TEM-FAST 48
(MANUAL)

(Version 8a)

© Applied Electromagnetic Research (AEMR), the Netherlands 2016

CONTENTS 2

Chapter 1. Check list of the TEM-FAST system 3

Chapter 2. What is TEM-FAST 48 system? 4

Chapter 3. Description of the TEM-FAST 48 components 6
Transmitter (generator) 6
Receiver 10
Data acquisition system 12
Analog to digital converter 14
Controller 14
Power supply 15
Choice of the shunt value 15
The case and connectors of the device 17
Connection of the device, tests and technology of soundings 18
Field measurements, the personnel 19
Computer 19
Antennas 19
Measurements 20
Technical specification 21
Complete TEM-FAST 48 set 22

Chapter 4. The system interface of TEM-FAST 48 (Windows OS) 22
What is dynamic range of measurements 26
How the errors of measurements are calculated? 26
The warnings and other information 32
Formats of the used files 33

Chapter 5. The system interface of TEM-FAST 48 (DOS) 35

Chapter 6. The system interface of TEM-FAST 48 (Win CE) 47
TEM-FAST data converter 61

Chapter 7. TEM. Theory and experiment 63
Practical conclusions and recommendations 65
Superparamagnetic effect in TEM 66
Effect of induced polarization IP 72
Applications in urban conditions 77
Monitoring 81
References 83

Chapter 1. CHECK LIST OF THE TEM-FAST SYSTEM

I. Transmitter, receiving block with the standard battery in a single case (main unit)

II. Peripheral units, cables and manuals

1. Cable for connection of the main unit with 1-loop antenna
2. Charging device with cable
3. Extra pins for antennas (8 pieces) and battery clips
4. Cable to connect the main unit with the Notebook through the USB cable
5. Test - coil
6. Cable for connection of the external battery "Power 24V".
7. Cable for connection of the external battery "Power 12V"
8. Cable for connection of the main unit with 2-loop antenna
9. Antenna cable 25×25 m (2×50 m)
10. Antenna cable of 100 m length and 1 mm^2 section
11. Rugged handheld
12. Manual for the rugged handheld
13. Socket for the rugged handheld
14. Charger for the rugged handheld
15. Cable for connection of the rugged handheld with the main unit
16. Cable connection of the rugged handheld
17. Dongle (electronic key)

III. Bag for transportation and keeping of the device

Chapter 2. WHAT IS TEM-FAST 48 SYSTEM?

TEM-FAST 48 is the new instrument in family of portable geophysical tools developed by the AEMR Ltd. company. In a channel of the chosen strategy it is "*simple - fast - robust*" system. The new tool, as well as its predecessors, is intended for electromagnetic researches of massifs of rocks within the limits of first 300-500 m based on TEM technology.

The main areas of application:

- search of mineral deposits;
- hydro-geological researches;
- geological researches, previous to construction of buildings;
- ecological researches;
- archaeology and special searches of unique targets;
- monitoring of dangerous geological and engineering objects;
- research of rock samples.

In spite of the fact that in the geophysical market as minimum dozen of EM and TEM of tools with similar area of application is submitted, the family TEM-FAST occupies stable positions in the field of small depths researches.

What are the advantages of TEM-FAST?

- There is no tool, which in a complete set, including antennas, battery and PC, needs in such small case and weighed 5 kg.
- There is no competitor with opportunities to receive the information simultaneously about the first meters, and about depths in hundreds meters.
- Application of a ultra-rugged Handheld computer allows TEM-FAST to see and to estimate results of soundings directly in field conditions and if necessary to correct the process of measurements.
- There are no competing TEM devices capable provide robust work in urban streets and industrial areas at levels of noise in the receiver in volt and more.
- Due to easy rearrange algorithms of work, TEM-FAST guarantees qualitative results even in the most adverse conditions.
- Any of TEM competitors do not provide so high efficiency and cost efficiency of researches as TEM-FAST.

TEM-FAST originally was developed within the framework of the international program MARS-94” and intended for installation on landed Martian module with the purpose of TEM sounding of a surface “of a red planet”. It is natural that by development the increased requirements to reliability of the tool in extreme conditions were set. All these qualities have inherited all “terrestrial” variants of TEM-FAST.

So, for example TEM-FAST 48:

- has increased crashworthiness;
- provides stable results of measurements at sharp changes of temperature (till to 3°C/minute);
- provides measurements in a completely automatic mode in current practically of unlimited time;
- equipped with the system of auto-calibrating and testing, tracing a correctness of work of the device during measurements.

Among the features TEM-FAST 48 favorable distinguishing it from the competitors is the possibility to allocate following.

TEM-FAST 48 uses for creation of sounding magnetic field a special sequence of uni-polar rectangular current pulses with ratio a pulse/pause = 3/1. Such form of pulses provides at registration of long slow processes in well conducting media the minimal

dynamic error caused by imposing of transients from both fronts of current pulses in transmitting antenna.

As a rule, TEM instruments use pulses of a current with the ratio pulse/pause = 1/1. Correction of a dynamic mistake in this case occurs during inversion of a section given within the class of layered models. However, at such approach the opportunity of use the various TEM transformations of the data **E(t)** (for example, dependence of apparent resistivity versus effective depth of researches - **ρ(h)**) is lost. The transformations TEM of signals do not contain any restrictions on horizontal uniformity of a researched section. On the contrary, **ρ(h)** transformation of the data allows to do enough reliably interpretation of the data in conditions of sharp non-horizontal media that in most cases is a subject of study TEM.

TEM-FAST provides the possibility to start the process of measurements of decay of current beginning from 4 μs. This parameter, determining the minimal time of registration of a signal and minimal depth of research in TEM-FAST is the shortest of all submitted on the market TEM tools. This circumstance at use of antennas with small sizes allows carry out inversion of data (by traditional way or using transformation **ρ(h)**) for depths, since 0.5-1 m.

In TEM-FAST the special gating system is applied, integration and storage of the analog information (**DAS**) is allowed,

The system provides measurements even in case when the noise level on an input of receiver achieves 1-2 V. Thus, the device provides a dynamic range of measurements of the **E(t)/I** value within the limits of 140 dB. It allows using effectively TEM-FAST in urban conditions and within the limits of the industrial enterprises that is important for engineering and ecological tasks.

It is possible to use TEM-FAST with different size of antennas - from several centimeters up to hundreds meters. It allows carry out researches in conditions of a limited area - on urban streets or in territory of industrial objects. Besides it is possible to use the tool for research of samples of rocks in laboratory (for example superparamagnetic effect), or to carry out physical modeling of TEM processes.

Together with multi-turn antennas by the size 1×1- 5×5 m TEM-FAST can be used as metal detector with limiting depth of search up to 3-5 m depend on a material and size of a target. This property is used for archaeological and special researches.

At the sizes of antennas ~ 5×5 - 10×10 m TEM-FAST well detects electrically contrast zones of the lowered resistance, produced by water or pollution.

In cases of well conducting sections with ρ < 5-10 Ohm-m use of small antennas allows allocating caves in rocks on depth up to 5-7 m.

In TEM-FAST the automatic mode of operations is stipulated, at which the device through the given intervals of time makes measurements and writes down the data in PC memory. This mode can be used for continuous monitoring of a condition of various targets during several weeks or months. The goals of monitoring can be artificial and natural tanks keeping petroleum, gas, industrial wastes, fault zones, the natural detector of tectonic processes, dam, etc.

In the following chapters the information on the device TEM-FAST 48, description of the system interface, elements of the TEM theory and examples of use of the equipment in some geological situations is given.

Chapter 3. DESCRIPTION OF THE TEM-FAST 48 COMPONENTS

TEM-FAST includes:

- the generator of uni-polar rectangular pulses (transmitter),
- the measuring block providing registration of the signals (receiver),
- the control block (controller),
- the power supply (battery).

All devices are assembled in a single case.
The block diagram of the device is given in fig. 2-1.

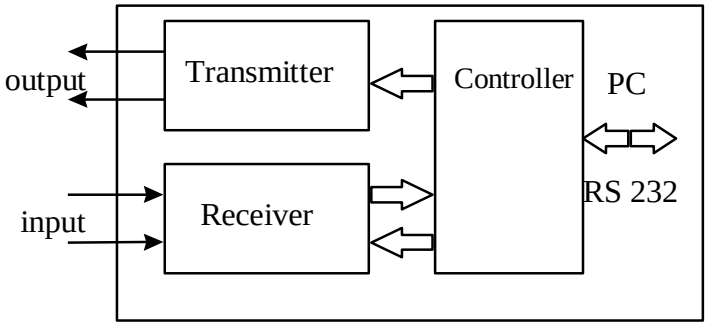


Fig. 2-1

Transmitter (generator)

The generator develops rectangular pulses of a current, which are passed through the transmitting antenna. Form of the pulses is shown in fig. 2-2.

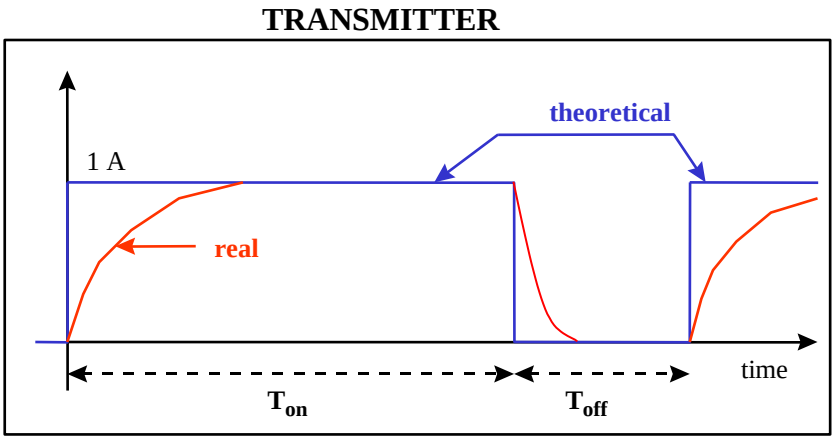


Fig. 2-2

The real antenna can be presented as inertial electrical system with distributed inductance, capacity and resistance. At the moment of switching off (namely this moment represents the special interest at measurements of transients), current in the antenna sharply differs from the ideal. Voltage profiles in the transmitter antenna of 50×50 m and 20×20 m size at the moment of the current off, measured by the digital oscilloscope THS720 (Tektronix) are shown in fig. 2-3. The graph of the current off process calculated using the voltage's oscillogram **E(t) ~ i'(t)** is shown in fig. 2-4.

The value $\mathbf{R_{TR}}$ of the resistor connected across the antenna is equals to 560 Ω. The current **I** in the antenna is equal to 1A.

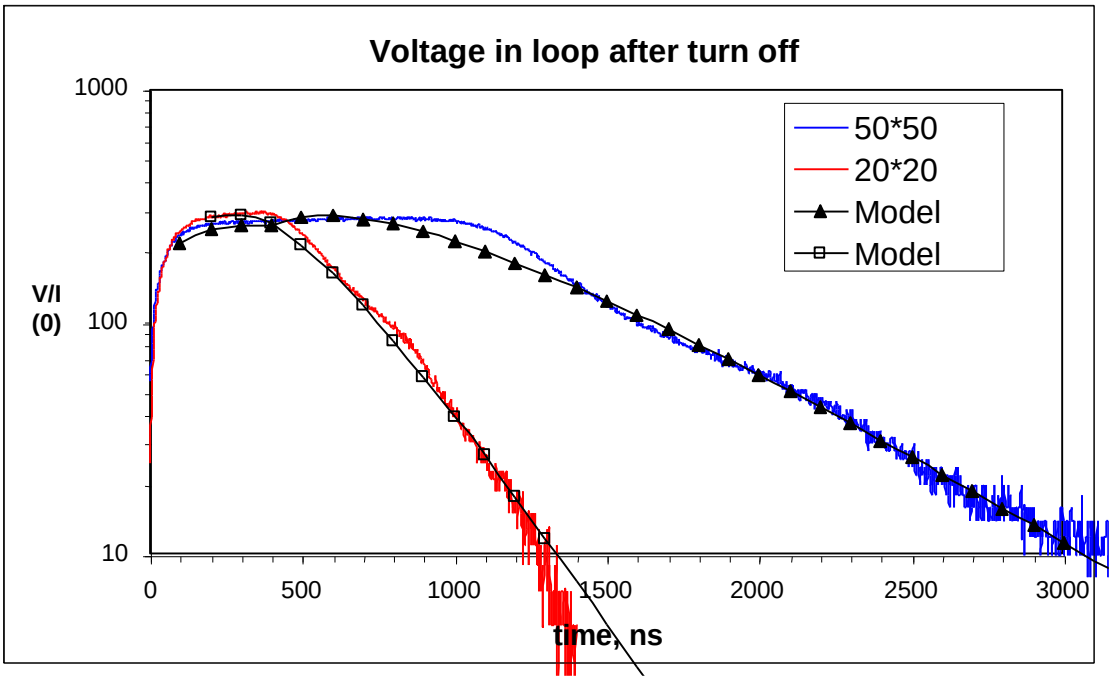


Fig. 2-3

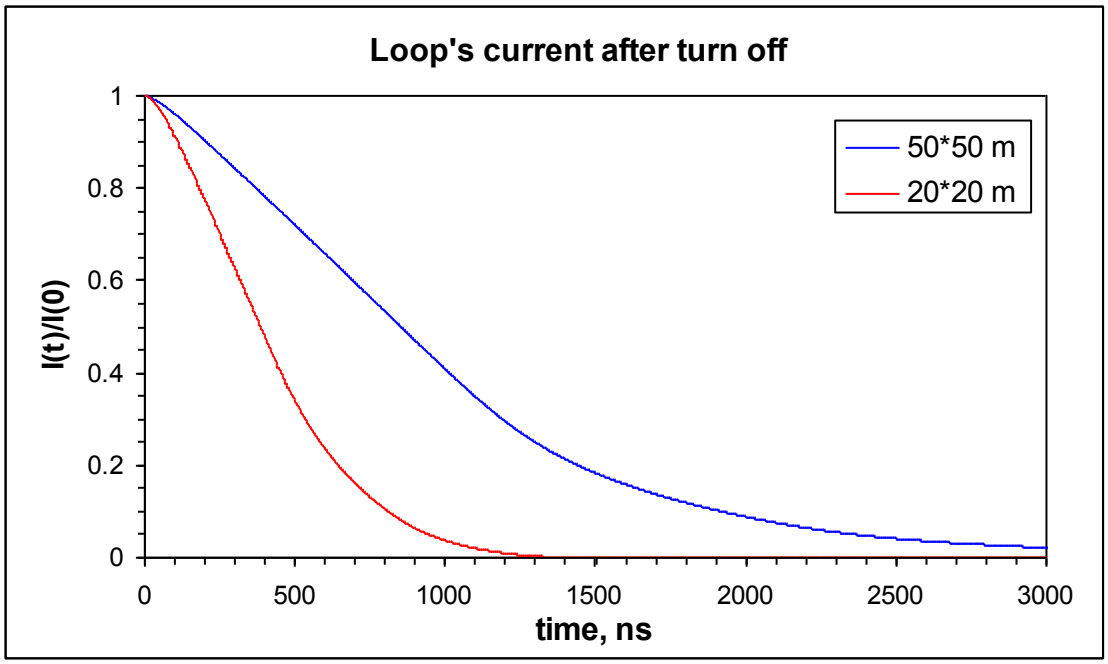


Fig. 2-4

Graph of the voltage (Model) calculated for the line with distributed parameters is presented in the fig. 2-3.
Numerous experiments give us possibility to estimate the values of parameters L_0 ,C_0 for different antennas and cables, impedance Z_0 and the period of natural oscillations. These data are given in the table below:

$s=\pi r^2$	antenna l*l	inductance	Lo	Co	$T=8l*(LoC^{1/2}$	$Zo=(Lo/C^{1/2}$
mm^2	m*m	μH	μH/m	pF/m	ns	Om
0.5	12.5x12.	110	4.4	8.2	*600*	**733**
0.5	25x2	200	4.0	7.6	*1100*	**727**
1	50x5	460	4.6	8.5	*2500*	**736**
1	100x10	860	4.3	8.2	4750	**724**

The exact theoretical estimation of the value of resistor R connected to terminals of the antenna and providing shortest aperiodic mode of cutting off the current, found *for a line with distributed parameters L_0 and C_0* is equal $\mathbf{R = Z_0}$.
Wave resistance $\mathbf{Z_0 = (L/C)^{1/2}} \approx 730$ Ohm remains (with an error no more than 5 %) a constant for antennas with the size from 12×12 up to 400×400 m^2 at distance from the antenna's wires to the surface of the ground h~0.1-0.5 m and at normal humidity of soil. However, taking into account the capacity of the power transistor and change of the distributed capacity at increase of humidity and consequently dielectric permeability of superficial soil, find

$$\mathbf{R \sim 0.8\ Z_0 \sim (560\text{-}600)\ Ohm}$$

The problem of optimal choice of the resistor's value providing the minimal duration of the current's front for different antennas will be discussed specially (see "*Choice of the shunt's value"*).

It is necessary to note, that there is one more important factor, which essentially influences the form and time of attenuation of a current, it is maximum allowable voltage of the output transistor. In fig. 2-5 the oscillogram of a voltage for the antenna 50×50 m and current I = 1 A and I = 4 A are given. Extreme voltage of the output transistor used in the unit is equal to ~850 V, one can see non-linear character of E/I signal. This effect can distort the measured transient process at a time less than 6-7 μs (20×20 m), 15-20 μs (50×50 m) and till 40 μs (100×100 m). Fig. 2-6 demonstrates distortion of the signal for different value of the current in loop.

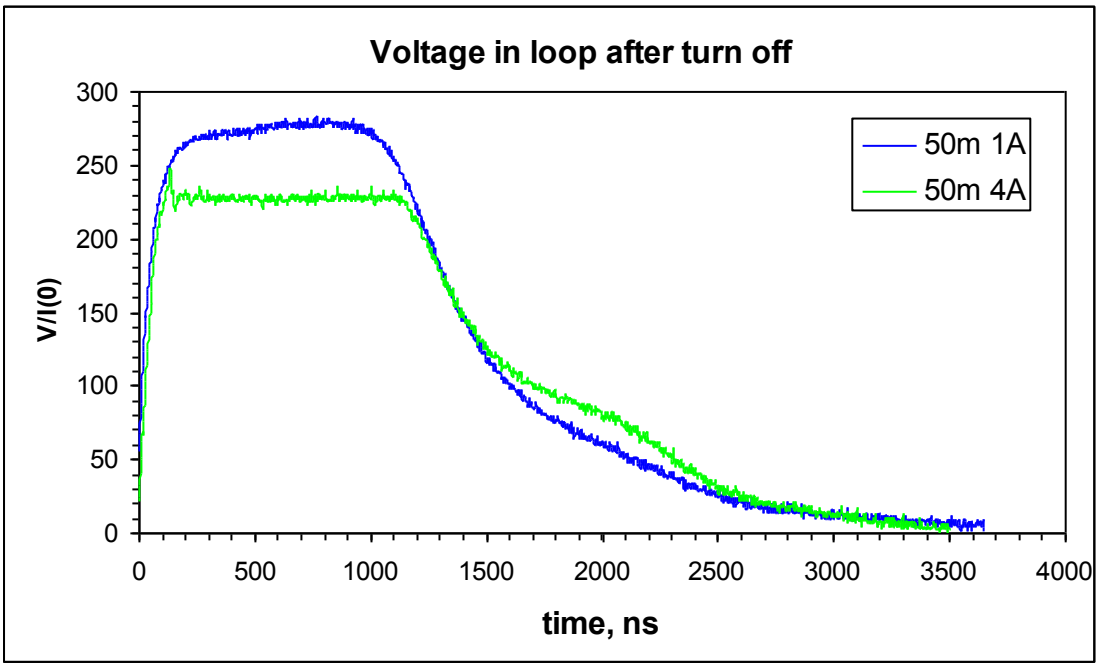

Voltage in loop after turn off
V/I(0)
300
250
200
150
100
50
0
0
500
1000
1500
2000
2500
3000
3500
4000
time, ns
50m 1A
50m 4A

Fig. 2-5

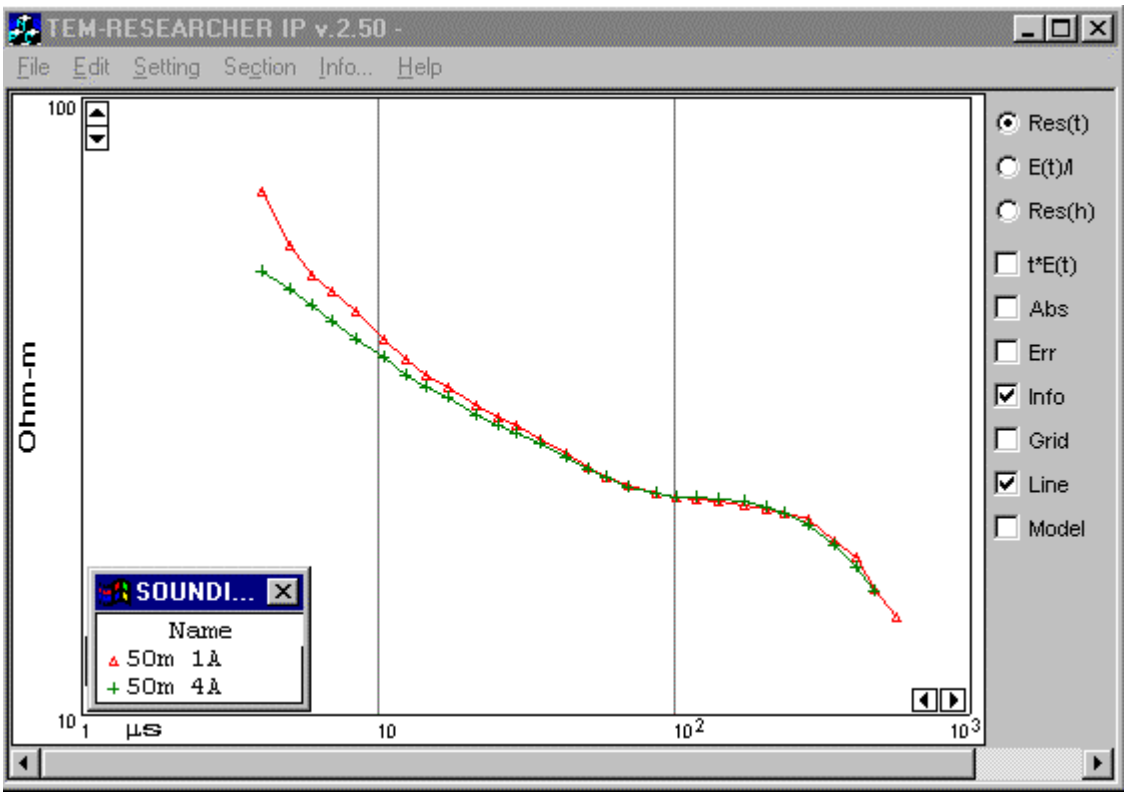

TEM-RESEARCHER IP v.2.50 -
File
Edit
Setting
Section
Info...
Help
Ohm-m
100
10
1
µs
10
10²
10³
Res(t)
E(t)/I
Res(h)
t*E(t)
Abs
Err
Info
Grid
Line
Model
SOUNDI...
Name
50m 1A
50m 4A

Fig. 2-6

The error of measurements conditioned by a non-linearity of the process at the moment of voltage restriction at output transistor $\mathbf{E_{1A}(t)/I - E_{4A}(t)/I}$ for time **t**=10 μs is of order of 3-4%.

The parameter **Ton + Toff** of the current's pulses TEM-FAST 48 (Fig. 2-2) depending on a measurement mode (FILTR = 50/60 Hz) is given in table 2-1.

Table 2-1.

Key	Max time (μs)	Active Time gates	Analog Stack	Ton+Toff (50Hz) (ms)	Ton+Toff 60Hz) (ms)
1	64	16	1024	0.3125	0.26
2	128	20	512	0.625	0.52
3	256	24	256	1.25	1.042
4	512	28	128	2.5	2.08
5	1024	32	64	5	4.17
6	2048	36	32	10	8.33
7	4096	40	16	30	25
8	8192	44	8	50	41.67
9	16384	48	4	90	75

The modes of the generator's operation are given in table 2-2

Table 2-2

U power (V)	**I** range (A)	**r** TR (Ohm)	**I** real (A)	Accuracy (%)
12	1	0-8	1	5
24	1	8-20	1	5
12	4	1-2.	4.0	10
24	4	2-4.4	4.0	10

1. The voltage of power supply U power = 12 V is created by the internal battery or external battery "Power 12V", connected through a socket Extern power. The voltage U power = 24 V is connected to the device through a socket Extern power through a cable "Power 24V". The modes of operations " **I** range " are established in the system interface.

If the resistance of load "**r** TR" is exceeded the values given in the table, the generator leaves from a mode of stabilization and " **I** real " is established according to a ratio **r** and **U** power.

However output of the generator from a mode of stabilization of a current does not result in increase of errors of measurements, at least, at level 1%.

Receiver

Measuring block consists from:

- Devices of protection from a high input voltage **HVP**,
- Multi-channel strobe system, integration and storage of the analog information – **DAS**,

- The multiplexer of channels - **MX**,
- The Analog-to-Digital Converter - **ADC**.

The block diagram of the receiver is given in fig. 2-7.

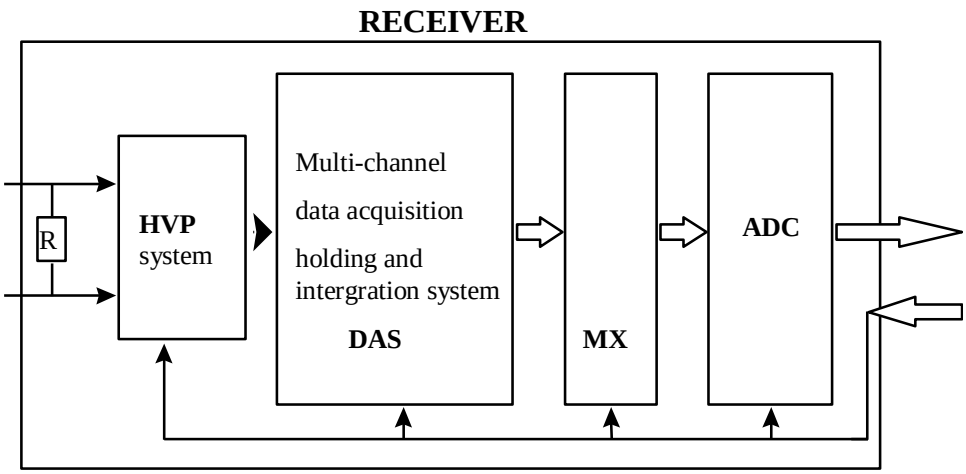


Fig. 2-7

The protection **HVP** *device against high input voltage*

The signal from the measuring antenna shunted by the resistor **R= R_{TR}** gets in **HVP**, which on an output dumps the voltage acting in **DAS**.
The work of this device is illustrated in fig. 2-8.

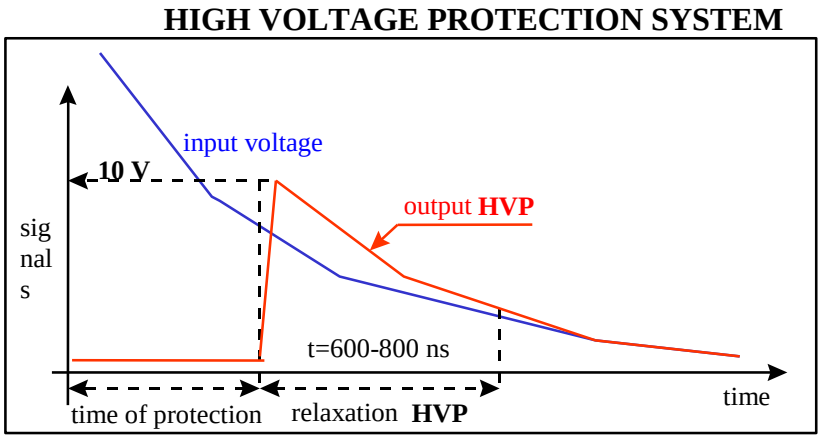


Fig. 2-8

The system **HVP** TEM-FAST 48 operates in three modes:

1. Automatic restriction of a signal on a level 10 V,
2. Time, given by the operator, of protection - *time protection* $\mathbf{t_{HVP}}$,
3. Automatically given time of protection $\mathbf{t_{HVP}}$, determined by the size of TR-loop.

The first mode of protection is turning on by hardware only in that case, when after the ending of *time protection* the voltage on an input of the system exceeds 10 V.

Operator in a window "TOOLS" of the system's interface selects HVP operation

mode. The work **HVP** is not ideal, as it dumps significant energy of an input signal in a rather short interval of time. This "imperfect " is expressed in occurrence of relaxation process, which duration depends on size of a current's pulse "**I** real" and size of the receiving - generating antenna and usually does not exceed 800 ns.

DAS system - multi-channel strobe system, integration and storage of the analog information

The signal after passage of the protection device **HVP** gets in **DAS**. This device is intended for:

- stacking of a measured signal,
- integration of a signal in readouts (strobes) for suppression of noise and compressing of a dynamic range,
- storing and stacking of the analog information.

The main principles of **DAS** operation are shown in figs. 2-9 and 2-10.

