Magnetic field monitoring – instrumentation and methodology

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MAGNETOMETERS APPLICATIONS

Ground geophysics:

- prospecting of raw materials;
- study of the Earth's interior from surface to ~ 1000 km;
- science, medicine, biology, industry;
- military applications, detection and orientation.

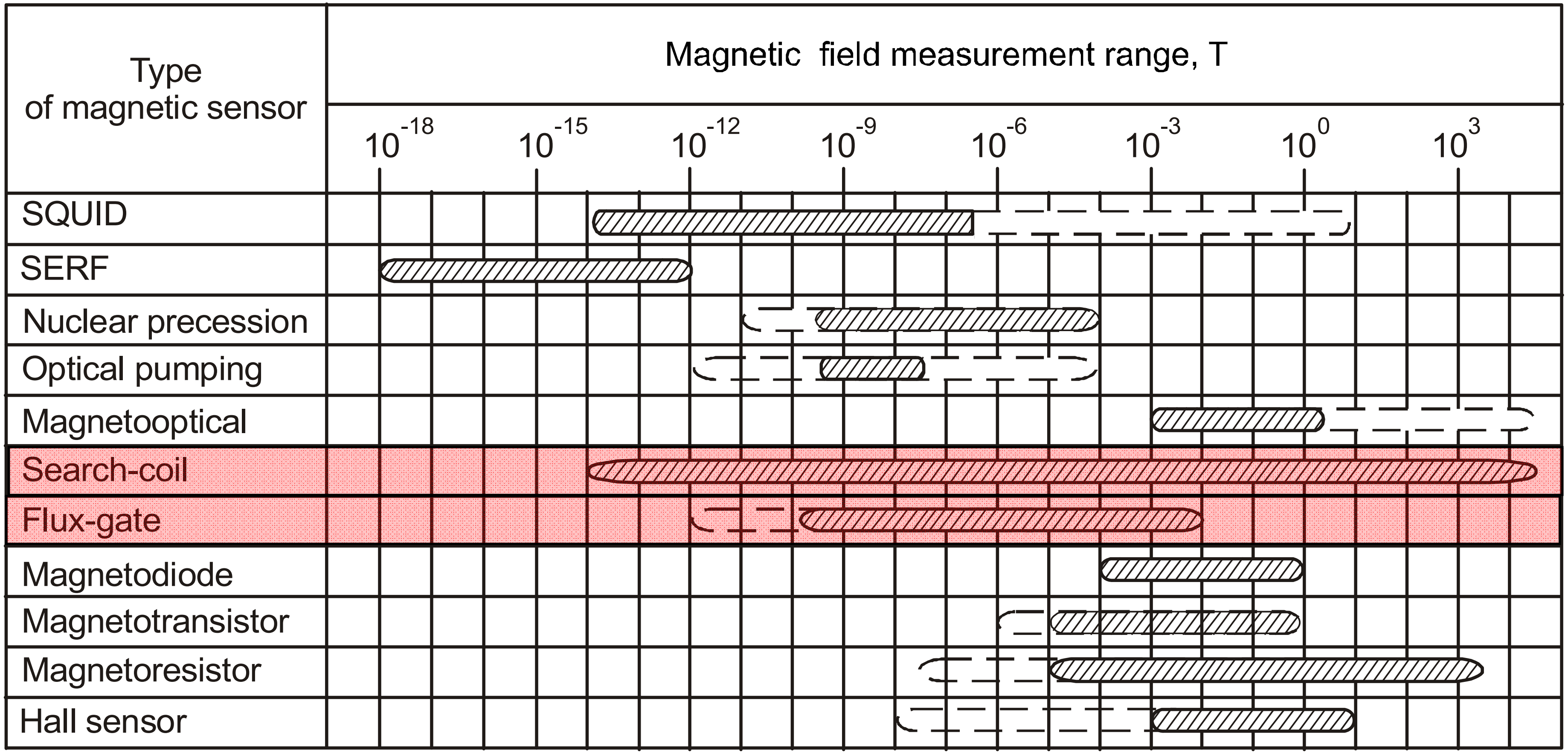
Space geophysics:

- study of different borders in space plasma (bow shock, magnetopause, boundary layers, lobes etc.
- study of waves, storms and current systems in space;
- Space Weather forecast

SELECTION CRITERION

- Minimal sensitivity threshold.
- Dynamic range not less than 120 dB.
- Wide frequency band (DC to ~ 1 MHz).
- Low time and temperature zero drift.
- Possibility to measure magnetic field vector components.
- As low as possible power consumption.
- Ease of use in field conditions.

