresses of the beacons with which you plan to work; The parameter "Salinity" allows you to enter the relevant salinity value into the system for more accurate determination of the speed of sound (and as a consequence, a more accurate determination of the distance); The "Maximum distance" parameter affects the timeout for the beacon response.

The value of the "Data aging threshold" field specifies the time after which the data in the beacon properties window will be marked with the abbreviation OBS (obsolete). In the presence of a satellite navigation system receiver and magnetic compass, the system makes it possible to recalculate the relative coordinates of the

responding beacons into geographical ones. To do this, check the boxes "Use GNSS" and "Use compass" with the appropriate ports to which the devices are connected.

The "Correction" field specifies the angular deviation of the zero of the base station antenna and the zero of the magnetic compass.

After selecting the item of the main menu "Connect", the software interfaces with the base station, as indicated by the inscription in the status line "OK".

To change the beacon address, select the item of the main menu "Actions" -> "Beacon" -> "Change address". After that, in the dialog box that appears, you should specify the current address of the beacon (by default all beacons have address # 1) and the new address that you want to specify. The beacon should be switched on and located next to the base station (if the address is changed in the air) - not more than 10-15 cm.

When the main menu item "Auto" is activated, the system will automatically process all beacons that were marked in the settings dialog box.

In order to change the beacon address or send a user command, you need to deactivate the "Auto" mode.

When the timeout occurs, the beacon will be displayed with a dashed line in the Radar panel.

The menu item "Station" contains the sub-items "Information" - when clicked on (with active connection), a window with information about the serial number and software version of the base station is displayed, the appearance of the window is shown in Figure 5.

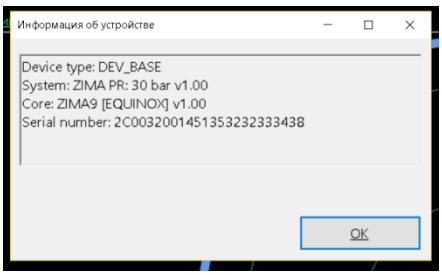

Figure 5 - Appearance of the "Device Information" window

Sub-item "Station" -> "Set" -> "Accept current pressure for atmospheric" allows you to set the value of atmospheric pressure to more accurately determine the depth of the base station. Calibration of atmospheric pressure should be performed only when the base station is not submersed underwater!

The "History" submenu of the "Actions" menu item contains items for working with log files.

The "Track" submenu becomes available only if the ZimaHost software accumulates a track of beacons, which is only possible with a magnetic compass and a GNSS receiver. In this case, the absolute geographic coordinates of the beacon-responders are determined, and it becomes possible to save their tracks in the Google KML format.

1.1.2. Maintenance and storage

The base station does not have special storage and maintenance requirements, except for the following:

- When used in sea and/or heavily polluted water, desalination (sediment and washing in fresh water) is necessary;
- Do not use any organic solvents, strong acids, alkalis and other corrosive substances;
- If necessary, washing in household soap solutions is possible;
- Impacts or significant static loads are not allowed;
- Do not bend the cable (with a radius of less than 5 cm);

1.2. Zima-R: beacon responder of USBL navigation system

1.2.1. General information

The beacon-responder is made in the form of a maintenance-free monoblock on a cable filled in a high-strength polyurethane compound. The appearance of the Zima R beacon is shown in Fig. 6. The beacon structure contains a cable entry, a mounting slot, a pressure sensor hole and a work surface. The opening of the pressure sensor and the working surfaces (the cylinder and the end of the cylinder opposite the cable entry) must not be blocked or shielded. For proper operation of the acoustic coupling, a direct visibility is required between the base station and the beacon-transponder.

Figure 6 - Appearance of the beacon-responder Zima R in standalone version. The beacon is connected by cable to the battery canister

Table 2 shows the technical characteristics of the beacon-responder.