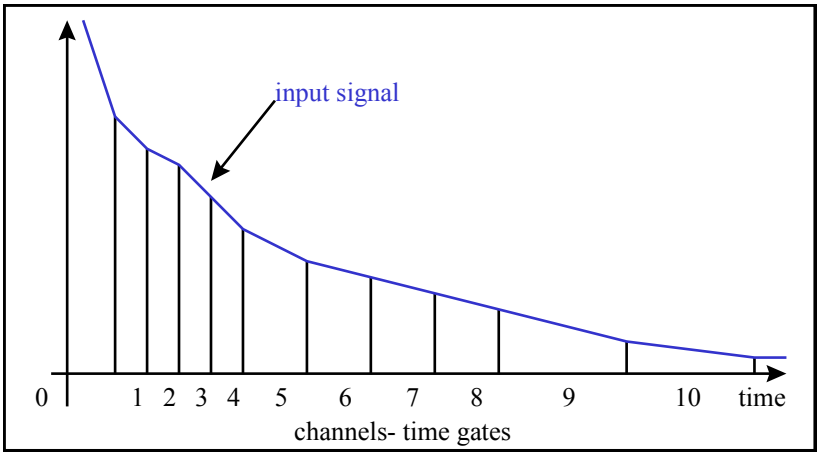


Fig. 2-9

Multi-channel data acquisition holding and intergration

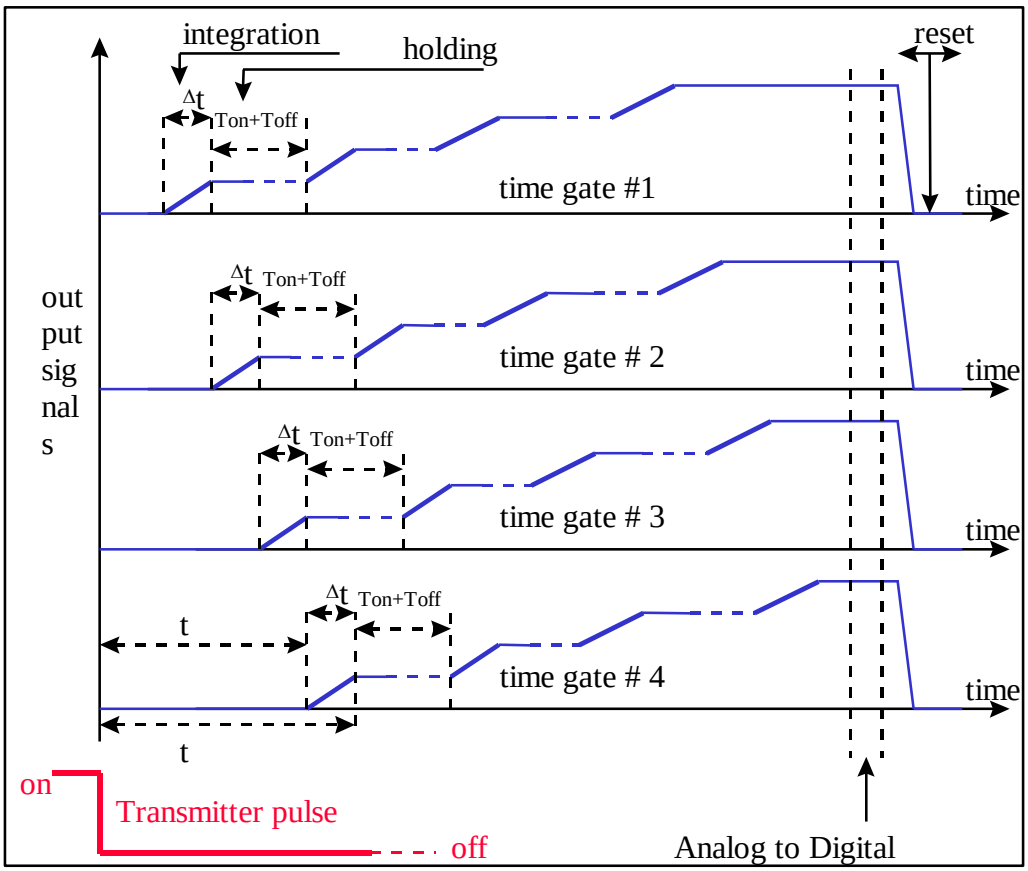


Fig. 2-10

Figs. 2-9, 2-10 show schematically measured transient **E(t)** and arrangement of strobes in limits of which further integration is made. The moment "0" on an axis of time corresponds to the moment of turning off the current's pulse ("0" in fig. 2-2).

The interval of time between the termination previous and following behind it strobe (in the figure is not designated) depends on speed of strobe keys and $\mathbf{t_{1finish} - t_{2start}} < 100$ ns does not exceed. Thus, the transient is gated practically continuously without "of dead zones".

The algorithm of **DAS**'s work depend on time for first four strobes is shown in fig. 2-10. The intervals of time $\mathbf{t_{finish} - t_{start}}$ determine location of a strobe on time axes, **Δt** is the gate's width and time of integration, $\mathbf{T_{on}+T_{off}}$ is time of keeping determined by the period of recurrence of the generator's pulses. Thus, strobe pulses periodically act on each integrator **DAS**, on output of each channel the signal is proportional to $\mathbf{U=\Sigma E(t_{center})}$ for the period of analog stacking.

After termination of the process of analog stacking, the output signals are digitized by **ADC**, transfer to the control block, and the integrators reset in an initial condition. Number of strobe-pulses participating during analog stacking at various modes of operations of the device, are given in Tab. 2-1 (Analog stack). The parameters of strobe pulses of TEM-FAST 48 are given in Table 2-3.

Table 2-3

#Time Gates	t start µs	t finish µs	T center µs	Δt µs	# Time Gates	t start µs	t finish µs	t center µs	Δt µs
1	3.6	4.6	4.06	1	**25**	255.6	319.6	285	64
2	4.6	5.6	5.07	1	**26**	319.6	383.6	350	64
3	5.6	6.6	6.07	1	**27**	383.6	447.6	414	64
4	6.6	7.6	7.08	1	**28**	447.6	511.6	478	64
5	7.6	9.6	8.52	2	**29**	511.6	639.6	570	128
6	9.6	11.6	10.53	2	**30**	639.6	767.6	699	128
7	11.6	13.6	12.55	2	**31**	767.6	895.6	828	128
8	13.6	15.6	14.56	2	**32**	895.6	1023.6	956	128
9	15.6	19.6	17.44	4	**33**	1023.6	1279.6	1152	256
10	19.6	23.6	21.46	4	**34**	1279.6	1535.6	1408	256
11	23.6	27.6	25.49	4	**35**	1535.6	1791.6	1664	256
12	27.6	31.6	29.50	4	**36**	1791.6	2047.6	1920	256
13	31.6	39.6	35.28	8	**37**	2047.6	2559.6	2304	512
14	39.6	47.6	43.30	8	**38**	2559.6	3071.6	2816	512
15	47.6	55.6	51.40	8	**39**	3071.6	3583.6	3328	512
16	55.6	63.6	59.41	8	**40**	3583.6	4095.6	3840	512
17	63.6	79.6	71.60	16	**41**	4095.6	5119.6	4608	1024
18	79.6	95.6	87.60	16	**42**	5119.6	6143.6	5632	1024
19	95.6	111.6	103.6	16	**43**	6143.6	7167.6	6656	1024
20	111.6	127.6	119.6	16	**44**	7167.6	8191.6	7680	1024
21	127.6	159.6	143.6	32	**45**	8191.6	10239.6	9216	2048
22	159.6	191.6	175.6	32	**46**	10239.6	12287.6	11264	2048
23	191.6	223.6	207.6	32	**47**	12287.6	14335.6	13312	2048
24	223.6	255.6	239.6	32	**48**	14335.6	16383.6	15360	2048

The multiplexer of channels and Analog-to-Digital Converter (ADC-system)

Both these devices are intended for consecutive digitizing of signals from outputs of the **DAS** system.

The multiplexer **MX** consistently connects outputs **DAS** to **ADC**, which will transform an analog signal to a digital code and transfers it in the control block.
Word length of **ADC** is ~16 bits, smallest unit is 1 µV.

The joint work **DAS + ADC** provides measurement of sizes **E(t)/I** in a dynamic range 1µV/A -10 V/A. The dynamic range of the signals **E(t)/I** depends on the value of parameter **Time range** and is various for different **t**.

The working area of allowable input signals (work zone) for each of nine modes of operations of the device (**Time range**) can be shown by the system interface in a window "E(t)/I". Diagnostics of work **HVP + DAS + ADC** is present in a window "TOOLS".

The control block (controller)

The controller is executed on the basis of a Programmable Logic Device and is intended to control of all process of measurements and transfer of the information to the computer.

At start of the device the controller leaves from a condition "sleep" and accepts from the computer through port RS232 special "start vector" containing the information on

modes of operations. After that the controller analyzes a condition of the battery providing energy for all blocks of the device, and transfers this information in the computer.

If a condition of the battery is normal, the computer confirms start and the device begins work. The results of digitizing of a signal from **ADC** periodically are sent in the computer through RS232. The port works on frequency 38400 bps.

During work, the control block constantly checks condition of the battery and inform the computer on a voltage on it.

To exclude parasitic connections between the computer and TEM-FAST 48, ports of the controller are manufactured with the optical isolation of all channels. Connection between the controller and generator are also optical isolation.

Power supply

In TEM-FAST 48 the opportunity to use several power batteries is stipulated:

- Standard internal battery 12V 2000 mAh (**B_0**).
- External battery 12 V for supply of the receiver and generator (**B_1**).
- External battery 12-24 V only for supply of the generator (**B_2**).

The battery **B_1** is used usually at monitoring long-term supervision. At the moment of turning on the **B_1**, the battery **B_0** is automatically disconnected. **When turning on the B_2, the internal battery B_0 automatically is used only for the receiver.**

The charge of the battery is made with the help of charging device (charger), providing complete charge of the discharged battery (U < 10 V) within 16 hours by a current 200 mA. The charger works from a power 50/60 Hz with voltage 90-250 V and at final stage the charger is automatically disconnected. An external power and charger are connected to TEM-FAST 48 through a socket (Extern. Power). For connection of batteries **B_1** or **B_2**, the special cables, with markers "Power 12V" and "Power 24V" are used. In both cases the protection of the device from polarity mistake at connection of batteries is stipulated.

ATTENTION!

1. **Don't leave an internal battery (accumulator) discharged during long time.**
2. **Connection of the cable "Power 12V" to battery with a voltage more than 15 V is forbidden categorically.**
3. **Connection of the load with r < 3 Ohm to output of the generator is categorically forbidden if an external battery "Power 24V" being used.**
4. **Work of the device with connected charger is forbidden.**

Choice of the shunt's value

As already it was marked at the description of the generator work, the form and duration of turning off the current's pulses depend on value of the input resistor **R_{TR}** (see fig. 2-3). The basic problem consists in a choice of **R_{TR}** value for which the own processes of used antennas with the sizes from several meters up to 500×500 m would be optimum short and the registered processes did not deform.

The numerous field experiments have shown, that optimum value of the resistor can be **R_{TR}** = 550-600 Ohm. For antennas from a copper wire with resistance **r** = 10-40 Ohm and size within the limits of 10 × 10 m to 200×200 m, the value of the resistor is estimated **R_{TR}** ~ 560-570 Ohm.

In fig. 2-11 the results of sounding of sedimentary rocks on Russian platform with the combined antennas 100×100 m are submitted. The experiment was directed at estimation of optimum value of the input resistor **R_{TR}**.

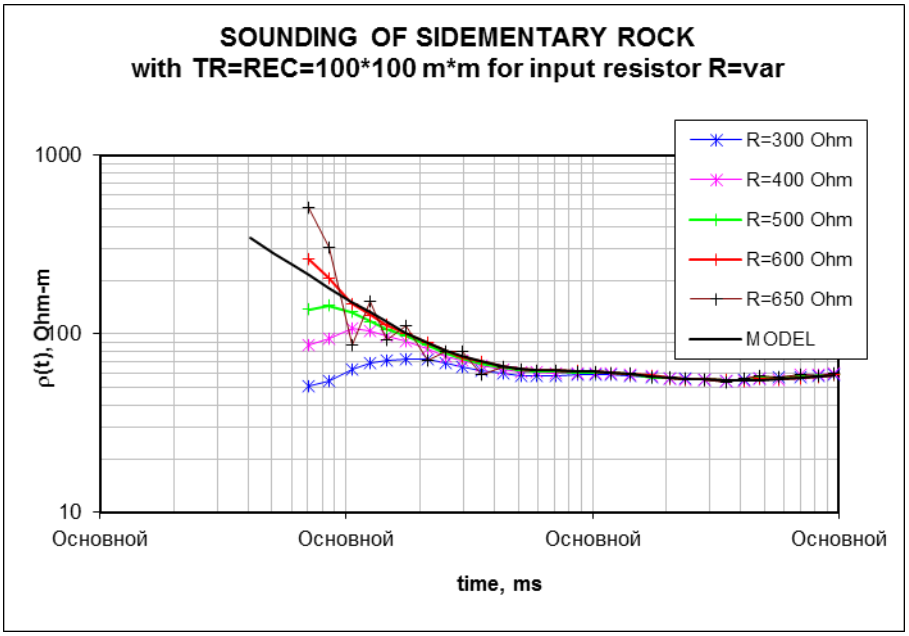


Fig. 2-11

The theoretical curve (Model) is designed on the data DC and TEM.
At small value **R**= $\mathbf{R}_{\mathbf{TR}}$ on curves of apparent resistivity the false minimum connected to influence of own processes in the antenna are observed. With increase **R** the own processes decrease, however at **R**= 650 Ohm resonant oscillation of a signal is observed. The process is optimum with **R** ~ 550-600 Ohm. However, even in this case distortions take place at observable process down to times t = 10-12 μs.

The fig. 2-12 illustrates results of sounding of the high-resistance granite block of breeds with the single loop antenna 100×100 m with **R** = 570 Ohm.
In this case the signal from induced currents in rocks is weak, so own process in the antenna deforms the observable transient characteristic till times t = 20-25 μs.

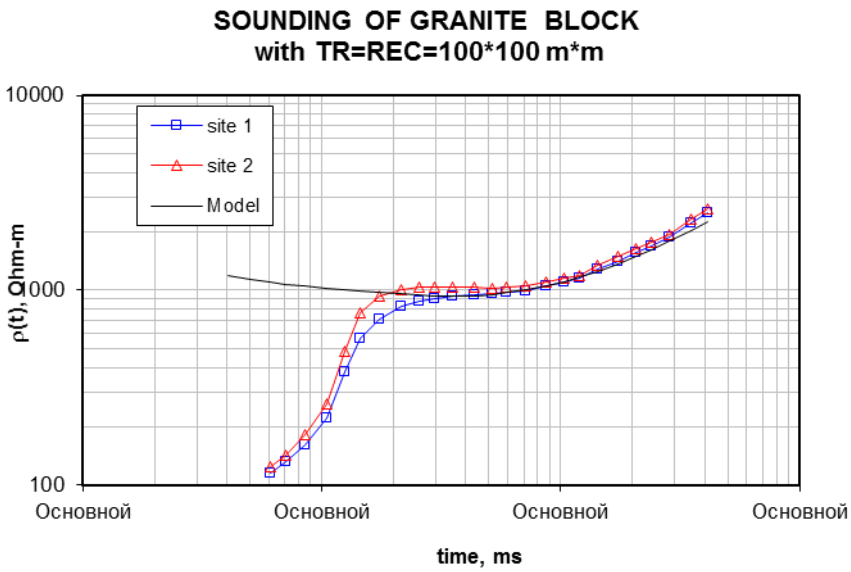


Fig. 2-12

At use of copper wire with **r** < 10 Ohm/km, the own process is increased because of skin-effects in the wire.

ATTENTION!

1. **Use of wires with r < 10 Ohm/km for loops TR>100 m.**
2. **Use of steel-copper cables is categorically unacceptable.**
3. **Use of sockets containing magnetic (steel) components is categorically unacceptable for antenna connectors.**

The case and connectors of the device

All blocks of the device, including the internal battery, are assembled in the uniform duralumin case with protection of IP65 type.

Three connectors on the forward panel (8 way- RS232, 4-way - TR + REC and 4-way - Extern Power) have protection IP15 (IP65 with the closed covers).

The arrangement of blocks of the device in the case illustrates fig. 2-13.

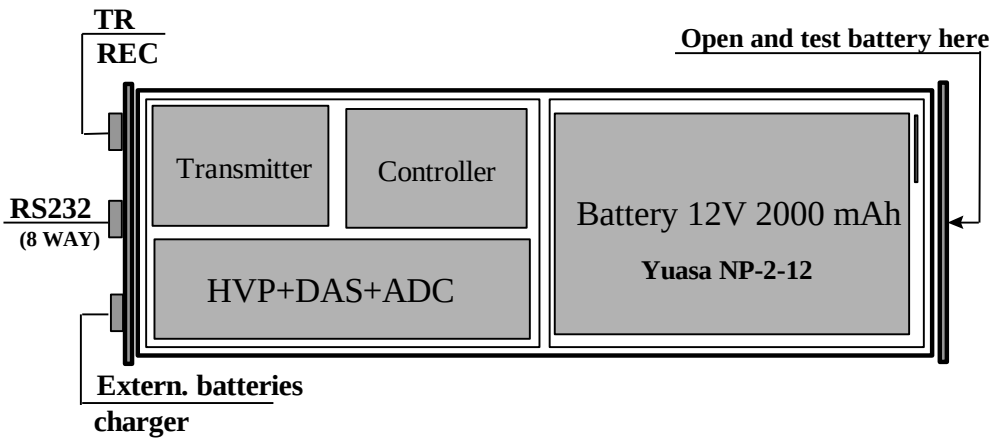


Fig. 2-13

In fig. 2-14 the face panel of the device with connectors is shown.

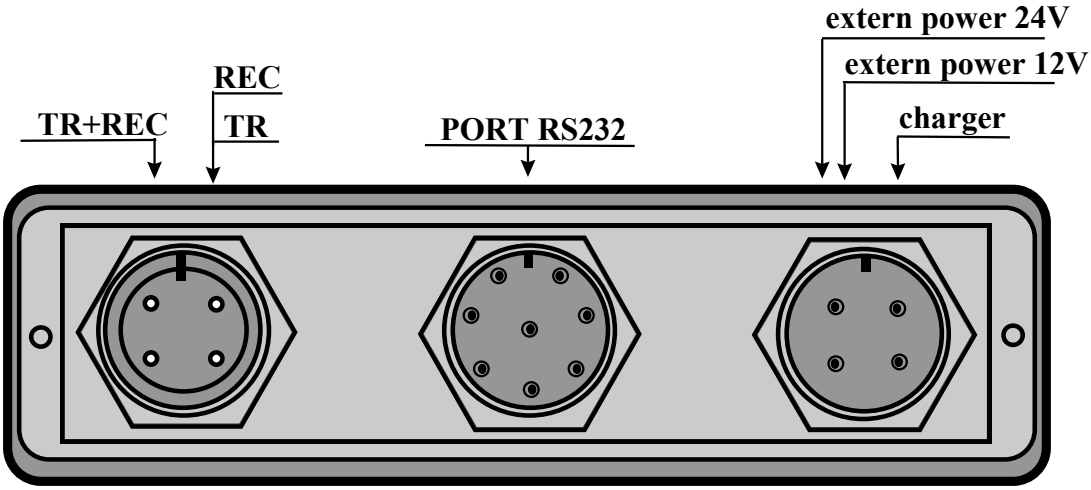


Fig. 2-14

The circuits of the connection of wires "**TR + REC, TR REC**" in two modes of measurements (two antennas and one antenna) is given in fig. 2-15.

Two resistors on $\mathbf{R_{tr}}$=560 (10%) Ohm and $\mathbf{R_{rec}}$=560 (10%) Ohm are established inside the device.

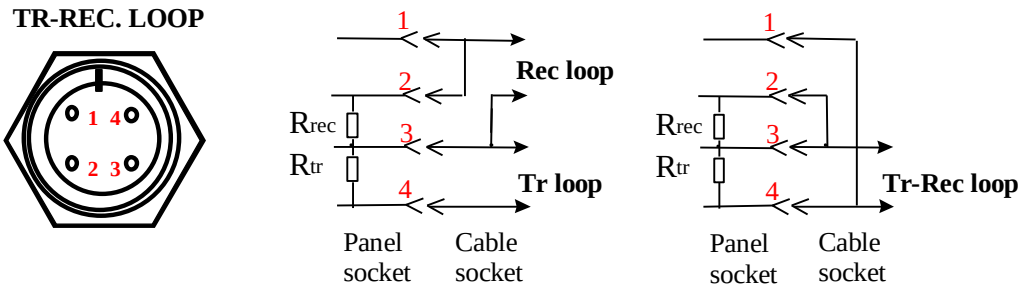


Fig. 2-15

The complete set TEM-FAST 48 (*HPC-Handheld Portable Computer*) is completed by the cables:

1. **RS232** - for connection with a RS232 port of the Notebook computer;
2. **USB** - for connection with a USB port of the Notebook computer;
3. **TR + REC** - for connection of the receiving-generating antenna in one-loop configuration;
4. **Transmitter/Receiver** - for connection of the receiving-generating antenna in two-loop configuration;
5. Cable for connection of the external battery "Power 12V";
6. Cable for connection of the external battery "Power 24V";
7. Cable for connection of the charger with the main device;
8. Cable for connection of the handheld computer with the main device.

Connection of the device, tests and technology of soundings

Before departure to a fieldwork site, operator has to do the following:

- connect by the cable "**RS232**" TEM-FAST 48 and Desk-Top PC (or Handheld),
- connect the cable " **TR + REC** " to TEM-FAST 48 and connect "test - loop" to a cable, then put the test loop on the metallic box of the device,
- run the device after start of the system interface to establish parameters: **Time=**8, **Stack**=10, **TR**=1, **REC**=1, **Turn**=1 and **TR-current** = 1 A, **HVP**=auto, **Amplifier** =OFF (in the window SETTING).

After cycle of measurements of a signal, check absence of any mistakes or warnings. In the window **E/I (V/A)** you should see smoothly attenuating process down to times 10-16 ms. In an operating time pay attention to the right top corner of the screen. If the image of the battery from 50 % by filling has appeared, it is necessary to charge or to replace the battery (charged battery provides 20-25 soundings with **Stack** = 10, **TR-current** = 1 A).

At absence of the warnings and mistakes the device is ready to work.

Field measurements, the personnel

For works with antennas by size no more than 100×100 m optimum structure of a brigade - 3 men: the operator and two workers.
One operator can execute the work with antenna 25×25 m.

Computer

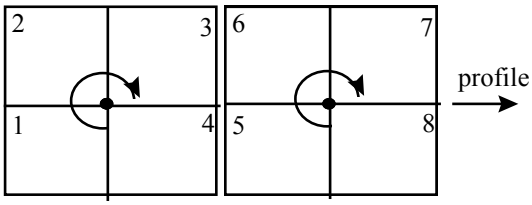
For field researches it is expedient to use NOTEBOOK with screen 640 × 480 pixels (minimum) or Handheld computer.
The operational system is Win95/98/XP/7 for NOTEBOOK or Windows CE for Handheld computer (necessary: COM port (RS232) with 9-pin socket). The built - in manipulator "mouse" is desirable. The strictest requirement is minimal power consumption of PC, because namely this factor determines duration of work in field conditions.

Antennas

For manufacturing antennas it is expedient to use cables (11-17 wires) with **only copper wires** in bright (yellow, red, white etc.) PVC isolation with resistance
r = 12-50 Ohm/km.
It is desirable to prepare 2×50 = 100 m cable with **r** = 4-8 Ohm (for the antenna 25×25) and four pieces of a wire on 100 m with **r** = 2-2.5 Ohm everyone (for 50×50 m and 100×100 m). 100 and the 50-meter pieces of a wire are marked at the centers by bright labels. In a complete set of the device there are connecting sockets for antennas. If necessary it is possible to make additional sockets from **non-magnetic materials**.

Mounting of antennas

At profile or array measurements the maximal productivity is achieved at technology of mounting of the combined antennas of a type "side-to-side". At flat relief and absence of a bush, the team of 3 men makes till 40-50 soundings with antennas 50×50 m for 6-8 hours.
At array measurements from one "central" point one able to mount 4 loops, in the order specified in the following figure.



If it is necessary to carry out small (10-15 points) profile measurements in geologically unknown area, we recommend to do double amount of points of sounding (as shown in figure) to receive a double structure. At insignificant increase of time of measurements one can estimate an influence of horizontal inhomogeneities and error of one-dimensional inversion of TEM data.
The work with installation "loop-in-loop " is expedient only at presence of intensive SPM effects and detailed searches of local objects (archaeological and other special researches).

Measurements

On several first points of a structure it is expedient to choose suitable for the chosen size of the antenna, noise and the value of resistance mode of TEM-FAST operations.

Start with **Stack** = 2-3, **Time** = 5 (1024 μs). Manipulating these parameters reach most by "long" and smooth curve **ρ(t)** and **E(t)**. The more **Time** is, the more distorted is the result of measurements because of influence of the noise. Usually temporary range can be expanded so long as the errors of measurements for a signal at the maximal time will not exceed 10-20 %. Influence of industrial noise (50/60 Hz especially is sharp) begins to have an effect at parameter **Time** > 6 (2048 μs). At very intensive industrial noise it is recommended to repeat measurements several times for identification of strobe effect (deviation of industrial frequency concerning frequency of the internal filter of the device).

During a choice of operation mode of TEM-FAST it is recommended to include a window viewing of a working zone of measurements for the control of a level of an accepted signal.

Before start TEM-FAST 48, be convinced that the size of antennas in the system interface is exposed correctly because the automatic system of protection of an input of the device from high voltage is adjusted to this parameter.

Technical specification TEM FAST 48

The transmitter

Time of turning off the current's pulse (TR=REC, I=1 A) (μs)
TR=25m ..... < 3
TR=50m ..... < 8
TR=100m ..... < 20
- The amplitude of current's pulses (A) is (selective)..... 1, 4
- Ratio pulse/pause (time range = 1-6) 3/1
- Active resistance of load *) (Ohm) ..... 0 - 20
- Inductance of a load (I=1A) (H).....……..... < 0.01

The receiver

- Frequency band (MHz) ..... > 4
- Allowable constant voltage at input (mV) ..... -2 + 5
- Number of automatically registered delays..... 48
- Suppression of industrial noise 50/60 Hz (dB)..... > 60
- Internal noise**) (RMS- root mean square, μV)
  (Stack =20, TR=REC, I=1A, resistance at input r = 2-8 Ohm) 1
- Dynamic range***) (max /min) (μV) ..... 10^7/1(0.1)
- Systematic errors****) (%)..... 1
- Measured parameters:
  E.M.F./CURRENT ..... V/A
  Errors of measurements ..... V/A
- Allowable types of measuring antenna's configurations:
  One-loop with the sizes of antennas (m) ..... 0.01×0.01 up to 400×400
  "loop-in-loop" - size of a TR-loop (m) ..... 500×500
  size of a REC-loop ..... REC< TR/2 with Amplifier=ON

Optimum configuration - one loop by the size (m) ..... 18×18 - 100×100
Time of measurements (Stack = 1) min/max (sec) ..... 18 / 30

Power consumption

- Standard internal battery……..... 12V, 2000 mAh
- Maximum number of soundings with standard battery:
  (I = 1A, Stack = 10) ..... > 50
- Consumption in a mode - "sleep" (μA) 1
- Average consumption in a mode - "work I = 1A" (mA)..... 350

Other characteristics

Operation with IBM - compatible PC with standard port RS 232,
or Windows 95/98/XP/7 or Handheld computer with OS Windows CE
Weight (kg) 1.5
Size (mm) ..... 103×27×310
Operating temperature range ..... -20° - + 65° C
Change of temperature (°C / minute) 3
Power of protection of the case of the device..... IP15 (65)

*) see tab. 2-2 of the description. Max inductance at output/input - 5mH
**) see window " Functions " ,"Diagnoses" ,"Real voltage" of the system interface: [E (on-off) < 1]
***) see function "Zone " in the system interface, 0.1μV-with Amplifier=ON and "loop in loop" style.
****) are measured on models of thin metal plates: comparison of settlement and experimental data.

Chapter 4. THE SYSTEM INTERFACE OF TEM-FAST 48 (Win-95/98/XP/7)

The system program TEM-FAST (TEM-48WIN) is intended for work with the device and provides the following functions.

- Transfer from PC in the device start-vector, determining modes of operations.
- Check the state of the power supply (battery).
- Receiving and preprocessing of a flow of the data.
- Visualization of the sounding data in form of transfer functions -**E(t)/I** or curves of apparent resistivity - **ρ(t)**.
- Record of the data of sounding in ASCII-file.
- Long-term, periodically repeating soundings (monitoring) in automatic mode.
- Diagnostic check of the device state.
- Program change of a configuration of the device for work in various modes.

For work with the system interface it is necessary to have:

- IBM compatible computer with mouse,
- OS Windows 95/98/ME system,
- serial port COM1-4 with the standard interface RS232 (38400 bps),
- the file TEM-48WIN. EXE - program.

After start of the program TEM-48WIN.EXE, the head menu of the system interface shown in fig. 3-1 arises on the PC's screen.

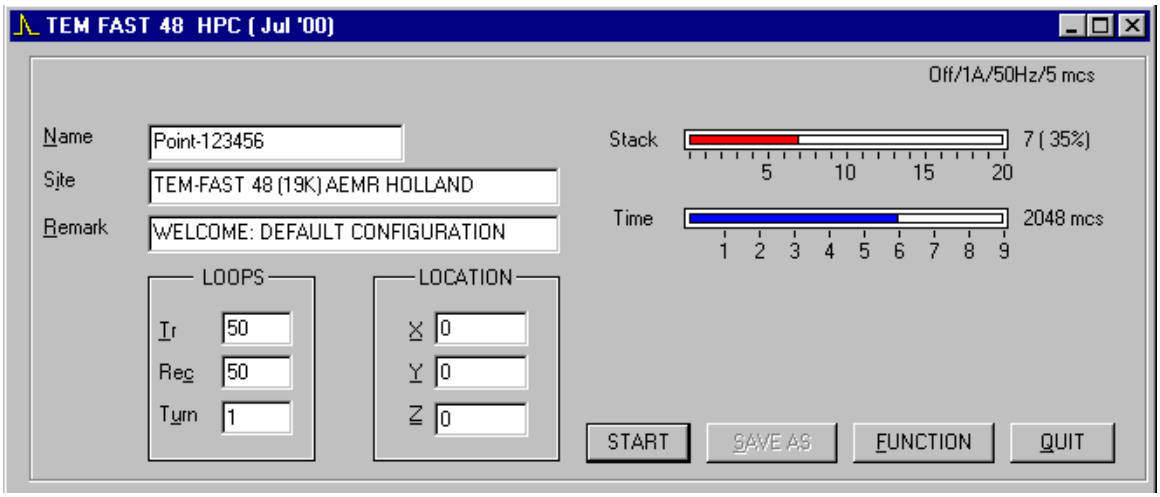


Fig. 3-1

NAME - name of the location of sounding (12 charts).
SITE - name of territory (area) or profile of soundings (30 charts).
REMARK is any commentary (30 charts).
TR - size of a square transmitting loop. If a loop is not square then $(L_1 \times L_2)$ is the size of a square **TR** loop with equivalent area equal to **TR**$=(L_1 \times L_2)^{1/2}$.
REC is the size of square receiving loop. If the loop is not square, one should replace $(l_1 \times l_2)$ by equivalent square loop **REC** $= (l_1 \times l_2)^{1/2}$.
TURN is product of number of coils in transmitting and receiving loops - $\mathbf{n_{REC} \times n_{TR}}$.