TYPES OF MAGNETIC SENSORS



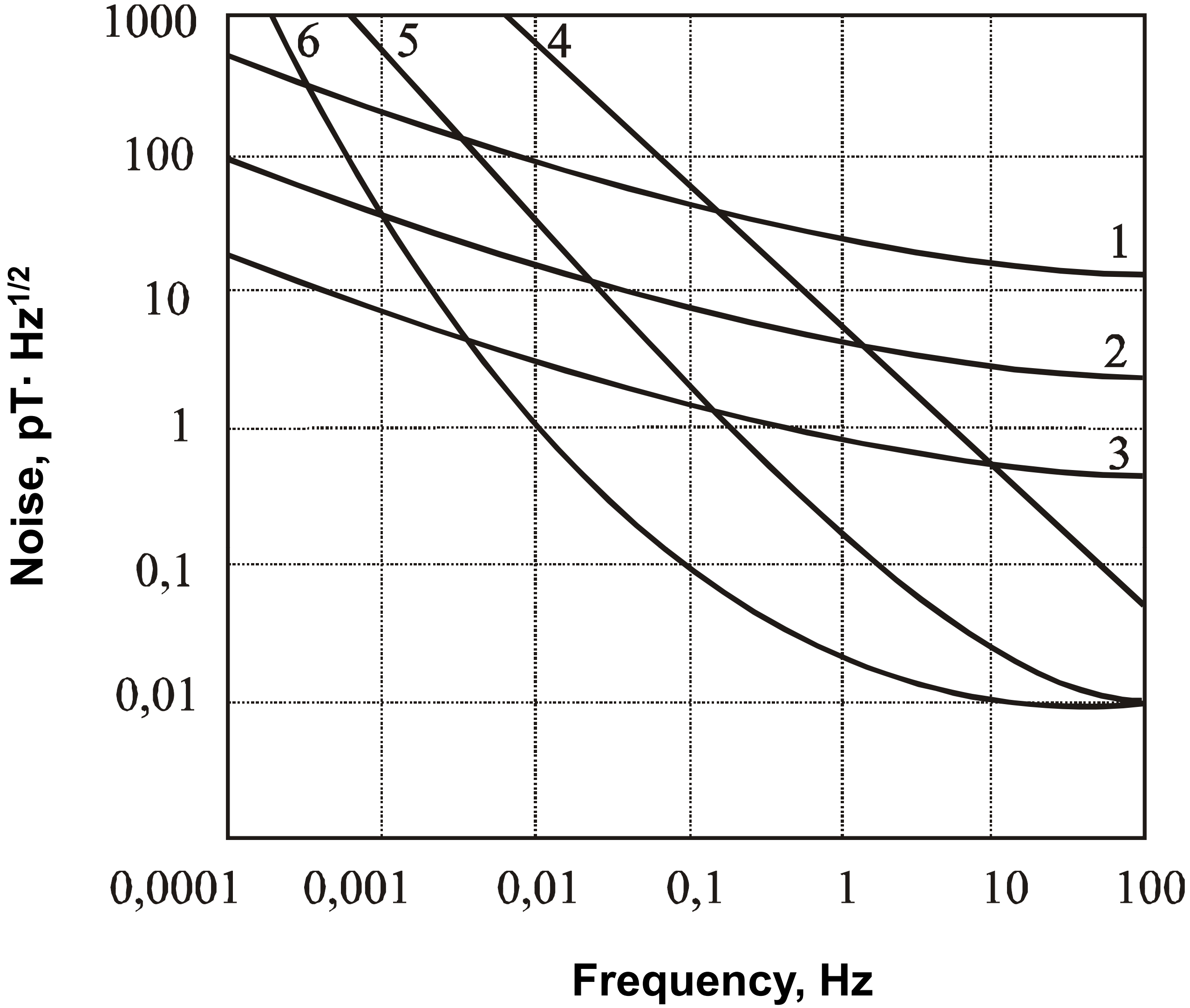
MAGNETOMETER TYPE SELECTION

- **For the measurement of magnetic field variation vector components– induction magnetometers**

  (frequency band - ~ 10^{-4} – 10^{6} Hz)
- **For the measurement of quasy-stationary magnetic field vector components and their slow variations - flux-gate magnetometers**

  (DC - ~ 1000 Hz)

Noise levels of flux-gate (1,2,3) and induction (4,5,6) magnetometers

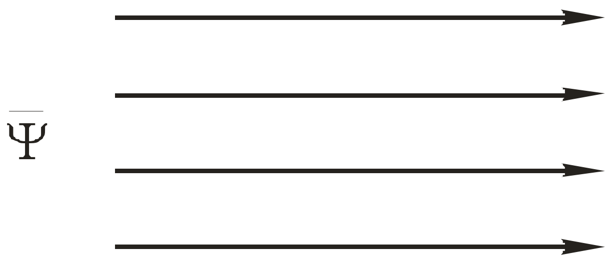


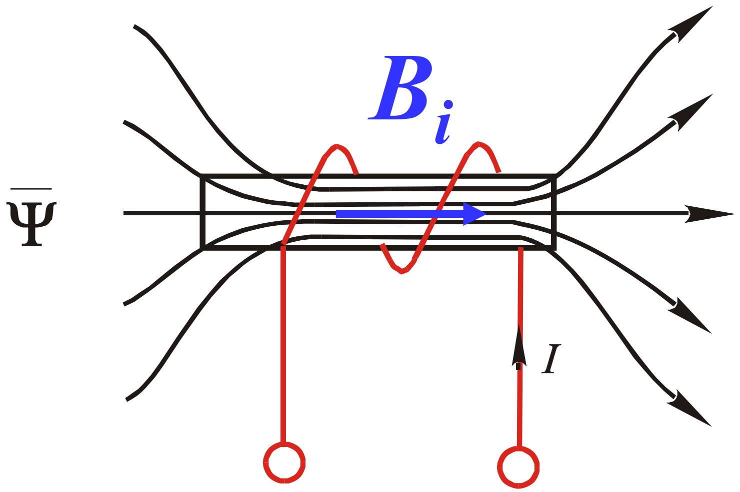
Induction magnetometer operation principal

