LONG-PERIOD MAGNETOTELLURIC INSTRUMENT LEMI-424

User Manual

LVIV

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CONTENTS

1. DESTINATION

The Long-Period Magnetotelluric Instrument (LMTI) LEMI-424 (see figure below) is developed for the super-deep magnetotelluric sounding – the signals with periods of 20…100.000 seconds and more can be picked up with reasonable error. In order to realize such design major attention was paid to such principal parameters as thermal and temporal stability and noise level for magnetic channel and high input impedance and low drift for electric channels. For this the magnetic sensor of flux-gate type, which mainly determines these parameters, was manufactured using well-proved technology on the base of glass ceramics housing implementing recent findings in the excitation circuit construction. For field use the waterproof sensor has bubble level on its body or on the support to provide its proper leveling at the selected place. For electric channels, a filter-free technology of input stages was accepted in order to let super-long period signals to pass. Also, taking into account recent trends to measure additionally vertical component of telluric field or the component along some local geological structure, four electric channels are procured.

General view of LEMI-424 set (without FG sensor).

2. MAIN TECHNICAL PARAMETERS

Parameter	Value
Data Logger	
Frequency band	DC-0.5 Hz
Measuring range for electrometer	±2450 mV
Resolution	2 nV
Sample rate	1 per s
SD card	8 GB
Digital output and control	USB
GPS timing, coordinates and altitude determination	
Operating temperature range	Minus 20 to +60°C
Power supply	(5-20) V
Power consumption	<0.5 W
Weight: Electronic unit Unsealed lighting protection unit	 2.0 kg 1.1 kg
3-component Flux-Gate Magnetometer	
Measured range at analog output	±70000 nT
Frequency band for magnetometer	DC-10 Hz
Transformation factor of analog output	20 μV/nT
Noise level at 1 Hz	≤10 pT/√Hz
Temperature drift	< 0.3 nT/°C
Components orthogonality error	< 30 min of arc
Operating temperature range	minus 20 to + 55° C
Power consumption	< 0.5 W
Power supply	5 V ±0.1V
Weight: sensor with 20 m cable	~5 kg

LEMI-424 FG sensor

3. DELIVERY SET

The delivery set of LEMI-424 includes (see right):

- Flux-gate Magnetic Sensor with Cable
- Electronic Unit
- Electric Lines Terminal Box with Lightning Protection and copper stick
- GPS Antenna with Cable and Holder
- PC USB Connection Cable (double-side connector)
- Power Supply Cable (with one-side connector)
- User Manual and Control Software are delivered through email
- Non-polarised Electrodes (optional, not shown)

LEMI-424 delivery set

4. SERVICE AND SHELF LIFE AND GUARANTEE

Mean lifetime of the LEMI-424 – about 10 years.

The term of guarantee is 18 months after delivery if all requirements of the present instruction as to maintenance, applied voltage, weather conditions, vibrations and shocks are observed and any unit is opened. During this term the manufacturer is liable to repair the defects occurred through no fault of the consumer or force majeure, or if not possible to repair, to change the device by other equivalent specimen.

The manufacturer maintains its obligations to make free service and repair the station for still 2 years if necessary. By this the user has to cover the necessary spare parts price and transportation/visit fees only.

LEMI-424 No: **147**

DELIVERY DATE: QUALITY CONTROL:

DECEMBER, 2020 Name: ***Andrii Prystai***

5. STRUCTURE AND OPERATION

5.1. Construction Description

The LEMI-424 LMTI includes flux-gate (FG) magnetic sensor with a cable, the electronic unit, the terminal box with lightning protection and copper stick, SD Card for data storage, GPS receiver for data sampling synchronization and coordinates determination, connection cables and USB digital output for data/commands exchange with external PC. Optionally, non-polarised electrodes are provided. User-friendly operation software is procured which allows controlling of the instrument, data registration and viewing.

Front panel of LMTI electronic unit (Fig. 1) has minimum number of control and commutation facilities. There are LCD panel with resistivity touch screen for control and slot for SD CARD in the centre of front panel. The connectors for coupling with external battery (“12V DC”), GPS antenna (“GPS”), USB connector for communication with PC, electric lines terminal box (“EL.LINES”) and fluxgate sensor (“FG SENSOR”) are installed on the left side panel (Fig. 2).

Fig.1. Front panel of LEMI-424

Fig.2. Side panel of LEMI-424

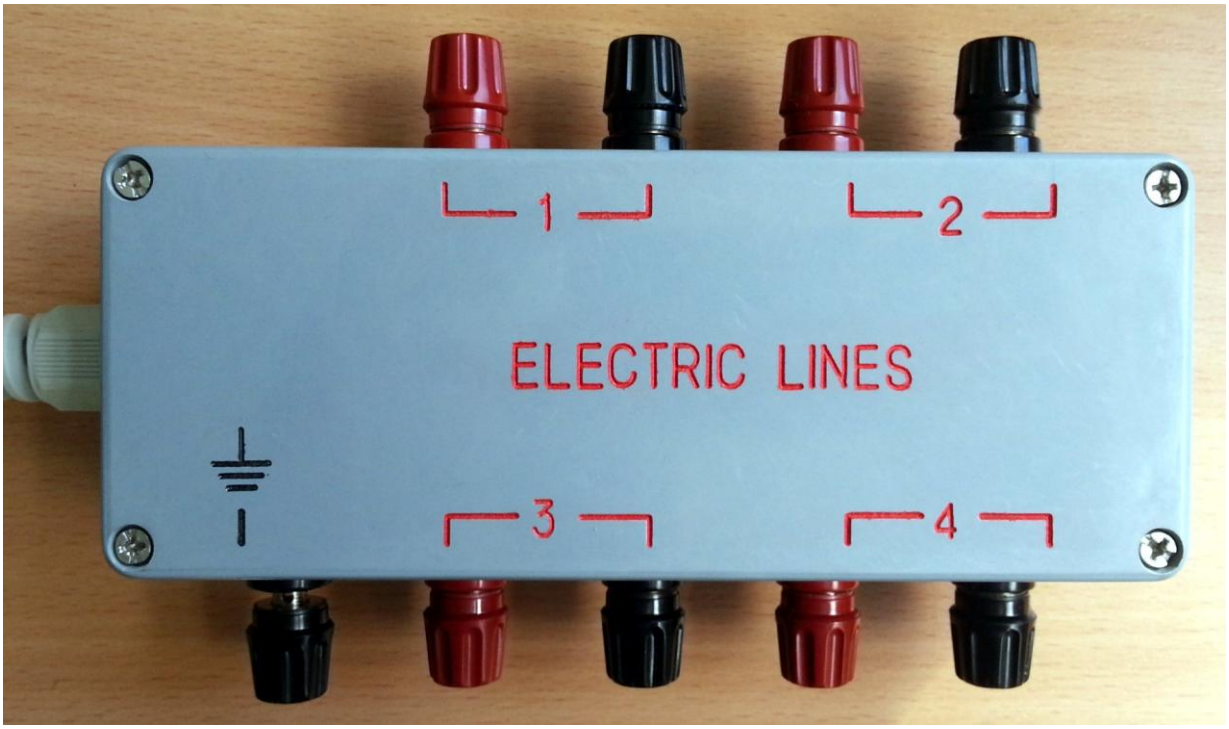


Fig.3. Terminal box with lightning protection for electric lines connection

On the side panels of the terminal box (Fig.3) the binding posts for four pairs of electric lines and for earthing are placed. Red posts correspond to positive direction of electric lines.

The housing of electronic unit is PELI™ 1150 case (IP67 protection group). WITH THE LID CLOSED, it is waterproof, protected against dust, moisture and rain,

but must not be immersed in water! The FG sensor housing is completely sealed and can withstand temporary immersion in the water.

The FG sensor unit has three orthogonal sensors fixed in one body.

Each sensor consists of the flux-gate probe in the shape of racetrack (40 mm long), a core of which is made from low-noise μ-metal tape. Special means are applied to make the initial non-orthogonality of magnetic axes not worse than 30 minutes of arc. After calibration the non-orthogonality can be known with an error less than 2 minutes of arc and this error practically does not change during all exploitation period.

The body of the sensor is made of glass ceramic with extremely low thermal expansion factor and is sealed hermetically with silicon compound inside the housing made of PVC. The compensating windings are wound on the frame made from the same glass ceramic material. The sensor has a thermometer inside the housing to monitor the temperature. The thermometer data, after calibration, can be used to reduce magnetometer thermal drift to a negligible value. In LEMI-424, all FG magnetometer electronics is placed inside sensor unit which is connected with electronics unit by a special cable.

The electronic unit description is given in the next paragraph.

The flux-gate sensor unit and the electronic unit are calibrated in a pair as one complete set. Using separate units from different instrument sets is not recommended because this may decrease the accuracy of measurements. To restore the precision in a necessity to use different units, re-calibration is required.

One end of the connecting cable has special waterproof connector (responsive part of FG connector at side panel, Fig.2), and other end is fixed to the sensor housing permanently to avoid water leakage. It can be unsoldered from the sensor only in a case of replacement of the damaged cable, using following procedure: unscrew the sealed cable inputs on the top of the sensor, unscrew six screws on the lid and remove it, carefully remove silicone filler, unsolder old cable, remove old cable from the cable inputs and insert new one, solder a new cable following color marking of wires. After verification of the sensor operation cover with silicone filler soldered place and close the sensor, screw six screws and screw the sealed cable inputs.