Examples:

1) at use of the combined loop **TR** = **REC** with two turns of a wire, $\mathbf{n_{REC}}\times\mathbf{n_{TR}} = 2\times2 = 4$;
2) if the remote detector with the effective area **S** (m^2) and **REC < TR/5** is used, we recommend to put: **REC** = 1 m**,** $\mathbf{n_{REC}}\times\mathbf{n_{TR}}$ **= S.**

X, Y, Z are three coordinates of location of the center of the receiving antenna.

TIME is range of measurement of the transitive characteristics. This parameter essentially influences at noise stability of the unit and carefully is selected at trial soundings in each new territory. The narrower range of the registered times, the higher accuracy of measurements, however too narrow range can bring to losing the information about late stages of transients.

STACK is parameter of digital stacking of a signal (1-20). To each number of this parameter corresponds 13 complete cycles of work of **DAS** system described above (see table 2-1, fig. 1-6). Parameter **Stack** effectively improves quality of the results of measurements only in case of noise of "white noise" type.

SAVE AS is the window for saving at a disk of results of sounding. This function is accessible only after successful termination of measurements.

In case of automatic saving the results of measurements (ref. SETTING), the name change automatically to **SAVE**.

FUNCTION is the window for various transformations of the transient functions, diagnostics of results, installation of a configuration of the device, monitoring and viewing of results before executed and saving of soundings in a file.

START means start of the device for measurements (the key "ENTER").

At start, after testing a state of the device the image of progress-string is displayed on the screen. The termination of measurements is accompanied by a melody or by a sound signal.

In case of restart of the device, the program asks to save the previous data.

However, even at refusal of saving, last cycle of measurements enters the name in a work file **#TEM-48#.TEM**.

QUIT is exit from the program. During termination (exit) the program asks to save last measured data. *Last **N** sets of measurements always are kept in* **#TEM-48#.TEM**.

The parameter N is determined in the window SETTING.

The current configuration mode of operations of the device **Off/1A/50Hz/4μs** is displayed in the right top corner. These parameters are amplifier's condition, size of a current, frequency of the notch filter of industrial noise and time of **HVP**.

The virtual POP-MENU can be opened by write mouse's key in any place of the active window. This menu has the options:

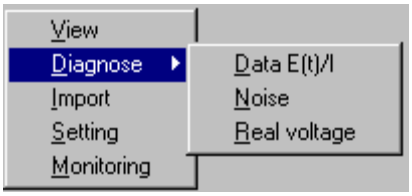


Fig. 3-2

Window **Function**

Fig. 3-3

VIEW - viewing **ρ(t)** or **E(t)/I.**
DIAGNOSE- window for diagnostics.
IMPORT - reading and viewing the data of soundings from memory
SETTING - change of a configuration of the device
MONITORING - menu of automatic operation mode of TEM-FAST 48

Window to view the results of measurements - **VIEW**

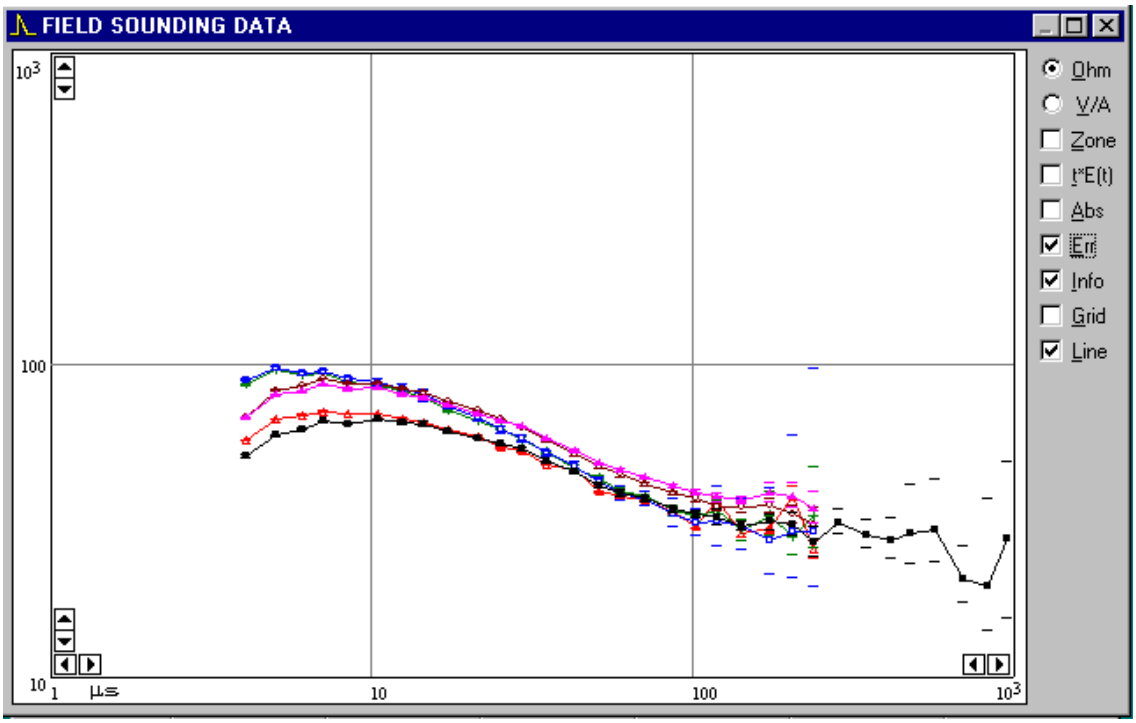


Fig. 3-4

In the corners of a logarithmic coordinate grid the arrows of change of scales on vertical and horizontal axes are located. In the left bottom corner there is a window of state of the graphic buffer, in which the data of six soundings are located.

Tools:

Ohm – display resistivity **ρ(t)** in Ohm-m

V/A – display signals **E(t)/I** in V/A

Zone - viewing of dynamic range of measurements

t*E(t) - display signals **t*E(t)/I** [ms*V/A] or **t*ρ(t)** [ms*Ohm-m]

Abs - absolute values **abs[ρ(t)]** or **abs[E(t)/I]** for testing of IP effects

Data **ρ(t)<0** are marked by square

Err - confidential intervals - mistake of measurements

Info – display short field sounding information (window **INFO**)

Grid - viewing grids

Line – display lines between points

Pressing of the write mouse's knob calls the virtual POP MENU for fast invoking the functions:

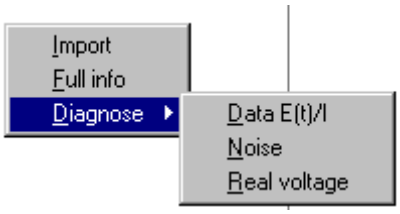
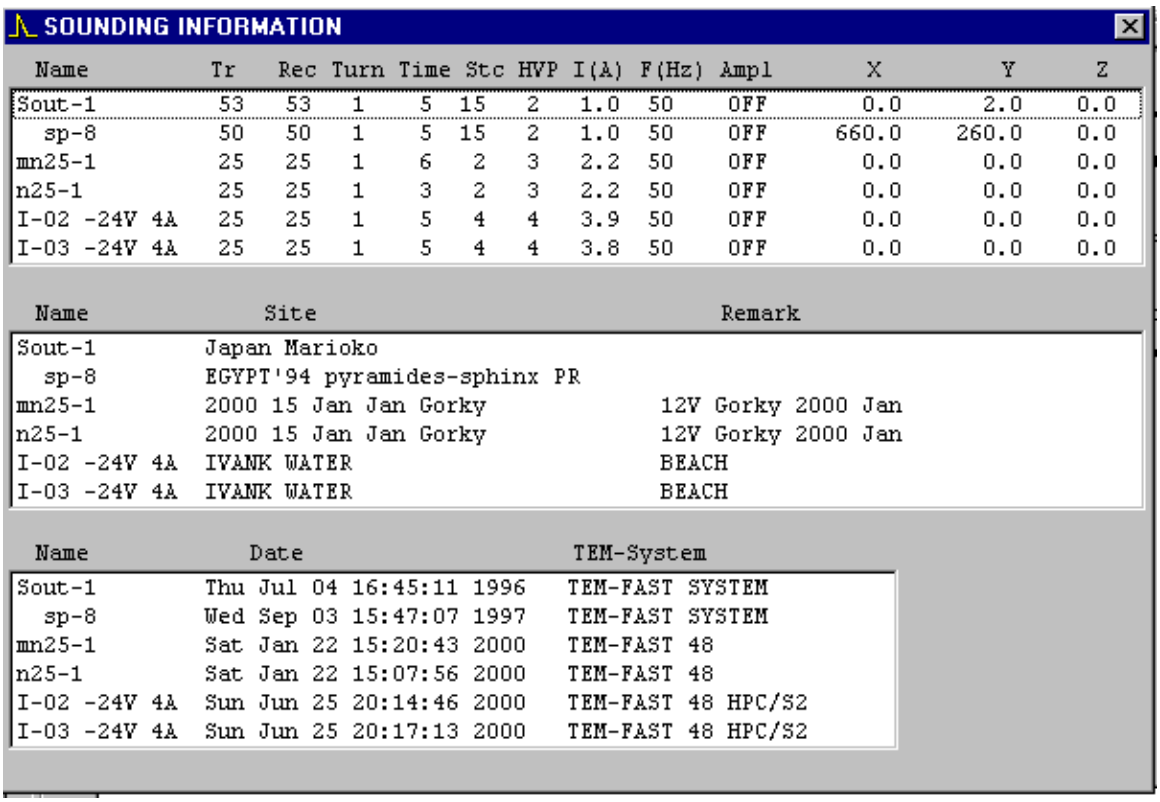


Fig. 3-5

Window **Full info**



SOUNDING INFORMATION

Name	Tr	Rec	Turn	Time	Stc	HVP	I(A)	F(Hz)	Ampl	X	Y	Z
Sout-1	53	53	1	5	15	2	1.0	50	OFF	0.0	2.0	0.0
sp-8	50	50	1	5	15	2	1.0	50	OFF	660.0	260.0	0.0
mn25-1	25	25	1	6	2	3	2.2	50	OFF	0.0	0.0	0.0
n25-1	25	25	1	3	2	3	2.2	50	OFF	0.0	0.0	0.0
I-02 -24V 4A	25	25	1	5	4	4	3.9	50	OFF	0.0	0.0	0.0
I-03 -24V 4A	25	25	1	5	4	4	3.8	50	OFF	0.0	0.0	0.0

Name	Site	Remark
Sout-1	Japan Marioko	
sp-8	EGYPT'94 pyramides-sphinx PR	
mn25-1	2000 15 Jan Jan Gorky	12V Gorky 2000 Jan
n25-1	2000 15 Jan Jan Gorky	12V Gorky 2000 Jan
I-02 -24V 4A	IVANK WATER	BEACH
I-03 -24V 4A	IVANK WATER	BEACH

Name	Date	TEM-System
Sout-1	Thu Jul 04 16:45:11 1996	TEM-FAST SYSTEM
sp-8	Wed Sep 03 15:47:07 1997	TEM-FAST SYSTEM
mn25-1	Sat Jan 22 15:20:43 2000	TEM-FAST 48
n25-1	Sat Jan 22 15:07:56 2000	TEM-FAST 48
I-02 -24V 4A	Sun Jun 25 20:14:46 2000	TEM-FAST 48 HPC/S2
I-03 -24V 4A	Sun Jun 25 20:17:13 2000	TEM-FAST 48 HPC/S2

Fig. 3-6

The window described in fig. 3-6 gives full information on sets of sounding.

Window **INFO**

SOUNDING INFORMATION

Name	Tr	Rec	Stc	Time	HVP	F(Hz)	I(A)
ger-1	25	25	15	3	2	50	1.00
ger-2	25	25	15	3	2	50	1.00
ger-3	25	25	15	3	2	50	1.00
ger-4	25	25	15	3	2	50	1.00
ger-5	25	25	15	3	2	50	1.00
ger-6	25	25	15	5	2	50	1.00

Fig. 3-7

This window contains brief information on sounding: Size of the loops **TR-REC ,** Stack **(Stc),** time range **(Time), HVP (μs),** filter **(F)** и real current **I(A)** [Amperes].
Double press of the left knob over the set's name (for instance, **ger-3**) remove the graph **E(t)/I** or **ρ(t)** from the window. Press again to restore the graph.
Double press of the write knob of the mouse over the set's name (for instance, **ger-1**) delete all information about set from the program's memory (all the data will be lost) .
If the user made a mistake and deleted the data received in result of measurements which were not saved, the procedure **SAVE AS** in main menu will save them.

What is dynamic range of measurements

The range is represented on the screen as two step lines, limiting from above and from below work area of measurements at the mode, given in the head menu (**Time**). The low border $\mathbf{E_{min}}$ is calculated as the ratio of minimally possible readout **ADC** (unit) to the measured value of current at the given channel of measurements - **1 ADC/I.**
The top border $\mathbf{E_{max}}$ is calculated as the ratio of the maximally possible readout **ADC** (max) to the measured value of current at the given channel of measurements - **max ADC /I.**
In the window **ρ(t)** the work zone is calculated as transformation $\mathbf{E_{min}(t)}$ and $\mathbf{E_{max}(t)}$ into apparent resistivity **ρ(t)** with accounting of parameters **TR**, **REC** and
$\mathbf{n = n_{REC} \times n_{TR}}$.
The transformation **E(t) - ρ(t)** is made according asymptotic formulas of near zone of transient process above uniform half-space for co-axial round loops. Equivalent radius **R** for calculations is determined from a formula $\pi R^2 = L^2$, where **L = TR** is side of a square loop, $\pi r^2 = REC^2$, **r**-equivalent radius of a receiving loop.

$$E(t)/I = n \times (\pi^{1/2}/20) \times \rho(t) \times (r^2/R^3) \times t_0^{-5/2} \quad \text{for} \quad t_0 = t/(\mu_0 R^2/\rho(t)) >> 1$$

The calculations carried out for *round* and *square* loops laying above homogeneous conducting half-space have shown that difference of signals at **REC=TR**, $t_0 > 0.01$ and $\pi R^2 = L^2$ does not exceed 2.5 % ($t_0 > 1$ is not more than 0.5 %) and are comparable with errors originated by superficial inhomogeneities and mistakes when putting of loops.

How the errors of measurements are calculated?

At **Stack = k** the system interface accepts **n = 13×k** of codes **ADC** by each active channel (temporary window-gate t_i), which are used for evaluation of the value of $E(t_i)/I$.
The error of measurements **Δ** for each t_i is calculated under the formula:

$$\Delta = [1/(n \times (n-1)) \times \Sigma_j (E_j - E_0)^2]^{1/2} \qquad E_0 = 1/n \times \Sigma_j E_j \qquad j = 1,2,.. 13 \times k$$

At maximal parameter **Stack** = 20, **n** = 13×20 = 260, i.e. the estimations of errors **Δ** are made on ensemble from 260 numbers. On the screen at activation of a window "**error bar**" three symbols corresponding to values of a signal: $\mathbf{E_0+\Delta}$, $\mathbf{E_0}$ and $\mathbf{E_0-\Delta}$ are presented for each time $\mathbf{t_i}$.

Window **SETTING**

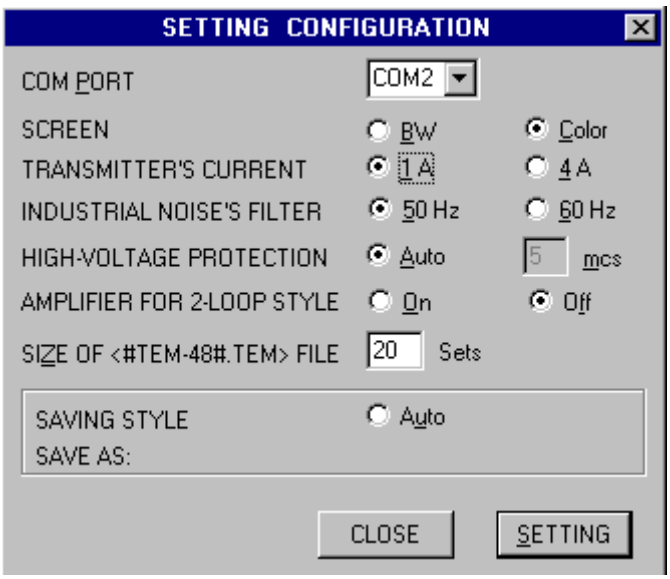


Fig. 3-8

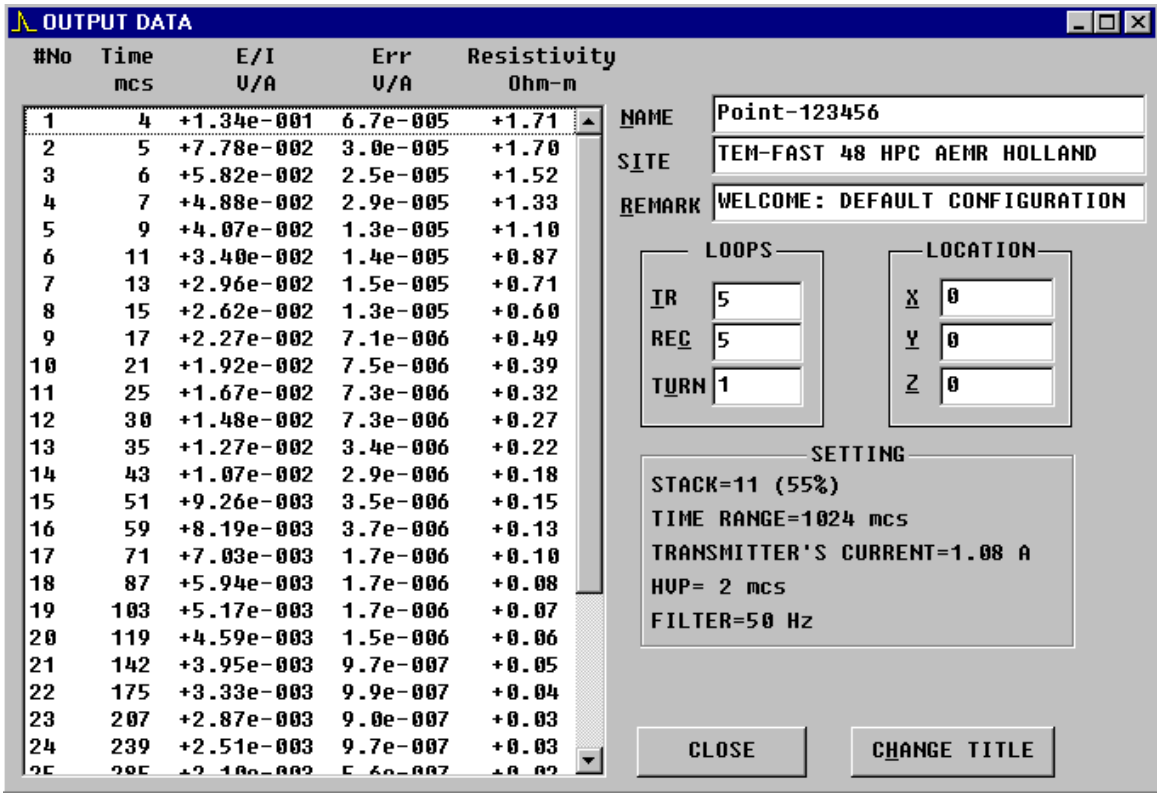
COM PORT - choice of a serial port.
After start of the system, the program makes analysis of the state of all serial ports and activates most convenient. If all ports are busy, the system informs on that and deactivates **START** function. In this case the operator should release the port (it can be occupied by another process) and restart the TEM-48WIN.EXE program.
SCREEN - color of the screen.
TRANSMITTER CURRENT is amplitude of current's pulse.
INDUISTRIAL NOISE'S FILTR means installation of the filter at frequency of an industrial noise.
HIGH-VOLTAGE PROTECTION - configuration of **HVP** system (see Chapter 3).
The time of protection $\mathbf{t_{HVP}}$ is shown in the right window. It means, that the signals at times $\mathbf{t< t_{HVP}}$ should be excluded and will not appear on the diagrams **E(t)/I** or **ρ(t)**.
At use multi-turn of antennas, amplifiers etc. the mode **HVP** is selected by the operator experimentally for curves **E(t)/I.**
Auto - the program will establish automatically the necessary mode of operations of the system, being guided on the size of the loop given in the head menu.
AMPLIFIER FOR 2-LOOP STYLE – gives possibility to switch ON or OFF an amplification of the signal (approximately 10 times) when using two-loop (**TR** and **REC**) configuration of measurements.
Attention: avoid an impact of voltage U>2 V to the **REC**'s input when active regime **Amplifier=On**.
It is not advisable to use regime **Amplifier=On** during measurements with two close located antennas of the same size. To avoid of overloading the amplifier, use the receiving antennas with area 2-10 times less than the area of the transmitter antenna.

SIZE OF <#TEM-48#.TEM>FILE – sets a size of file for saving of sounding data. For example 20 Sets means that last 20 soundings will be written to the file with the name **#tem-48#.tem** independent on user's application of function **SAVE AS** before.
SAVING STYLE – this function automatically writes the results of sounding in a file with the name determined by user. When selection of **Auto,** the file's dialog is activated and gives to user the possibilities for automatic saving of data.

If the flag **Auto** is activated, the function **SAVE AS** in the main menu become inaccessible (the name of the key change to SAVE) and after each sounding the data are saved automatically to a file with the name determined by user. At the same time the data are saved in the file **#tem-48#.tem**.

Window **Diagnose**

All three windows are accessible for viewing only after successful terminating of the process of measurements.
Window "**Data E(t)/I**" contains the digital information on the measured signal, which subsequently will be written down in *.tem a file of results of measurements.



#No	Time mcs	E/I V/A	Err V/A	Resistivity Ohm-m
1	4	+1.34e-001	6.7e-005	+1.71
2	5	+7.78e-002	3.0e-005	+1.70
3	6	+5.82e-002	2.5e-005	+1.52
4	7	+4.88e-002	2.9e-005	+1.33
5	9	+4.07e-002	1.3e-005	+1.10
6	11	+3.40e-002	1.4e-005	+0.87
7	13	+2.96e-002	1.5e-005	+0.71
8	15	+2.62e-002	1.3e-005	+0.60
9	17	+2.27e-002	7.1e-006	+0.49
10	21	+1.92e-002	7.5e-006	+0.39
11	25	+1.67e-002	7.3e-006	+0.32
12	30	+1.48e-002	7.3e-006	+0.27
13	35	+1.27e-002	3.4e-006	+0.22
14	43	+1.07e-002	2.9e-006	+0.18
15	51	+9.26e-003	3.5e-006	+0.15
16	59	+8.19e-003	3.7e-006	+0.13
17	71	+7.03e-003	1.7e-006	+0.10
18	87	+5.94e-003	1.7e-006	+0.08
19	103	+5.17e-003	1.7e-006	+0.07
20	119	+4.59e-003	1.5e-006	+0.06
21	142	+3.95e-003	9.7e-007	+0.05
22	175	+3.33e-003	9.9e-007	+0.04
23	207	+2.87e-003	9.0e-007	+0.03
24	239	+2.51e-003	9.7e-007	+0.03

Fig. 3-9

In the case of user's mistake when setting of sounding's head, (incorrect stated **TR, REC, TURN** or coordinates **X,Y,Z** or there are mistakes in the **Name, Site** or **Remark**), then these mistakes in the window can be corrected before saving the data. These windows are accessible for editing in the case if the data did not save earlier.

Window "**Real voltage**" contains the digital information on work of **HVP**, **DAS** and **ADC**. Here measured values are submitted in r.m.s. units of **ADC** and reflect work of the device in the internal system cycles.

REAL INPUT DATA (unit ADC)

#No	I on	I off	Ion-off	err	E on	E off	Eon-off	err
1	2765	2496	+268.7	1.2	3729	2290	+1439.0	0.7
2	2970	2707	+263.2	1.0	3499	2681	+818.2	0.3
3	2939	2678	+261.3	1.1	3294	2685	+608.8	0.3
4	2917	2651	+265.7	1.0	3184	2666	+518.6	0.3
5	3206	2672	+534.2	0.8	3531	2661	+869.8	0.3
6	3195	2661	+534.0	0.9	3389	2662	+726.5	0.3
7	3239	2707	+531.8	1.2	3360	2730	+629.5	0.3
8	3139	2594	+544.6	1.5	3199	2628	+571.2	0.3
9	3707	2630	+1076.5	0.9	3604	2626	+977.7	0.3
10	3798	2721	+1076.4	1.2	3583	2755	+828.7	0.3
11	3729	2665	+1064.7	1.3	3376	2663	+712.9	0.3
12	3767	2693	+1073.5	1.0	3359	2722	+637.3	0.3
13	4850	2691	+2159.6	1.2	3796	2697	+1099.3	0.3
14	4826	2661	+2165.3	1.7	3594	2666	+928.0	0.3
15	4862	2700	+2162.1	1.2	3511	2709	+801.4	0.3
16	4701	2551	+2150.7	1.6	3281	2576	+704.8	0.3
17	6858	2656	+4201.4	2.2	3846	2663	+1182.5	0.3
18	6944	2722	+4221.8	2.1	3740	2736	+1003.5	0.3
19	6961	2704	+4256.9	2.3	3590	2709	+880.2	0.3
20	6909	2660	+4249.3	2.1	3445	2665	+779.9	0.3

Fig. 3-10

This window is intended for diagnostics of malfunctions and at adjustment TEM-FAST. It is used by the operator in emergencies for record of the diagnostic information in a file and transfers to the manufacturer.

The window "**Noise**" (fig. 3-11) is intended for the analysis of an external electromagnetic noise, induced by the receiving antenna. Horizontal axes is time **T**, given in intervals of work **DAS**, i.e. each division is equivalent to an interval of analog stacking of a signal.

Each unit of **Stack** contains 13 analog cycles of stacking of a signal. Along vertical axes the values of the measured signal **E(T)** are described, the scale is conditional and is defined by magnitudes of fluctuations of **ADC** codes for each channel **ADC**.

In the upper left part of the diagram below, there are shown:

#13 – number of channel (time delay),

1099 – mean value of the signal (AVG) in ADC units,

10 – scale of the vertical axes (all values are inside the interval (1099-10) - (1099+10) of ADC units).

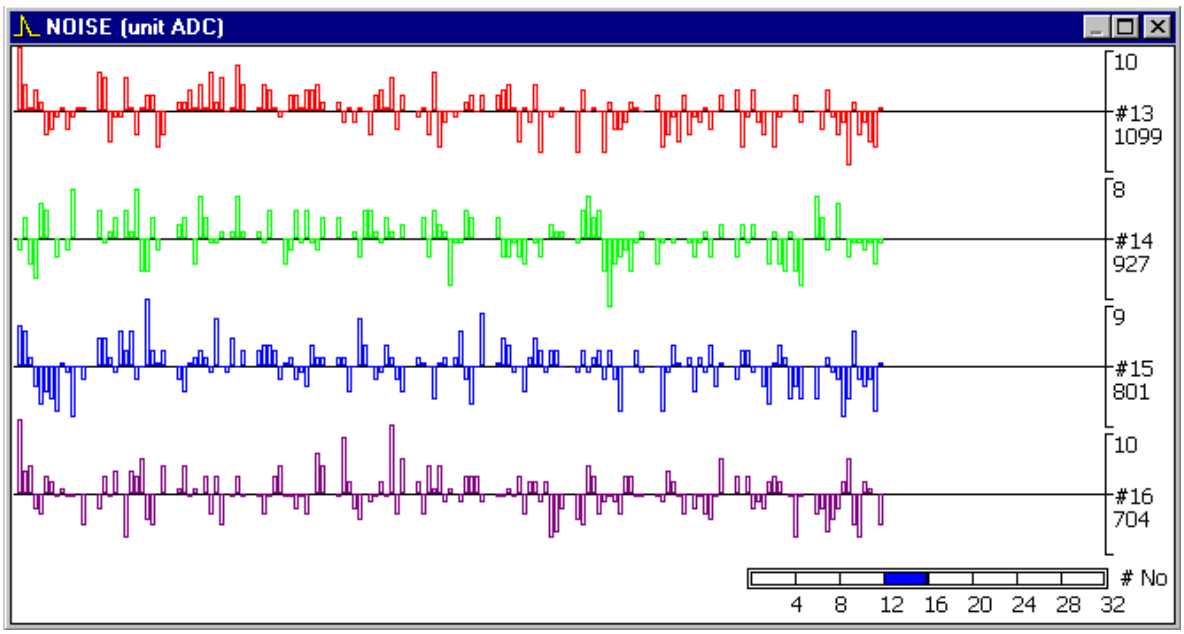


Fig. 3-11

If the noise is "white noise", the readout **E(T)** looks as a sequence of chaotic pulses, the determined signal (usually because of small (1-2 %) instability of frequency of the internal filter (50/60 Hz, $\delta \sim 0.1$ %) and real frequency of an industrial noise) otherwise is observed. It is necessary to note, that the internal notch filter is effective at a stable noise with a set of frequencies 50, 100, 200... Hz (60, 120, 240, ...). In this "ideal" case the suppression of a noise is ~ 1000-3000 times. If the spectrum of a noise contains unmultiple frequencies: 75, 150 Hz etc., suppression of a noise is sharply reduced. At presence at input of the device of a sine wave signal with frequency 50/60 Hz (0.1 %) and used frequency of the filter 60/50 Hz, the suppression of this signal makes approximately 30-50 times. Therefore at small levels of an industrial noise (up to 50 μV) the measurements with the filter 50 or 60 Hz are practically identical. As to suppression of quasi-periodical type of noise (in absence of industrial one), the operator can use both 50 and 60 Hz mode of measurements depending on quality of the received data.

Window **MONITORING**

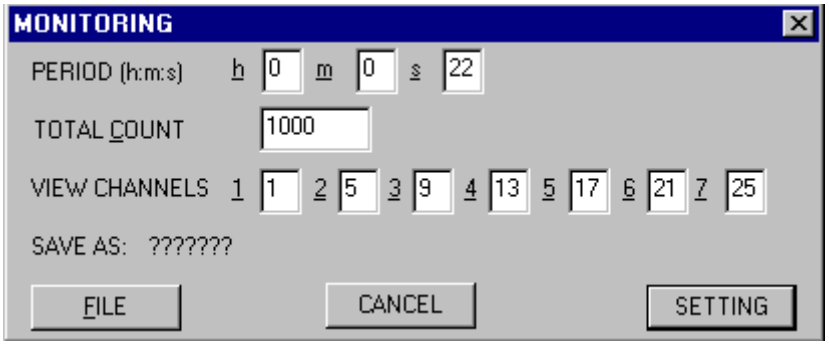


Fig. 3-12

In comparison with the head menu, some parameters in the monitoring menu are added.

