

Hardware/software system for 3D subsurface exploration

Multi-Array Ground Radio Tomographic Scanner GRT-3X

Product information
User manual



2020r.

1. Purpose

The device is designed for detection and spatial localization of latent objects and heterogeneities in various media (soil/ground, pavement, engineering structures, etc.) Objects and heterogeneities having electric permittivity different from the background electric permittivity of the environment can be found. The software allows obtaining 3D data of the investigated environment. It is possible to display layer-by-layer 3D images as a set of pictures obtained along the selected direction for different sections of the volume being explored; 3D visualization of heterogeneities is also available. Based on the obtained image, operator identifies presence and location of buried objects and heterogeneities within continuous media.

Main fields of system application:

Building and construction

- Search and localization of various defects in wood and timber, brick, reinforced concrete building structures;
- Detection of reinforcement, concealed wiring, utilities supply lines;
- More precise characterization of geotechnical and groundwater conditions on construction sites.

Roads, railways, aerodromes

- Determination of thickness and structure of pavement layers, railway embankment, flight strip/runway elements, aerodrome taxi tracks;
- Determination of structure for natural foundation's top and ballast;
- Mapping of underground objects;
- Conformity control of designed/built structure of pavement layers, railway embankment, flight strip/runway;
- Identification of ground humidity;
- Examination of reinforcement details of concrete pavement slabs;
- Studies of geotechnical settings of the areas subject to strains;
- Studies of geotechnical settings of the areas adjacent to aerodromes.

Housing and communal services

- Determination of underground objects, cables, sewer and drain networks position, etc.

Archeology

- Search for archaeological objects (burial places, basements and walls of ruined buildings);
- Determination of cultural layer thickness.

Security

- Search for criminal burials, fire-arm caches, explosives, people caught in avalanche.

2. Set for delivery

1. The control computer with the software installed;
2. Main set of Multi-Array Ground Radio Tomographic (GeoRadioTomograph “GRT-XX”) unit (LFM-synthesizer, antenna-switching block, and A/D converter);
3. Antenna array module with fasteners and RF connectors;
4. Metal profile with holes for fixing antenna modules;
5. Associated cables;
6. USB flash drive with software and user manual;
7. Safe plastic case for the device transportation;
8. Navigation unit (encoder and/or RTK GPS and/or optical positioner) - **optional**;
9. Crawler transporter for autonomous operation of the device – **optional**.

3. Specification (GRT-3X)

Frequency range	0.5-3 GHz
Radiating power at transceiver output, at least	up to 50 mW
Number of antennas in transceiver modules	8-16-24-32
Width of scanning	525 - 2325 mm
Antenna type	synthetic aperture array from combined antenna elements
Acceptable level of deviation of all characteristics, not exceeding	5%
Maximum sounding depth	up to 3 m
Continuous sounding on the go	100+ km/h
Scanning resolution along antenna strip	>7.5 cm
Sizes of antenna strip modules	67.5x50x24 cm
Weight	from 5 kg (one antenna module)
Power feeding voltage	12.5-13.5 V
Power consumption	up to 20 W
Protection rating	IP54 (antenna module)
Mean time between required services	at least 3000 hours
Ambient temperature (operation)	-15 to 40 °C;
Relative humidity (operation)	up to 80%

The manufacturer reserves the right to modify component parts and product characteristics with no deterioration of its functional and qualitative characteristics.

4. Principle of operation

Antenna array with distributed receiving and transmitting high frequency (HF) antennas used to scan structure environment; this array helps sounding environment from different angles. For detection and localization of heterogeneities, we apply the method of mathematical focusing and technology of Synthetic Aperture Radar (SAR) where all the HF signals registered by the array are summed in phase for each specified focusing point with correction for the existing delay.