Any shocks with acceleration more than 5 g both for sensor and electronic units and vibrations other than occurred during transportation are not admissible. Especially it is necessary to avoid the fall of the sensor by the lateral side!

5.2. Functional Diagram Description

The functional diagram of the LMTI is given in Fig. 4. The analog output of the FG magnetometer (Fluxgate Sensor on Fig.4) is connected to the ADC Power in the electronic unit and then to microcontroller MC through digital isolator (GI) and port UART1. The four-channel telluric field meter (electric sensors on Fig.4) is connected to the ADC in electronic unit which output is coupled to MC through digital isolators (GI) and port UART2. The SD Card module, LCD display, GPS unit with antenna ANT and Control unit are coupled online with MC. The data exchange with external PC is realized through serial interface USB. The overall stability of the electronics, both of magnetic and electric channels, is provided by using the best available voltage reference and other stable components.

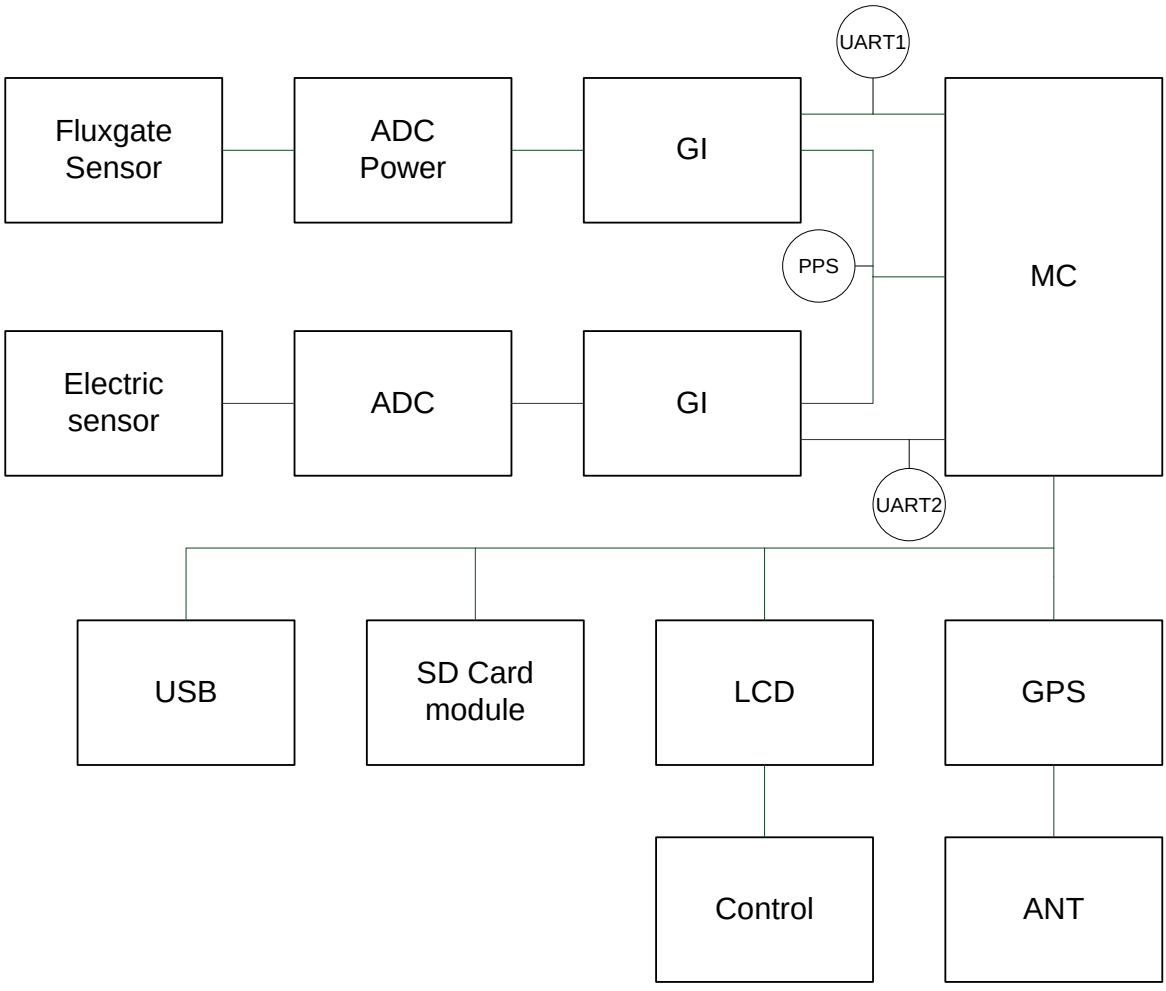


Fig.4. Functional diagram

The electronic unit consists of three printed boards. Main board contains data acquisition system, the second one contains four-channel ADC and power supply for FG magnetometer and the third board contains four-channel telluric field meter.

6. OPERATION INSTRUCTION

6.1. Preparation for Operation

6.1.1. Open the transportation housing and take out the parts of the set.

6.1.2. Make a hole at the place where the FG sensor has to be installed and put the sensor to the hole. Level it using bubble level and turn its housing in such a way that the arrow on the top of the cover points the North approximately. Positive directions of the magnetic components are: X – to the North, Y – to the East, Z – down. Accurate orientation can be done later using magnetometer readings: usually the orientation is accomplished by sensor rotation to achieve zero value of Y component, then X component will point Geomagnetic North exactly.

6.1.3. Cover the hole with sensor by soil and, if available, by sun-reflecting film.

6.1.4. Special attention has to be paid to the electrodes installation, especially if long-term measurements have to take place.

6.1.4.1. First, the proper selection of places where the electrodes have to be buried has to be made. It is important to select as much as possible similar places for the two electrodes composing one measuring line (if LEMI-701 electrodes are used, the matched pair should be used for one line). The principal requirements are to have the same soil composition, orographic features (i.e., hill-hill or valley-valley, under the tree – under the tree etc.) and especially moisture conditions. Clayish grounds are recommended to select, if possible, for long-term measurements.

6.1.4.2. Then the hole for electrodes installation has to be dug at the selected places. Experimental practice shows that for majority of soils the hole depth about 70-80 cm is enough to avoid daily thermal variations. At the hole bottom it is recommended to make a round cavity with diameter ~7-8 cm and depth ~15-18 cm (a half-liter bottle could be a suitable forming tool). Further instructions how to install electrodes, especially efficient if LEMI-701 non-polarized electrodes are used, are given in the Electrodes Manual section (page 29). They are useful for other electrode types too.

6.1.5. Make following connections:

a) Couple the end of the FG sensor cable with the connector “FG SENSOR” on the left side panel;
b) Couple GPS antenna cable with the connector “GPS”;
c) Install GPS antenna using the holder to provide free view of sky (the holder construction allows installing of the antenna on soft and rocky ground)
d) Couple electric lines to the binding posts on the electrodes terminal. If a long period installation is planned, clean thoroughly the contact surfaces of cables and posts, then fix the cables, trying to provide as big contact surface as possible, and

then cover the connections with any weatherproof grease. Normal directions of telluric lines pairs have to be: 1st line – positive (RED terminal) to the North, negative (BLACK terminal) to the South; 2nd line – positive to the East, negative to the West. The directions of 3rd and 4th lines, if used, have to be chosen by operator.

e) The earthing binding post ⏚ must be connected to any metallic earthing electrode that has to be inserted into the ground directly near the electronic unit.

Without this connection, the telluric channels will be unstable and even may be in saturation.

If any of the telluric channels is not in use, short-circuit corresponding pair of terminals and couple it to the earthing connector.

NOTE. As all 4 telluric channels are fully isolated and have differential inputs, any other connection of telluric lines can be realized by operator decision.

6.1.6. Special precautions have to be taken when POWER connector is coupled to the 12 V battery. The wire with RED mark of the power cable has to be coupled to the POSITIVE terminal of the battery, the wire with BLUE mark – to the NEGATIVE one.

Please, check the power supply voltage and polarity before connection!