PERIOD is interval between sequential measurements (in format h:m:s).

TOTAL COUNT is the number of measurements that is supposed to execute.

FILE - defines name of a file where the results of measurements will be written down.

VIEW CHANNELS – sets the number of channels (time delays for **E(t)/I)** in which the variations of signal will be drawn at the screen during monitoring process. In the fig. 3-12 example, the channels 1 (**t=4 μs**), 5 (**t=8.5 μs**), 9 (**t=17.4 μs**), 13 (**t=36.3μs**), 17 (**t=71.6 μs**), 21 (**t=143 μs**) и 25 (**t=295 μs**) will be presented at the screen. If in the windows VIEW CHANNELS the 0 value is established, the next window will be not active.

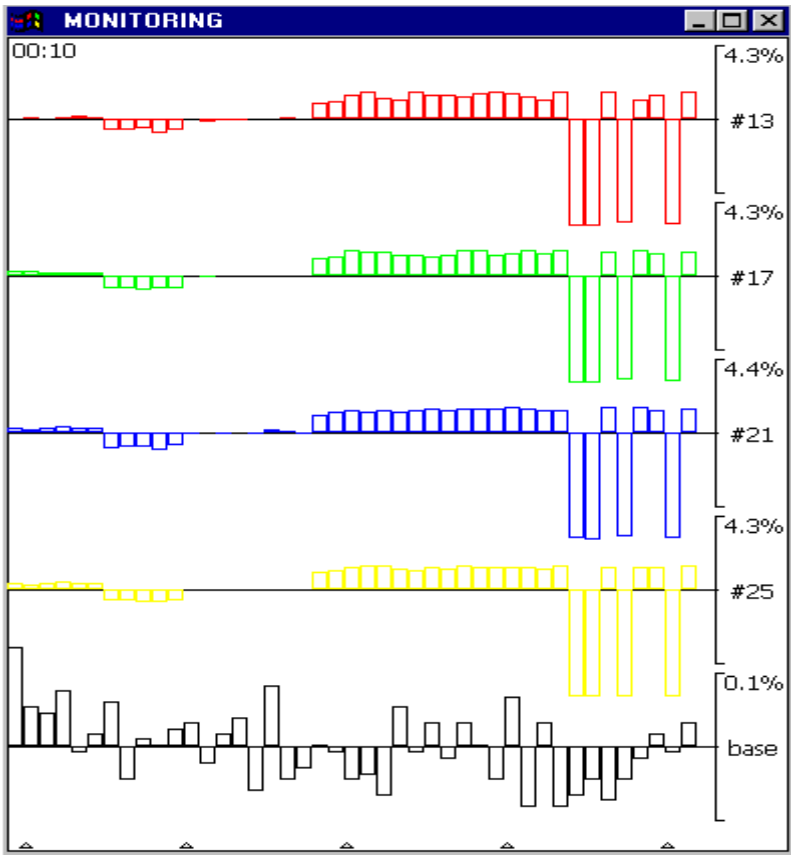


Fig. 3-13

In the right upper corner of the screen (Fig. 3-13) the time remnant till the next cycle of measurements is shown (00:10 sec).

#13 is the number of channel (time delay (**t=36.3 μs**)).

base is the system channel, expressive internal state of measuring circuits of TEM-FAST 48. Variations along this channel, as a rule, characterize the dynamics of temperature regime of the instrument. This channel is used for control of TEM-FAST unit stability. Captures in the upper corners determine the scale of variations for each channel. For example, the scale of variations **Δ(T)** of #13 channel has the scale from –4.3% to +4.3% (horizontal axes drawn at the level **Δ=0)**

$$\Delta(T_i)=100\%*[E(T_i)/I-E^*/I]/(E^*/I),$$

where **E*/I** is the mean value of normalized signal **E(T)/I, calculated for the time interval T=(0, T_i), T_i** is the current time, **0** is the time of start. In this example the

data on the screen present 43 cycles of measurements. Averaged **E*/I** values were calculated using 43 measurements for each channel.

Window **IMPORT**

After selection of a file with the data (in the example Profile.tem) the window arises:

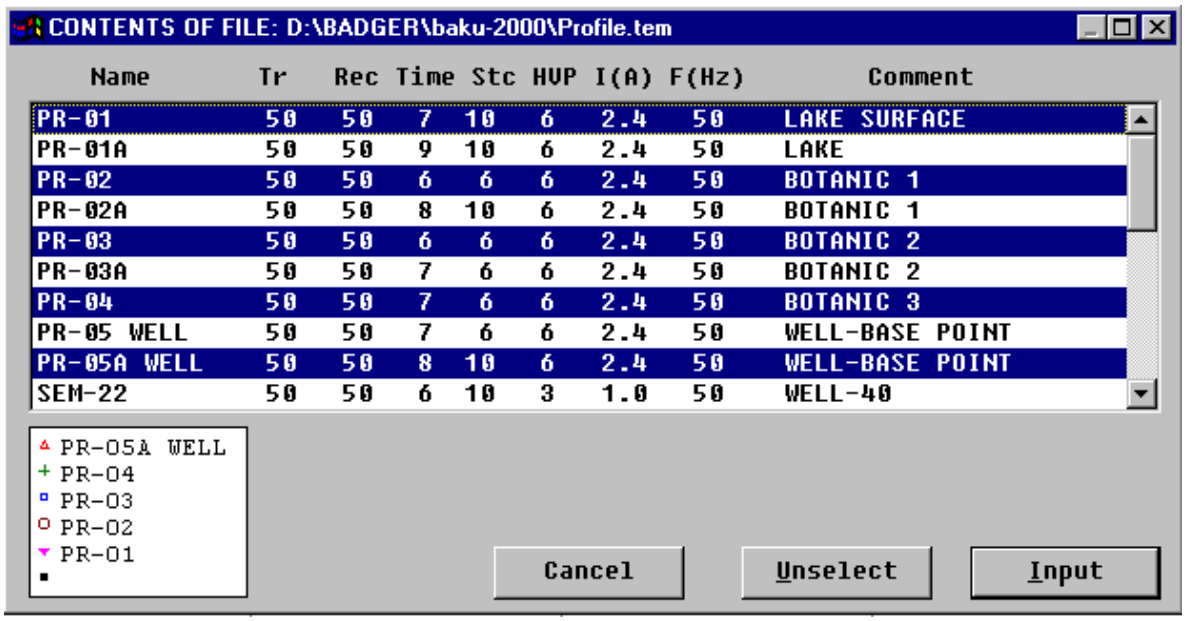


Fig. 3-14

Mark selected sets of sounding (not more than 6) and press **Input**. Double click of left mouse knob over the set's name in the left low corner will clear (or restore) the information in the buffer memory.

THE WARNINGS AND OTHER INFORMATION

1. At work, the system interface does analysis a condition of the connected batteries (standard and external "Power 12V") at levels not less than 50 % and less than 25% of the capacity. The measurements of the battery's voltage are produced at the moments of measurements of E(i) as well as during the intervals between the measurements. Three power levels are used to characterize the state of the battery:
   less than 25% - **U<10.5V** ,
   25-50% - **10.5V<U<11.5V**
   50-100% **U>11.5V**.
   Inaccuracy in determination of these levels is ~ 100-150 mV.
   It should be note, that residual capacity of the battery can be determined on voltage **U** (**Iwork** ~ 1-4 A) only with an error of the order 10 % in temperature interval is -15+25 ^{0}C. Outside this temperature range the error can reach 20-30%. The condition of batteries is displayed in a left top corner of the head menu:

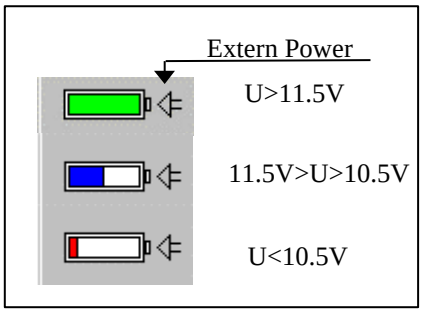


Fig. 3-15

If the fresh battery being used, the voltage at the moments of the current flow (I=1A), **Uwork** and the voltage during the pause **Upause** between current's pulses are differ at **ΔU**=0.2-0.3 V. When I=4 A, the **ΔU** value of the standard battery (2 Ah) can achieve 1 V. In this case some jumps from 25% to 100% in the readouts can take place during the measurements.

Blinking of the indicator of discharge of the battery from 100% to 25% when I=1A informs on its discharge (or badness), and in case I=4A – about non-standard regime of measurements.

We recommend to use regime I=4A with external battery (12V или 24V) when capacity is more than 5-7 Ah.

In case the voltage **Uwork** ~ 9-9.5V, the RS232 port of the equipment is switched off and the message about error of COM-port is communicated.

FORMATS OF THE USED FILES

Configuration file **TEM-48CNF.CNF**
This of ASCII- the file is automatically created by the program interface at each regular exit from TEM-48WIN.EXE on a team "**Quit**".

NAME 1234567	- the name of measurement's site **Set**
TEM-FAST48 HPC AEMR NETHERLAND	- the name of research area or profile
WELCOME: DEFAULT CONFIGURATION	- commentary **Remark**
50.00	- the size of the generator loop **TR**
25.0	- the size of receiver's loop **REC**
1.00	- the parameter $n_{REC}*n_{TR}$
100.00	- **X** coordinate (m)
500.00	- **Y** coordinate (m)
200.0	- **Z** coordinate (m)
10	- the parameter **stack**
6	- the parameter **time range**
COM1	- active port
I_1A_4A=1	- the intensity of current's pulse
FILTR50_60=50	- the frequency of industrial notch filter
1	- color flag (0=B&W)
20	- size of file **#tem-48#.tem**

At start of the program the parameters appropriate to last set of measurements and which have been written down in TEM-48CNF.CNF, are loaded automatically.

If TEM-48CNF.CNF file is absent, given above parameters are established "by default".
The file of the results of measurements *.TEM

TEM-FAST 48 HPC/S2 Date: Thu Apr 27 22:48:49 2000
Place: BAKU -2000 LANDSLIDE
#Set PR-01
Time-Range 7 Stack 10 deff=6 us I=2.4 A FILTR=50 Hz Amplifier=OFF
T-LOOP (m) 50.000 R-LOOP (m) 50.000 TURN= 1
Comments: LAKE SURFACE
Location: x= +430.000 y= -1730.000 z= +102.16

Channel	Time	E/I[V/A]	Err[V/A]
1	4.06	1.077e-001	7.025e-003
2	5.07	6.266e-002	5.036e-003
3	6.07	3.383e-002	6.131e-003
4	7.08	1.887e-002	6.295e-003
.....	.....	.....	.....
.....	.....	.....	.....
47	13312	-5.159e-008	8.009e-006
48	15360	-1.804e-006	9.058e-006

ATTENTION!

It is not recommended to edit *.tem files by any editor, except for the program TEM-RES, because the file contains invisible codes, which can be destroyed by the editor that results in mistakes at reading.

File "MONITORING"

TEM-FAST 48 Date: Wed Aug 20 16:30:43 1997
Place: SEVASTOPOL «George'97»
Set Geor-0 Sens. 2 Stacks 20 deff=4 us I=1.0 A FILTR=50 Hz Amplifier=OFF
T-LOOP (m) 50.000 R-LOOP (m) 50.000 TURN= 1
Comments: c.Phialent «George-fault» POINT-0
Location: x= +0.0 y= 0.0 z= +115.00

#Set	1	2	.....	28	C_base	Noise	DATE
	4.0	5.0	.....	478			
1	4.47E+00	2.97E+00	.....	2.47E-04	2602	89	Wed Aug 20 16:30:44 1997
2	4.48E+00	2.97E+00	.....	2.45E-04	2601	88	Wed Aug 20 16:35:44 1997
3	4.48E+00	2.97E+00	.....	2.55E-04	2602	90	Wed Aug 20 16:40:44 1997
.....	.....	.....	.....	.....	.....	.....	.....
.....	.....	.....	.....	.....	.....	.....	.....
292	4.49E+00	2.96E+00	.....	2.43E-04	2623	87	Thu Aug 21 16:40:40 1997
293	4.48E+00	2.91E+00	.....	2.57E-04	2622	86	Thu Aug 21 16:45:40 1997

In this file the values **E(t)/I** [**V/A**] for each active channel (in the given example 1,2,...28) are written line by line. The time (date) specified at the end of a line, corresponds to the termination of everyone set of measurements.

The period of measurements is equal in the given example to 5 minutes number of sets is 293.

The column **C_base** [**μV**] is intended for control of temperature fluctuations during measurements, and **noise** shows mean root square values (r.m.s.) of noise [**μV**].

Chapter 4. THE SYSTEM INTERFACE OF TEM-FAST 48 (DOS)

The system program TEM-FAST is intended for work with the device and provides the following functions.

- Transfer from PC in the device start-vector, determining modes of operations.
- Check the state of the power supply (battery).
- Receiving and preprocessing of a flow of the data.
- Visualization of the sounding data in form of transfer functions -**E(t)/I** or curves of apparent resistivity - **ρ(t)**.
- Record of the data of sounding in ASCII-file.
- Long-term, periodically repeating soundings (monitoring) in automatic mode.
- Diagnostic check of the device state.
- Program change of a configuration of the device for work in various modes.

To work with the system interface it is necessary to have:

- IBM compatible computer with coprocessor, mouse and VGA-adapter,
- DOS system,
- serial port COM1 or COM2 with the standard interface RS232 (19200 bps),
- the files TEM-48. EXE - program, fonts - TMSRB.FON, VGASYS.FON and VGAFIX.FON.

After start of the program TEM-48.EXE, the head menu of the system interface shown in fig. 4-1 arises on the PC's screen.

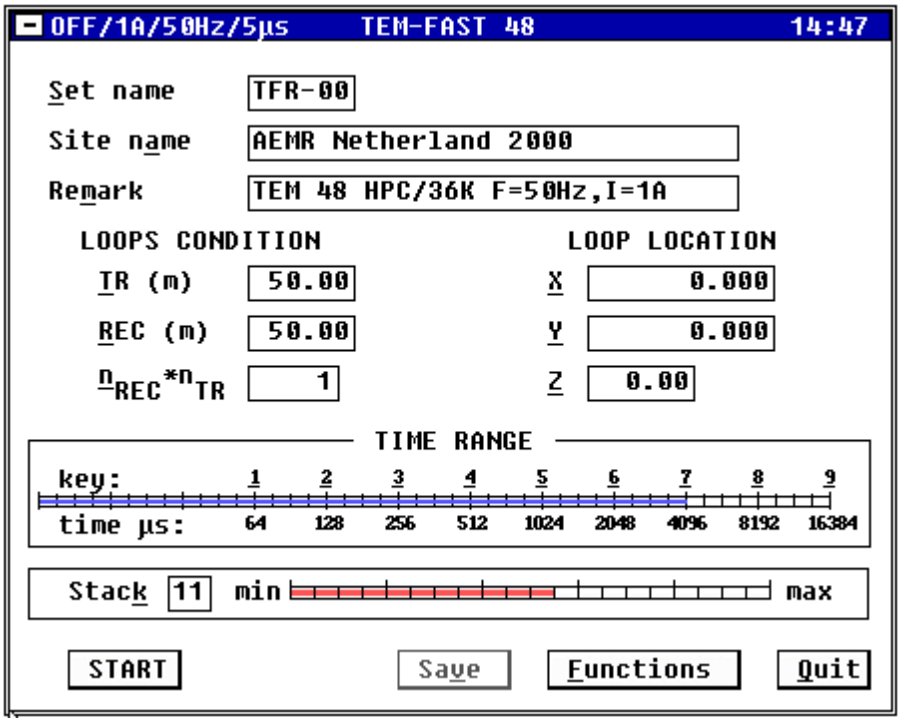


Fig. 4-1

Set name - name of the location of sounding (6 charts).
Site name - name of territory (area) or profile of soundings (30 charts).
Remark is any commentary (30 charts).
TR - side of a square transmitting loop. If a loop is not square then $(L_1 \times L_2)$ is the side of a square **TR** loop with equivalent area equal to **TR**$=(L_1 \times L_2)^{1/2}$.

REC is the side of square receiving loop. If the loop is not square, one should replace $(l_1 \times l_2)$ by equivalent square loop **REC** = $(l_1 \times l_2)^{1/2}$.
$\mathbf{n_{REC}} \times \mathbf{n_{TR}}$ is product of number of coils in transmitting and receiving loops.
Examples:

1) at use of the combined loop **TR** = **REC** with two turns of a wire, $\mathbf{n_{REC}} \times \mathbf{n_{TR}} = 2 \times 2 = 4$;
2) if the remote detector with the effective area **S** (m^2) and **REC < TR/5** is used, we recommend to put: **REC =** 1 m**,** $\mathbf{n_{REC}} \times \mathbf{n_{TR}}$ **= S.**

X, Y, Z are three coordinates of location of the center of the receiving antenna
TIME RANGE is range of measurement of the transitive characteristics. This parameter essentially influences at noise stability of the unit and carefully is selected at trial soundings in each new territory. The narrower range of the registered times, the higher accuracy of measurements, however too narrow range can bring to losing the information about late stages of transients.
Stack is parameter of digital stacking of a signal (1-20). To each number of this parameter corresponds 13 complete cycles of work of **DAS** system described above (see table 1, fig. 6). Parameter **Stack** effectively improves quality of the results of measurements only in case of noise of "white noise" type.
Save is the window for saving at a disk of results of sounding. This function is accessible only after successful termination of measurements.
Function is the window for various transformations of the transient functions, diagnostics of results, installation of a configuration of the device, monitoring and viewing of results before executed and saving of soundings in a file.
START means start of the device for measurements (the key "ENTER").
At start, after testing a state of the device the image of a watch-glass is displayed on the screen. The termination of measurements is accompanied by a melody or by sound signal. In case of any mistakes at work of the device sounds the fragment from the fifth Beethoven's symphony "Destiny is knocked on a door" and the reason of stop of the device is displayed.
In case of restart of the device, the program asks to save the previous data. However, even at refusal of saving last cycle of measurements enters the name in a work file **#TEM-48#.TEM**.
Quit is exit from the program. During termination (exit) the program asks to save last measured data. *Last 20 sets of measurements always are kept in* **#TFR-48#.TEM** .
The current configuration mode of operations of the device **OFF/1A/50Hz/5µs** is displayed in the left top corner.
These parameters are: Amplifier's condition, size of a current, frequency of the notch filter of industrial noise and time of **HVP**.

Attention
Several hidden functions, accessible only from the keyboard: present in the main menu. They are function keys F1-F10 determine the parameter **Stack**:

keys:	**F1**	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**	**F8**	**F9**	**F10**
Stack:	2	4	6	8	10	12	14	16	18	20

C/c - change of color palette of the screen: B&W or COLOR and colors of the mouse's cursor.
Insert - installation/deinstallation of operation mode of a serial port:

1) default mode of receiving of the interruptions,

2) mode of receiving of the data with use of interruption (this **IRQ**-mode of installation is displayed in heading of the menu).

At complete IBM-compatibility PC and complete functional support of port RS232 the work in both modes is identical. However, for some "non-standard" PC the various modes of operations can give failures.

Test PC! Choose suitable mode of operations. In case of failure, contact the manufacturer of TEM-FAST 48.

The system interface works only in DOS mode in regime of operations with TEM-FAST 48. Regime of DOS emulation under OS WINDOWS is not supposed. In WINDOWS 95/98/NT it is possible to work only in regime of viewing of written down results of previous measurements.

Window to view the results of measurements - **Preview data**

This window arises on the screen direct after successful termination of measurements or it can be caused from **Function** (Fig. 4-2).

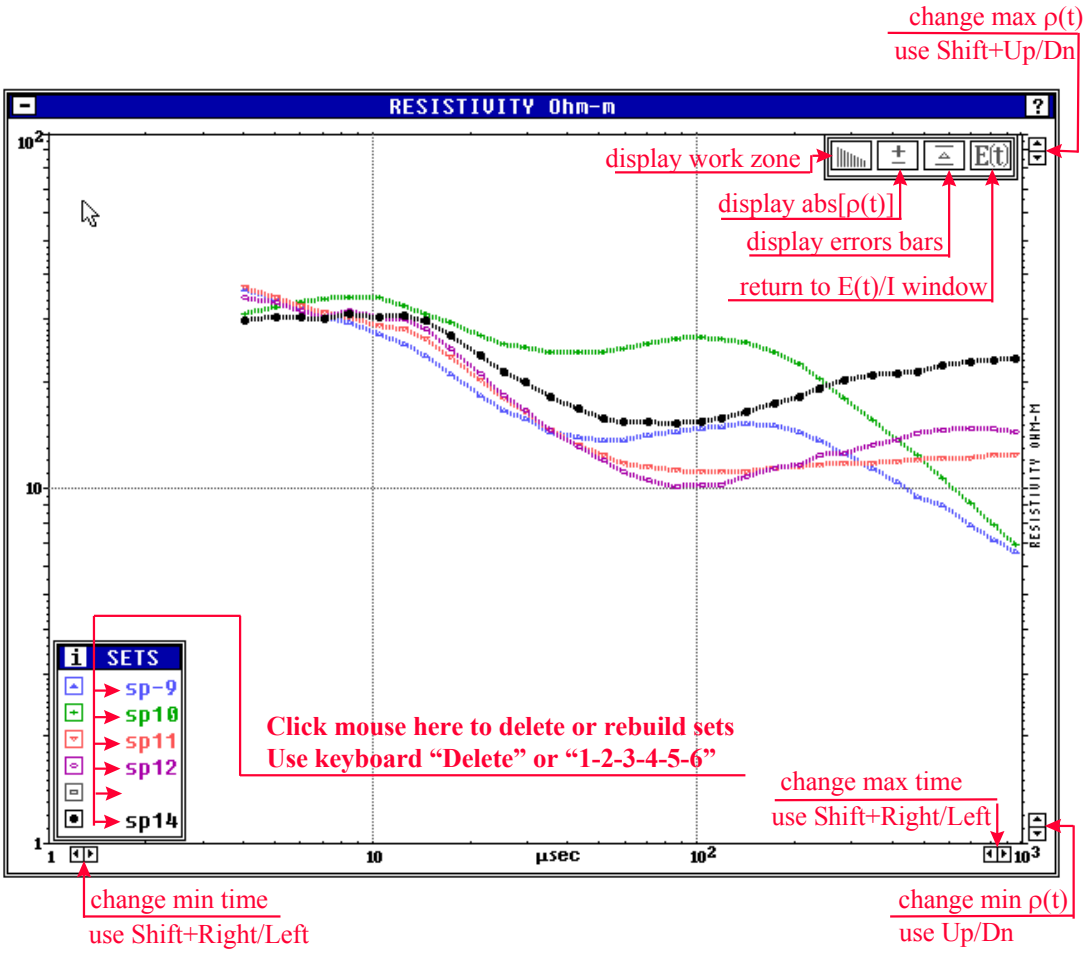


Fig. 4-2

In the corners of a logarithmic coordinate grid the arrows of change of scales on vertical and horizontal axes are located. For change of scales it is possible also to use keyboard functions: ⇆ ⇅ in combination with **Shift**.

In the left bottom corner there is a window of state of the graphic buffer, in which the data of six soundings are located. The location of this window on the screen can be changed with the help of **Tab** key. More detailed information on the data can be received in a window "**i**". To clear the buffer press **Delete**, to remove one data set the keys 1,2,3,4,5,6 are used. The windows of functions of work with the data are located in a right top corner of the screen.

Functions:

- Viewing of dynamic range of measurements **ρ(t)**
- Absolute values **abs[ρ(t)]** for testing of IP effects
- Confidential intervals - mistake of measurements
- Transition in a window of signals **E(t)/I**

Window **SIGNAL**

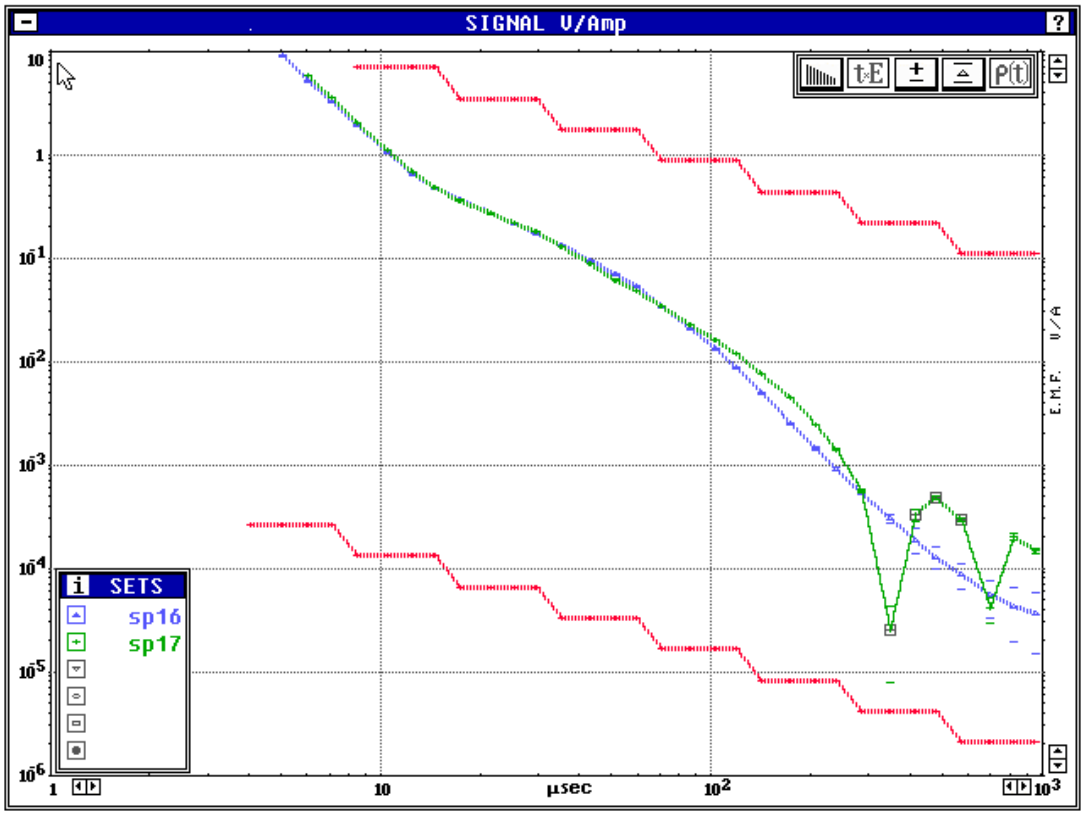


Fig. 4-3

Functions:

- To view dynamic range of measurements **E(t)/I**
- Function **tE(t)/I** - for testing SPM-effects
- Absolute values **abs[E(t)/I]** - for testing of IP-effects
- Confidential intervals - mistake of measurements
- Transition in a window of data **ρ(t)**.

All possible keyboard functions are described in the window **HELP-?**

What is dynamic range of the measurements?

The range is represented on the screen as two step lines, limiting from above and from below work area of measurements at the mode, given in the head menu (**Time range**). The low border $\mathbf{E_{min}}$ is calculated as the ratio of minimally possible readout **ADC** (unit) to the measured value of current at the given channel of measurements - **1 ADC/I.**
The top border $\mathbf{E_{max}}$ is calculated as the ratio of the maximally possible readout **ADC** (max) to the measured value of current at the given channel of measurements - **max ADC /I.**
In the window **ρ(t)** the work zone is calculated as transformation $\mathbf{E_{min}(t)}$ and $\mathbf{E_{max}(t)}$ into apparent resistivity **ρ(t)** with accounting of parameters **TR**, **REC** and $\mathbf{n = n_{REC} \times n_{TR}}$ **.** The transformation **E(t) - ρ(t)** is made according asymptotic formulas of near zone of transient process above uniform half-space for co-axial round loops. Equivalent radius **R** for calculations is determined from a formula $\pi R^2 = L^2$, where **L = TR** is side of a square loop, $\pi r^2 = REC^2$, **r**-equivalent radius of a receiving loop.

$$E(t)/I = \mathbf{n}\cdot(\pi^{1/2}/20)\cdot\rho(t)\cdot(r^2/R^3)\cdot t_0^{-5/2} \quad \text{for} \quad t_0 = t/(\mu_0 R^2/\rho(t)) >> 1$$

The calculations carried out for *round* and *square* loops laying above homogeneous conducting half-space have shown that difference of signals at **REC=TR**, $t_0 > 0.01$ and $\pi R^2 = L^2$ does not exceed 2.5 % ($t_0 > 1$ is not more than 0.5 %) and are comparable with errors originated by superficial inhomogeneities and mistakes when putting of loops.

How the errors of measurements are calculated?

At **Stack = k** the system interface accepts **n = 13*k** of codes **ADC** by each active channel (temporary window-gate t_i), which are used for evaluation of the value of $E(t_i)/I$. The error of measurements **Δ** for each t_i is calculated under the formula:

$$\Delta = [1/(n\cdot(n-1))\cdot\Sigma_j(E_j - E_0)^2]^{1/2} \qquad E_0 = 1/n\cdot\Sigma_j E_j \qquad j = 1,2,..\ 13*k$$

At maximal parameter **Stack** = 20, **n** = 13×20 = 260, i.e. the estimations of errors **Δ** are made on ensemble from 260 numbers. On the screen at activation of a window "**error bar**" three symbols corresponding to values of a signal: $E_0 + \Delta$, E_0 and $E_0 - \Delta$ are presented for each time t_i.

Window **Function**

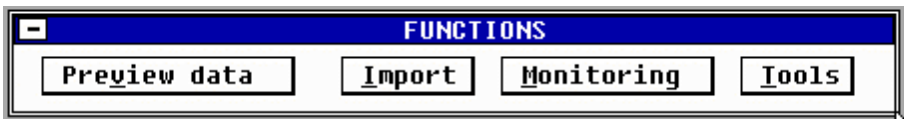


Fig. 4-4

Preview data - viewing **ρ(t)** or **E(t)/I.**
Import - reading and viewing the data of soundings from memory.
Monitoring - menu of automatic operation mode of TEM-FAST 48.
Tools - window for diagnostics and change of a configuration of the device.