$$e = -\frac{\partial\psi}{\partial t};\psi = wB_i s$$

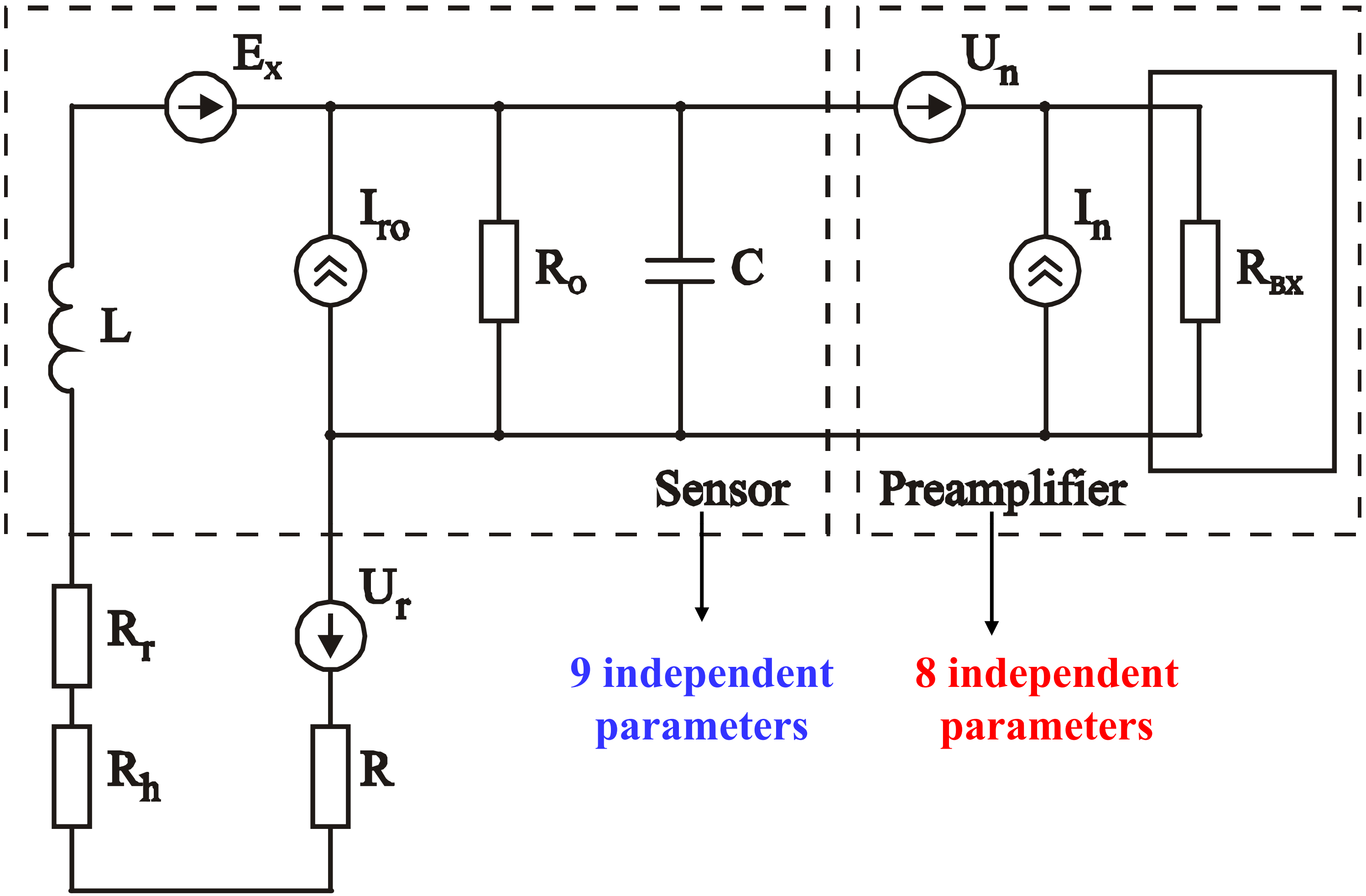
$$B_i = \mu_s B_e$$

$$\mu_s = \frac{l^2}{5s};$$





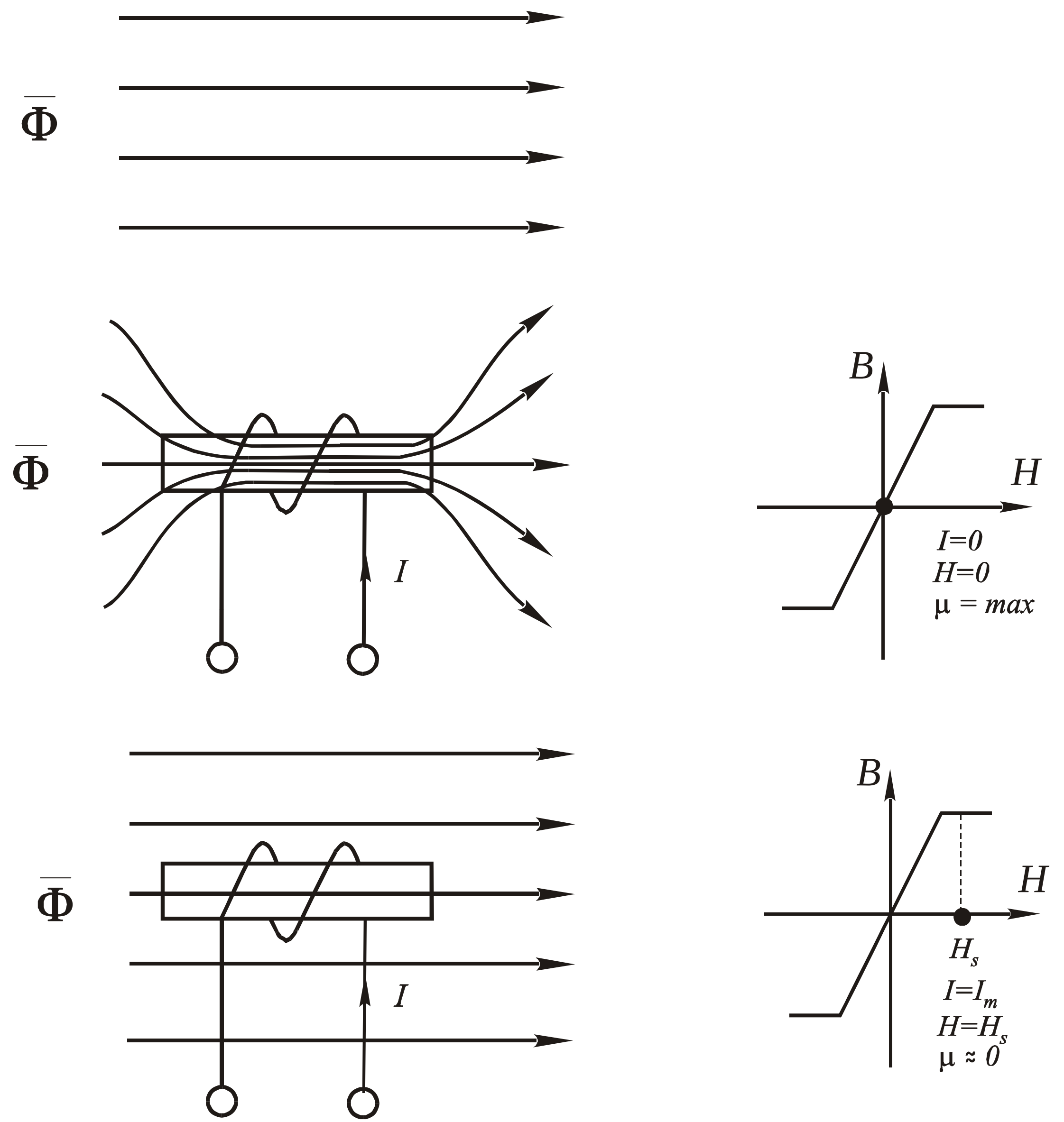
Equivalent circuit
Sensor-Preamplifier



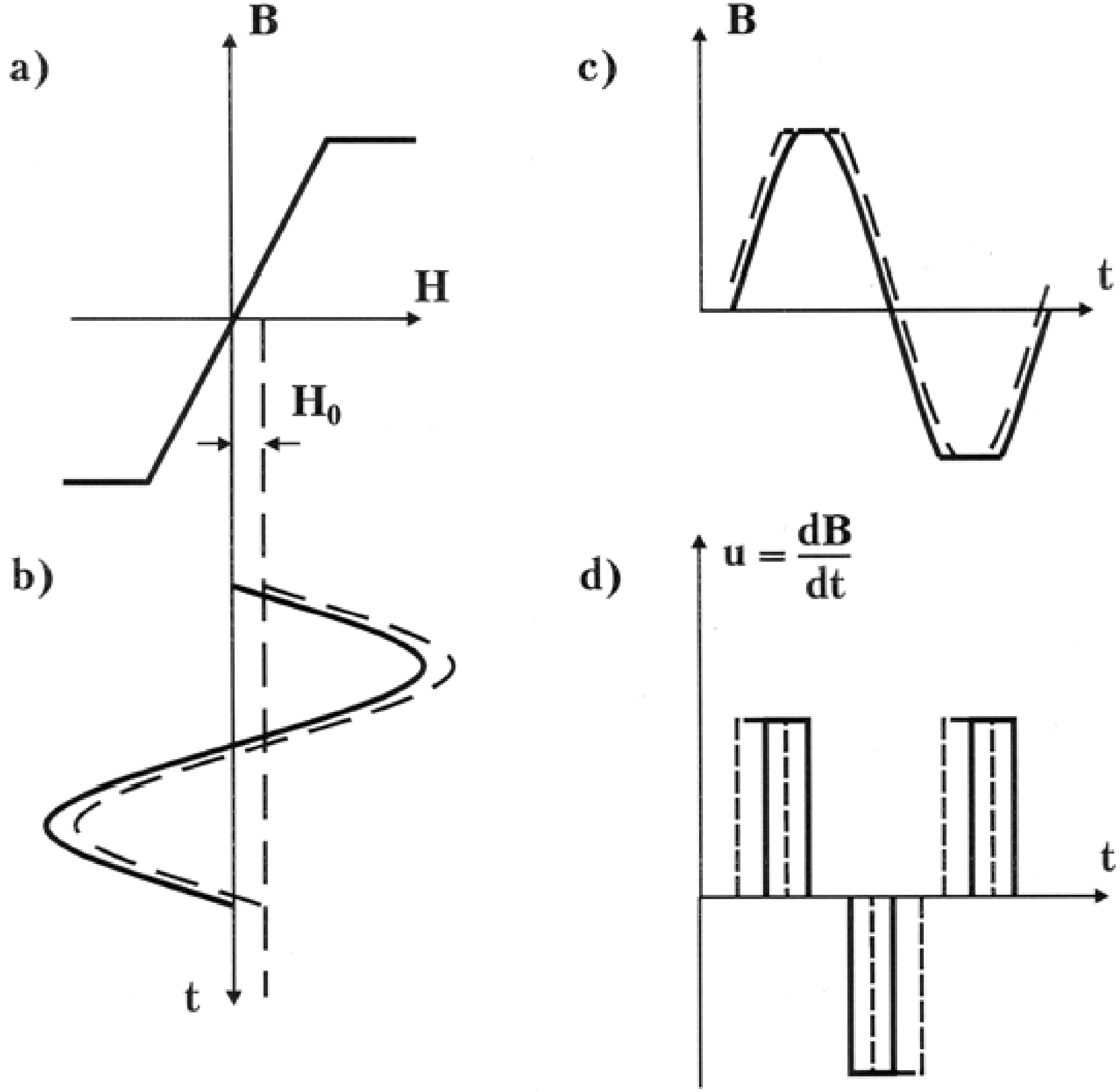
Generalized parameters of induction magnetometers