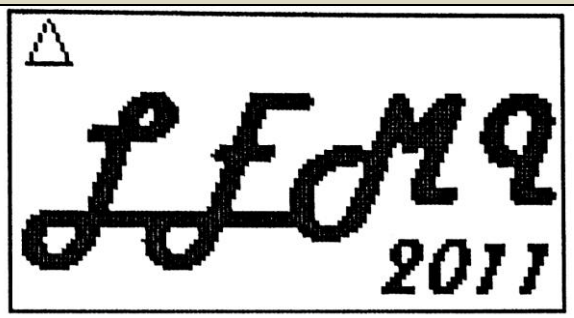
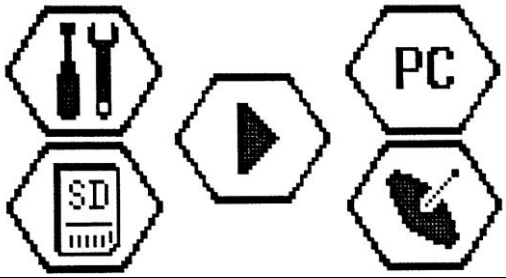
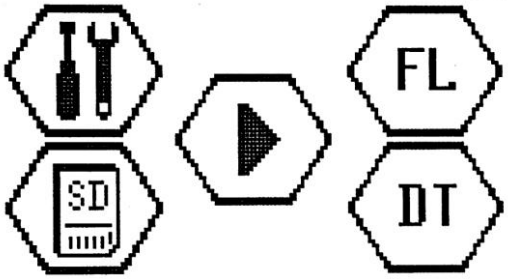
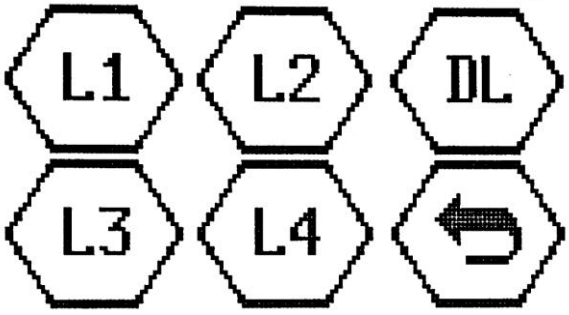
Power supply voltage must be in (5-20) V range.

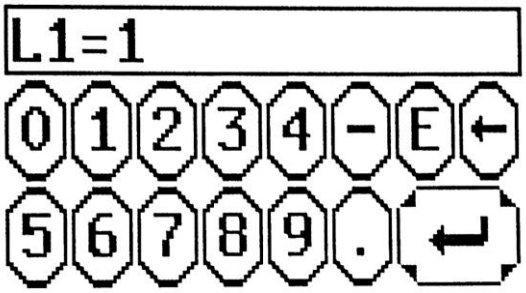
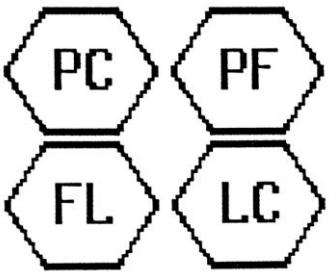
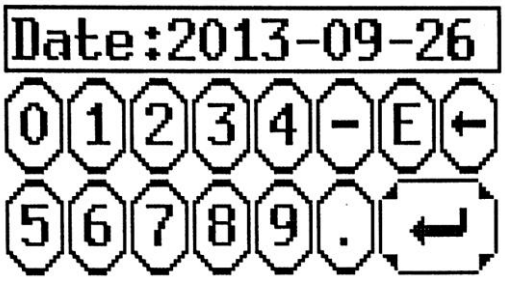
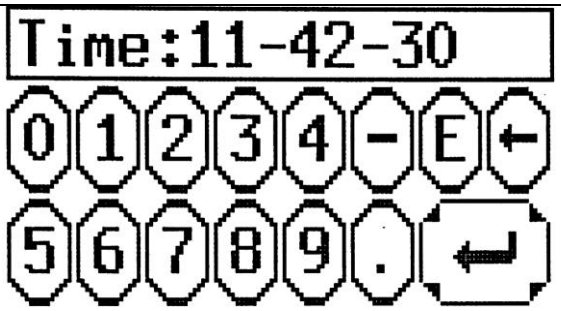
The instrument is ready for operation.

6. 2. Operation

6.2.1. Connect power cable to the connector “12V DC”. With this the LMTI is switched on.

6.2.2. After POWER is switched on following information appeares at the display. First Fig.7 a1, then in 2 sec Fig.7 a2, then in 2 sec Fig.7 b1 (if SD CARD is inserted).

	1	2
a		MAGNETOTELLURIC STATION LEMI-424 #0026 Firmware V1.0 Flash Card
b	SD Card-inserted write prot - No Init SD Card Cap. 7687MB Free 7686MB	Waiting for GPS or touch pad work without GPS
c		
d		Time 08:39:07 Ubat 12.66V MODE - FL Free 7686MB
e		Time 08:39:21 L1 1.0m L2 1.0m L3 1.0m L4 1.0m

f		Time 08:42:21 L1 23.0m L2 1.0m L3 1.0m L4 1.0m
g	SD Card-inserted write prot - No Cap. 7687MB Free 7686MB	
h	Date 2013/05/20 Time 16:00:15 	
i		Time 08:36:11 PC Bx +20071.55nT By -8911.47nT Bz +35918.02nT TE+28.3 TF+21.3C
j	Time 08:36:23 PC E1 -18117.5uV/m E2 -12621.4uV/m E3 -12279.9uV/m E4 -15940.9uV/m	Time 16:01:42 FL Ubat 12.66V MODE - FL 20130520160l.txt Free 7686MB
k	Date 2013/09/26 Time 08:39:49 Lat 4947.9232,N Lon 02400.5542,E Alt 357.9,m 7 1	

l		REMOVE SD Card
m	INSERT SD Card	SD Card-inserted Init SD Card

Fig.7. Messages at the display.

Next display (Fig.7 b2) allows the operator to select operation mode of the station. If GPS antenna is connected to the station – GPS module will synchronize internal clock and appear display Fig.7 c1. If GPS antenna is not connected to the station – touch the screen to work without GPS synchronization, after that appear display Fig.7 c2.

6.2.3. On the main display we have five buttons (Fig.7 c1, c2).

 - the button to enter in the system menu (Fig.7 d1);

- the button to see information about SD CARD (Fig.7 g1);

 - the button to start operation, display Fig.7 i2 will be shown;

- selection of the station operation mode. It could be PC, PF, FL, LC (Fig.7 g2);

 , 

- buttons to see GPS data (Fig.7 k1) in GPS synchronization mode and change DATE and TIME (Fig.7 h1) in work mode without GPS;

- this button open display Fig.7 d2, where you can see time, power supply voltage, operation mode and free memory on SD CARD;

- this button open the display Fig.7 e1;

 - this button back to previous display;

…


- this button open the display Fig.7 f1, where you can edit length of electric lines. By default, the length of electric lines is equal to 1 m. Meaning of the buttons is the same as PC keyboard. For finish editing push ENTER button.

- this button open the display Fig.7 e2, where you can see all length of electric lines;

The display Fig.7 f2 shows the result of electric lines length edition.

- Button for edit date, open the display Fig.7 h2;

- Button for edit time, open the display fig.7 i1;


- Button for change SD CARD without stopping record. Follow the instructions on the e display;


- Button for stop data record, back to the display Fig.7 c1;

6.2.4. In data record mode screen Fig.7 i2 we have possibility to see all information about LMTI conditions. By short pressing on the screen we can see electric values on the lines Fig.7 j1, length of electric lines Fig.7 e2, GPS data Fig.7 k1 and system information Fg.7 j2. If you push the right side of the screen then changing screens will be in the order described above, left side - changing screens will be in opposite order. To stop recording you should press in any part of the screen longer than 2 seconds, appear screen Fig.7 k2. If you use work mode without recording to SD CARD you will see screen Fig.7 l1.

6.2.5. It's possible to operate LMTI by using USB connection to the PC and any terminal or LEMI-424 software. After connection first time PC will see LMTI like virtual COM port. Use this port to operate LMTI. All possible commands you can see in table 1.

Attention! It is not recommended to change values of coefficients specified by the Manufacturer!

Table 1. List of commands station LEMI-424

#	Command	Parameter	answer	notes
1	START	-	%START WORK	
2	STOP	-	%STOP WORK	
3	STATUS		%Date 2013/03/04 %Time 09:48:42 %Ubat 12.43V %MODE - LCD %Free 1224MB %Lat 4947.9334,N %Lon 02400.5473,E %Alt 333.0,m 8 1	
4	ID		%LEMI424 #001 %FIRMWARE Ver.1.0 %MADE in UKRAINE	
5	SET	KXH 2.189319 KYH 2.199247 KZH 2.216984 KXL 3.67057e-4 KYL 3.68667e-4 KZL 3.70292e-4 AX 0 AY 0 AZ 0 KTE 4.882808e-2 KTF 4.882808e-2 KUIN 8.366936e-4 ATE -1.0e+2 ATF -100 AUIN -3 KXY 0 KYZ 0 KXZ 0 KE1 1.164153e-3 KE2 1.164153e-3 KE3 1.164153e-3 KE4 1.164153e-3 AE1 -2.188e+4 AE2 -2.188e+4 AE3 -2.188e+4 AE4 -2.188e+4 L1 1 L2 1 L3 1 L4 1 KTE1 0 KTE2 0 KTE3 0 KTE4 0 SKX 1.294886e-1 SKY 6.810740e-2 SAX 4.101524e+1 SAY 2.982450e+1	%KXH = 0.0e+00 %KYH = 0.0e+00 %KZH = 0.0e+00 %KXL = 3.670570e-04 %KYL = 3.686670e-04 %KZL = 3.702920e-04 %AX = 0.000000e+00 %AY = 0.000000e+00 %AZ = 0.000000e+00 %KTE = 4.882808e-02 %KTF = 4.882808e-02 %KUIN = 8.366936e-04 %ATE = -1.000000e+02 %ATF = -1.000000e+02 %AUIN = -3.000000e+00 %KXY = 0.000000e+00 %KYZ = 0.000000e+00 %KXZ = 0.000000e+00 %KE1 = 1.164153e-03 %KE2 = 1.164153e-03 %KE3 = 1.164153e-03 %KE4 = 1.164153e-03 %AE1 = -2.188000e+04 %AE2 = -2.187700e+04 %AE3 = -2.187900e+04 %AE4 = -2.193500e+04 %L1 = 1.000000e+00 %L2 = 1.000000e+00 %L3 = 1.000000e+00 %L4 = 1.000000e+00 %KTE1 = 0.000000e+00 %KTE2 = 0.000000e+00 %KTE3 = 0.000000e+00 %KTE4 = 0.000000e+00 %SKX = 1.294886e-01 %SKY = 6.810740e-02 %SAX = 4.101524e+01 %SAY = 2.982450e+01	