.Window **Tools**

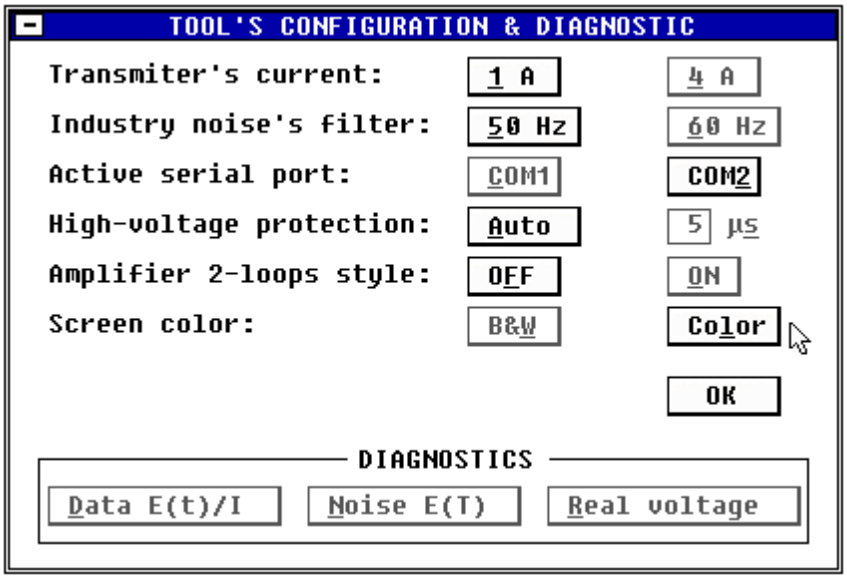


Fig. 4-5

Transmitter current is amplitude of current's pulse
Industry noise filter means installation of the filter at frequency of an industrial noise.
Active serial port - choice of a serial port (3F8 or 2F8 address)
High-voltage protection - configuration of **HVP** system (is described earlier).
OK (Enter) is used for installation of a new configuration.

At work with one-turn receiving-transmitting antenna we recommend to use a mode **HVP** - "**Auto**", the program automatically will establish the necessary mode of operations of system, being guided on the size of the loops given in the head menu.

The time of protection $\mathbf{t_{HVP}}$ is shown in a right window.
It means, that the signals at times $\mathbf{t < t_{HVP}}$ should be excluded and will not appear on the diagrams **E(t)/I** or **ρ(t)** (interface automatically will appropriate **E(t)/I** = 1e-9 V/A).
At use multi-turn of antennas, amplifiers etc. the mode **HVP** is selected by the operator experimentally for curves **E(t)/I.**
Amplifier 2-loops style – turn On or turn **Off** amplification of a signal (around 10 times) at measurements with small receiving antenna.
Screen color – change the color palette.

Window **Diagnostics**

All three windows are accessible for viewing only after successful terminating of the process of measurements.
Window "**Data E(t)/I**" contains the digital information on the measured signal, which subsequently will be written down in *.tem a file of results of measurements.
Window "**Real voltage**" contains the digital information on work of **HVP**, **DAS** and **ADC**. Here measured values are submitted in terms of **ADC** and reflect work of the device in the internal system cycles.

This window is intended for diagnostics of malfunctions and at adjustment TEM-FAST. It is used by the operator in emergencies for record of the diagnostic information in a file and transfers to the manufacturer.

The window "**Noise E(T)**" is intended for the analysis of an external electromagnetic noise, induced by the receiving antenna. Horizontal axes is time **T**, given in intervals of work **DAS**, i.e. each division is equivalent to an interval of analog stacking of a signal.

Each unit of **Stack** contains 13 analog cycles of stacking of a signal. Along vertical axes the values of the measured signal **E(T)** are described, the scale is conditional and is defined by magnitudes of fluctuations of **ADC** codes for each channel.

Vertical scale can be changed using "**Zoom Up**" and "**Zoom Down**".
Average values of a signal (AVG), root mean square (r.m.s.) and peak-to-peak (p-p) estimations of fluctuations of noise are shown in the right part of the screen in terms. of **ADC**.

If the noise is "white noise", the readout **E(T)** looks as a sequence of chaotic pulses, the determined signal (usually because of small (1-2 %) instability of frequency of the internal filter (50/60 Hz, $\delta \sim 0.1$ %) and real frequency of an industrial noise) otherwise is observed.

It is necessary to note, that the internal notch filter is effective at a stable noise with a set of frequencies 50, 100, 200... Hz (60, 120, 240, ...). In this "ideal" case the suppression of a noise is of order of ~ 1000-3000 times. If the spectrum of a noise contains unmultiple frequencies: 75, 150 Hz etc., suppression of a noise is sharply reduced.

At presence at input of the device of a sine wave signal with frequency 50/60 Hz (0.1%) and used frequency of the filter 60/50 Hz, the suppression of this signal makes approximately 30-50 times. Therefore at small levels of an industrial noise (up to 50 μV) the measurements with the filter 50 or 60 Hz are practically identical. As to suppression of quasi-periodical type of noise (at absence of industrial one), the operator can use both 50, and 60 Hz mode of measurements depending on quality of the received data.

Window **MONITORING**

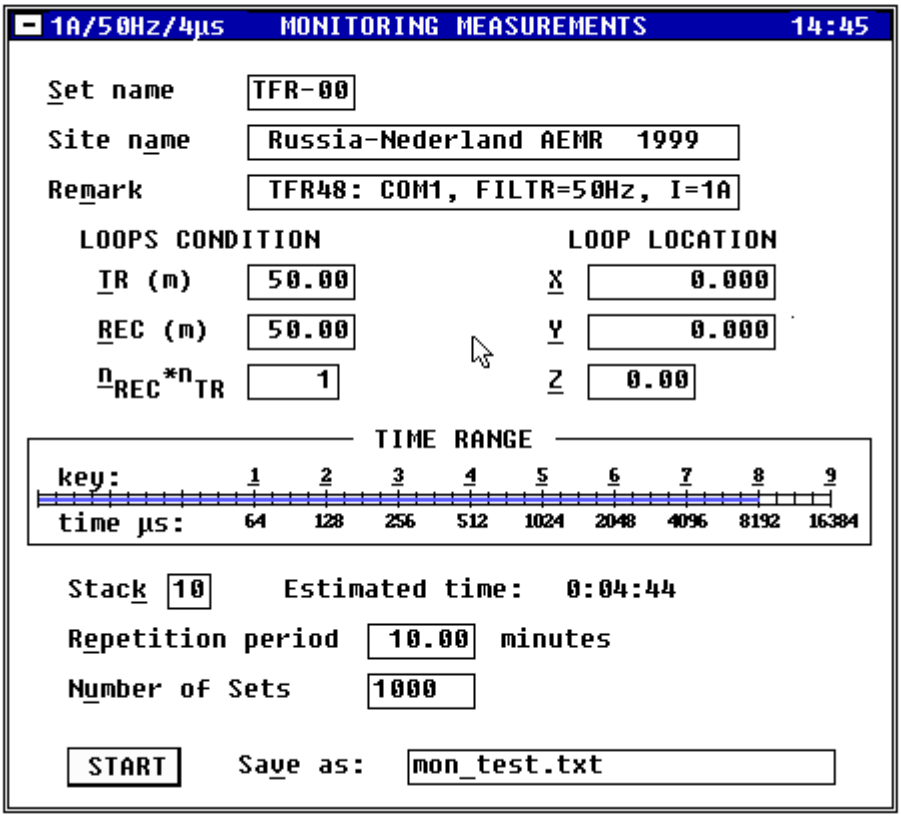


Fig. 4-6

In comparison with the head menu, in the monitoring menu some parameters are added.

Repetition period is interval between sequential measurements (in minutes).
Number of sets is the number of measurements, which is supposed to execute.
Save as is the name of a file where the results of measurements will be written down.
Estimated time -is duration of one measurement in minutes and seconds.

Window **IMPORT** and **SAVE**

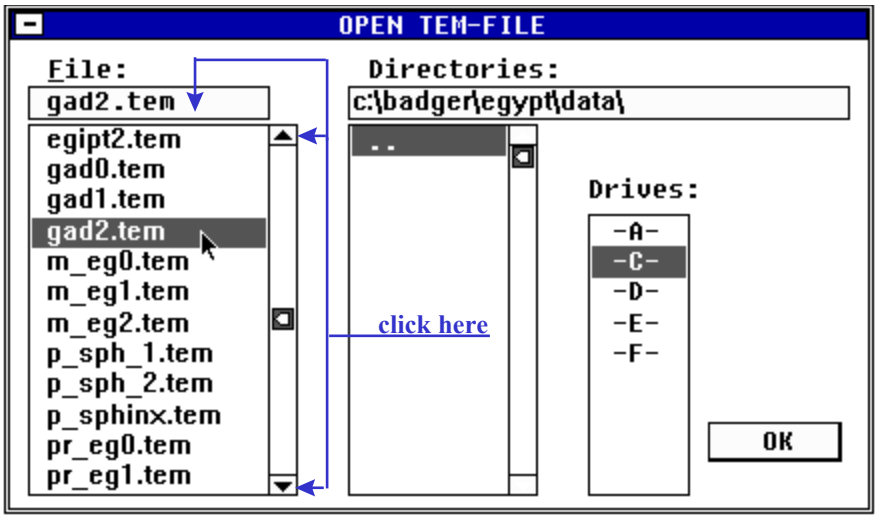


Fig. 4-7

Windows **Save** and **Import** are standard interfaces to work with files.
Moving the appropriate pointer with the mouse manipulator carries out the choice of a file or directory. The left button means slow moving (through 0.5 s of waiting moving is faster), right one means very fast. Besides for convenience of manipulations in field conditions (if the work with the mouse is complicated) in the current directory it is possible to use keys ⇑⇓ for a choice of files. To terminate - Esc, OK = Enter.

After choice of the necessary file (for example, KOLSK0.TEM) the menu of a choice of soundings' sets is appeared on the screen.

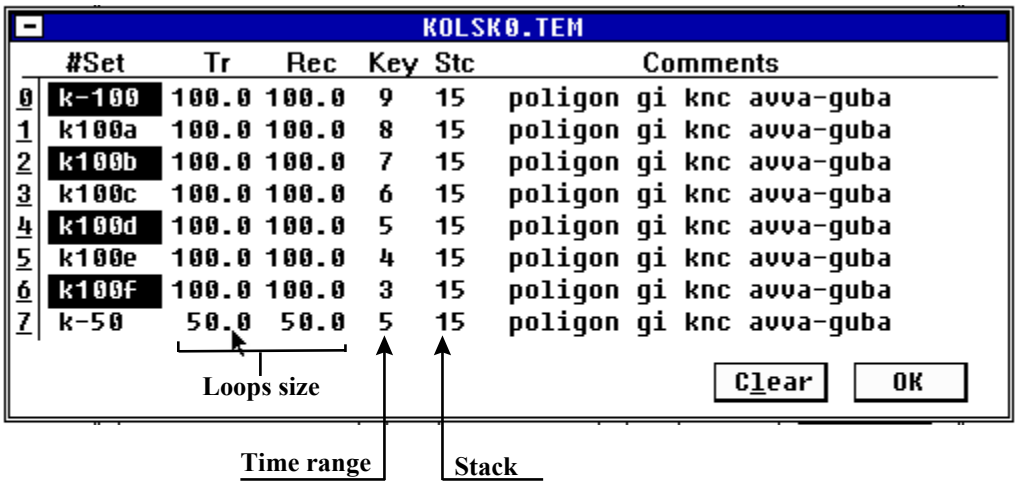


Fig. 4-8

Using the mouse or keyboard, note the sets, which are necessary for importing. If the buffer of sets has appeared is full, return to a window **Preview data** and clear the buffer (**Delete** - completely or **1-6** - partially). If more than 20 sets is written down in the file, page viewing of information is organized. A page is caused by function keys F1-F5 or mouse in windows in the left bottom part of the screen.

ATTENTION!
The size of the buffer for one complete of soundings is 100 sets, therefore it is not recommended to record more than 100 sets in one file.

ERROR MESSAGES

1. TEM-48 is not ready
Check RS232 connector
Check TEM-48 battery

The interface did not receive the necessary code from port

The possible reasons of the mistake:

- PC and TEM-FAST 48 do not connected by a cable RS232,
- there is no battery or it is not charged,
- TEM-FAST 48 is connected to inactive port (see configuration), the used port is not active.

2. Can't send START command
PC-port RS232 is busy
Restart (turn off) PC

The interface has failed to send start - vector in the device, as the port is engaged.

The possible reason of the mistake:
- the used port is not active or is used by any resident program.

3. Can't receive bytes
Detected Time-out
Check RS232 and DOS-system

After start the inadmissible break in a flow of data is found out.

The possible reason of the mistake:
- used port is not active or it is used by any resident program,
- the used port (information channels 2 and 3) is out of order,
- are you sure that you work in real DOS system?

4. Can't receive bytes
Detected Time-out
Check your battery

After start, the inadmissible break in a flow of data from TEM-FAST 48 and a low voltage of battery is found out.

The possible reason of the mistake:
- The battery is not charged.

5. Frame error: overwrite byte
PC-port RS232 is not in order
Do you start in WINDOWS 95?

During the operation the fact of byte missing from COM-port to PC is found out.

The possible reason of the mistake:
- the used port is used by any resident program,
- the operational system does not support standard protocol RS232,
- your NOTEBOOK was switched in a mode "sleep" (see. SETUP PC),
- you have started under the WINDOWS 95/98/ NT.

6. Low loop's current
Break transmitter's circuit

During operation too small amplitude of current's pulse was find out.

- Break in circuits of the transmitter - TR-antenna is not closed.

THE WARNINGS AND OTHER INFORMATION

1. The indicator of the battery discharge arises in the upper right corner of the screen. Detailed description one can find in chapter 4 of the manual.
2. Message "**Loop's current is not fixed, Loop's resistance is very large**" testifies that the transmitter has left a mode of stabilization of a current because of too small value of the ratio of voltage to resistance of the load **Upower/r_{TR}**. *However it does not mean, that the measurements of the value* E(t)/I *will be erroneous*!
3. In case when measured signals partially or completely leave the top limits of a dynamic range of the device, the program automatically includes a mode of showing of a working zone borders in windows **ρ(t)** and **E(t)/I.** If during stacking of the measured signal the voltage **U(t_i)** leaves the limits of a dynamic range **ADC** (-2500>U> 59904), the value **E(t_i)/I** = 10^{-9} [V/A] replaces the measured value when the results of sounding are saved in a file. Manipulating parameter **TIME RANGE**, one can correct this situation.

FORMATS OF THE USED FILES

Configuration file **TFR-48.CNF**
This ASCII file is automatically created by the program interface at each regular exit from TEM-48.EXE using key "**Quit**".

TFR-00	- the name of measurement's site **Set**
Russia-Nederlands AEMR 1999	- the name of research area or profile
TFR48: COM1, FILTR=50Hz, I=1A	- commentary **Remark**
50.00	- the size of generator loop **TR**
50.00	- the size of receiving loop **REC**
1	- the parameter $n_{REC}*n_{TR}$
0.000	- **X** coordinate
0.000	- **Y** coordinate
0.00	- **Z** coordinate
10	- the parameter stack
6	- the parameter time range
COM	- active port порт
I_1A_3A=1	- the intensity of current's pulse
FILTR50_60=50	- the frequency of industrial noise filter

At start of the program the parameters appropriate to last set of measurements and which have been written down in TFR-48.CNF are loaded automatically.

If TFR-48.CNF file is absent, given above parameters are established "by default".
The file of results of measurements *.TEM

TEM-FAST 48 Date: Sat Sep 19 17:39:02 1998
Place: KOVDOR SEP'98
#Set KOV-13 Sens. -3 Stacks 20 deff = 4 us I = 1 A FILTR = 50 Hz
T-LOOP (m) 50.000 R-LOOP (m) 50.000 TURN = 1
Comments: Poligon "gi knc upolocsha"
Location: x = + 2346000.0 y = -235110.0 Z = + 210.00

Channel	Time	E/I [V/A]	Err [V/A]
1	4.06	1.077e-001	7.025e-003
.....		.....	.....
48	15360	-1.804e-006	9.058e-006

ATTENTION!

It is not recommended to edit *.tem files by any editor, except for the program TEM-RES, because the file contains invisible codes, which can be destroyed by the editor that results in mistakes at reading.

File "MONITORING"

```
TEM-FAST 48     Date:  Wed Aug 20 16:30:43 1997
Place:    SEVASTOPOL «George'97»
Set  Geor-0        Sens.    2   Stacks 20   deff=4 us   I=1 A  FILTR=50 Hz
T-LOOP (m)       50.000   R-LOOP (m)      50.000  TURN=   1
Comments:        c.Phialent «George-fault» POINT-0
Location:  x=   +0.0   y=  0.0          z=  +115.00
#Set      1              2        .......        28        C_base  Noise        DATE
          4.0            5.0      .......        478
1       4.47E+00   2.97E+00   .......      2.47E-04   2602     89       Wed Aug 20 16:30:44 1997
2       4.48E+00   2.97E+00   .......      2.45E-04   2601     88       Wed Aug 20 16:35:44 1997
3       4.48E+00   2.97E+00   .......      2.55E-04   2602     90       Wed Aug 20 16:40:44 1997
.....................................................................................................
.....................................................................................................

292   4.49E+00   2.96E+00   .......      2.43E-04   2623     87       Thu Aug 21 16:40:40 1997
293   4.48E+00   2.91E+00   .......      2.57E-04   2622     86       Thu Aug 21 16:45:40 1997
```

In this file the values **E(t)/I** [V/A] for each active channel (in the given example 1,2,...28) are written line by line. The time (date) specified at the end of a line, corresponds to the termination of everyone set of measurements.

The period of measurements is equal in the given example to 5 minutes number of sets is 293.

The column **C_base** [μV] is intended for control of temperature fluctuations during measurements, and **noise** shows mean root square values (r.m.s.) of noise [μV].

Chapter 6. SYSTEM INTERFACE TEM-FAST (Win CE)

The system program TEM-48 is intended for work with the device and provides the following functions:

- transfer from PC in the device start-vector, determining modes of operations;
- check the state of the power supply (battery);
- receiving and preprocessing of a flow of the data;
- visualization of the sounding data in form of transfer functions **-E(t)/I** or curves of apparent resistivity - **ρ(t)**;
- record of the data sounding;
- diagnostic check of the device state.

For work of the system interface it is necessary to have:

- Rugged Handheld computer (Recon, Nomad, any Windows CE compatible Handheld computer)
- Windows CE operational system;
- the file: TEM-48.EXE

After start of the program TEM-48.EXE, the head menu of the system interface shown in fig. 5-1 is appeared on the PC screen.

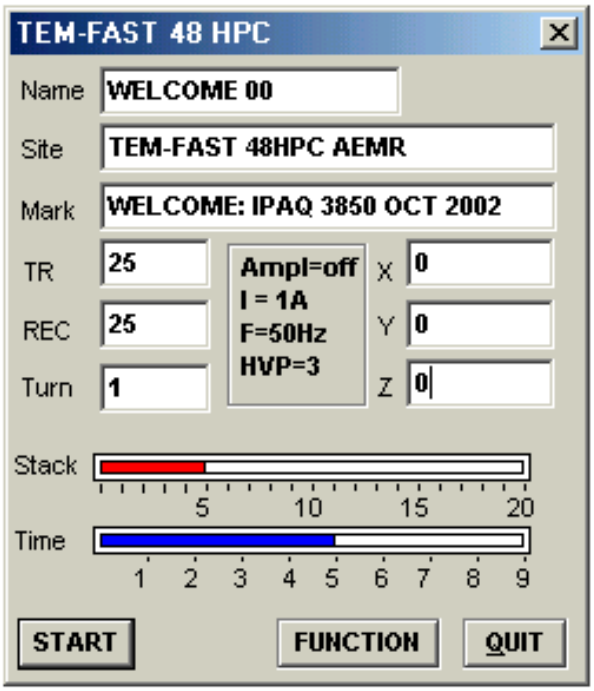


Fig. 5-1

Name is a name of a point of sounding (12 symbols)
Site is a name of area or a sounding profile (30 symbols)
Mark is any comment (30 symbols)
TR is the size (in meters) of a side of square **generating** loop. If a loop is not square ($L_1 \times L_2$), the size of a square loop TR is replaced by an equivalent loop's size $TR=(L_1 \times L_2)^{1/2}$.

REC is the size (in meters) of a side of a square **receiving** loop. If the loop is not square ($L_1 \times L_2$), the real size is replaced by an equivalent square loop $REC=(L_1 \times L_2)^{1/2}$.
Turn is the product of the number of turns in generating and receiving loops.
Examples: at use of the combined loop **TR** = **REC** with two turns of a wire,
$\mathbf{N_{REC} \times N_{TR}} = 2 \times 2 = 4$; if the remote detector with the effective area **S** (m^2) and **REC < TR/5** is used, we recommend to set: **REC =** 1 m**,** $\mathbf{N_{REC} \times N_{TR} = S}$.
X, Y, Z are three coordinates of the receiving loop's center position (meters)
Time is a range of measurement of transient characteristics (see the table of the description of the device). This parameter essentially influences on the noise stability of the tool and should be carefully selected at trial soundings in each new territory.
Stack is a code of digital accumulation of a signal (1-20). 13 full cycles of work of DAS system described earlier (see tab. 2-1) correspond to each unit of the **Stack parameter.**
Application of stacking is effective only in case of white noise.
FUNCTION activates the functional menu.
START means start of the device for measurements.
QUIT - exit from the program. In case of exit command the program proposes to save last measured data. *The file* **#TEM-48TMP#** *always keeps last 50 sets of measurements.*
SAVE is the window for saving the results of sounding. This window is accessible only after successful end of measurements (in figure is absent).
The current parameters of the device are displayed in the center of the screen:

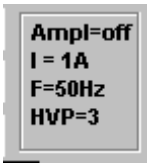


Fig. 5-2

Amp=off or **on** means that the amplifier is switched off or switched on when measurements in a two-loop configuration (at measurements with one loop TR=REC the amplifier is always switched off),
I=1A or **I=4A** is a current in the generating loop,
F=50 Hz or **F=60 Hz** is frequency of the filter,
HVP=3 is parameter of HVP-protection of the device against overloading (**HVP** =1-16 μs).
Putting the pen (Stylus-is the special stick which is carrying out a role of the mouse in Handheld computers) to a zone of installation (the rectangular shown in figure 5-2), one can call a window of installation **Setting** in which it is possible to change parameters of the device. Button **FUNCTION** causes the menu shown in fig. 5-3.

Fig. 5-3

First three lines of the menu are accessible always and intended for:
View - viewing of sounding results as diagrams **E (t)/I** or **ρ(t),**
Import - loading the data of fulfilled measurements from a file,
Setting - setting of operation modes of the device.

In this version of the program additional service providing for TEM-FAST possibility of autonomic work in regime of monitoring. If this option is active, then after running START the unit begin continuous measurements with the parameters prescribed in the main menu and write the results in the directory **iPAQ/Nomad File Store** to file with name corresponding to start time (for instance, M_17-08-05__18_05_2005.tem - which means that this file has been created in May 18 2005 year in 17 hours 08 minutes and 5 seconds). Every 50 soundings are saved in separate file. The names of the sets in the files correspond to the time of measurements as well (for instance, M_17:18:05 -17 hours 18 minutes and 05 seconds).
Parameter X (distance along the profile) in the file is saved in seconds under the assumption that X change as 1m/s. This regime can be used at measurements afoot.

Other four lines are accessible only after successful termination of a full cycle of measurements and are intended for:
Edit Head - editing of parameters TR, REC, Turn, X, Y, Z ,
ADC data - viewing of operation mode of the Analog-Digital Converter (it is used for adjustment and diagnostics of the tool),
Input Noise - analysis of characteristics of an external noise,
Output data - viewing of **E (t)/I** data and **ρ(t)** in a digital form.

To exit from the menu touch by the pen any point outside of the menu.

*Window **View** for viewing of the measurements results*

This window appears on the screen after successful end of measurements or may be caused as **Function-> View** (Fig. 5-4).

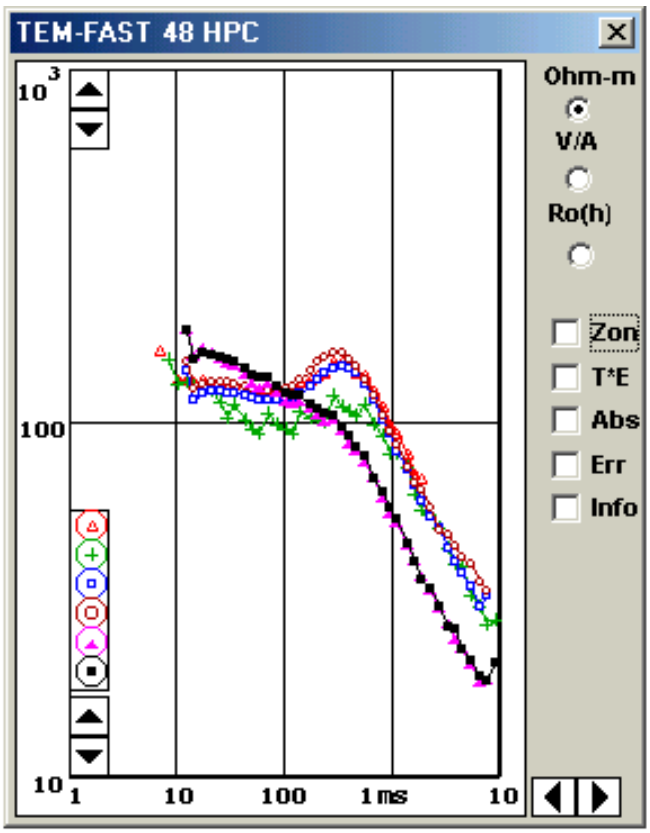


Fig. 5-4

In the corners of a logarithmic coordinate grid the arrows for change of scales on vertical and horizontal axes are located.
In the left bottom corner, the window of a condition of the graphic buffer is located. The icons (symbols) corresponding to curves **E (t)/I** or **ρ(t)** are described in this window.
The touch by pen to the appropriate symbol results in removal or restoration of the curves at the screen.

Menu in the right strip of the screen is intended for:

Ohm-m - viewing of **ρ(t)** curves (the vertical axis has dimension Ohm-m)
V/A viewing of **E (t)/I** curves (the vertical axis has dimension V/A)
Ro(h) - viewing of **ρ(h)** transformation (the vertical axis has dimension m, the horizontal one - Ohm-m)
Zon viewing of a working zone of the device *(dynamic range of measurements)*
T*E viewing of **t∗E(t)/I** or **t∗ρ(t)** curves (ms∗V/A or ms∗Ohm-m) (useful at analysis of superparamagnetic effect **(SPM)**
Abs viewing of the curves of absolute values **E (t)/I** or **ρ(t)** (useful at analysis of induced polarization - **IP** effects
Err analysis of errors of measurements
Info viewing of the detailed information about soundings

What is the dynamic range of measurements?

The range is highlighted on the screen as two step lines, limiting working area of measurements from above and from below at the mode of measurements given in the head menu.

Bottom border $\mathbf{E_{min}}$ is calculated as the ratio of minimally possible readout of **ADC** (unit) to the measured value of a current for the given channel of measurements - **1 ADC/I**. Top border $\mathbf{E_{max}}$ is calculated as the ratio of highest possible readout of **ADC** (max) to the measured value of a current for the given channel of measurements - **max/I.**

In the window **ρ(t)** the working zone is calculated as transformation $\mathbf{E_{min}(t)}$ and $\mathbf{E_{max}(t)}$ in apparent resistance **ρ(t)** with consideration of parameters **TR**, **REC** and **Turn=n.** Transformation
E(t) → ρ(t) is made according asymptotic formulas of a near zone of transients above homogeneous half-space for coaxial round loops. Equivalent radius **R** for converting is calculated from a ratio $\pi R^2=L^2$, where **L=TR** is the side of a square loop, $\pi r^2=REC^2$ is equivalent radius of a receiving loop.

$$E(t)/I = \mathbf{n}\cdot(\pi^{1/2}/20)\cdot\rho(t)\cdot(r^2/R^3)\cdot t_0^{-5/2} \quad \text{for} \quad t_0=t/(\mu_0 R^2/\rho(t))$$

The calculations fulfilled for *round* and *square* loops, laying above homogeneous conducting half-space, have shown, that difference of these signals at **REC=TR**, $1> t_0>0.01$ and $\pi R^2=L^2$ do not exceed 2.5 % (at $3>t_0>1$ less than 0.5 %) and are commensurable with errors caused by influence of superficial inhomogeneities and by inaccuracies when putting the loops.

How errors of measurements are calculated?

At **Stack=k** the system interface accepts **n=13∗k** codes **ADC** by each active channel (a time window) which are used for calculations of **E(t)/I** values. The error of measurements **Δ** for everyone **t** is calculated under the formula:

$$\Delta=[1/(n\cdot(n-1))\cdot\Sigma_i(E_i-E_0)^2]^{1/2}, \qquad E_0=1/n\cdot\Sigma_i E_i$$

At maximal parameter **Stack=20 n=13∗20=260**, i.e. estimations of errors **Δ** are made on ensemble from 260 numbers. Three symbols appropriate to values of a signal $E_0+\Delta$, E_0 and $E_0-\Delta$ are highlighted on the screen for each time t at activation of window Err.

Window **Setting** *for installation of the device's parameters*

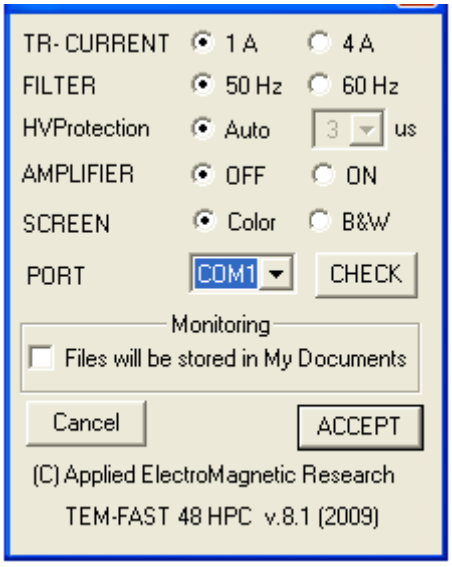


Fig. 5-5

TR-CURRENT - amplitude of a current's pulse
FILTER - setting of the filter at frequency of an industrial noise
HVProtection configures the HVP system (see the description of the device)
At work with one-turn loop it is recommended to use mode **HVP - «Auto».** In this case the program automatically establishes the necessary mode of operation of system, being guided on the size of a loop given in the head menu. Time of protection $\mathbf{t_{HVP}}$ (in μs) is shown in window **Setting**.
It means, that signals on times $\mathbf{t<t_{HVP}}$ will be **excluded** and will not appear on diagrams **E(t)/I** or **ρ(t)** (the interface automatically fixes **E (t)/I=1e-9**).
When using multiturn loops, amplifiers etc., **HVP** mode is selected by operator experimentally on curve **E(t)/I**.
AMPLIFIER - setting of amplification of a signal (κ=11.0-11.5) at work with two-loop configuration (appropriate normalization of the data is carried out automatically and does not demand intervention of the operator).
SCREEN – change of the color palette of the screen
PORT –select active COM port
Monitoring – set monitoring mode. If window is active TEM-FAST will start measurement automatically after press button START Fig 5.1.