Thus, focusing is carried out by means of sequential summing of received signals with time delays equalization of the pulses scattered by the point with specified coordinates. Delays corresponding to the total time of the signal propagation from the transmitter to the object and back from the object to the receiver are introduced into the received signal. As next step amplitudes of the signals corresponding to calculated delays are summed up. The obtained result is a pixel/point of the radio-image with the appropriate coordinates. 3D image can be created by means of focusing for each point of the selected volume. Focusing is carried out in frequency domain with the use of the fast processing algorithms; thus, allowing real-time realization of 3D radio images for the studied volume.

5. Brief technical description of the Scanner

The Scanner is a modular system consisting of the unit of HF pulses formation and receiving based on chirp generator and the antenna array unit. In addition to chirp generator of HF pulses and the antenna modules, the Scanner also includes the navigator unit and the control computer.

Navigator unit can be realized using optical quadrature encoder together with RTK GPS module or any other positioning unit. Further data association with the track of travel distance is carried out according to navigator data.

Antenna array construction is module-based. Each module consists of four receiving and four transmitting antennas for 0.5 to 3 GHz band. The antenna modules can be cascaded together in a strip in order to expand the width of coverage when sounding a continuous media. Fig. 1 shows a schematic diagram of the Scanner and presents the main parts of the system. Function of the system parts and electronic units is listed in Table 1.

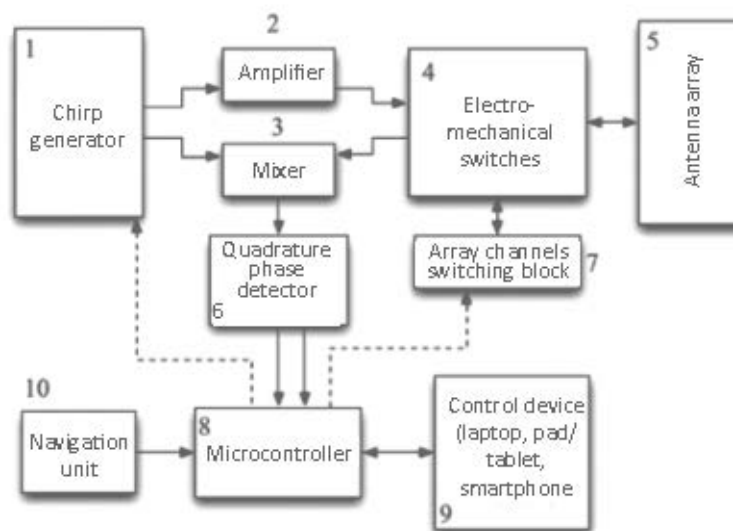


Figure 1 Schematic diagram of Multi-Array Ground Radio Tomographic Scanner

Table 1.

No.	Name	Function
1	Chirp generator	Provides a signal with tuning 0.5-3 GHz in chirp (LFM - linear frequency modulation) mode. Tuning frequency is up to 10 kHz
2	Amplifier	Provides amplification of output chirp signal up to 100 mW
3	Mixer	Provides separation of the received signal at the intermediate frequency (IF) for registration by low-frequency A/D converters
4	Electronic switches	Provide commutation/switching of receiving and transmitting elements of antenna array. Switching time is about 50 μ s
5	Antenna array	One antenna module contains 4 or 8 receiving and 4 or 8 transmitting antennas with linear polarization.
6	Quadrature receiver	Provides reception of signal C and S components, which are used to calculate a signal amplitude and phase.
7	Array channels switching block	Provides switching of receiving and transmitting antennas in triggering mode. As a result, the equivalent array of the same aperture is realized, which consists of N transceiver antennas.
8	Microcontroller	Produces sync/clock pulses for chirp generation, switching channels according to specified program, digitizing of received signal, primary processing of chirp signal (FFT).
9	Laptop	Is used to post-process the signals and to create 3D radio image of the space being investigated.
10	Navigation unit	Ensures positioning of data over the traversed path.

6. General operating instructions

Before you start working with GeoRadioTomograph “GRT-XX” make sure the casing parts are not damaged, and check the completeness of the equipment according to the List in the paragraph 2.

To avoid possible failures in the course of work, it is necessary to operate the equipment according to its protection rating (IP-54).