Table 2 - Technical characteristics of the beacon-transponder Zima-R

№	Parameter	Value	Note
1	Dimensions, mm	Φ64x62	Without cable
2	Weight, kg	0.3	Dry, excluding cans
3	Energy range of communication, m	8000	
4	Maximum relative speed (Tx / Rx), m / s	+/-2	
5	Operating temperature range, ˚C	-5..50	
6	Power consumption (Rx / Tx), W	0.3/25	
7	Supply voltage, V	4-12	
8	Maximum depth, m	300	
9	Nominal error in depth, m	0.1	With the correct setting of salinity
10	Interface	UART 9600	+ NMEA0183 PZMA
11	Voltage of data lines, V	0..3	
12	BER	10-6	
13	Start time, msec	100	
14	Signal to interference ratio in the band, dB	-4	Without considering multipath propagation and the Doppler effect
15	Nominal accuracy of the built-in temperature sensor, ˚C	0.1	
16	Cable length, m	1.5	
17	Code separation scheme (commands / subscribers)	32/23	

18	Nominal accuracy of determining the horizontal angle of arrival of the signal, ˚	1	
19	Nominal accuracy of distance determination, m	0.3	
20	Frequency band, kHz	6-18	

Table 3 - Specifications of a standard battery canister[1]

№	Parameter	Value	Note
1	Dimensions, mm	Ф50x165	
2	Weight, kg	0.58	
3	Battery type	Nickel-Metal Hydride	
4	Capacity, Ah	2.9	
5	Rated voltage, V	12	
6	Number of elements, pcs.	10	
7	Maximum depth, m	300	
8	Operating temperature range, ˚C	-5..50	

1.2.2. Versions

The Zima R is a beacon-responder of ultrashort baseline navigation system and can interface with the control system energetically and informationally. In this case, it is possible if the control system has a magnetic compass to determine the distance and the heading angle to the base station, as well as receive remote control code commands from the base station.

In the stand-alone version, the beacon is equipped with a battery canister, as shown in Figure 6. In this case, it is completely self-contained and does not require interface with the carrier.

1.2.3. Operating with the device (standalone version)

In the case of stand-alone execution, the beacon is completely autonomous. For work, it must be fixed on the carrier in such a way that the working surfaces of the monoblock (cylindrical surface and end). They did not overlap with fasteners (a special

[1] Standard equipment, can be changed without notice.

groove should be used for fastening) and were not shielded by various elements of the carrier structure. To activate the beacon, it must be connected to the battery pack using the connector, as shown in figure 7.

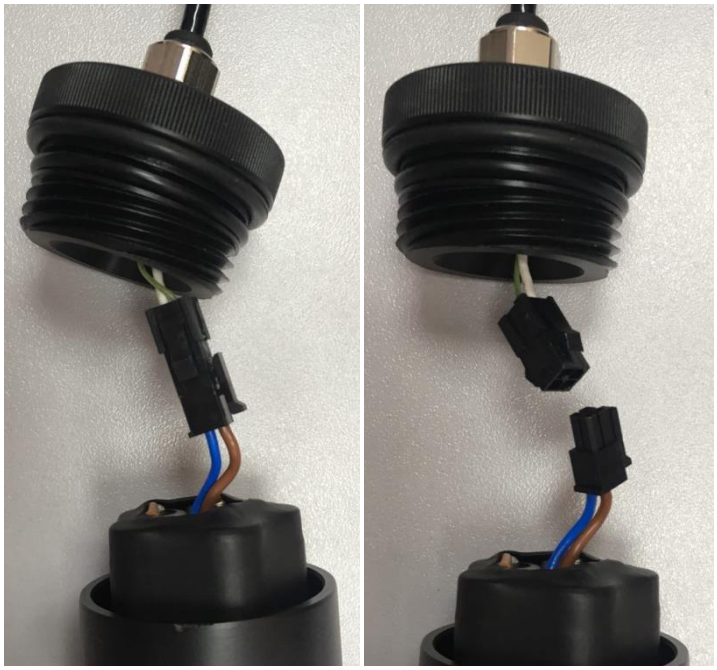

Figure 7 - Connection of the beacon-responder to the battery pack.
Left-to-right: the connector is connected, the connector is disconnected

In this version, the beacon is equipped with a nickel-metal hydride battery of 10 elements.