Window of loading of the data from file **Import**

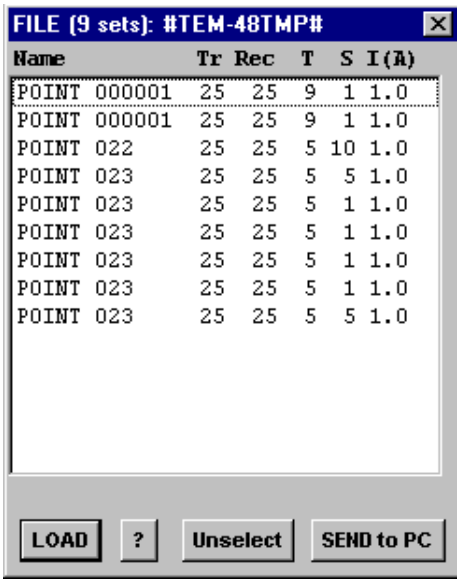


Fig. 5-6

At activation, there is a standard file dialogue where the user chooses a file for loading. Mark the sets (not more than 6), which you want to load and press key **LOAD** (fig. 5-6). If the buffer of the data is full, proceed in window **View** and remove the data unnecessary at present, then load new ones.

The button **SEND TO PC** intended for transmitting of the data from Handheld to DeskTop PC.
The data in Handheld are written down in a special binary code of system WinCE and may not be read directly by programs TEM-RES, TEM-48, TEM-48WIN, working under DOS or Windows. For transmitting the data there are two ways.

First way

1. Start program TEM-48CONV.EXE on DeskTop the computer.
2. Connect computers with cable RS232 (standard complete set).
3. Press button START, the program will enter the mode of waiting the data from Handheld computer.
4. Press button SEND TO PC on yours Handheld computer, the data will be converted in textual ASCII format on DeskTop PC.
5. Save the copied data.

Second way

1. Install at the DeskTop PC the program *Microsoft ActiveSync*, which is included into the complete set of your Handheld computer.
2. In Handheld computer enter window ***Start → Setting → Communications → PC*** and set the flag ***Automatically synchronize when serial cable is connected*** in position **ON** (square of a flag will be ticked).
3. Connect computers with cable RS232.
4. Synchronize computers and copy (binary) selected file from Handheld to DeskTop PC (follow instructions of company MicroSoft).
5. Enter window ***Start → Setting → Communications →> PC*** and set the flag ***Automatically synchronize when serial cable is connected*** in position **OFF** (tick in the square of a flag will be removed).
6. Start the program TEM48CONV.EXE on DeskTop computer.
7. Press button From File and load the file copied earlier.
8. Save the copied data.

Open simultaneously two windows on the Working panel of yours DeskTop PC: window *Microsoft ActiveSync* in which the directory My Handheld-size PC is shown and files contained in it (the file with the data here has the name **test-tem-file**, fig. 5-7) and window PC EXPLORER or any other window for work with files DeskTop PC (window WINDOWS COMMANDER and specially created directory BIN_DATA FROM_HANDHELD_TOP in this example are open).
(It is possible to copy the data directly on working table DeskTop PC or to use Explorer inside *Microsoft ActiveSync* to work with files both Handheld, and DeskTop PC).
Click with the left button of the mouse on a file **test-tem-file** and, not releasing the button, transfer a file to window BIN_DATA_FROM_HANDHELD_TOP (moving the mouse with the pressed button). After you release the button, the file will be copied to DeskTop PC in the chosen directory - fig. 5-7.

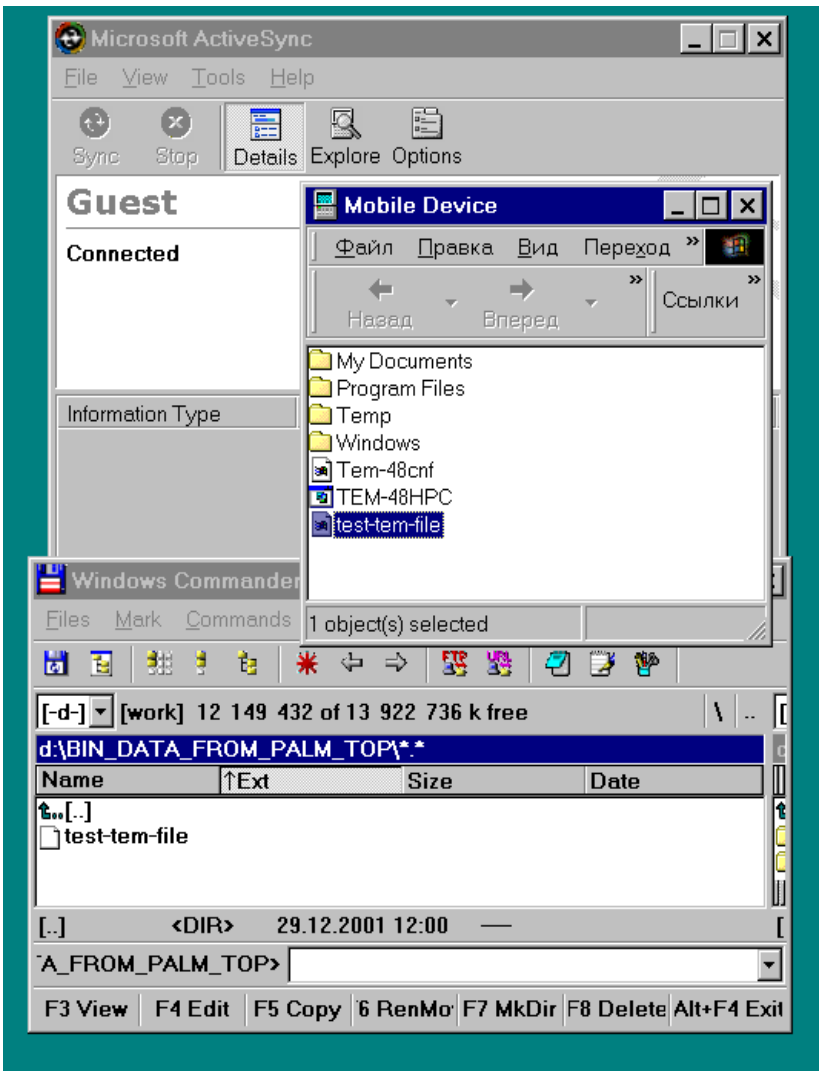


Fig. 5-7

Similarly you can transmit the files (binary files with the data or exe-files, for example TEM-48.EXE) from a window of DeskTop PC in Handheld computer (for example, in case of loss of the program TEM-48.EXE).

Window **Edit Head** *for data editing*

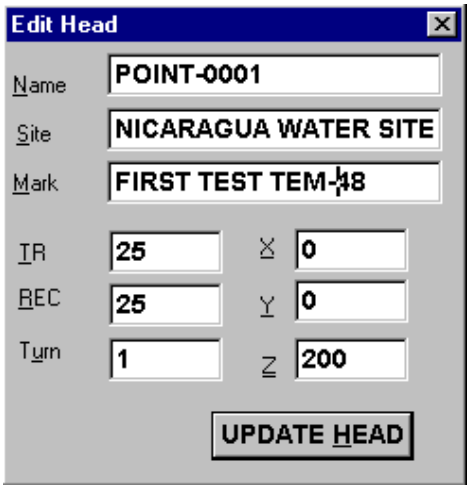


Fig. 5-8

The window for data editing is accessible after termination of measurements in case if an operator ***has not saved the data*** (when detection of any mistakes in heading, for example, incorrect given coordinates of a sounding site or incorrect given name of a site).

After correction the information it is possible to write down the data in a file without mistakes.

This window is used at entering exact coordinates of a sounding site, received with GPS already after termination of TEM-FAST 48 work in the given site.

Analysis of input noise

Window **Input Noise** *for analysis of input noise*

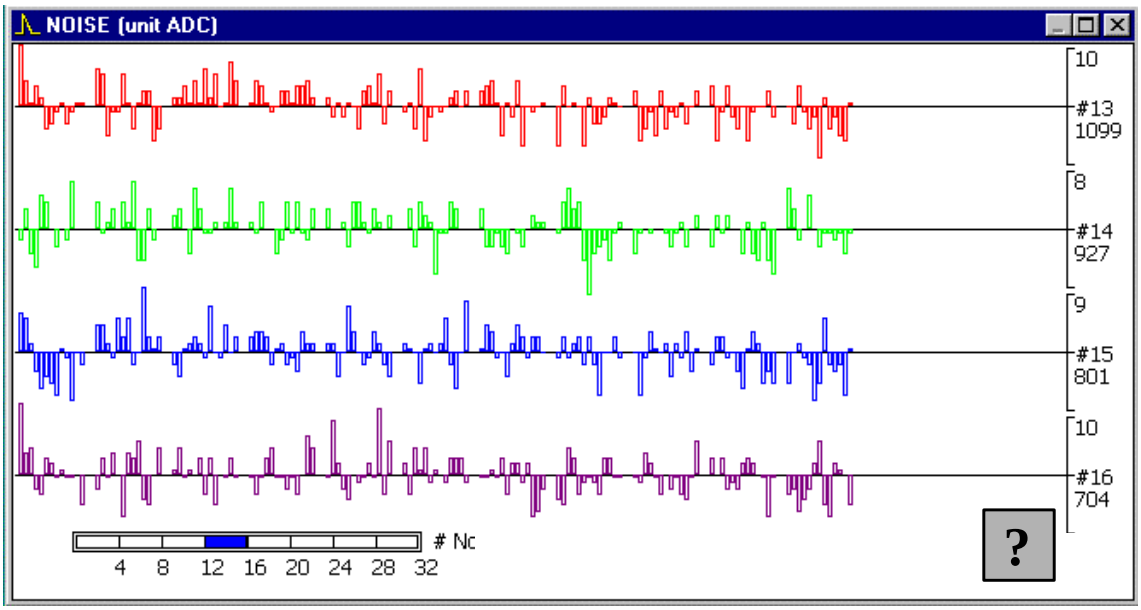


Fig. 5-9

The Window is intended for the analysis of an external electromagnetic noise, induced in the receiving loop.

Horizontal axes is time **T** given in intervals of **DAS** work, i.e. each point is equivalent to an interval of analog accumulation of a signal.

Each point **Stack** contains 13 analog cycles of accumulation of a signal (i.e. at accumulation **Stack=10** it is possible to see on the screen 130 lines for each time window, in case shown in fig. 5-9 for windows with numbers 13,14,15 and 16).

The values of measured signal **E(T)** are drawn along vertical axes, the scale conditional and is determined by size of fluctuations of **ADC** codes for each channel. Average values of a signal (AVG), root-mean-square (rms) and peak (p-p peak-peak) estimations of fluctuations of noise are shown in the right part of the screen in terms of ADC.

By pressing the button "**?**" it is possible to receive the detailed information on statistical characteristics of noise and useful signal. At a touch to the right extreme side of the screen (zone of the axes) on the screen, one can see an autocorrelation function of noise which gives possibility to estimate real "whiteness" of the noise.

If the noise represents white noise, the function **E(T)** looks like a sequence of chaotic pulses. The determined signal is observed usually because of small 1-2 % of discrepancy of frequency of the internal filter (50/60 Hz, $\delta \sim 0.1$ %) with real frequency of an industrial noise.

It is necessary to note, that the internal filter of industrial noises is effective in case of a stable noise with a set of frequencies 50, 100, 200... Hz (60, 120, 240...). In this "ideal" case suppression of an industrial noise achieves ~ 1000-3000 times.

In practice the spectrum of a noise can contain aliquant frequencies: 75, 150 Hz etc., in this case effectiveness of suppression of noise is sharply reduced.

At presence on an input of the device of a sine wave signal with frequency **50/60** Hz (0.1 %) and the frequency of the filter **60/50** Hz (obviously erroneous setting of frequency of the filter) suppression of this signal makes approximately 50-80 times. Therefore at small levels of an industrial noise (up to 50 μV p-p) the measurements with the filter 50 or 60 Hz are practically indistinguishable.

As to suppression of quasi-periodical noise (in absence of industrial noise) an operator can use either 50 or 60 Hz mode of measurements depend on quality of the received data.

Трансформации Ro(h)

If it is required, before calculation of transformations of transient characteristics into apparent resistivity depend on effective depth, it is necessary to modify the data.
In fig. 5-10 the data complicated with resonant process originated from a transmission line are submitted. For successful smoothing of the data and their subsequent transformation it is enough to remove some erroneous points on a curve r(t) or E(t). To do that, touch a cursor an erroneous point, and it will change the color on grey. It means, that the given point of a curve will not be taken into account during smoothing and transformation of the data. After necessary editing the data, press **Ro(h)** and after the small pause necessary for calculations, the window of transformations (fig. 5-11) will appear on the screen.

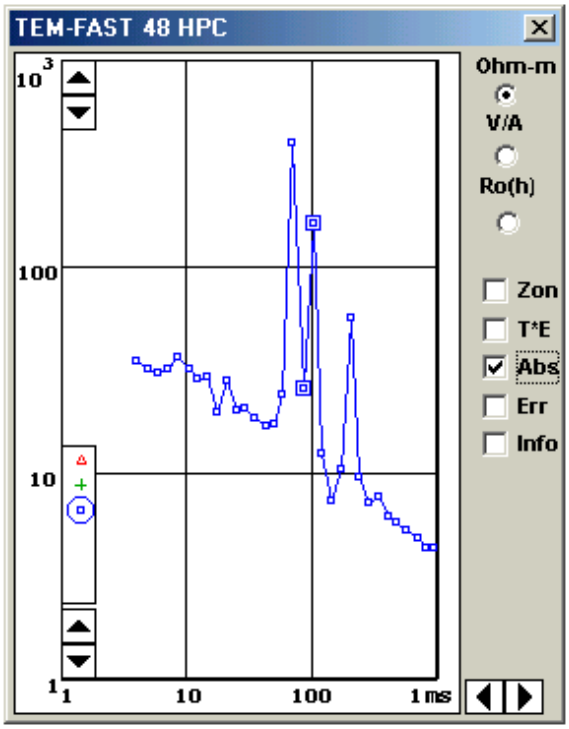


Fig. 5-10

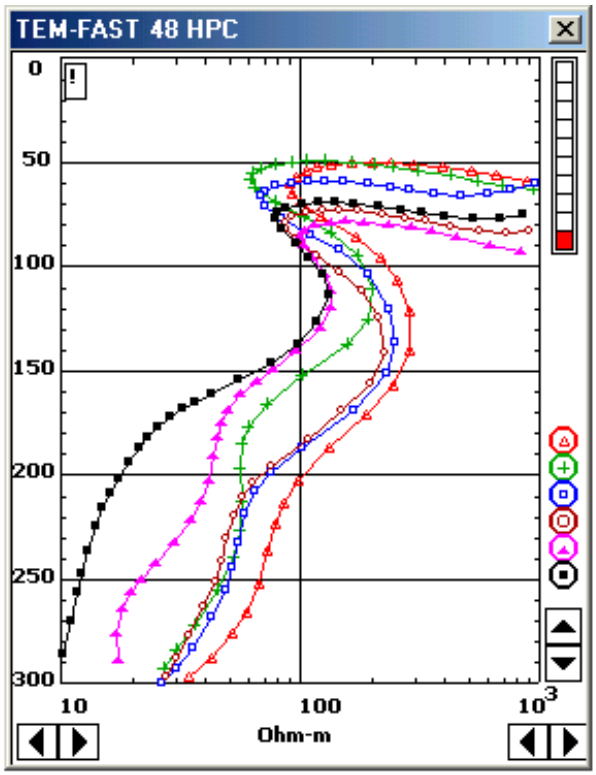


Fig. 5-11

This window gives user possibility to do preliminary interpretation of the data directly in field conditions. The pseudo-section ρ(h) reflects the geological structure of the media

with adequate accuracy. In many cases this transformation appears more precise, than result of inversion made in the class of horizontally layered section.
The vertical strip in a right top corner allows change the resolution of pseudosection: the more cells are filled, the higer resolution of transformation.
The button "**!**" in the left top corner activates a window for setting of smoothing parameters (fig. 5-12) when transformation ρ(t) curve to curve ρ(h).

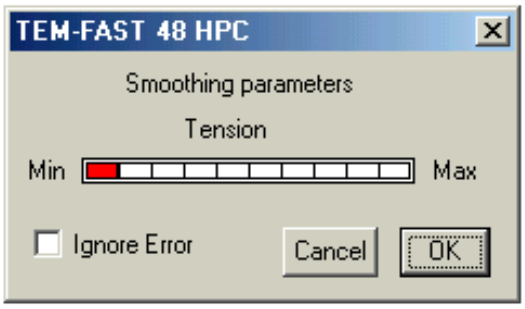


Fig. 5-12

The more value of parameter "**Tension**", the more detailed is pseudosection.

Notice!
The time necessary for calculation of transformation is essentially depends on value of parameter Tension. For Handheld computer at Tension=5 it makes about 3 minutes for calculation of one transformation.

Ignore Error – switch, permissive to make calculations of transformation taking into account inaccuracy of measurements **(**if **Ignore Error** is marked), or without taking inaccuracies into consideration, as it is shown in fig. 5-12. After clicking OK, the curves will be automatically recalculated with the new smoothing parameters.

Sounding

After installation of the sizes of loops and parameters in window **Setting** , one can start TEM-FAST 48. After automatic testing of an internal state of blocks the device starts accumulation of the data and their transferring to Handheld computer.

On a place of buttons **START FUNCTION QUIT** the gradually filling line, indicating the process of accumulation of the data is appeared.

For interruption of work it is necessary:

to touch by pen the indicator of the battery (see further)

to press the button **"X"** (ESC)

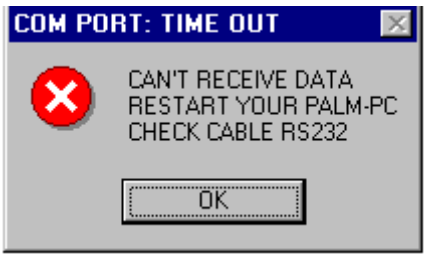
to press the button (ESC) (see instruction for Handheld computer)

After successful completion of measurements the window **View** is activated, all sections of menu **FUNCTION** including the button **SAVE** become accessible. If an operator sure in correctness of the entered data (X, Y, Z, TR, REC, Turn) in headline, it is possible to save the data in a file, using standard file dialogue of Windows CE. Otherwise it is necessary to open **FUNCTION → Edit Head** and to edit the data, then to save down them in a file.

Let's note, that in one file it is possible to save not more than 127 sets of sounding, however we recommend to save 50-60 sets to accelerate reading.

For secure TEM-48 saves last 50 data sets in a special **#TEM-48TMP#** file. Record being made just after successful end of process of data acquisition, therefore is not subject to editing. This file is intended for restoration of the information at mistakes of the operator during record of the field data. If mistakes are absent, we recommend to delete or rename this file daily after transferring the data to DeskTop PC.

If after start of the device the window of mistake (**COM PORT: TIME OUT**) is arrived, first of all check up list-box ***Enable synchronization when cradled using*** in the window ***Start->ActiveSync-Tools->Options.***



The flag <**USB**> should be activated in order to get into contact with Desk Top PC via USB (because RS232 port is occupied by TEM-48).

At each stage of work, the device tests a voltage of the internal accumulator, and result is highlighted in a right top corner of the screen in form of stylized battery - indicator.

At work with current I=4A the internal battery (C=2000 Ah) sharply loses a voltage when flashing the current and quickly restores it in pauses.

Therefore in this mode infill the indicator can change during measurements from 100 up to 50 % or from 50 up to 25 % - it is standard mode of operation.

If the accumulator is unloaded or is out of order, infill of the indicator change by jumps from 100 up to 10 % or 50 up to 0 %. In this case charging or replacement of the battery is required.

Breakdown situation!

Like any electronic device, Handheld computer can temporarily lose capacity for work. Most often this is because of discharging of the internal battery. Therefore, the charging of the battery should be produced **at least one times a two weeks, even if the Handheld computer does not used for work!** Even in a sleeping regime (switch off state) Handheld computer consumes power of the battery to support an internal resources. The state of the battery is controlled by the window **Start->Setting->Power.**

Attention

In case of full di scharge of the battery, all information created by you in Handheld computer vanishes! It is possible to restore only the program TEM-48, restoring of sounding data in this case is impossible!

To minimize loss of the information stored in Handheld computer, one should make:

- daily copy of the field data to Desk PC,
- avoid discharge of Handheld computer battery lower 30% of indicator,
- keep *Microsoft ActiveSync* program and reserve copy of TEM-48.EXE in DeskTop PC,
- when long-term storage of Handheld computer, copy all the data to DeskTop PC.

TEM-FAST DATA CONVERTER (TEM-48CONV.EXE)

This program intended for transferring the data from binary format WinCE in textual TEM-format (ASCII) Win95/98/ME.

Section **Ports** is intended for serial RS232 port setting for communication with Handheld computer.

At start **tem-48conv,** the program automatically chooses free port (**COM1-COM4**) and initializes it for work. If free ports are absent, the error of initialization is highlighted. In this case it is necessary to delete the program occupying the necessary COM-port and start **tem-48conv.exe** again.

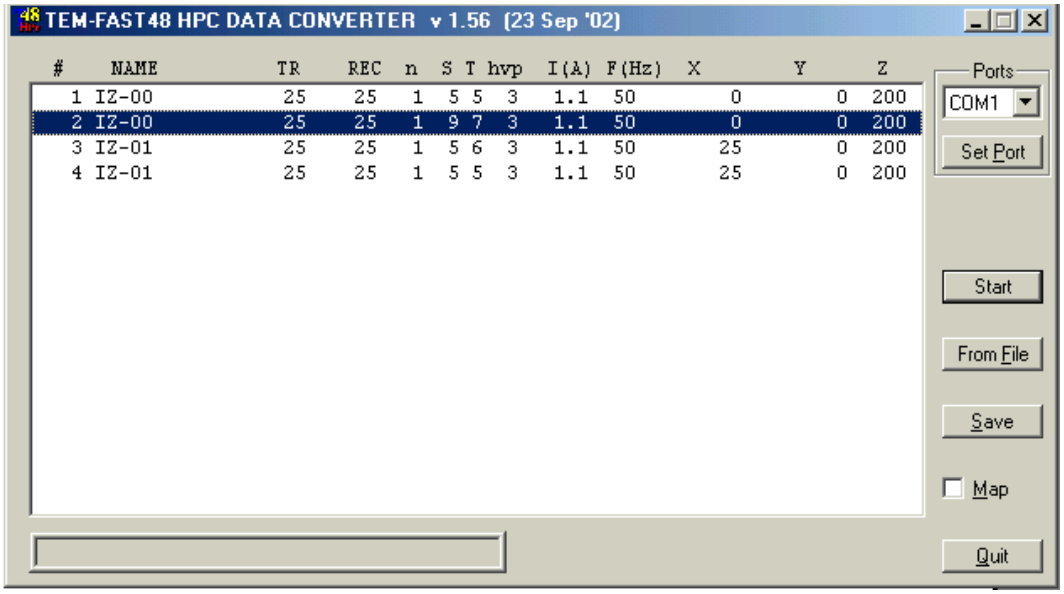


Fig. 5-13

If the port is successfully initialized:

- Connect computers cable RS232.
- Press button **START**, the program will enter a mode of waiting of the data from Handheld computer.
- Start the program **TEM-48** at Handheld computer.
- Enter in **Function → Import** and load a file intended for transferring.
- Press the button **SEND TO PC** on yours Handheld computer, the data will be converted in textual format on Desk-Top PC.

If you have preliminary used the program *Microsoft ActiveSync* and have copied the binary data from Handheld to Desk-Top PC (Fig. 5-7), it is necessary to press button **From File** to find the copied file and to load it (in this case there is no necessity to activate the port and use the cable RS232).

For viewing and editing the data, transferred from Handheld computer, click the left button of the mouse, having directed the cursor on any set of sounding. After that the window shown in fig. 5-11 is arrived.

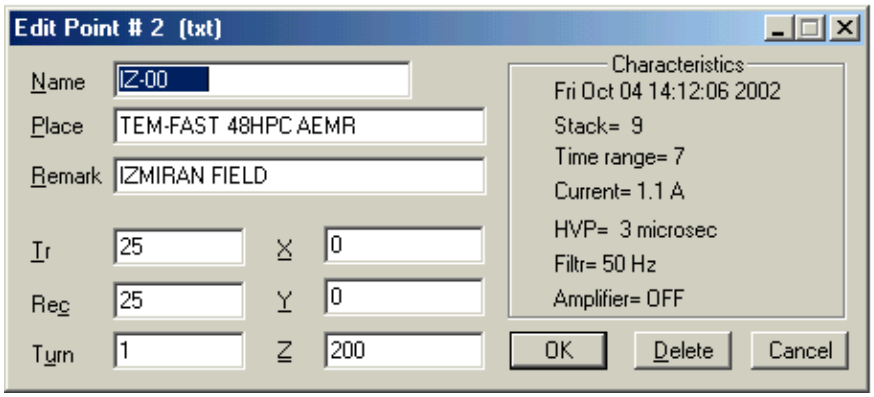


Fig. 5-14

The information in active windows may be edited.
After completion of editing, use button **Save as** to save the data.

Attention!

Before the beginning of the work with **TEM-48CONV.EXE** in communication mode with Handheld through RS232, enter window ***Start->ActiveSync*** in Handheld computer and check up the flag ***Enable synchronization when cradled using.*** The flag should be in position **"OFF"** (tick in a square of a flag is absent), or USB port (for Handheld computer equipped by USB bus) should be active.

Chapter 7. TEM. THEORY AND EXPERIMENT

Physical and mathematical bases of TEM enough well and full are described in the literature (for example, F. Kamenetsky (in Russian) "Electromagnetic geophysical researches" Moscow, GEOS, 1997). Here we shall state only the basic aspects of the theory having the direct relation to technology of soundings with TEM-FAST 48.

Transients above half-space.

One of few models of media, for which the formulas, simple and accessible to the analysis of TEM signals are received, is the model of homogeneous half-space. For understanding and estimation of opportunities TEM we shall consider asymptotic estimation of signals for late and early stages.

The late stages of transient $\mathbf{t_{\square}=t/(\mu_0 R^2/\rho) >>1}$ for one-turn, round antennas **R** and **r**, laying above homogeneous half-space with resistivity ρ and magnetic permeability of vacuum μ_0, are described by the formula:

$$\mathbf{E(t)/I = 0.05*(\pi^{1/2}\mu_0^{5/2})/\rho^{3/2}(r^2R^2)\ t^{-5/2}} \qquad (6.1)$$

The registered signal is proportional to conductivity $\sigma^{3/2} = 1/\rho^{3/2}$ and to product $\mathbf{R^2r^2}$. Thus, in TEM the amplitude of signals at late stages is rather sensitive to changes of conductivity of section in comparison, for example, with methods of direct current. Besides, the signals **E(t)/I** at $\mathbf{t/(\mu_0 R^2/\rho) >>1}$ *do not depend* on a site of receiving loop **r<R**.

The formula (6.1) is fair as well for raised on height **h** above a surface of half-space of antennas.

At late stages of transient the signal, registered in the receiving antenna, is caused by currents induced in the current's ring inside section with effective radius $\mathbf{R_{eff}}$ and "attitude" depth $\mathbf{H_{eff}} \sim \mathbf{R_{eff}}$. $\mathbf{R_{eff} = (t\rho/\mu_0)^{1/2}}$, in some times exceeding radius of transmitting loop $\mathbf{R_{eff}} >> \mathbf{R}$ (Fig. 6-1).

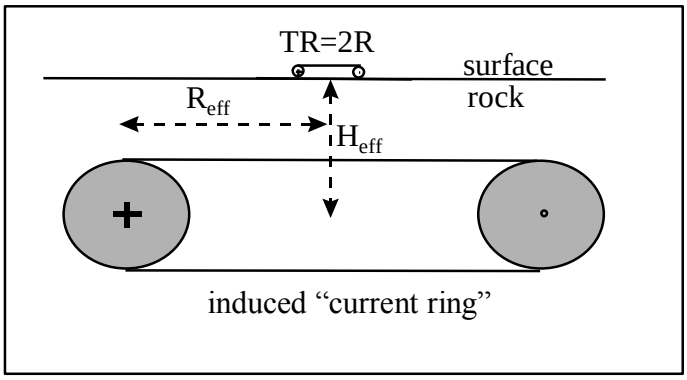


Fig. 6-1

The vertical magnetic field created by this contour, practically is homogeneous within the limits of its area at $\mathbf{h<R_{eff}}$, therefore registered signals proportional to derivative of magnetic field over time, do not depend on a site of their receiving.

This property of late stages TEM determines high depth of researches in a combination with good resolution of the method($E \sim \sigma^{3/2}$).

Early stages of transient $\mathbf{t_0<<1}$ for the coincident antennas **R=r do not depend** *on resistivity of media:*

$$\mathbf{E(t)/I = \mu_0 R/(2t)} \qquad (6.2)$$

At early stages ($\mathbf{t_0<<1}$) for small receiving antennas **r/R <<1** the signals are proportional to specific resistivity of media ρ and do not depend on time **t**:

$$\mathbf{E(t)/I = 3\pi\rho\ (r^2/R^3)} \qquad (6.3)$$

In fig. 6-2 the signals **E(t)/I** above uniform half-space with resistivity ρ=10 Ohmm for the coincident antennas **TR=REC**=50×50 m, raised above a surface on height **h** are submitted.