		MODE PC MODE FL MODE LCD MODE PC+FL	%MODE PC %MODE FL %MODE LCD %MODE PC+FL	
6	GET	KXH KYH KZH KXL KYL KZL AX AY AZ KTE KTF KUIN ATE ATF AUIN KXY KYZ KXZ KE1 KE2 KE3 KE4 AE1 AE2 AE3 AE4 L1 L2 L3 L4 KTE1 KTE2 KTE3 KTE4 SKX SKY SAX SAY	%KXH = 0.0e+00 %KYH = 0.0e+00 %KZH = 0.0e+00 %KXL = 3.670570e-04 %KYL = 3.686670e-04 %KZL = 3.702920e-04 %AX = 0.000000e+00 %AY = 0.000000e+00 %AZ = 0.000000e+00 %KTE = 4.882808e-02 %KTF = 4.882808e-02 %KUIN = 8.366936e-04 %ATE = -1.000000e+02 %ATF = -1.000000e+02 %AUIN = -3.000000e+00 %KXY = 0.000000e+00 %KYZ = 0.000000e+00 %KXZ = 0.000000e+00 %KE1 = 1.164153e-03 %KE2 = 1.164153e-03 %KE3 = 1.164153e-03 %KE4 = 1.164153e-03 %AE1 = -2.188000e+04 %AE2 = -2.187700e+04 %AE3 = -2.187900e+04 %AE4 = -2.193500e+04 %L1 = 1.000000e+00 %L2 = 1.000000e+00 %L3 = 1.000000e+00 %L4 = 1.000000e+00 %KTE1 = 0.000000e+00 %KTE2 = 0.000000e+00 %KTE3 = 0.000000e+00 %KTE4 = 0.000000e+00 %SKX = 1.294886e-01 %SKY = 6.810740e-02 %SAX = 4.101524e+01 %SAY = 2.982450e+01	

Each command ends with 0X0D 0x0A.
If the command does not was recognized, the station returns «Command error»
If the parameter is not recognized by the station returns «Parameter error»

Every second data gives by station LEMI-424 in PC and PC+FL mode (with GPS sync.)

#	Data	description	Notes
1	2013	Year	
2	03	Month	
3	04	Day	
4	10	Hour	
5	23	Minute	
6	45	Second	
7	19755.092	Bx	
8	196.757	By	
9	43688.332	Bz	
10	26.86	TE	
11	18.36	TF	
12	-5463.926	E1	
13	-5446.182	E2	
14	-5393.664	E3	
15	-5482.824	E4	
16	12.87	UIN	Input voltage
17	353.4	altitude	
18	4947.9356	Latitude	
19	N	Hemisphere	
20	02400.5697	Longitude	
21	E	Hemisphere	
22	8	Satellites number	
23	1	GPS fix quality (1 = GPS fix, 2 = DGPS fix)	
24	0	Difference between internal time and GPS	Seconds

Every second data gives by station LEMI-424 in PC and PC+FL mode (without GPS sync.)

#	Data	description	Notes
1	2013	Year	
2	03	Month	
3	04	Day	
4	10	Hour	
5	23	Minute	
6	45	Second	
7	19755.092	Bx	
8	196.757	By	
9	43688.332	Bz	
10	26.86	TE	
11	18.36	TF	
12	-5463.926	E1	
13	-5446.182	E2	
14	-5393.664	E3	
15	-5482.824	E4	
16	12.87	UIN	Input voltage

Formulas for calculation measured data:

Bi = ((double)(EE*KiL)+Ai-((TE-20)*KiH));

Where i – could be X, Y, Z;

Bi – calculated magnetic field for each vector accordingly;

EE – binary data from ADC 32-bit;

KiL – amplification coefficient;

Ai – additive coefficient;

KiH – coefficient of temperature correction.

Ei = ((double)(EE*Kei)+Aei-((TE-20)*KTei))/Li;

Where i – could be1, 2, 3, 4;

Ei – calculated electric field for each channel accordingly;

EE – binary data from ADC 32-bit;

Kei – amplification coefficient;

Aei – additive coefficient;

KTei – temperature correction coefficient;

Li – electric line length.

Ti = (EE*Kti+Ati);

Where i – could be E, F;

Ti – calculated temperature of electronic unit(E) and fluxgate sensor (F);

EE – binary data from ADC;

Kti – amplification coefficient;

Ati – additive coefficient.

U_in = (EE * KUin) + AUin;

Where i – could be E, F;

U_in – calculated voltage of the battery;

EE – binary data from ADC;

KUin – amplification coefficient;

AUin – additive coefficient.

ATTENTION!

1. LMTI LEMI-424 operates with SD CARD with FAT16 and FAT32 files system only. If the SD CARD is formatted under other file system it has to be reformatted on a PC with any standard SD card reader.

2. The maximal size of one file is about 12..13 MB (in GPS sync. mode).

3. Every new day at midnight the LMTI microcontroller creates a new file. This is highly advised, in order to make possible recording, to clean the card before long-term record.

4. The user can clear SD CARD on PC.

5. Before using the station in field conditions tightly close the electronic case lid with side double-step latches to make it weatherproof!

6.3. Program Manual (LEMI-424) 24.02.2016

General Information

The program allows fulfilling the following operations:

- LMTI control
- Real time data acquisition and visualization (magnetic fields Bx, By, Bz, telluric fields E1, E2, E3, E4, temperatures of FG sensor and electronic unit, power supply voltage, altitude and GPS coordinates, satellites number, GPS fix quality and difference between internal time and GPS);
- Writing LMTI data text file to the PC hard disk.

The program set consists of following files:

Lemi424.exe	LMTI control, real time data visualization, data acquisition
***.def**	Reserve copy of coefficients of the LMTI
lemi424.log	Log-file
***.txt**	Text data files

Data files

- Program operates with text files. In PC or FLASH+PC modes the data files in the text format are stored in PC memory.
- Data exchange between PC and magnetometer is realized through the USB interface at the rate 115200 bit/sec (start bit, 8 data bits, stop bit, no parity).
- Every line of the text files corresponds to one sample of all measured components for the given time moment (see example below).

Data Text File Example

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20,21,22
2013	01	31	09	29	40	19314.503	-202.000	24760.625	23.14	19.24	0.080	0.725	0.768	-0.256	12.43	362.2	4947.9227	N 02400.5509	E 9 1 0
2013	01	31	09	29	41	19311.549	-203.223	24760.026	23.14	19.14	0.029	0.664	0.668	-0.283	12.43	362.2	4947.9227	N 02400.5508	E 8 1 0
2013	01	31	09	29	42	19310.100	-204.321	24760.182	23.14	19.24	0.049	0.734	0.807	-0.309	12.43	362.2	4947.9227	N 02400.5508	E 8 1 0
2013	01	31	09	29	43	19309.292	-204.868	24760.723	23.14	19.24	-0.010	0.695	0.910	-0.277	12.43	362.2	4947.9226	N 02400.5508	E 9 1 0
2013	01	31	09	29	44	19307.931	-205.870	24762.401	23.14	19.24	0.152	0.627	0.896	-0.270	12.43	362.2	4947.9226	N 02400.5508	E 7 1 0
2013	01	31	09	29	45	19305.209	-206.757	24763.147	23.14	19.24	0.039	0.717	0.820	-0.189	12.42	362.2	4947.9226	N 02400.5508	E 8 1 0

Data text file structure is following, according to columns**:**

Column	Example	Meaning	
1	2013	Year	UTC time
2	01	Month	
3	31	Day	
4	09	Hour	
5	29	Minute	
6	40	Second	
7	19314.503	Bx, nT	Magnetic field components values
8	-202.000	By, nT	
9	24760.625	Bz, nT	
10	23.14	TE, ^{o}C	Electronic unit and FG sensor temperatures
11	19.24	TF, ^{o}C	
12	0.080	E1, μV/m	Telluric field values
13	0.725	E2, μV/m	
14	0.768	E3, μV/m	
15	-0.256	E4, μV/m	
16	12.43	UIN, V	Uin
17	362.2	H, m	altitude
18	4947.9227		Latitude
19	N		Hemisphere
20	02400.5509		Longitude
21	E		Hemisphere
22	9	N	Satellites number
23	1		GPS fix quality (1 = GPS fix, 2 = DGPS fix)
24	0		Difference between internal time and GPS

Columns are separated by spaces. Each line is ended with characters 0x0D 0x0A (hex). Time step (1 sec).

Data File Name

Text data file names are created automatically from UTC time. For example: “20130115135000.txt”. The structure of file name is: yyyy mm dd hh nn ss.txt, where yyyy-YEAR, mm-MONTH, dd-day, hh-HOUR, nn-MINUTE, ss-SECOND.