Normobaric case (canister) has a cover with a double seal and a four-threaded thread, which allows you to close the cover of the canister for 3/4 turn. Before dipping into water, make sure that the canister cap is tightly twisted (by hand).

After connecting the beacon connector to the battery pack during the first ten seconds, the device calibrates the atmospheric pressure, therefore it is not allowed that in the first ten seconds after switching on the device, apply any (negative or positive) pressure to it other than atmospheric - this will lead to an incorrect measurement of depth by the responding beacon.

With standalone versions of the beacon Tx and Rx wires (see Figure 8) are connected, and after switching on the beacon sends a command via the serial interface, and if it accepts (the wires are connected), then the UART module is turned off for energy saving purposes.

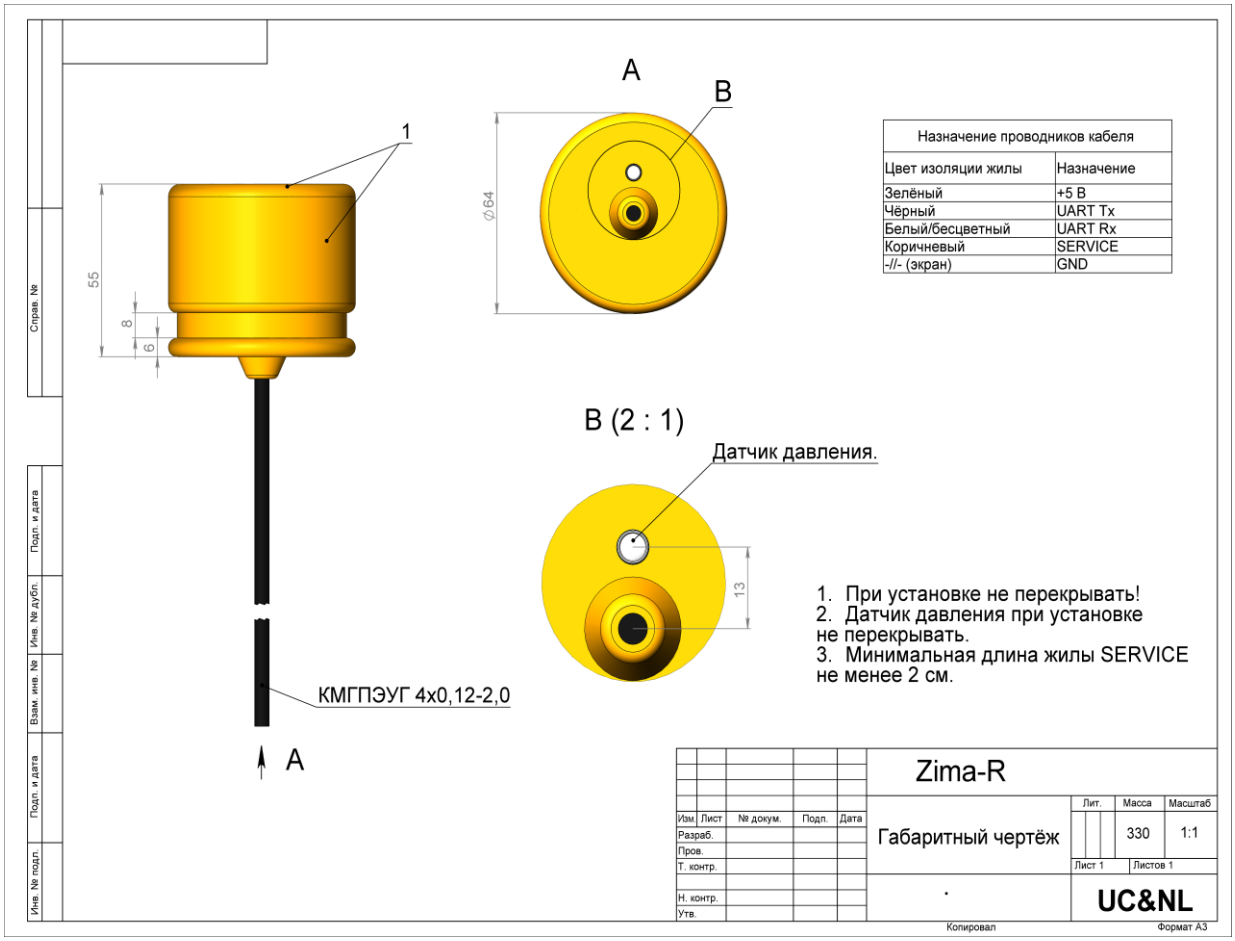

Figure 8 - Dimensional design of the beacon-responder Zima R

1.2.4. Operating with the device (integrated version)

With the power and information interface with the carrier, the beacon transmits the distance to the base station and the azimuth to the beacon to the carrier (only when the magnetic compass is connected to the base station). In addition, in this case, the base station can transmit up to 28 code commands, which is being sending to the carrier in

accordance with the pairing protocol (see the document "Zima Protocol of Information Conjugation").

1.2.5. Maintenance and storage

The beacon-responder does not require any special maintenance procedures, except for desalination and washing in fresh water, after use in sea and/or contaminated water.

Do not use any lubricants or solvents, aggressive detergents, etc. when removing contaminants from the beacon-responder and its cable.

In the case of using a beacon in standalone version, additional requirements are imposed and maintenance measures for the battery pack and canister are assigned. In particular:

- the long-term (more than one day) storage of the battery pack in the condition connected to the beacon is not allowed;
- long-term storage of the battery pack without scheduled recharging (1 month) is not allowed;
- O-rings and thread of the battery canister in the presence of contaminants must be cleaned with water, a soft brush and soap solution, followed by washing in fresh water and lubricating the sealing rings with silicone grease;