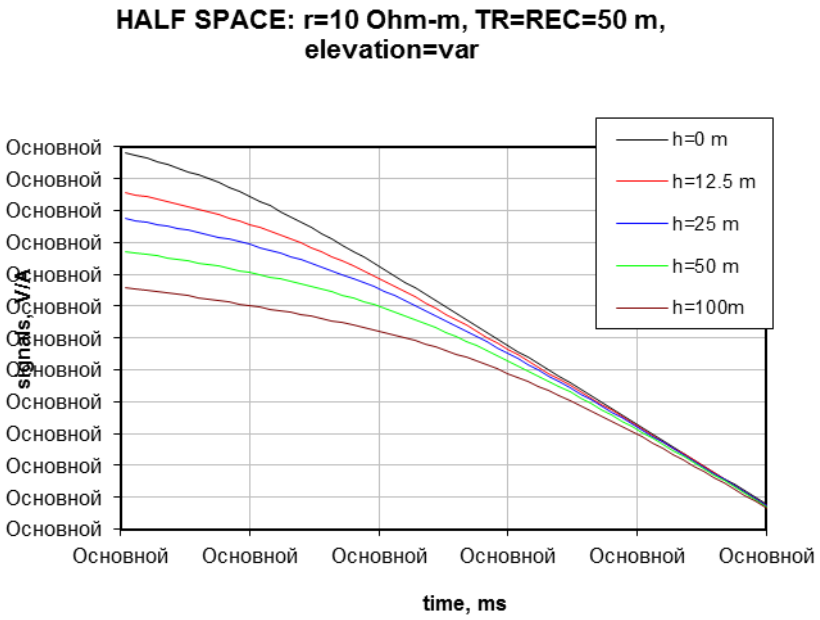


Fig. 6-2

The signals considerably differ only for **t**<10 ms, at the large times they coincide. At late times the size of induced in media current's contour is so great, that even the uplifting of antennas at height **h=2*TR** does not result in essential attenuation of a signal.

In fig. 6-3 the results of calculation of signals for half-space with ρ= 10 Ohm-m in traditional for TEM normalization as apparent resistivity **ρ(t)** under the formula (6.1) for the various sizes of the coincide antennas **TR = REC** are submitted.

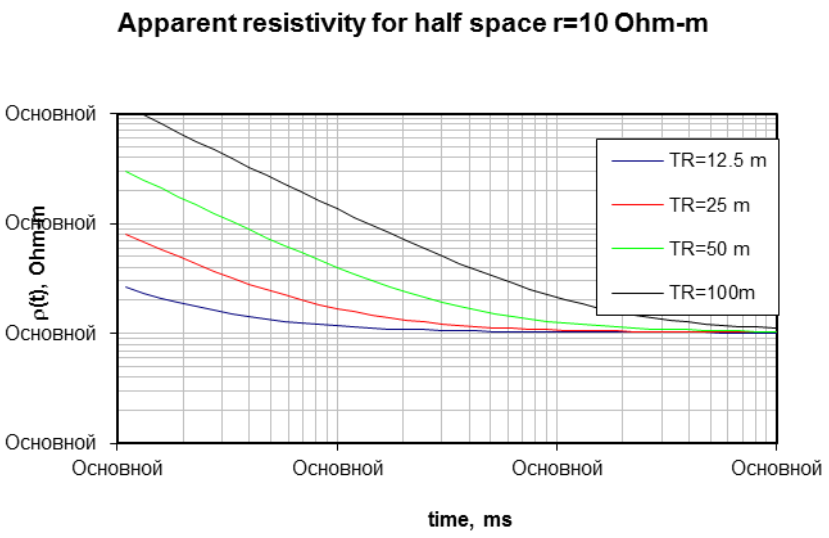


Fig. 6-3

In opposite to DC methods, <u>the form of apparent resistivity curve in TEM depends on the size of receiving-transmitting antenna,</u> at early times **ρ(t)** it appear overestimated. This fact should be taken into account at the express evaluation (without application of the strict inversion of TEM data) of geoelectrical sections.

Practical conclusions and recommendations

1. The increase of the size of antenna in TEM results in increase of a level of registered signals. At late stages the ratio signal/noise is proportional to the area of the transmitting antenna ~$\mathbf{TR^2}$.
2. Maximal depth of researches ($\mathbf{H_{eff}}$, fig. 6-1) is determined by the maximal time **t**, on which it is possible reliably to register a signal **E(t)/I**.
3. Maximal depth of researches with configuration loop-in-loop theoretically is identical to the coincident configuration.
4. TEM effectively works in sections with high conductivity: the layers, for example, with ρ = 1 and ρ = 1.5 Ohmm are reliably stratified.
5. Stratification of section with high levels of resistivity is extremely complicated - it is practically impossible to distinguish layers with ρ = 1000 and ρ = 10000 Ohmm.
6. The application of "super-small" antennas (less than 10-15 meters) for stratification of layers at small depths is possible only at low resistivity of rocks - ρ < 5-10 Ohmm.
7. At high levels of resistivity it is necessary to use antennas of the large sizes (for ρ> 1000 Ohmm **TR** > 100×100 m and more).
8. The most favorable range of specific resistivity for stratification of rock lays within the limits of 10 Ohmm < ρ < 300 Ohmm.
9. Optimum range of the sizes of transmitting-(receiving antennas for TEM-FAST 48 is **TR**=**REC**=18×18 - 100×100 m.
10. At a choice of the optimum size of antennas it is necessary to remember that large size antennas increase limiting depth of researches, however does not allow to stratify subsurface horizons. Estimations of a range of depths **h**, for which reliable interpretation of the received results is possible, at use of coincide antennas with the side **TR=REC=L** usually lay in limits: $\mathbf{h_{min}}$ > **L/10** and $\mathbf{h_{max}}$ < **3L**.

In real practice of TEM application two physical phenomena can essentially act at efficiency of geological interpretation of results of measurements. These both phenomena are connected with frequency dispersion of electromagnetic properties of rocks:

- *Superparamagnetic effect (**SPM** effect)*
- *Effect of induced polarization (**IP** effect)*

Depend on a task facing to the researcher, both effects can be considered and as "harmful" (noise), and as "useful", containing the additional information on researched structure.

SUPERPARAMAGNETIC EFFECT IN TEM

Superparamagnetic effect (SPM) was studied by many researchers (L.Neel 1949, T. Nagata 1965, V. Averyanov 1965, G. Buselli 1982, T. Lee 1984, P. Barsukov & E. Fainberg 1997, 2001 etc.).

In some publications SPM effect is called as effect of magnetic viscosity.

SPM effect in rocks is connected with processes of orientation/disorientation of the magnetic moments of very fine (Angstrom) particles of magnetic minerals in the initial moments of power on/power off of exciting magnetic field. The researches of SPM effects in various areas of the world with TEM-FAST system (1985-98 y.) have shown the following.

- Most intensive SPM effects exist in areas of effusive and volcanic-sedimentary rocks. Superficial clay formations covering parent rocks are most superparamagnetic.
- SPM effects take place in conditions of long-term permafrost and usually are located on border of zones of thawing frozen rocks.
- Significant SPM effects are observed on glaciers.
- SPM is created, as a rule, by particles ($r \sim 10^{-9}$-10^{-7}m) magnetite and maghemite.

In practice, EM (TEM) SPM effects is usually treated as frequency dispersion of a magnetic susceptibility of rocks (by analogy with frequency dispersion of conductivity or IP phenomena).

The transient characteristic (reaction to step-type power off a magnetic field) of magnetic susceptibility χ_{SPM} is convenient for using as relaxation model of SPM in TEM.

$$\chi_{SPM}(t)=\chi_{SPM}*K/t, \qquad (6.4)$$

where the factor **K** is $K=[\exp(-t/\tau_1) - \exp(-t/\tau_2)]/\ln(\tau_1/\tau_2)$ (6.5)

The time constants $\tau_1 >> \tau_2$ depend on many factors and usually (for TEM) can be taken equal τ_1=1 s and τ_2=1 μs.

Slow speed of the transient characteristic decay in time as $E(t) \sim 1/t$ is characteristic of SPM (for induction processes **E(t)** decreases not slower, than $\sim 1/t^{5/2}$).

For identification of SPM in the registered data, the function **tE(t)** is provided in the system interface. The late stages of transient containing SPM component, at multiplication to time represent function, almost not varied in time. In practice, because of different reasons, contrary to the Neel's theory, observable SPM processes decrease as $E \sim 1/t^{1+\delta}$, where $-0.2 < \delta < 0.2$. For coaxial round antennas **R** (TR) and **r** (REC), located above superparamagnetic half-space at height **h**, SPM transients are described by the formula:

$$E(t)/I=\mu_0\chi_{SPM}(t)\, F(R,r,h) \qquad (6.6)$$

The geometrical function **F** is

$$\mathbf{F(R,r,h) = 1/2\ \ (Rr)^{1/2}\ Q_{1/2}(x)} \qquad (6.7)$$

Here $\mathbf{Q_{1/2}(x)}$ is the Legendre function of **1/2** order with argument $\mathbf{x=(4h^2+r^2+R^2)/2rR}$.
In case of the coincident configuration at **R**=**r** and small parameters **h/R << 1** the geometrical function **F** is proportional to the antenna's perimeter.

$$\mathbf{F(R,R,h)=1/2\ R*ln\ (R/h)} \qquad (6.8)$$

and at **h** = 0 **F** is equal to the antenna's inductance **L**.
At **r < R** and **h** = 0 function **F(R,r,h)** is equal to mutual inductance **M** of antennas.

At reduction of the size **r** of the receiving antenna, the function **F** sharply decreases in interval **1> r/R > 0.9**, and further leaves on asymptote proportional to the area of the receiving antenna:

$$\mathbf{F(R,r,h) \sim r^2.}$$

The precise calculations of transients for horizontal layered conductive and superparamagnetic media have shown, that the interaction of induction currents in media and SPM effects can be neglected, i.e. it is possible to consider these effects as additive. For reduction of SPM effect influence at the results of TEM soundings it is possible to use three ways:

- to reduce mutual inductance of antennas **M**
- to increase the size of the coincident installation
- to uplift the coincident antenna above a surface of media

Variant 1.

Use of coaxial configuration "loop in loop" is most preferable, because distortion of induction processes does not occur and the received data can be easily interpreted by conventional methods. However, even in the most favorable conditions the ratio of SPM effects to induction can be improved only in 3.5-4 times, that can appear insufficient. At remote of a small receiving antenna off a contour of transmitting loop the effect of attenuation is more significant, however interpretation of the registered transient at small and average times is extremely complicated.

At last, it is possible to use as TR and REC loops two identical antennas shifted at some distance, ensuring practically zero stream coupling (mutual inductance of antennas **M**). This way provides 50-100 times suppression of SPM, however in real field conditions it is rather time-consuming.

Variant 2.

As it was shown earlier, the signal in the coincident configuration is proportional to the square of the loop's area ~$\mathbf{R^4}$, while the SPM effect at small depth of bedding of magnetic layers, is proportional to size of antenna ~**R.**
Thus, at increase of the antenna's size from 25 to 50 m, the ratio between "useful" induction and "harmful" SPM effects will increase as minimum at 8 times (~$\mathbf{R^3}$)!

Variant 3.

If SPM effect in a soil layer (in practice it is 80 % of cases) is not too intensive, using small coincident antennas with a size not more than 50×50 m is rather effective way both from the point of view of results, and from the point of view of minimization of work time. The rising of the antenna 25×25 m at 1-1.5 meters is easily realizable and allows

practically without distortions to reduce SPM effects at 3-4 times.

In fig.. 6-4 the transients in the coincident antennas received above terrigenous sedimentary rocks in conditions of permafrost (of Norilsk, Taimyr Peninsula, Russia) are given. At first sight the field data show presence of well conducting horizon with **ρ**<10 Ohmm at rather large depth (**h** ~ 200-300 m). However at change of the antenna's size the curves **ρ(t)** should coincide at the large times (see fig.6-3), that does not occur.
Just this fact speaks about distortions of processes SPM by effects.
Superparamagnetic effect is produced by a layer in a sole of frozen rocks at depth about 20-23 m.

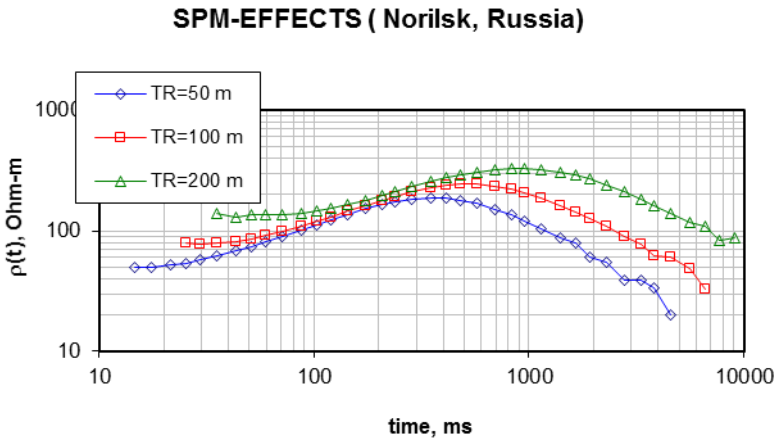


Fig. 6-4

In this case SPM effect was considered as a "useful" signal, as just its location in the geoelectrical section has helped to locate the horizon of thawing of rocks, which was not marked by any other method, except of geothermal researches in well.

The depth **h** of bedding of "SPM layer" was calculated using ratio of signals on times **t** = 2-6 ms for the different size of antenna (analysis of function **F (R,R,h)**).

As the induction processes in rocks with **ρ**> 1000 Ohmm are at some orders less than SPM, the errors of estimation **h** are determined only by heterogeneity of distribution of magnetic minerals in "SPM layer".

As it was already noted, TEM has restricted effect (or in general is inapplicable) at research of high resistive media or at use of very small antennas because the signals of TEM are proportional to square of the area of antennas and to conductivity $\sigma^{3/2}$. It does not give an opportunity, for example, to determine conductivity of samples of rocks. However SPM effect is proportional to inductance of the coincident antenna, i.e. for small multi-turn (**n** of turns) coil (or solenoid) with the core made from rocks, signal **E(t)** is proportional to ~ $\mathbf{n^2 \cdot R}$.

As the elementary demonstration of SPM measurements in laboratory the flat coil with **n** = 20-30 turns with diameter 5-7 cm, placed on a surface of usual "red" clay brick can be served. Fired clay has intensive superparamagnetic properties. Despite of very high resistivity of fired clay, after measurements with TEM-FAST on the PC screen it is possible to see a powerful signal **E(t)~1/t**.

In Figs. 6-5 and 6-6 the results of measurements of magnetic and superparamagnetic susceptibility of samples of superficial deposits (sample W ~ 50 g taken from depth 20-25 cm at the area 12 hectares) are given. The researches were carried out with the purpose of

search gold - silver ore in scarns (Khakasia, Russia) on a net 10×20 m×.

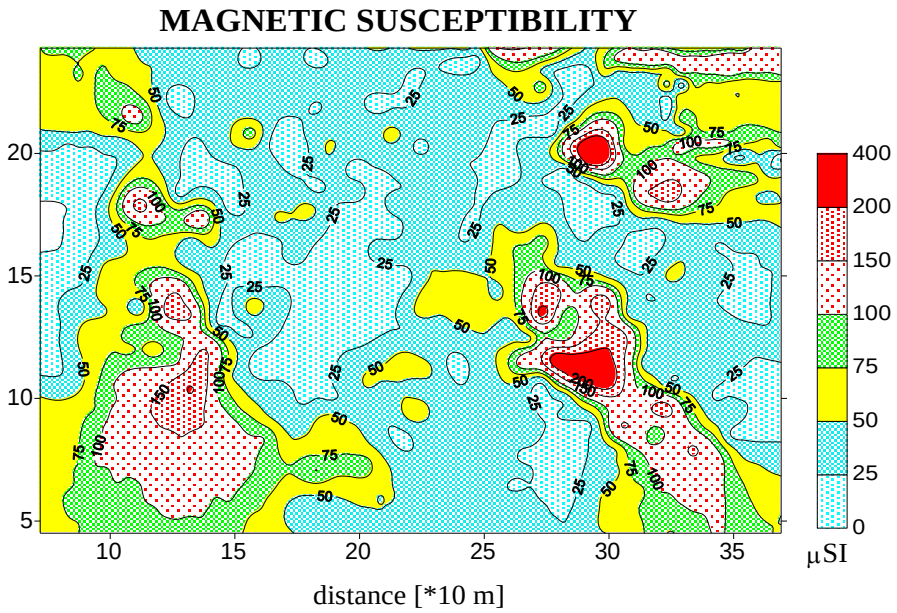


Fig. 6-5

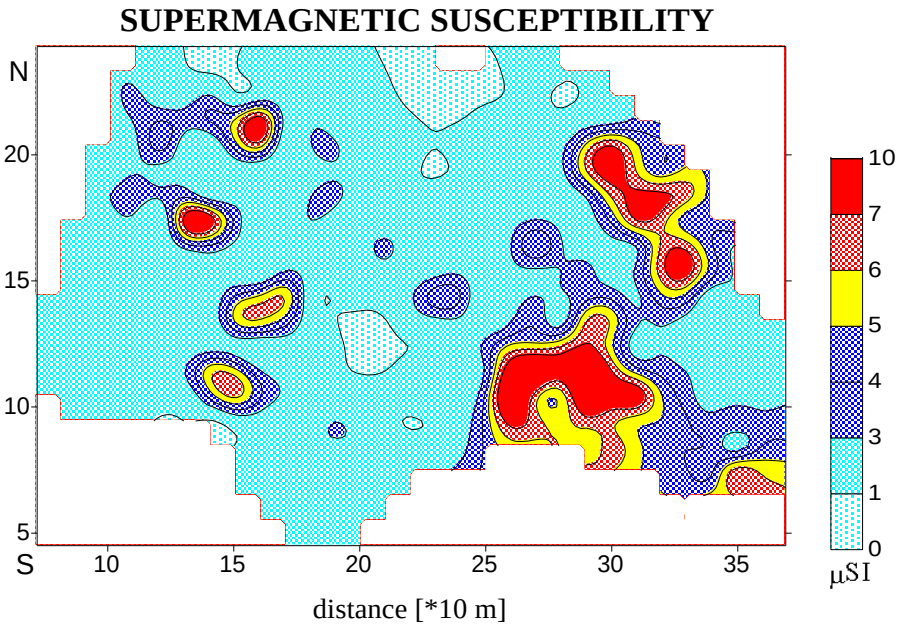


Fig. 6-6

The magnetic susceptibility was measured by viscometer, and SPM susceptibility by solenoid with L = 100 mm, d = 12 mm, number of turns n = 200. The dried up samples were filled in a cavity of the solenoid ~ 10 cm^3 and the measurements of SPM signals carried out with TEM-FAST.

The estimations of χ_{SPM} in terms of SI are made under the formula (6.4-6.5) (τ_1 = 1s, τ_2 = 1 μs) with accounting of inductance of the solenoid. Comparing the data submitted in figures, it is possible to notice in western part of the area four local χ_{SPM} anomalies. The subsequent drilling of boreholes has opened sub-meridian ore-bearing zone crossing all these anomalies.

The results of measurements of SPM effects on a structure through rich stream-gold are submitted in fig. 6-7. The deposit is located at depth about 40 meters and is blocked by terrigenous sedimentary layer of rocks.

For the analysis the samples of superficial clay (V ~ 1.5 liters) extracted from depth 20 cm and after drying were located in a cavity of the special high-sensitive SPM sensor manufactured as hollow tore. After measurements of SPM susceptibility χ_{SPM}, additional parameter δ which is small increment of measurements $\mathbf{E(t) \sim 1/t^{1+\delta}}$ was determined**.**

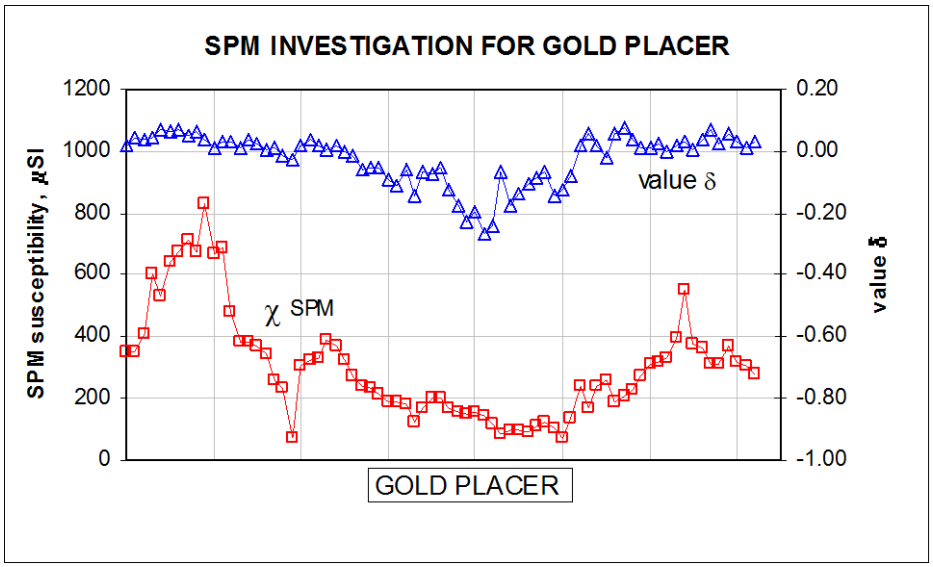


Fig. 6-7

The local minimum δ is precisely correlated with a contour of a deposit conditionally submitted in figure. The nature of the registered close spatial correlation of speed of decay of SPM processes with mineral deposits up to now did not accomplish. There are only hypothesis.

It is known that in fault zones the flows of gases and fluids ascending from a depth are observed. These agents, being leaked through mineral deposits, can grasp particles of substance of deposits (not necessarily basic "useful" component, which makes shares of percents, most likely accompanying minerals and elements). The superficial clay rocks (soil), having increased sorbing properties "clean" gases and fluids of impurity, accumulating them in themselves. Under influence of intensive deflation processes to which superficial layer of rocks constantly is exposed, occurs formation of the new aggregative forms of magnetic minerals with specific defects of crystal lattice filled with extrinsic atoms, invected from deep horizons. Namely these defective magnetic elements produce SPM processes different of theoretical.

THE CONCLUSION

1. When realization of field researches it is necessary to do analysis of registered data to control distortions originated by SPM effects and if it is necessary to change a configuration of antennas.

One has to remember three characteristic attributes of SPM distortions.

- *The late stages of process are proportional to* **E(t) ~ 1/t**
- *The resistivity* **ρ(t)** *sharply decreases up to "unreal low" value.*
- *The curves* **ρ(t)** *on late times for different size of antennas have parallel abruptly falling down branches.*

2. In a number of cases SPM effects carry useful information about researched media, which can be taken from the results of soundings with different configurations of antennas.
3. It is possible to measure SPM in samples of rocks in laboratory or directly in field conditions, using special portable sensors.

EFFECT OF INDUCED POLARIZATION ***(IP)***

Physical nature and the displays of IP in electromagnetic fields at geophysical researches are studied intensively by very many researchers during last 3-4 decades. The interest to this phenomenon is mainly defined by the following factors:

- by wide circulation of the phenomenon in various geological media;
- by essential influence on results of practically all EM researches;
- by positive experience of use of IP effect in classical researches of mineral deposits using quasi-direct current methods,
- by perspective of use of IP for study of petrophysical properties of rocks.

Meantime, it is necessary recognize, that at present essential results and "practical technologies" which use IP effects in induction EM researches are very poor. There are developed a few useful but individual techniques allowing reduce the influence of IP effects in some concrete EM methods and geological situations. IP is considered as "noise" factor and the recipes of "struggle" with it are developed.

Let's consider briefly influence of IP effects on TEM research.

Model of a cell of media

For the convenient mathematical description of IP processes or frequency dependence of electric conductivity of rocks $\sigma(\omega)$, $\omega=2\pi f$, majority of the authors use Cole-Cole model:

$$\sigma(\omega)=\sigma_0\{1+\nu*[(i\omega\tau)^c/(1+(i\omega\tau)^c]\}, \qquad (6.9)$$

where ν is the dispersion parameter $\nu=\sigma_\infty/\sigma_0 -1$ and σ_∞/σ_0, is the ratio of conductivity σ_∞ at *high* (infinite) frequency to conductivity σ_0 at *low* frequency, τ is constant time of IP process, **c** is so-called "logarithmic speed" or "parameter **c**". Sometimes *polarizability* $\eta=1-\sigma_0/\sigma_\infty$ is used in the formula (6.9) as dispersion parameter. When the value σ_∞/σ_0 is close to 1, $\eta\sim\nu$.

In (6.9) concepts of high and low frequency is not strictly determined. In practice of TEM σ_0 is conductivity on a constant current, and σ_∞ is conductivity at frequency **f**=50-100 kHz (which is real measured limiting research frequency for TEM-FAST).

The formula (6.9) mathematically describes frequency characteristic of "infinitesimal" cells of media and, generally speaking, does not contain any restrictions on parameters, included in it.

From physical point of view the question on restrictions is more complicated.

As (6.9) describes passive electrical system with the distributed parameters, however, having "zeroth volume", it is possible to assume that the system consists only of the distributed resistors **R** and capacitors **C**.

Why there is no inductance? It is because the inductance (own or mutual) is connected with volumetric magnetic interactions of fields, i.e. the function of volume, which considered cell has no by definition.

As formula (6.9) describes the characteristic of a passive RC-circuit, according to the classical theory of electrical circuits, impedance or admittance as the complex function of frequency $p=s+i\omega$, has poles and zeros only at $s < 0$.

What are the restrictions on function $\sigma(\omega)$ that arise in this connection?

1. Parameter **c** with: $0 < c \leq 1$
2. $\nu=\sigma_\infty/\sigma_0 >1$ and $|\sigma(\omega)|$ is monotonously growing function of frequency.

Practically all laboratory and field experiments confirm validity of these restrictions.

Homogeneous half-space with dispersive conductivity

.

Omitting for simplicity an ungainly formulas, we shall consider only asymptotic approximation for small frequencies range $\mu_0\omega\sigma R^2 \ll 1$ or late times $t_0=t/(\mu_0\sigma R^2) \gg 1$.

In this approximation for uni-turn round antennas **R** and **r**, laying on the homogeneous half-space with conductivity $\sigma(p)$, $p=s+i\omega$, the signals in the receiving antenna are described by the formula:

$$E(p)/I=-p\pi\mu_0 r^2/8R*\left[F_0 - p\tau_0 q + 8/15\,(p\tau_0)^{3/2} + \ldots\right] \qquad (6.10)$$

Here F_0 is normal field of antennas in vacuum (~ mutual inductance of antennas), $\tau_0=\mu_0\sigma(p)R^2$, a $q = 1-1/8*(r/R)^2 + \ldots$ - a geometrical function from **r/R**.
The reaction of media to step power off magnetic field approximately consists of two addends:

$$E(t)/I=E_0+E_{ip} \qquad (6.11)$$

where $E_0 = (\pi^{1/2}\mu_0^{5/2}/20)\,\sigma_0^{3/2}\,(r^2R^2)\,t^{-5/2}$ describes induction process in media with conductivity σ_0 at constant current, and second addend determines the process of polarization with constant time $\tau = \tau_{ip}$:

$$E_{ip} = q\pi\mu_0^2/8\,(r^2R)*[\sigma_t(t)/\tau], \qquad (6.12.1)$$

where $$\sigma_t(t)= F^{-1}[p\sigma(p)] \qquad (6.12.2)$$

is derivative on time from a Fourier-image of function $\sigma(p)$.
In particular:

at $c=1$ $\quad \sigma_t(t)= -(\nu/\tau)*\exp(-t/\tau)$

at $c=1/2$ $\quad \sigma_t(t)= -[1/(2\pi^{1/2})]*(\nu/\tau)\,(\tau/t)^{5/2}$

at $0<c<1$ $\quad \sigma_t(t)= [1/\Gamma(-c)]*(\nu/\tau)\,(\tau/t)^{(c+2)}$ where $\Gamma(-c)$ is Gamma-function.

Thus, it is possible to consider induction and polarizing signals additive in near zone of TEM at $t/(\mu_0\sigma R^2) \gg 1$. However, as show exact calculations for horizontal layered media, this conclusion is valid only when $t/(\mu_0\sigma R^2) > 20\text{-}30$; at earlier stages the close interaction of induction and polarization signals is observed and the additive summation is inconvenient.

Usually, for calculations of IP in TEM the rather simple way is used: Conductivity of layers in the formulas used for integration of the TEM processes, are replaced to frequency dependent according to (6.4) and then make Fourier and Hankel transformation. All calculations, displayed in this chapter, are made under the program TEM-IPS (AEMR ltd.) that has been developed for solution of direct and return problem in layered models with IP and SPM effects.

Conclusions

1. The polarizing effect $\mathbf{E_{ip}}$ is proportional to derivative on time from the transient characteristic of conductivity ~ $\mathbf{d/dt[\sigma(t)]}$, while for galvanic exciting current in media having step function form (**DC**), voltage on receiving electrodes is proportional to ~ $\boldsymbol{\rho(t)=1/\sigma(t)}$.

   Just for this reason the anomaly DC-IP can weakly correlate with IP TEM anomalies and time ranges of their manifestation are essential various.
2. At any values of **c** $0 < \mathbf{c} <= 1$ the signal **Eip** has a sign opposite to $\mathbf{E_0}$, and monotonously decreases in time.
3. Greatest speed of decrease at $\mathbf{c} = 1$ $\mathbf{Eip(t) \sim - \exp(-t/\tau),}$

   and at $1 > \mathbf{c} > 0$ $\mathbf{Eip(t) \sim - (\tau/t)^{(c+2)}}$
4. At some parameters of polarization, the measured signal $\mathbf{E(t)/I=E_0+Eip}$ can change the sign at least twice).
5. The polarizing signal is proportional to product $\mathbf{Eip \sim (r^2R)}$, while induction signal is proportional to $\mathbf{E_0 \sim (r^2R^2)}$.
6. At the fixed size of the transmitting antenna **R** the ratio of induction and polarizing signals $\mathbf{E_0/Eip}$ *decreases with reduction of the size of the receiving antenna* **r**:

   $$\mathbf{E_0/Eip \sim 1/q = 1/(1-1/8\cdot(r/R)^2 + ...)}$$
7. At TR = REC (**R = r**) the ratio $\mathbf{E_0/Eip}$ is *increased* proportionally to perimeter of the receiving-transmitting antenna ~ **R**.