Parameter	Dimensions	Physical sense and tentative estimation
K_S	$V/(T \cdot Hz \cdot m^2 \cdot turn)$	Open-circuit sensitivity of SCS with 1 m length and one turn winding at 1 Hz; $1 \pm 20\ \%$
K_L	$H/(m \cdot turn^2)$	Inductance of the same SCS; $2 \cdot 10^{-7} \pm 25\ \%$
K_f	$Hz/(m^{1/2} \cdot turn)$	Own resonance frequency of SCS; $4 \cdot 10^7 \pm 25\ \%$
K_R	$Hz \cdot m^2$	Frequency, for which inductive and active resistances are equal for the same SCS; 0.5 … 3.5
f_F	Hz	Frequency, for Q- Foukeau = 1; $(5…500) \cdot 10^3$
Q_h	-	Q–factor by hysteresis losses in the core; $50 \div 200$
Q_0	-	Q–factor at the f–parasitic capacitances; $3 \div 10$

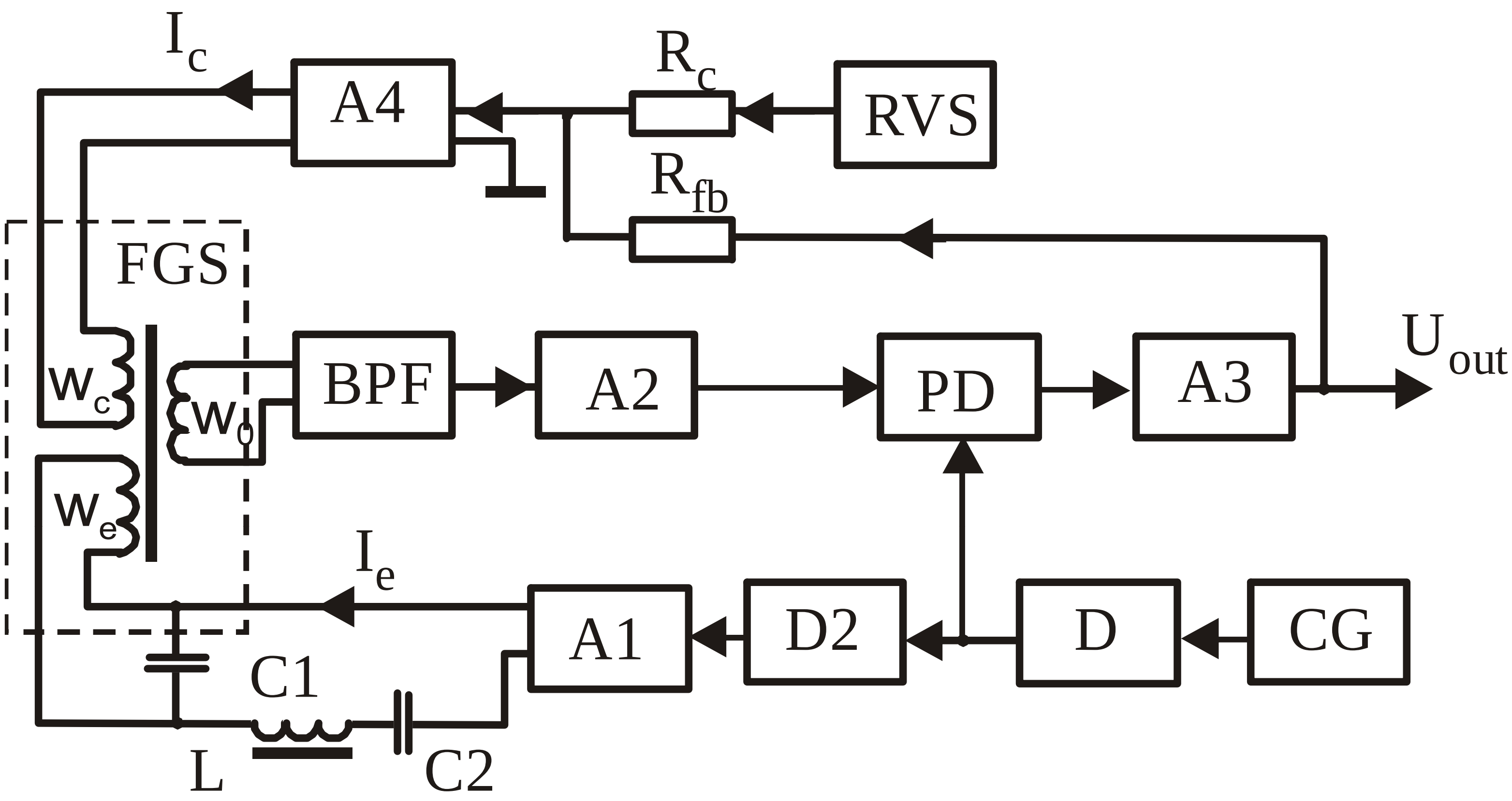
Flux-gate magnetometer operation principal