LMTI control program lemi424.exe

Before start control program lemi424.exe couple together connectors USB of the PC and LMTI with interface cable.

After lemi424.exe program starting the main window appears on the PC display (Fig.8 – with data visualization). In the main window header the name of the currently displayed data file can be seen. A user can select the LMTI channels that will be drawn on the screen by using corresponding menu items (see example on Fig.9). From 1 to 5 channels can be shown on display simultaneously (magnetic fields Bx, By, Bz, telluric fields E1, E2, E3, E4, temperatures of FG sensor and electronic unit, power supply voltage, altitude and

GPS coordinates, satellites number, synchronization fix quality and difference between internal time and GPS). The full control of the LMTI can be done from this window by corresponding menu items.

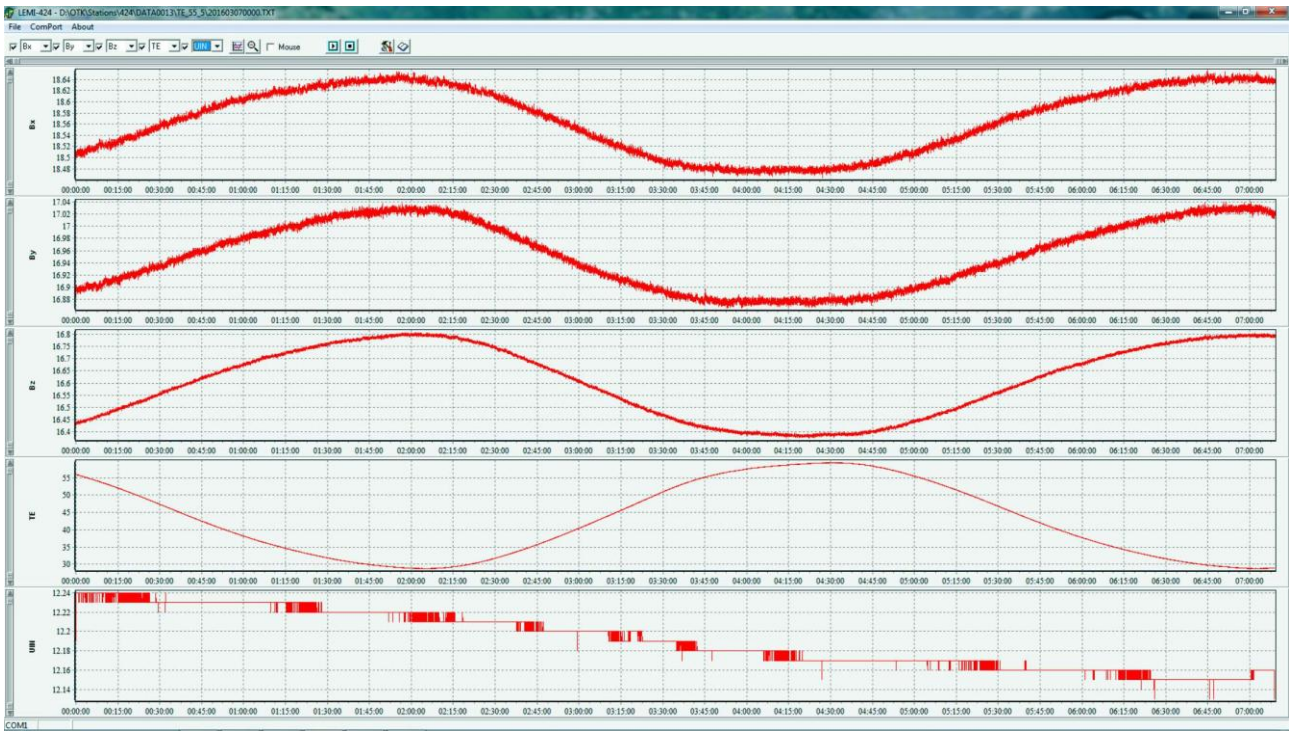


Fig. 8. Main program window

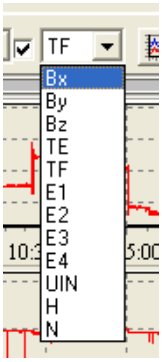


Fig. 9. Choice of displayed channels

Main program menus commands:

- **File → Open file –** Open file for visualization from hard disk (Fig.9)
  - **List of files –** show list of recently opened files
  - **Exit –** exit program
- **ComPort –** serial port number change
- **About –** information about program version

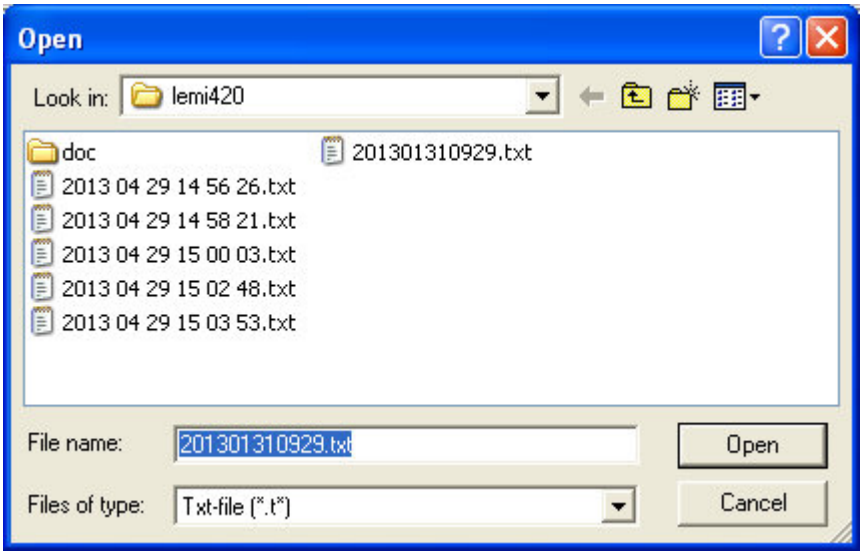


Fig.9. Dialog window “Open”

Program buttons

Fig. 10. Program buttons

 – start / stop recording;

 – choice of initial LMTI settings;

 – read log file;

 – **b**uttons «Range» and «Zoom» are used for graphics control. Button «Range» evens all selected plots on display, button «Zoom» changes the plot dimensions to show it on display in full. Button “Mouse” allows values measuring directly from the plots on display by positioning the mouse cursor on a necessary plot point.

Command window «Station»

For LMTI control and initial setting press button  . From window “Station” (Fig.11) it is possible:

1. Get LMTI ID.
2. Choose data acquisition mode (Flash / PC / Flash+PC/ LCD).
3. Open window “Coefficients”. (Fig.12). In this window calibration coefficients can be read from LMTI, edited and written back during calibration procedure.

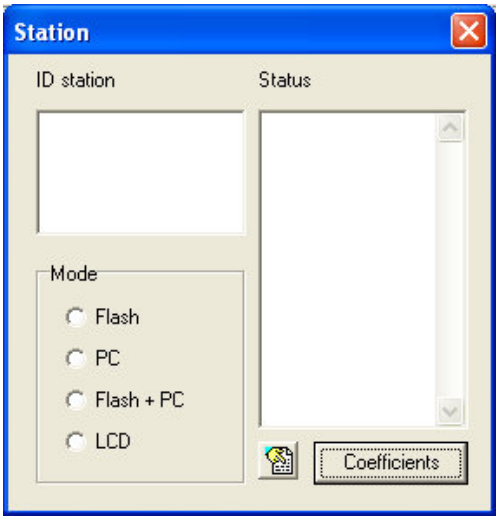


Fig. 11. Command window “Station”

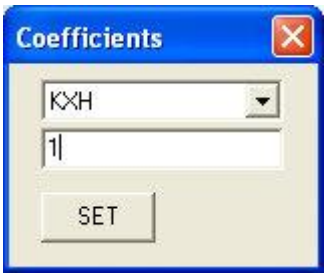


Fig.12. Dialog window “Coefficients”

Protocol File lemi417.log

For log-file viewing press button  (Fig. 13).

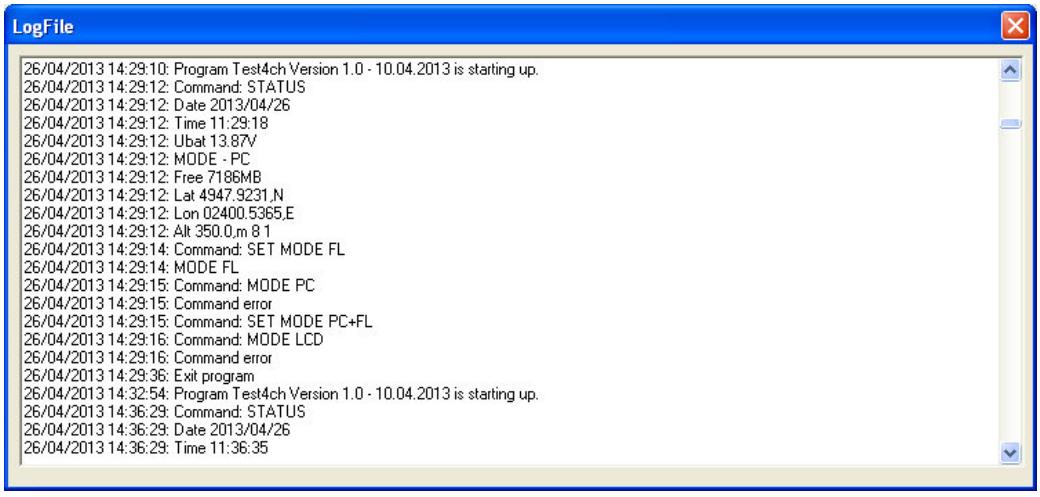


Fig. 13. Log-file viewing.