The IP effects are frequently very difficulty diagnosed on the field data TEM. The exceptions are cases of very powerful emergence of polarization at low levels of induction processes, when the observable signals repeatedly invert a sign. There are cases, when all observable signal at TR=REC from 4 μs till 4-10 ms has a negative sign. Much more often the polarizing process deforms measured signal, however change of a sign does not occur. At interpretation in these cases the false poorly conducting horizons come to light.

Investigations with TEM-FAST have shown that most adverse for interpretation of geoelectrical situations, in which the IP effects take place, are as follows.

- Thin, well conducting horizon of superficial clay deposits with ρ < 20-40 Ohmm, bedding on enough resistive layer of rocks with ρ > 300-500 Ohmm. At polarization of this layer η = 1-3 % Ohmm, late stages of transient will be deformed by IP effects.
- Glaciers and permafrost rocks.
- The superficial deposits intensively polluted with industrial wastes, (including petroleum pollution).
- Crust erosion in crystal rocks and fault zones.

However sometimes IP effect is shown in the most unexpected situations and its nature remains indefinite. The example is given in fig. 6-8.

Array TEM research were carried out in a famous triangle Sphinx - Cheops pyramid - Chephren pyramid (Giza, Egypt) with the coincident antennas 50×50 m.

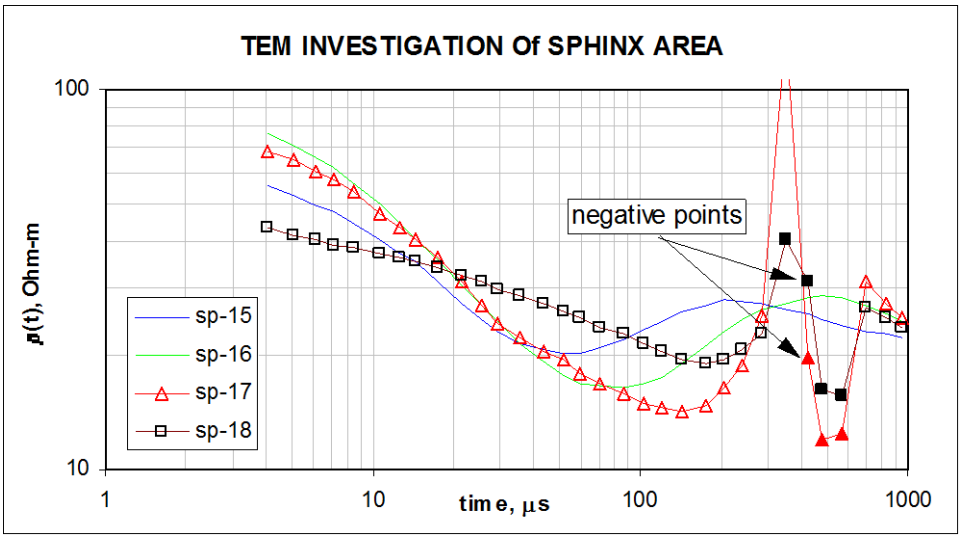


Fig. 6-8

In fig. 6-8 the results of soundings in four points of a structure are shown. Precisely it is visible, as the small local maximum of resistivity on times 200-600 µs in SP-15 and SP-16 at the further displacement of antennas to SP-17/18 are transformed to negative minimum of a signal.

Formally SP-15 and SP-16 curves suppose inversion within the class 4-layered of model with horizon ρ = 300-500 Ohmm and thickness **h** = 60-80 m at the depth about 60 m. However it does not prove to be true by result of soundings with the antenna 100×100 m. The registered maximum of apparent resistivity in SP-15/16 is not that other, as display IP effect, which further by amplifying, inverted a sign of observable transients (SP-17/18).

The analysis of numerous field experiments, in which the polarizing effect was observed, and mathematical modeling have shown, that:

1. the distortions in TEM bring in as a rule well conducting superficial horizons of rocks with ρ < 20-40 Ohmm by depth of bedding not more than 1-2 m with rather insignificant "background" polarizability η ~ 1-3 %;
2. the polarizing effects from rocks with ρ > 100 Ohmm are shown only at significant polarizability η > 10 %;
3. constants of time τ_{ip} lay in a very wide range 1-1000 µs;
4. for superficial IP effect, usually **c~1** ($\mathbf{E_{ip}(t) \sim \exp(-t/\tau)}$) and distortions are observed in a narrow range of times (see fig. 6-5), "deep" IP effect is characterized by **c** ~ 1/3-1/2 and deforms all late stages of a signal;
5. at presence of IP in superficial and deep horizons of section, two negative minimums on early and late times are observed simultaneously.

Example as IP affects the results of modeling of TEM signals above a two-layer section for the coincident antennas 25×25 m is given in fig. 6-9. Polarizability η_1 =2.5 % is "located" at first in a well conducting superficial layer, and then in deep poorly conducting layer with η_2=7.5%. For comparison in the figure the curves without IP effect η_{12} = 0% are given. In spite of the fact that thickness of superficial horizon is only 5 m with rather small polarizability, the observable distortions are significant: the late stages of process have a negative sign. At the same time, for polarizability of underlaid half-space 3 times larger than in previous case, the observable

distortions are hardly appreciable.

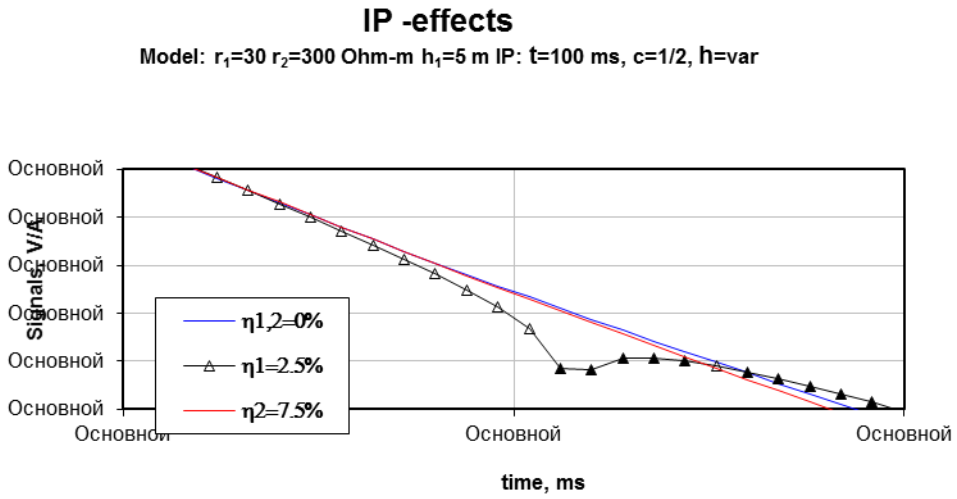


Fig. 6-9

In fig. 6-10 the example of *"double IP effect"* caused by presence of polarizability in superficial well conducting clay and lower bedding layer of crust deflation of granitoids is given. The results have been received at researches of a granite massif (Yenisei ridge, Russia).

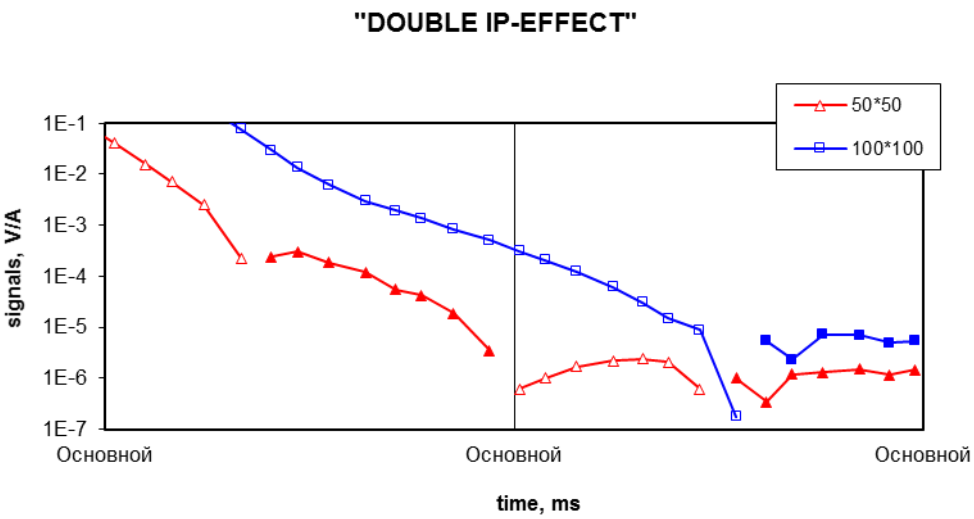


Fig. 6-10

To determine the depth of bedding of productive IP effect horizons it was possible only comparison of the results of soundings with various sizes of coincident antennas. The superficial effect has disappeared at increase of the size of antenna till 100 m, while "deep" has increased proportional to ~ $\mathbf{R}^3$ (induction process ~ $\mathbf{R}^4$).

THE CONCLUSION

1. When carrying out of field researches it is necessary to control the registered data for distortions by IP effects.

Characteristic attributes of IP distortions:

- *the monotony of recession* **E(t)** *is broken: on local sites of a curve the increase of a signal is observed:* $\mathbf{E(t_2) > E(t_1)}$ *when* $\mathbf{t_2 > t_1}$;
- *the signal* **E(t)** *changes polarity* **E(t)** < 0*;*
- *apparent resistivity* **ρ(t)** *for different on the size of antennas have essentially different form;*
- *the curves* **ρ(t)** *and* **E(t)** *sharply change at rise of antennas above a ground surface.*

2. IP effect is minimal in the coincident antennas.
3. The reduction of influence IP effects can be achieved by increase of the size of antennas: the ratio of induction and polarizing signals is proportional to the size of the coincident antenna ~ R.
4. Superficial IP effect is weakened at rise of antennas above ground.

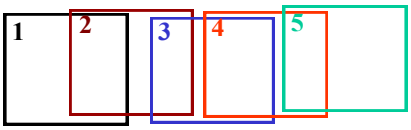
RESEARCHES IN URBAN CONDITIONS

TEM technology is part of modern complex used for solution of engineering and geological tasks connected to a problem of construction of buildings and structures, and for researches of media pollution. These researches as a rule are carried out in urban conditions.

There are four basic factors decreasing the efficiency TEM technology in these conditions:

- limitation of the area for putting of antennas;
- search of underground and ground metal objects;
- presence of electrical and telephone lines;
- powerful industrial noise.

First problem is solved by change of strategy of setting out of antennas.
The antennas 25×25 - 35×35 m are placed with overlapping 1/2-1/3 areas, depend on a concrete situation:



Besides it is necessary to use antennas of the different sizes for an estimation of various errors. The increase of "density" of sounding is necessary for correct inversion of the data complicated by "industrial noise ".

Second problem is connected with metal objects (pipe, rails, ferro-concrete plates, metal etc.) which can be located close to antenna inside or outside it. Having conductivity at 8-10 orders more than conductivity of rocks and magnetic permeability μ ~ 30-80 these objects create powerful noises processes, which deform geological signals.

In fig. 6-11 the results of special researches of influence of extended steel pipes at TEM processes are submitted. The piece of a steel pipe of length ~ 35 m and diameter ~ 15 cm settled down at various distances from the coincident antenna 25×25 m (l = 0.2, 1, 2 and 5 m) parallel to its side. The location of the antenna on a surface of ground

remained permanent.

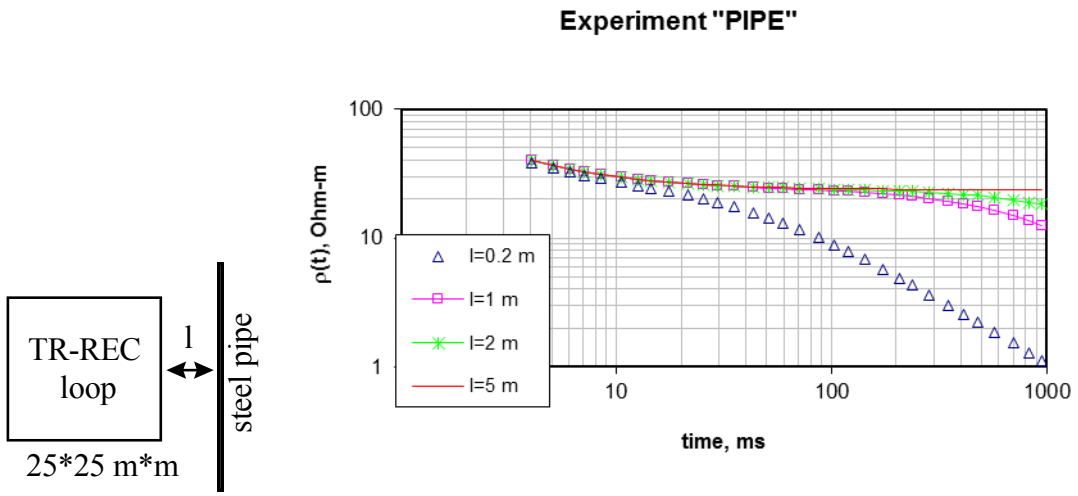


Fig. 6-11

At small distance the influence of pipe is so great, that the observable process does not contain the "geological" information. The measured process contains intensive superparamagnetic effect. However removing of pipe out of the antenna's contour at 1-2 meters essentially facilitates the situation: the processes in a range of times 4-200 μs practically are not deformed.

Thus, suppression of noise from metal objects is possible by two ways:

- by space disposal of antennas not less than 1-2 m from objects;
- by the greatest possible rise of antennas above a surface of object.

The combination of these receptions is usually used:

- 2 m poles are used for uplifting of antennas;
- the antennas are shifted far from known metal objects.

The real conditions sometimes do not allow to use square antennas. Use of rectangular antennas L1×L2 1> L1/L2 > 1/2 in this case is allowed, in the system interface it is necessary to establish TR = REC = $(L1 \times L2)^{1/2}$. Sometimes form of antennas happens rather curlicue - it is important to set correctly its equivalent (by the area) sizes.

Third problem is connected with arising of oscillatory (resonant) processes in electrical lines under influence of a broadband radio wave arising at the moment of power off a current in TEM-FAST antenna. The most intensive oscillatory processes arise in the poorly loaded long lines located at 3-10 meters from the radiating antenna. The period of resonant fluctuations is proportional to length of a line and, when it makes more than 0.1-0.5 μs, on the screen PC it is possible to see a picture submitted in fig. 6-12.

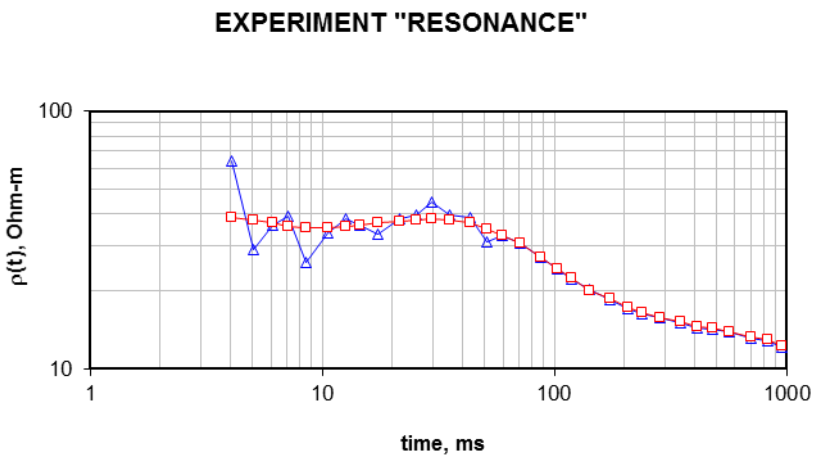


Fig. 6-12

The broken curve is received at location of the antenna directly above underground electrical line, length about 1 km, and smooth curve for antenna located 5-7 meters aside. The characteristic sign of "resonance" is the good repeatability of breaks at curves **ρ(t)** or **E(t)** when repeated control measurements. Usually fluctuations take place only at early times, because at the late times the **DAS** system of TEM-FAST effectively suppresses high frequency signals.

In case of resonance it is recommended to change base frequency of current pulses (by changing parameter **Time range** or switching the filter 50/60 Hz) and to try measure only early stages of process, and then to increase **Time range** and to measure the rest of a signal. In 75 % of cases such receptions permit to suppress resonance. Compiling of the received results is possible at a stage of processing and interpretation of the data.

At last, it is possible to sacrifice early stages of a signal and connect the resistor **r**~200-300 Ohmm in parallel to transmitting antenna and to reduce frequency band of signal.

Fourth problem. The electromagnetic noise created by power lines can achieve the values of ~ 50-200 μV/m^2. In the antenna 100×100 m the amplitude of noise (f ~ 50/60 Hz) achieves 1-2 V. In these conditions filters of the device effectively suppress the noise only up to levels in hundreds of μV. Below these level the suppression is inefficient.

In fig. 6-13 the results of measurements of transients with the coincident antenna 100×100 m executed at 100 m from a powerful electrical line in Moscow are given. The level of the noise in antenna had the value 1.3 V. The level of a signal at t = 500 μs was equal 700 μV. The indexes of **ρ(t)** curves correspond to value of the internal TEM-FAST filter.

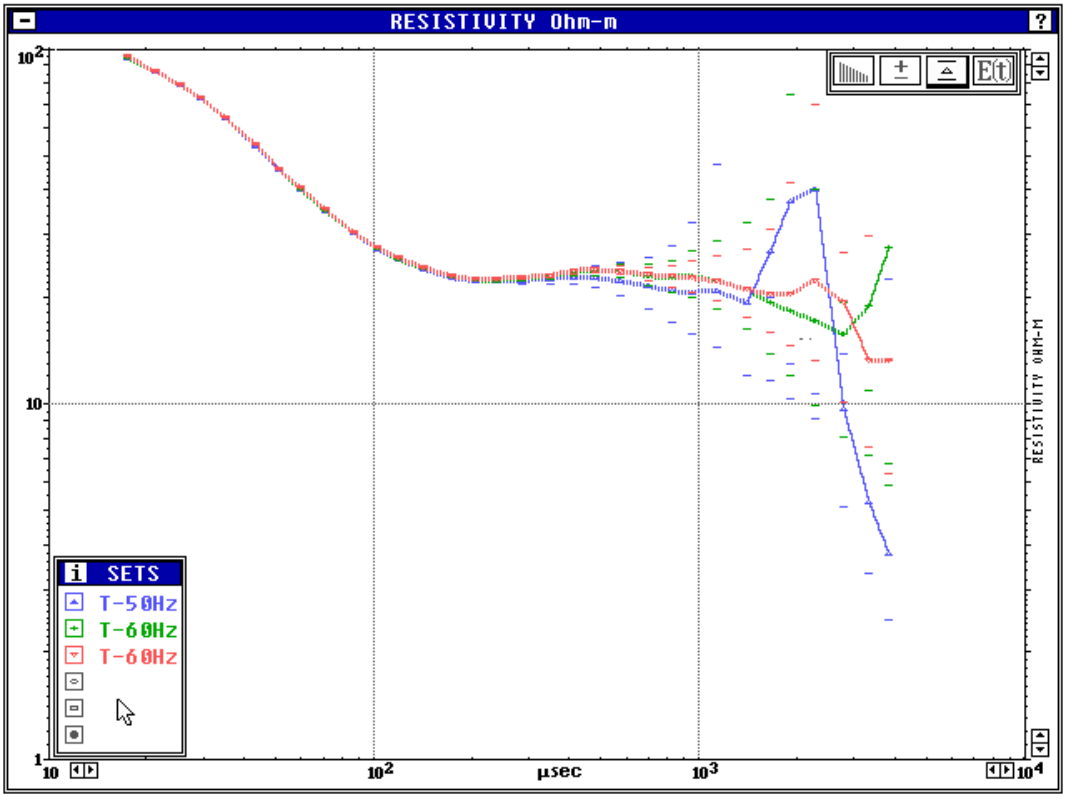


Fig. 6-13

As one can see, the essential differences in curves are observed at t > 500 µs at a level of a signal less than 700 µV. The signals are "scatter" because of insufficient suppression of the basic harmonic 50Hz and presence in noise of the signal with frequencies non-multiple to 50 Hz. *It is strange*, but the curves "T-60 Hz", look more robust in comparison with "T-50 Hz". However this is incorrect impression. The analysis of the data in the window "**Noise**" shows that both curves "T-60 Hz" contain so-called *aliasing* - a low-frequency noise caused by discrepancy of frequency of noise and the internal filter of TEM-FAST. Aliasing noise is rather steady, **however it always false**. It is necessary to pay attention to the fact, that increasig of stacking of a signal does not result in improvement of data: the curves with indexes "T-60 Hz" are measured with **Stack**=20 and 8, however, both they are **identical false** at t >0.5-1 ms.

Being based on our experience of field works, we recommend in conditions of intensive noise *multiple (5-6 times) repeat measurements with Stack = 4-6, <u>by adjusting the device at frequency of your power circuit</u>, in attempt to find out close under the form and level signals. If this procedure does not result in success, it is necessary to reduce parameter* **time range** *(in the given example till* **time range** *= 6 i.e. till to t = 2048 µs) and to be satisfied by achieved.*

As a rule, in conditions of intensive noise the depth of TEM researches don't exceed 1-1.5 sizes of the antenna for 25-100 meter loops. The increase of the antenna's size more than 100 m, as a rule, is inexpedient.

The results of inversion of the data "T-50 Hz" as **ρ(h)** for t < 1ms are given in fig. 6-14. The broken curve is the result of inversion, smooth curve is transformation **E(t)** -> **ρ(h)**.

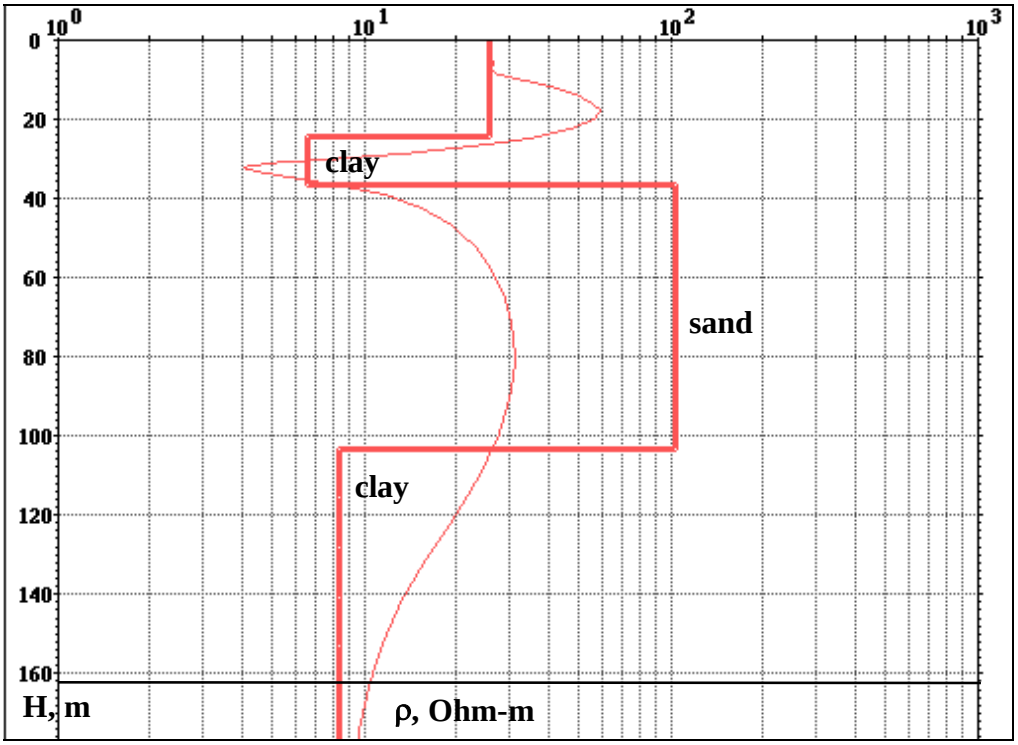


Fig. 6-14

It is not possible to receive the information on deeper horizons (h > 160 m) because of noise in initial data at t > 1 ms. According to geological data at depth 200-210 m there is a roof of limestone with resistivity ρ > 100 Ohmm. For localization of this horizon, it is necessary to have a signal at time **t** > 8 ms.

In conclusion it is necessary to note, that TEM (or EM) researches in urban conditions are rather time-consuming both when realization of field researches, and at a stage of interpretation of the data. They require high qualification of the operator and interpreter. This is why it is not necessary to expect for ideal "demonstration" materials of researches - they will be considerably worse, than in natural conditions. Nevertheless, our 15-year's experience shows, that the received results quite satisfy the geologists and engineers ordering these researches. As a rule, alternatives to TEM researches in these conditions are not present, and the other geophysical methods are much more expensive.

MONITORING

The automatic mode of operations under the program given in the system interface is stipulated in TEM-FAST. The mode "monitoring" is used for study of electro-conductivity variations or polarizing phenomena in local zones of mountain massifs. What for is it necessary? The basic objective of such measurements is determining or prediction of natural or industrial processes representing danger, using time variations of electrical properties of rocks. The objects of researches can be various tanks to storage gas, petroleum or industrial waists, clearing structures, oil-extracting chinks, dump, dam and etc. Among natural objects it is possible to allocate karst and slide zones, active geological breaks, territory of volcanic activity.

Despite rather wide spectrum of potential objects of monitoring, there is one common feature - change of electrical properties of rocks caused by change of a hydrogeological regime under action of those or other factors. Just the change of concentration and

structure of fluids in pores of rocks results in change of electrical properties, which can be fixed by TEM-FAST.

For maintenance of work in a "monitoring" mode the tool is connected through the socket **Extern power** with cables "Power 12V" or "Power 24V".

Attention! The cable "Power 24V" is intended for meal only of transmitter, thus a meal of receiver is provided with the internal standard battery (2000 mAh at consumption in a working mode 70-80 mA).

For example, if the researches within 100 day period are planned with frequency one measurement/one hour (Stack = 10, Twork ~ 3 minutes at I = 1A, mean power current at the moment of TEM-FAST measurement Iwork is ~ 350 mA), one has to connect the external battery 12V 60 Ah. PC should be connected to **AC** power through the universal power supply - **UPS**. After that any monitor service of measurements is not required.
In fig. 6-15 the fragment of variations of conductivity of rock massif in the interval of depths up to 250 m is submitted.

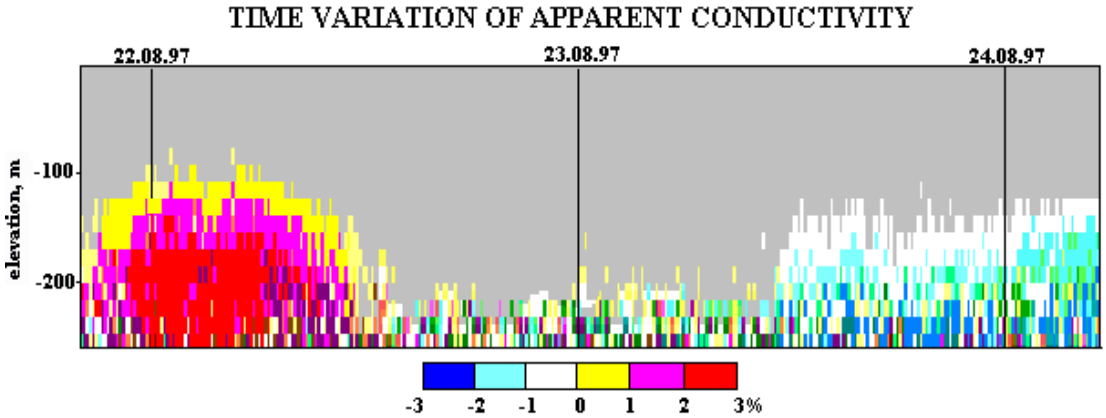


Fig. 6-15

The measurements were carried out near borehole for pumping of the highly concentrated salty solutions in penetrable layers of syncline structure - "trap". The depth of bedding of a roof and bottom of the most powerful penetrable layer is 150 and 190 m. For monitoring the coincident antenna 150×150 m has been used. Period of measurements was 5 minutes. So high frequency of measurements were necessary for suppression of intensive noise field caused by work of plants. The measured data were averaged by a sliding window **ΔT**=1 hour.

The submitted variations **$\Delta\sigma(h,T)$** were constructed using transformations **$E(t) \rightarrow \sigma(h)$**. Variations **$\Delta\sigma(h,T)=100*[\sigma(h,T)-\sigma_0(h)]/\sigma_0(h)$** for each moment of time **T** and each depth of researches - **h, $\sigma_0(h)$** is average value of conductivity for 3 day. The next portion of solutions pumped in period from August 21, $19^{\underline{00}}$ till August 23, $8^{\underline{00}}$. Practically at once after beginning of pumping, the conductivity in the bottom layers begins to grow, however after approximately 12 hours the growth stopped. On our hypothesis, the solutions pumped under pressure leak through waterproof horizons and leave on fault zone for limits of natural syncline "trap".

This conclusion is extremely important, because the break of solutions through a fault can catastrophically affect ecological safety of ground waters in vicinities of investigated special polygon. It is of interest to note that after termination of pumping there is slow restoration of conductivity during several days.

REFERENCES

1. Neel L. C.R. Acad. Scien. Paris. No 228, 1949, p. 664-684,
Ann. Geophysique. V.5, No 99, 1949, p. 1004-1023
2. T. Nagata. Rock Magnetism. M., the World, 1965
3. V.S. Averyanov. Izvestia AN SSSR. Physics of the Earth 1965, p. 82-89
4. Buselli G. Geophysics, V. 47, 1982, p.1315-1385
5. Lee T. Geophys. Prosp. V. 32, 1984, p. 480-496
6. Kaufman A. The theory of induction logging, 1965, Novosibirsk, NAUKA, 64-70
7. Kamenetsky F. Electromagnetic Geophysical research by the method of transient processes. Moscow, GEOS, 1997, 162 p.
8. Vanyan L. The principles of electromagnetic sounding. 1965, Moscow, NEDRA, 108 p
9. Strack K. Exploration with deep transient electromagnetics. Elsevier, Amsterdam. 373 p.
10. Nabigian M.N. Electromagnetic methods in applied geophysics. V. 1. Theory. SEG Academy series, Tulsa, USA, 528 p.
11. Barsukov P. and Fainberg E. Doklady RAN. Geophysics V. 353, No 6, 1997, p. 811-814
12. Barsukov P. and Fainberg E. European Journal of Enviromental and Engeneering Geophysics, No 6, 2001, p. 61-72
13. General information, additional references, publications and examples for applications of TEM-FAST 48 system - **www.aemr.net**