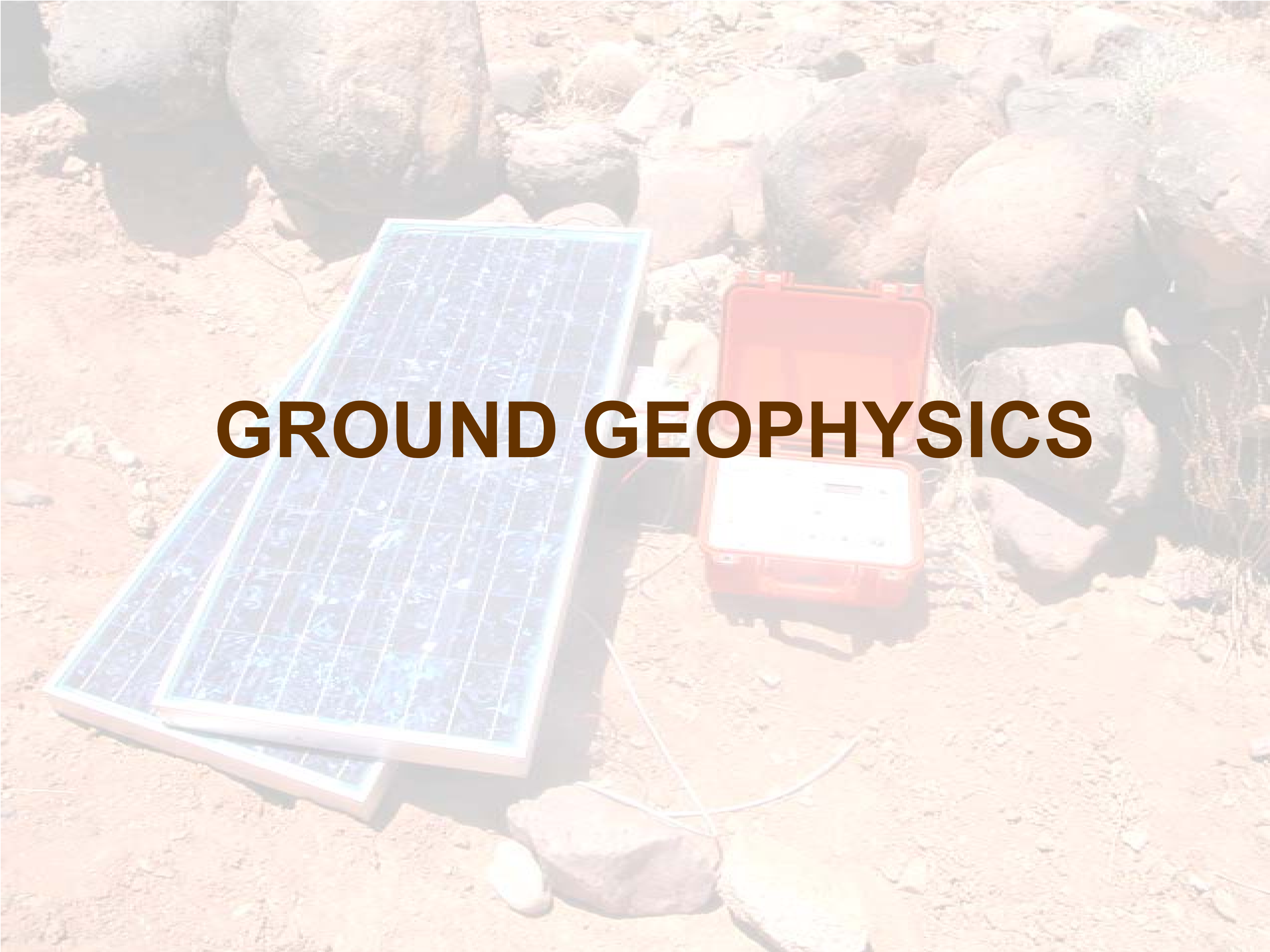
Flux-gate magnetometer operation principal