- the canister is stored with the lid closed;
- when using the device in sea and/or contaminated water, after completion of work, it is required to make it desalinated in flowing fresh water.

2. Effective use of the Zima navigation system

The Zima system is a underwater acoustic ultrashort baseline system that determines the relative position of the responding beacons as to the time of propagation of the acoustic signal in the water and the angle of arrival of the response signal of the responding beacons. In this regard, its effective application is based on the following conditions:

- ensuring a stable position of the base station of communication and direction finding during operation; This condition is ensured by reliable anchoring of the base station on the vertical rod, taking into account the direction of the zero direction finding the antenna. Angular deviations of the vertical axis of the station from the vertical, as well as the deviation and oscillation of its zero, negatively affect the accuracy of determining the angle of arrival of the response signal;

- providing direct visibility between the base station antenna and the beacon-transponder. Since the distance to the beacon-responder is determined by the time of propagation of the acoustic signal in water, any obstacles in the path of the signal greatly distort the measured propagation time, and hence the distance to the beacon-responder; Obstacles can be attributed as natural, associated with the relief of the bottom and/or shore profile, and artificial - piers, mooring walls, ships with deep draft, bridge supports, and other technical structures;

- working surfaces should be free from various contaminants (mud, algae, etc.).

In view of the specific nature of the propagation of sound vibrations in the aquatic environment, the base station should not be located at a distance from the surface of water less than 2 to 3 meters.

The antenna array of the base station is designed to determine the horizontal angle of arrival of the beacon-beacon signal, so it should be remembered that with such mutual arrangement of the antenna and the beacon-responder when they are on practically one vertical axis, the accuracy of determining the location of the transponder will be minimal. A good mutual arrangement of the antenna and the beacon-responder is considered to be such that the projection of the slant range on the water surface considerably exceeds its projection on the vertical axis.