To get started, you need to interconnect all the units of the system and ensure the reliability of the connection.

In the next step, switch on the equipment and check the battery voltage. Use DC-DC power supply with voltage 12,5-13,5V.

The working position of antenna strip modules relative to continuous medium is set within the range of 10 - 40 cm depending on the chosen measurement techniques. The farther from the surface of the media the antenna is located, the more contrasting is the first boundary (air/medium) on the radio image.

7. Self-safety

It is recommended to prevent ingress of moisture in the casing parts and interconnections of the Scanner; the equipment is not designed for working during the rain. Take all necessary measures to protect the main units in order to avoid adverse effects from excess moisture.

Follow the special service guides and observe all safety precautions when repairing the equipment.

8. Parallel (volume) sounding

The device operates as follows. On command from the controlling unit or when the motion begins (depending on the selected mode) the generator starts generating the HF signals, and the receiver starts registering scattered signal. The pulses induced in the antenna flow through mixer to quadrature receiver. Signal from the quadrature receiver digitized by the microcontroller is delivered to computer for the subsequent processing. Switching channels of the antenna array is performed by the electronic switches in the control unit that is created as multi-channel mechanical switches. The obtained data are transferred to the control unit where the signals are processed and 3D radio image of the media is formed.

9. Maintenance

GeoRadioTomograph “GRT-XX” is a sensitive measuring instrument and must be handled with care. It is necessary to avoid ingress of moisture into the device during operation. During the intensive use, ensure the integrity of contacts of plugs and connectors. Clean the internal hardware components with compressed air.

10. Storage

The device should be stored in the transport case supplied with the device. The storage conditions should meet requirements of Article 1 of GOST 15150-69.

Placement of the devices in the storage room should ensure their free movement and access.

Distance between the walls, ceiling, floor of storage room and devices should be at least 100 mm.

Distance to heating devices should be at least 0.5 m.

Storage room should not contain conductive dust, additions of corrosive gases and vapours, which may cause corrosion of materials the device is made of.

Prior to start of usage, the devices should be stored in manufacturer's packing at storage conditions meeting the requirements of Article 5 of GOST 15150-69.

11. Transportation

The devices must be transported in the cases they were delivered in. All the kinds of enclosed transport meeting the requirements of GOST R 52931-2008, GOST 15150-69 and the rules and regulations applicable to each kind of transport may be used.

In terms of the impact of the climatic factors of environment, transportation conditions should meet the requirements of Article 5 of GOST 15150-69.

The devices being transported should be secured in vehicles. In the case of non-enclosed transport, the devices should be protected from rain and water splashes.

Transportation of packed devices can be done to any distance by any kind of transport without speed limit. Placing and fixing the devices in transport vehicles should ensure their stable position and exclude the possibility of hitting other items and walls of the vehicle.

During air transportation, the devices should be placed in sealed and heated compartments. After transportation at temperatures differing from the operating conditions, keep the equipment under normal climatic conditions for at least two hours.

12. Re-calibration of the scanner

Calibration periodicity choosing by company that use the device, according to the conditions and the intensity of its operation, but not less than once every two years. Preparation and conduction of calibration are subject to safety requirements.

The following environmental conditions should be observed during calibration:

1. Ambient temperature, °C $+25 \pm 5$
2. Relative humidity, % 70 ± 10
3. Atmospheric pressure, mm.Hg 760 ± 50

Measurement instruments and instruments involved in determination of geometrical dimensions should be certified as measuring instruments.

Calibration is performed by carrying out scanner measurements in two steps. In the first step, relative accuracy of determining the distance between two parallel objects placed in the focus of the antenna (the X axis) is calculated. In the second step, the accuracy of determination of the distance over the Z axis perpendicular to the measurement area is calculated.