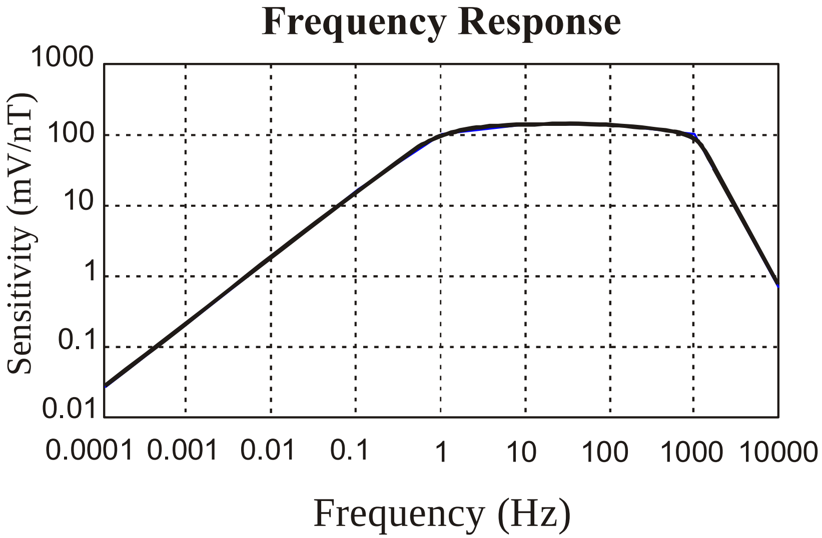
FGM principal diagram

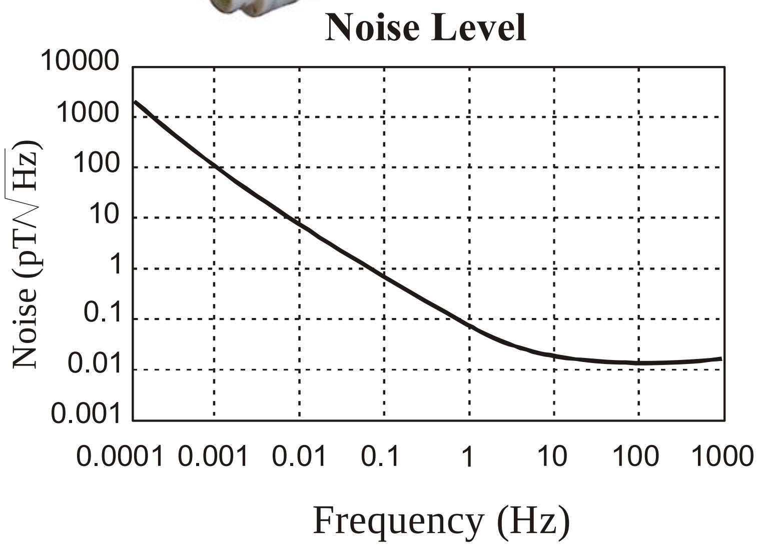


GROUND GEOPHYSICS



Induction magnetometer for geophysical research LEMI-120

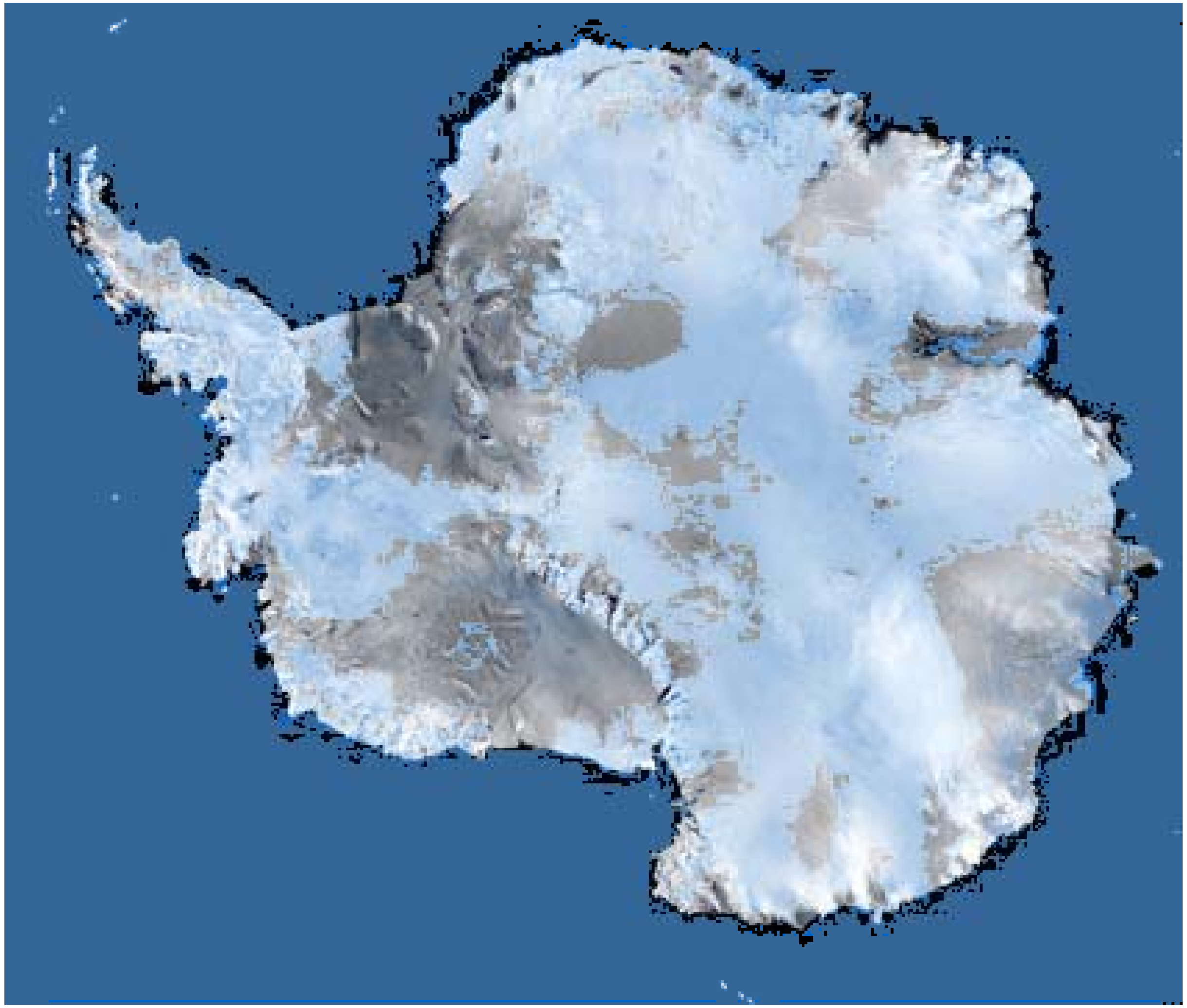




Frequency range	**0.0001 – 1000 Hz**
Transformation factor:	
at frequencies 0.0001 – 1 Hz	**200 mV/nT f***
1 – 1000 Hz	**200 mV/nT**
Power consumption	**< 330 mW**
Weight	**< 6.8 kg**
Dimensions	**diameter 85 mm length 1340 mm**