This file is created automatically and is appended continuously with protocol information. For example, start and stop time of the program are stored in this file, time of commands sending, errors information etc. **Please, never delete this file, as it will help designers to search the errors and modify the program if necessary.**

Serial port choosing

For serial port choosing open window “Setup” from main menu (Fig. 14). The current serial port number will be saved in *.ini file after program closing.

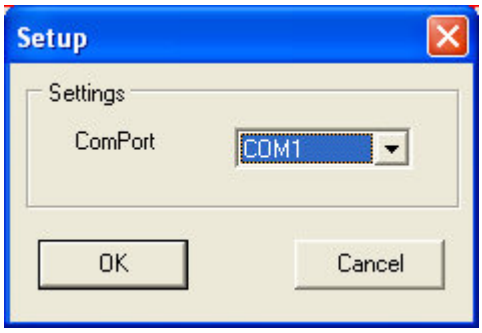


Fig. 14. Setup window

Program current version

To look information about current program version press button <About> in main menu (Fig. 15).

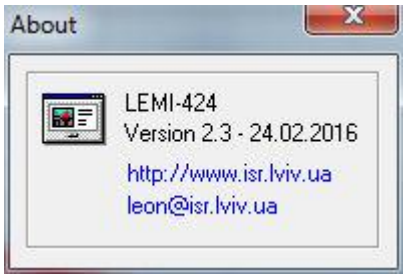


Fig.15. Window «About»

Note. The software of the magnetometer is continuously developed. That is why latest versions may have minor distinctions, which have no influence on its main operation possibilities.

7. STORAGE AND TRANSPORTATION

7.1. LMTI storage conditions:

- Temperature - from +5 to +40 °C;
- Relative humidity - not more than 85%.

7.2. LMTI can be transported by any transport vehicles without limitation

7.3. During storage and transportation the shocks more than 5 g are inadmissible.

7.4. As LMTI housing is hermetically sealed it is very desirable to keep under the LMTI cover the Peli™ desiccant cartridge with dry silica gel (Peli ref. number 1500D) to prevent water condensation from trapped air when case is opened in high humidity condition or an ambient temperature is decreased.

7.5. A user has to check periodically the color of the silica gel through the inspection window at the cartridge. When it becomes pink, the cartridge has to be reactivated by oven drying at 150 °C during 3 hours.

7.6. In order to keep the silica gel desiccant as long as possible, try to keep the case lid closed all the time during operation and storage of the LMTI.

7.7. To remove the cartridge for silica gel drying two fixing screws (at the lower surface of the case cover) have to be loosened. After drying, install the cartridge back and carefully fix it by screws.

IMPORTANT!

The electrodes have to be washed by spring- or rainwater after use. If a short break between the measurements is expected (up to one week), it is allowed to put the electrodes in the common can with clay-$CuSO_4$ suspension. If longer break is expected, put the electrodes back in their containers. Before this, moisture the porous plastic at the container bottom with 10% $CuSO_4$ solution.

The FG sensor before its placing into transportation housing must be carefully cleaned and dried.

Any questions about LMTI exploitation and operation can be sent to designers:

vakor@isr.lviv.ua – general and electrodes

pristaj@isr.lviv.ua – LMTI

leon@isr.lviv.ua – software for LEMI-424

The lead-free non-polarized electrodes LEMI-701

The lead-free non-polarized electrodes LEMI-701 are for the measurement of the electric field variations in the soil.

The quality of the electrodes used for electric field measurements in magnetotelluric (MT) soundings is the main limitation in accuracy, corresponding to the reliability of the resulting Earth models. Different types of electrodes as well as different materials are used to provide as low as possible electrode noise and long-term drift. The most common materials for non-polarized electrodes are combinations Ag-AgCl and Pb-PbCl (Petiau and Dupis, 1980). The latter is reported to be best (Petiau, 2000).

Recently, the new directive (Dir. 2011/65/EU (RoHS 2) of the European Parliament and of the Council of 2 January 2013) was adopted in Europe requiring elimination of lead and lead composites from use in every application. This led to the development of other electrode construction and materials. As a starting point, a standard Schlumberger electrode based on copper - copper sulphate was used. Its drawbacks were studied (Korepanov and Svenson, 2007), and new improved non-polarized electrode construction LEMI-701 based on Cu-$CuSO_4$ combination was developed.
Our long-term study revealed that the new LEMI-701 geophysical electrodes, besides their ecological safety, also have considerable metrological advantages compared to Pb-PbCl ones. The measured noise of randomly selected pair LEMI-701 non-polarized electrodes was ~20 nV at 1 Hz versus 0.4 μV for Pb-PbCl (Petiau and Dupis, 1980). For a matched pair selected by using a test assembly and special selection procedure, the drift over about 4 months was approximately 50 microvolt versus 1 mV/month for Pb-PbCl (Petiau and Dupis, 1980). The new electrode is shown in Figure 1 and in its transportation container in Figure 2 and the view of the contact surface made from porous ceramic, in Figure 3.

Figure 1: LEMI-701 non-polarized electrode.

Figure 2: Non-polarized electrode in its protective container.

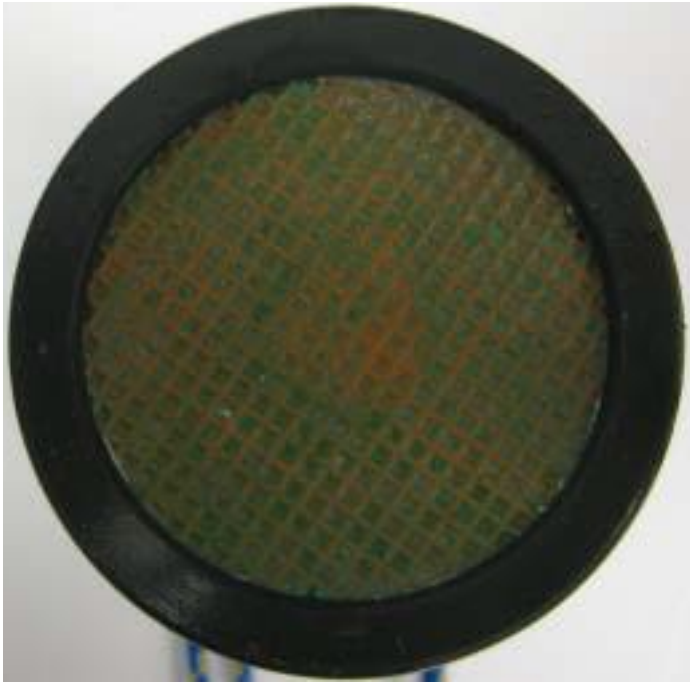


Figure 3: Electrode ceramic contact surface

The plot of LEMI-701 electrode noise density mean value spectral dependence is demonstrated in Figure 4.

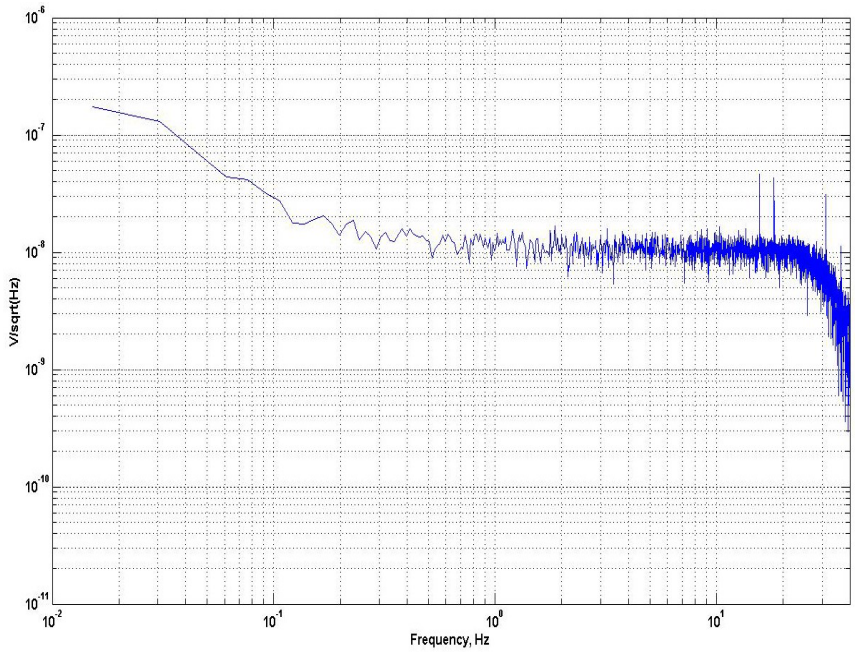


Figure 4: LEMI-701 electrode spectral noise density (mean value).