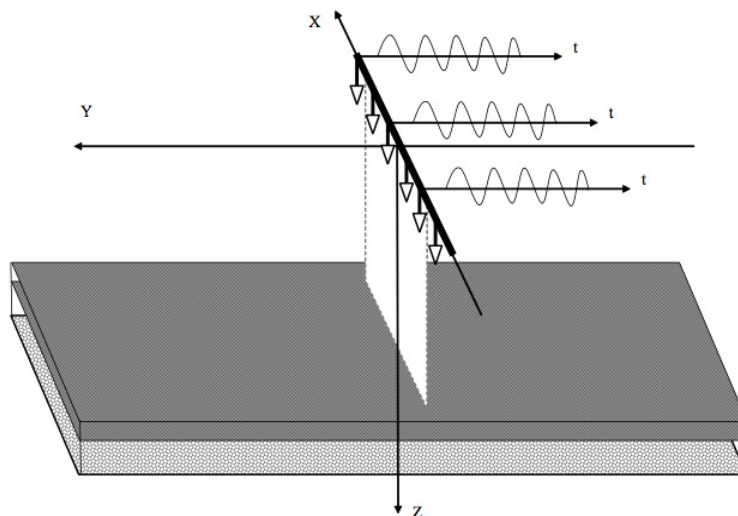


Fig. 2. Direction of XYZ axes relative to the antenna unit and the media being investigated.

The following operations should be carried out during the first calibration step.

1. Two aluminium cylinders (tubes) having the diameter of 3-6 cm are mounted on dielectric base stand (wooden or plastic table, workbench, etc.) at the distance of 10-15 cm from each other along the X axis.
2. The antenna unit of the scanner is placed in parallel to the cylinders at the distance of 1 m from the line connecting the centres of the cylinders.
3. Next, carry out the measurement cycle and build the radio image of the study volume using the software.
4. In the software, use the “Scale” tool to measure the distance between the images of the cylinders.
5. Apply the following formula to calculate the relative accuracy of determining the distance between two parallel objects placed in the antenna focus:

$$\delta_{r1} = 100 |D_m - D_r| / D_r, \text{ where}$$

D_m is the distance measured on the radio image, mm;

D_r is the actual distance measured using a certified instrument, mm;

Devices are considered calibrated if

$$\delta_{r1} \leq \delta_{add1}, \text{ where}$$

δ_{add1} is the maximum permissible error of determining the distance between two parallel objects placed in the antenna focus.

The following operations should be carried out during the second step of calibration.

1. Vertically place aluminum cylinder (tube) having the diameter of 3-6 cm on the dielectric base stand (wooden or plastic table, workbench, etc.).
2. Place the antenna unit of the scanner near the cylinder.
3. Next, carry out measurement cycle and build the radio image of the study volume containing the cylinder using the software.
4. In the software, use the “Scale” tool to measure the distance from the conventional boundary of antenna unit and center of the image of the cylinder.
5. Apply the following formula to calculate the relative accuracy of determining the distance to cylinder in the antenna focus:

$$\delta_{r2} = 100 |D_m - D_r| / D_r, \text{ where}$$

D_m is the distance measured on the radio image, mm;

D_r is the actual distance measured using a certified instrument, mm.

Devices are considered calibrated if

$$\delta_{r2} \leq \delta_{add2}, \text{ where}$$

δ_{add2} is the maximum permissible error in determining the distance from the antenna to the object being localized.

A device is considered calibrated if the maximum relative error of the device does not exceed the allowable limits.

11. Passport

GeoRadioTomograph "GRT-XX" complies with the technical requirements and is found suitable for operation. The device does not contain precious metals. The equipment has no hazardous substance and could be freely transported by air.

Release date < ___ > _____ 20__ y.

Model	GRT-
Serial number	

Date of sale < ___ > _____ 20__ y.

Seller _____

stamp

The warranty on equipment is valid for 12 months from the date of commissioning, but no more than for 18 months from the date of sale.

Explanation of marking:

GRT-XX

Working frequency range - **1** (0.1-0.4 GHz) or **2** (0.5-2 GHz) or **3** (0.5-3 GHz) or **8** (2-8 GHz) _____

The number of transceiver antenna modules:- **1-4** _____