INDUCTION MAGNETOMETER
LEMI-30

LOCATION OF UKRAINIAN ANTARCTIC STATION

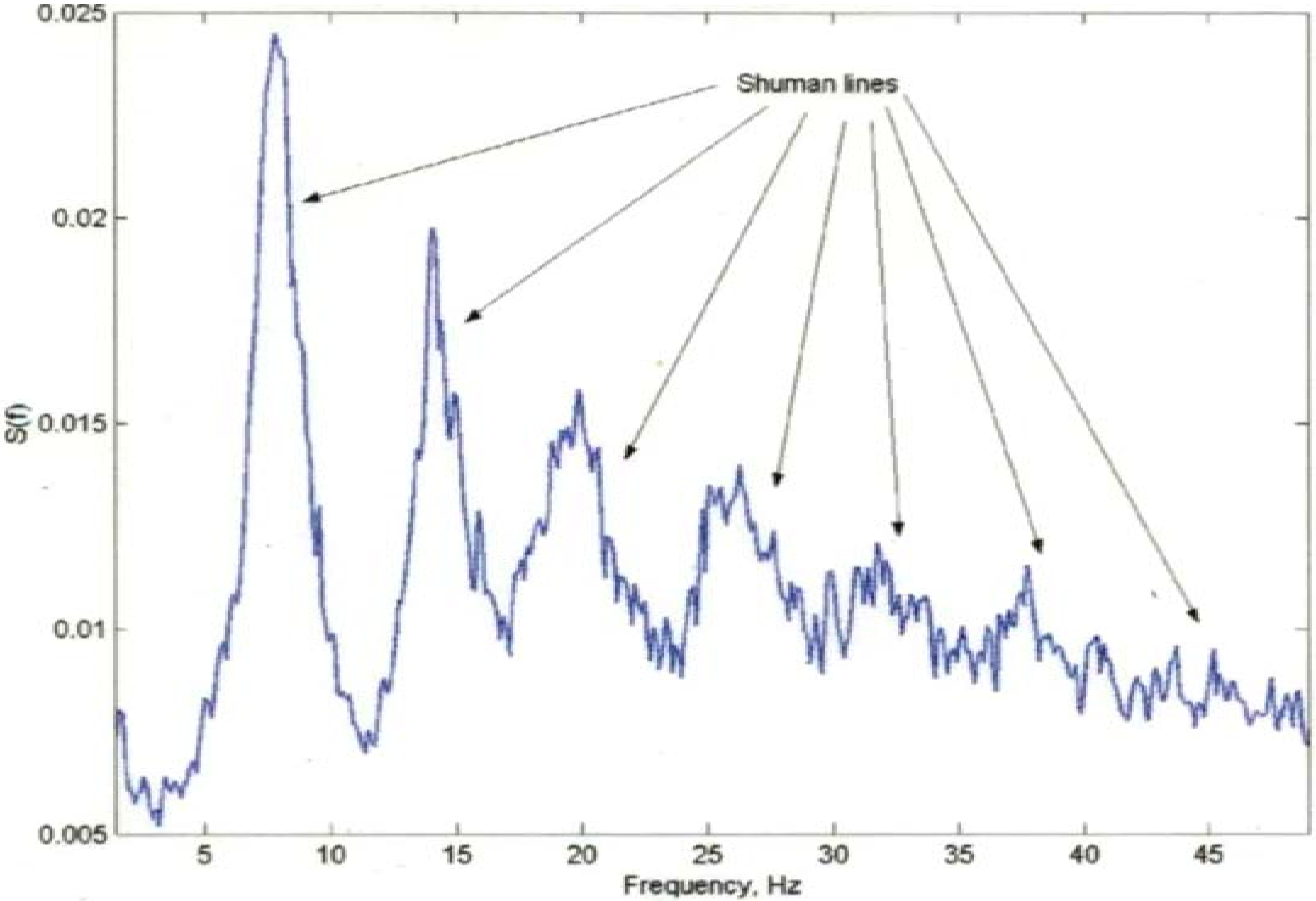


IM installation at the UAS area

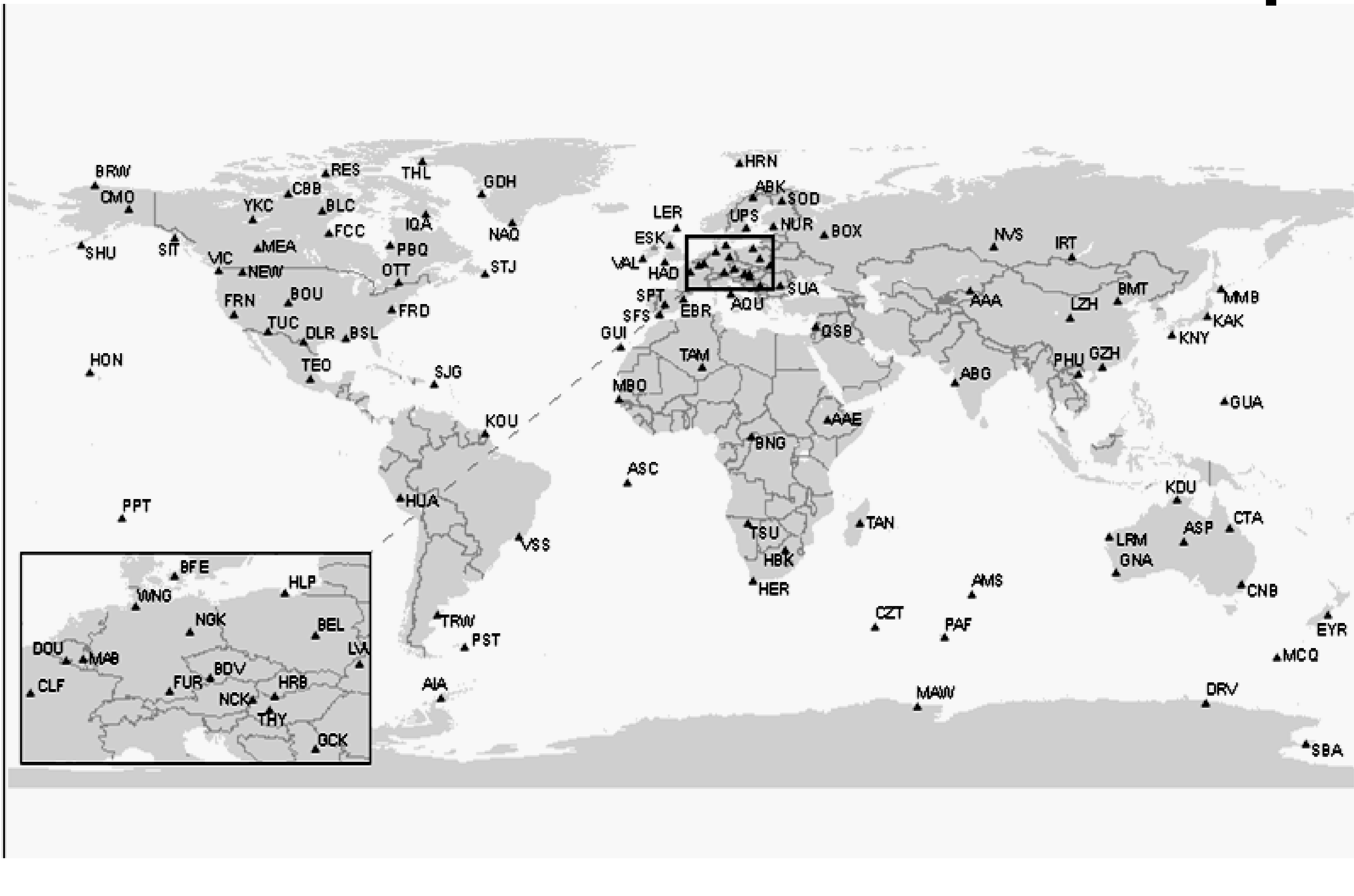
IDUCTION LOOP MAGNETOMETER
LEMI-112A3P

SCHUHMAN SPECTRUM

(averaging 10 min, resolution 0.12 Hz)



INTERMAGNET observatories map



Accepted parameters

	Data Res	Data Acc	Filter Prefs	Time Acc	Time Pos
Consensus	0.01 nT	NA	Digital	0.01 s	Centered on UT sec
LC ISR	0.001 nT	0.1%	Digital with linear phase	0.01 s	Centered on UT sec

FGM Noise level - better than 1pT/Hz$^{1/2}$ at 1Hz

Quantization noise $$\frac{1\,\mathrm{pT}}{\sqrt{12}\cdot\sqrt{0.5\,\mathrm{Hz}}} = 0.41\frac{\mathrm{pT}}{\sqrt{\mathrm{Hz}}}$$

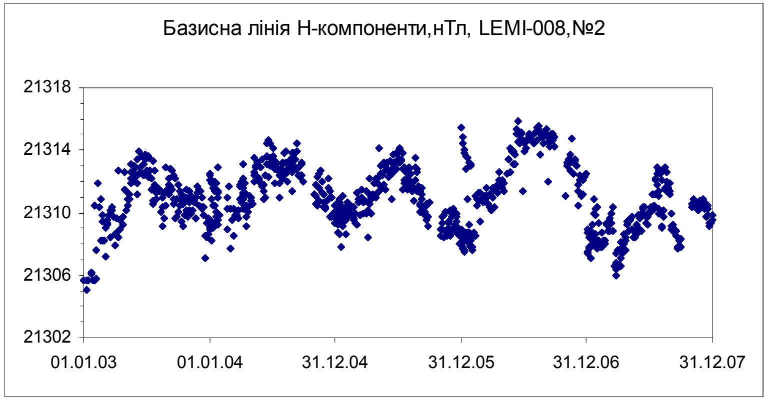
The immunity to industrial noise (50/60 Hz mains)