The next advantage of these electrodes is that, if all storage and handling requirements, as given in the Operation Manual are fulfilled, they do not need any maintenance during all their service life.

In Figure 5 the results of short-period (5 day) tests for selected matched pairs are given which show the worst-case rms error of about 13 μV.

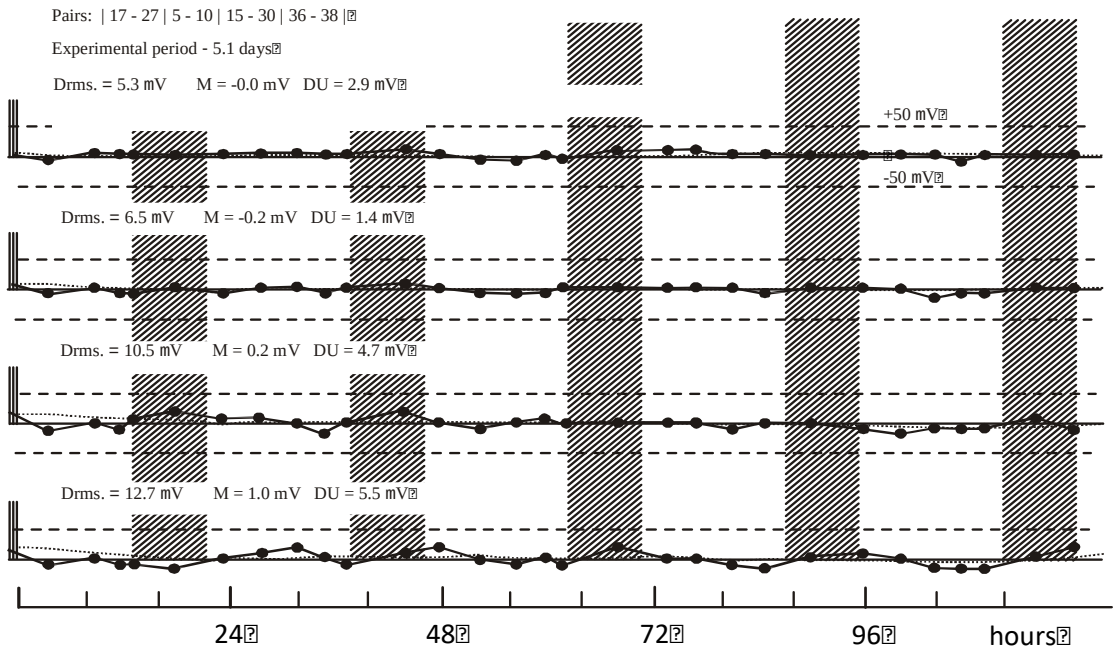


Figure 5: Drift of selected electrode pairs (short term): Drms – root mean square error; M – baseline shift; DU – averaged dispersion.

Next advantage of LEMI-701 electrodes is the possibility to restore their workability even after improper use or after drying or long-term storage. The conditions of this are the absence of the mechanical damages and enough big amount of electrodes (minimum 10). If these conditions are fulfilled, it is necessary to install all available electrodes in a tank

with 10% CuSO4 solution and keep there for a week. Then the electrodes may be re-used as they are, but already not in matched pairs combination providing minimal temporal drift. If again, minimal drift is required, the selection procedure exposed in (Korepanov and Svenson, 2007), should be used to combine matched pairs.

REFERENCES

Petiau, G., and Dupis, A., 1980. Noise, temperature coefficient and long time stability of electrodes for telluric observations. Geoph. Prospecting. 28 (5), 792-804.

Petiau, G., 2000. Second generation of lead-lead chloride electrodes for geophysical applications. Pure and Appl. Geophysics, 157 (3), 351-382.

Korepanov, V. E., and Svenson, A. N., 2007. High precision non-polarized electrodes for field geophysical prospecting. NAUKOVA DUMKA, Kiev, Ukraine, 96, (in Russian).

INSTALLATION PROCEDURE

Important! Special attention has to be paid to the electrode installation procedure, especially if long- term measurements are required. The best results may be used if the procedure given below will be strictly followed.

STEP 1: Select the proper places for the electrodes burial. It is important to choose similar places for the two electrodes in one line. The requirements are: similar soil composition, orographic features (i.e., hill-hill or valley-valley, same sun exposure), and especially the moisture conditions. Clayish grounds are recommended for long-term measurements as they keep the moisture longer.

STEP 2: Dig the electrode holes (deeper for long term - > 1 day and shallower for shorter recordings). Practice shows that for the majority of soils, a hole depth of about 70 - 80 cm is enough to avoid daily thermal variations. Make at the hole bottom a cylindrical hollow with a diameter of ~7-8 cm and depth ~15-18 cm. (A bottle is a useful tool to form this).

STEP 3: Next, the clayish suspension has to be prepared (about 3 liters for each electrode pair depending upon moisture condition). For this, light-colored clay has to be taken which does not contain ferrous oxides and calcareous impurities. To check this, about 200 g of clay is diluted with distilled (or at least boiled) water in a plastic can to form the consistency similar to yoghurt. Then add a 10% CuSO4 solution, stir it thoroughly and leave it for about 1 hour. The clay will deemed suitable if it conserves a blue color after this time. Instead of clay you can also use Bentonite.

STEP 4: For wetting the electrode plant, a suitable amount of clay is mixed with 10% CuSO4 solution (in as clean as possible water) into a yoghurt consistency emulsion (~ 3 liters for each electrode pair).

STEP 5: Take matched pair of electrodes (they are marked!) and remove them from their protective transportation containers. Each electrode fits tightly into these containers to avoid leakage of the $CuSO_4$ solution (the soft insert at the container bottom is impregnated with it). Pull the electrode from the container gently by hand, softly swinging it laterally. Do not pull it with force, especially by cable, as this may damage electrode!

STEP 6: Put extracted electrodes in the plastic can with the prepared clay-$CuSO_4$ mixture and keep them there until the moment of installation into the ground (at least for 15 minutes). Several pairs can be placed in one plastic can.

It is recommended to check the electrode pair transient resistance before and after installation!

For this, use a voltmeter with an input resistance >10 MOhm, 10 μV resolution and a 3-5 kOhm reference resistor R. First, connect the voltmeter to the electrodes output (of each matched pair in the can) and measure the voltage U1. Then connect to both electrode outputs of the pair the reference resistor R for a short time and measure the voltage U2. Then the value of transient resistance R_l has to be calculated as:

$$R_l = \frac{R(U1 - U2)}{U2}$$

Normally, the value of this resistance in the can is within 200-300 Ohm or lower.

STEP 7: In order to remove the electrodes safely back after measurements the pull cord on the electrodes is twisted and for long-time recording installation fixed to the electrode surface with adhesive tape. This will help to pull electrodes out without damaging them. Not following this may damage the electrodes, especially for heavy clayish and stony soils.

STEP 8: Just before the installation, take ~1.5 liters of emulsion from the can, and mix it with the soil taken directly from the bottom of the hole

STEP 9: Implant a pair of electrodes from the can into the hollow at holes bottom as follows: for long-time recording we recommend to install electrodes “bottom-up” (see Figure 6a); for short-time (≈ 1-2 days) in a tilted position as shown in Figure 6b.

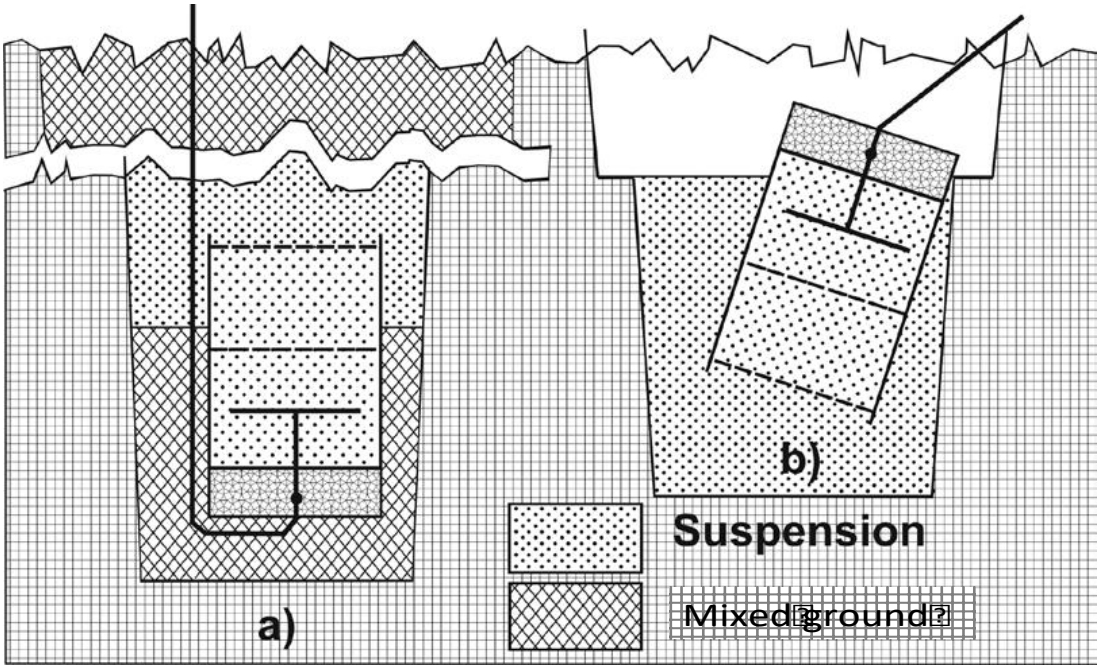


Figure 6: Electrode installation in operation position: a- left – long-time; b- right – short-time.

For this type of electrode, we DO NOT recommend to install the electrodes in a vertical position.

This is because the Cu-$CuSO_4$ solution in the water may produce free oxygen O_2 due to its dissociation even with very small currents flowing through the electrodes (often caused by wrong transient resistance measurements, particularly when an ohmmeter is directly applied to the electrodes). If the electrode is not tilted, oxygen is gathered below its ceramic partition, and significantly increases the transient resistance.

STEP 10 (a): For long-term recordings, as recommended, put the electrode in the hole with the contact surface up (Figure 9a).

- First fill in the hollow with soil taken from the hole bottom to cover approximately half of the electrode length.
- Pour the prepared mixture of emulsion & soil in the hole until you cover the sensitive part of the electrode by a layer of ~3-5 cm.
- Fill the hole with remaining ground.

After the hole is filled, water it with spring- or rainwater taken in the area (approximately 10 liters per one hole) and then cover with a plastic about 1x1 meter in size. This will protect the electrodes from instantaneous potential changes caused by rain.

STEP 10 (b): For short-time recordings fill the hollow with the emulsion/soil mixture, and again, fill up the hole with the ground taken from the hole and cover it with plastic.

STEP 11: The instrument cables are connected first to the electrode wires. In recent versions a special contact socket may be provided as shown in Figure 7. If a terminal box as given here is used, to the other end of the electrode line a fork-type contact has to be fixed for convenience (Figure 8).

Figure 7: Electrode contact socket

Figure 8. Fork-type connector to connect an electric line to the terminal box

STEP 12: To connect the cables to terminal box, the terminals are released, and then the cable ends are inserted into them and tightly fixed with plastic nuts observing the polarity of lines and nuts colors. For long-term recordings, to grease the connected places with any water-resistant grease is recommended. Also we recommended protecting the electric lines with plastic pipes or digging the lines into the ground at ~ 5 cm. This will help to protect them from animals.

STEP 13: A special procedure is recommended for dry sand. A plastic can without the top has to be filled with local sand impregnated with a 10% solution of $CuSO_4$ and local spring or rainwater. The electrode is placed inside the can as for short- or long-time recordings. Then bury the plastic for ~1 m deep in the sand and cover it with foil.

STEP 14: For a stony or rocky ground the only solution is to look for local cracks and then try to widen / deepen them. In this case, it is possible that exact orthogonality of the electric array may not be possible. This needs to be measured to allow correction during the processing.

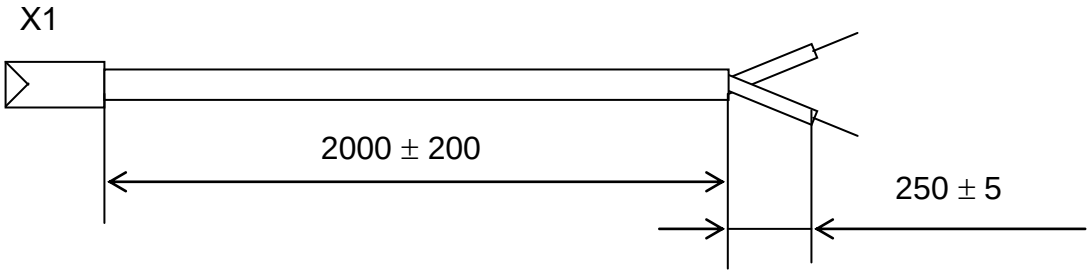
STEP 15: As it was stated, it is possible to use the LEMI electrodes that are not matched pairs as recommended, but in this case the initial voltage zero shift of the electrode pair may reach units of millivolts (no more than ~ 10) and its variations may be within ~ 100 microvolt.

As recommended, just after installation of electrodes in the ground, the same procedure of the transient resistance Rl verification possibly with the similar R should be repeated. (Recommended value of Rl is < 20-50 kOhm for sandy soil and < 10 kOhm for clayish soil.)

STEP 16: After recording, take from the ground and wipe every electrode with a wet and clean rag and then pour a small amount of the 10% CuSO4 solution into the transportation container to wet the soft material at the bottom. Then insert the electrodes as shown on Figure 2.

It is highly recommended to keep the matched electrodes pairs tied together for storage!

POWER SUPPLY CABLE

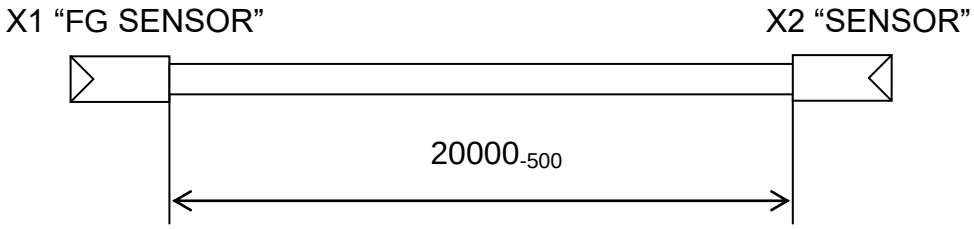


X1

circuit	contact	Marking
+VIN	A	“RED”
-VIN	B	“BLUE”

Connector X1 type – socket AMPHENOL PT06A-8-2S

SENSOR CABLE WIRING



	X1		X2		
Circuit	Pin	Wire	Pin	Circuit	Notes
X+	A	white	A	CA1	twisted 1
X-	B	brown	B	CA2	
Y+	C	grey	C	CB1	twisted 2
Y-	D	pink	D	CB2	
Z+	E	lilac	E	CC1	twisted 3
Z-	F	black	F	CC2	
		Short circuit on J X2	G	CD1	twisted 4
TF+	H	yellow	H	CD2	
AGND	J	green	J	SGND	
		shild	K	SGND	
+5V	L	red	L	+5V	twisted 5
GND	M	blue	M	GNDM	

X1 – УСНЦ144-19/15 РО12-NCK-H
X2 – PT06A-14-19S with cap MS3180-14CA
Cable HELUKABEL PAAR-TRONIC- CY 5 x 2 x 0.14

APPENDIX 3

Amplitude and phase characteristics of stations

LEMI-424 # 147

Amplitudes							
F [Hz]	Bx	By	Bz	E1	E2	E3	E4
0.500	0.811922	0.811910	0.812276	0.815709	0.815705	0.815711	0.815706
0.250	0.950624	0.951020	0.951211	0.951918	0.951917	0.951919	0.951917
0.200	0.968209	0.968507	0.968639	0.969071	0.969070	0.969071	0.969070
0.100	0.991988	0.992079	0.992115	0.992215	0.992215	0.992215	0.992215
0.050	0.997993	0.998017	0.998026	0.998050	0.998050	0.998051	0.998050
0.025	0.999498	0.999504	0.999506	0.999512	0.999512	0.999512	0.999512
0.010	0.999920	0.999921	0.999921	0.999922	0.999922	0.999922	0.999922
0.005	0.999980	0.999980	0.999980	0.999980	0.999980	0.999980	0.999980
Delay [s]							
F [Hz]	Bx	By	Bz	E1	E2	E3	E4
0.500	0.031690	0.033876	0.032407	-0.000954	-0.000929	-0.000969	-0.000917
0.250	0.031639	0.033472	0.031743	-0.000906	-0.000881	-0.000921	-0.000871
0.200	0.031643	0.033410	0.031640	-0.000903	-0.000878	-0.000918	-0.000867
0.100	0.031653	0.033322	0.031494	-0.000899	-0.000874	-0.000914	-0.000864
0.050	0.031657	0.033299	0.031455	-0.000899	-0.000873	-0.000913	-0.000863
0.025	0.031657	0.033293	0.031445	-0.000899	-0.000873	-0.000913	-0.000863
0.010	0.031658	0.033291	0.031443	-0.000899	-0.000873	-0.000913	-0.000863
0.005	0.031658	0.033291	0.031442	-0.000898	-0.000873	-0.000913	-0.000863
Phase [degree]							
F [Hz]	Bx	By	Bz	E1	E2	E3	E4
0.500	-5.704186	-6.097631	-5.833176	0.171647	0.167204	0.174420	0.165118
0.250	-2.847509	-3.012498	-2.856878	0.081557	0.079304	0.082902	0.078350
0.200	-2.278322	-2.405530	-2.278089	0.065008	0.063200	0.066080	0.062445
0.100	-1.139519	-1.199584	-1.133769	0.032379	0.031470	0.032912	0.031099
0.050	-0.569818	-0.599375	-0.566194	0.016177	0.015722	0.016443	0.015537
0.025	-0.284917	-0.299635	-0.283009	0.008087	0.007859	0.008220	0.007767
0.010	-0.113968	-0.119848	-0.113194	0.003425	0.003144	0.003288	0.003107
0.005	-0.056984	-0.059924	-0.056596	0.001617	0.001572	0.001644	0.001553