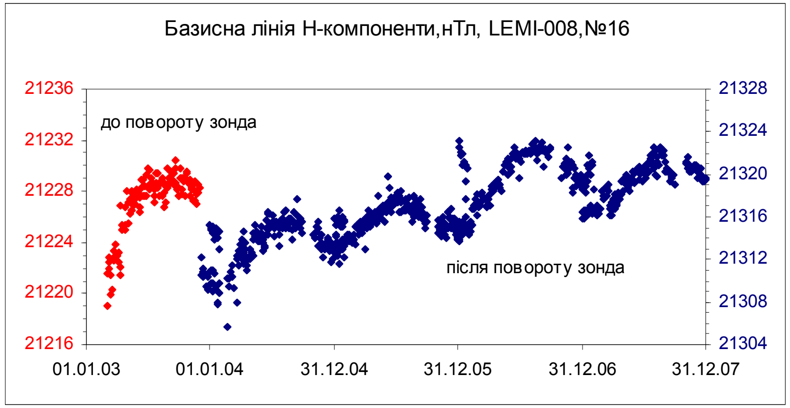
VECTOR PRECISION MAGNETOMETER LEMI-008

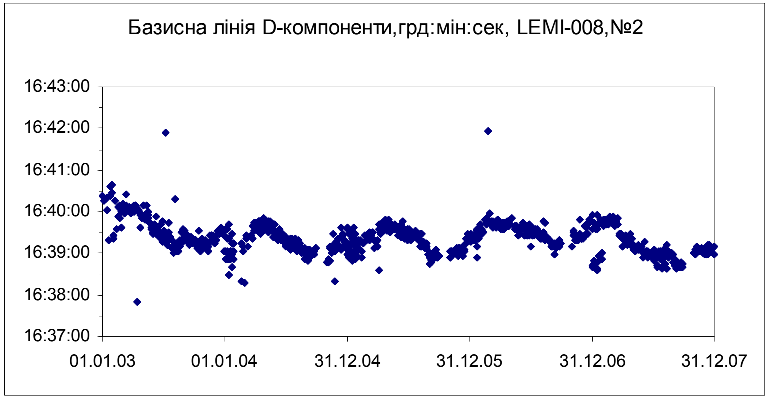
TECHNICAL PARAMETERS

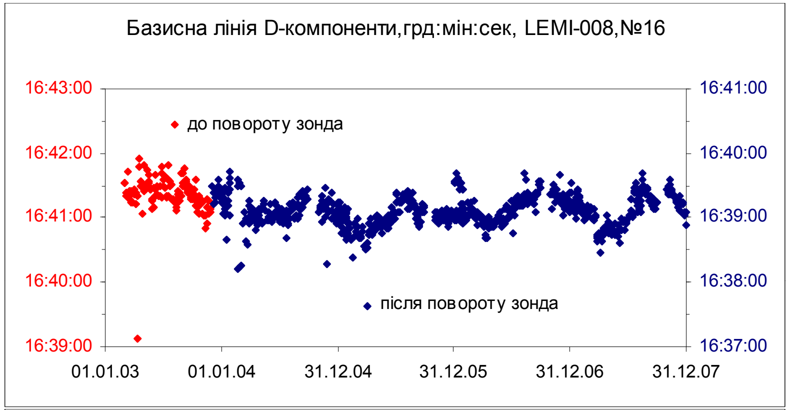
Measuring ranges of total magnetic field at the display:	65 000 nT
Resolution along each component at the display at total field measurement	0.1 nT
Measured range of magnetic field variations (after offset compensation)	6000 nT
Resolution along each component both the display and registered into internal FLASH-memory	0,01nT
Measured range at analog output	4500nT
Transformation factor of analog output	1 mV/nT
Noise level at 1 Hz	10 pT rms
Temperature drift	<0.1 nT/C
Components orthogonality error	<30 min of arc
Automated offset compensation band along each component	65 000 nT
Time of samples averaging at variation values registration into FLASH-memory	1…255 s
Volume of internal memory	16 MB
Operating temperature range	minus 5 to +50° C
Power supply, battery	12 V, 0.1 A
Weight: sensor with support	2,7 kg
electronic unit	1,8 kg
Length of connecting cable,	9 m

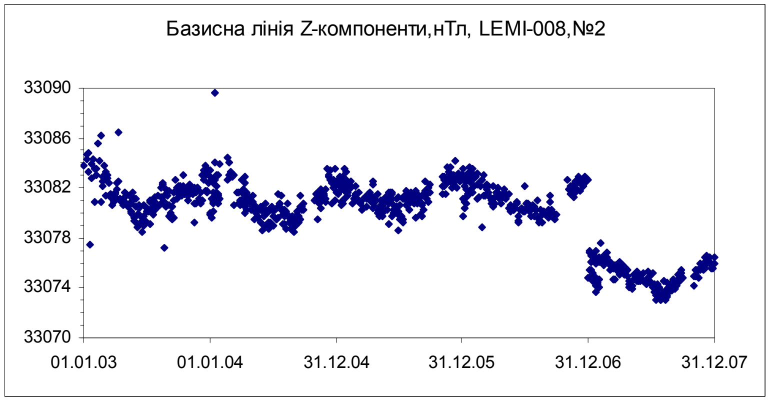
Baseline seasonal trend per 5 years

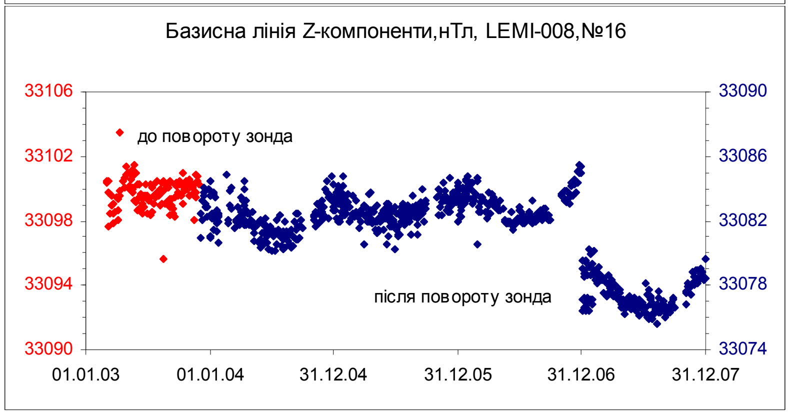








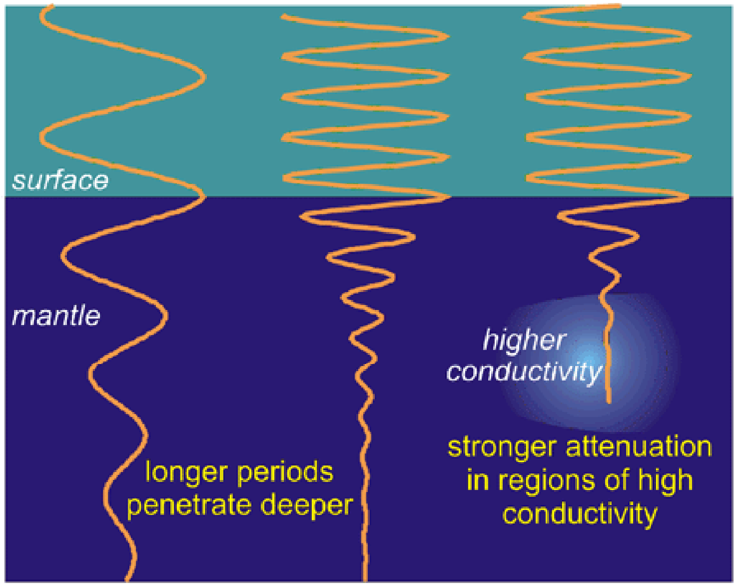




Magnetotelluric station LEMI-417

WHAT IS A GEOMAGNETIC (DEEP) SOUNDING?

Short variations of the field are associated to EM waves of external origin, generated by changes in the electrical currents in the ionosphere and magnetosphere, and penetrating into the Earth. Here in turn the electrically conducting layers of the Earth produce their own surface magnetic fields.



The depth of penetration is controlled by the *skin depth* relationship δ, expressed as follows:

$$\delta = 0.5\sqrt{\rho T}$$

given in km when ρ, the electrical resistivity is given in Ω.m and the period T, in seconds.

WHAT IS A GEOMAGNETIC (DEEP) SOUNDING?

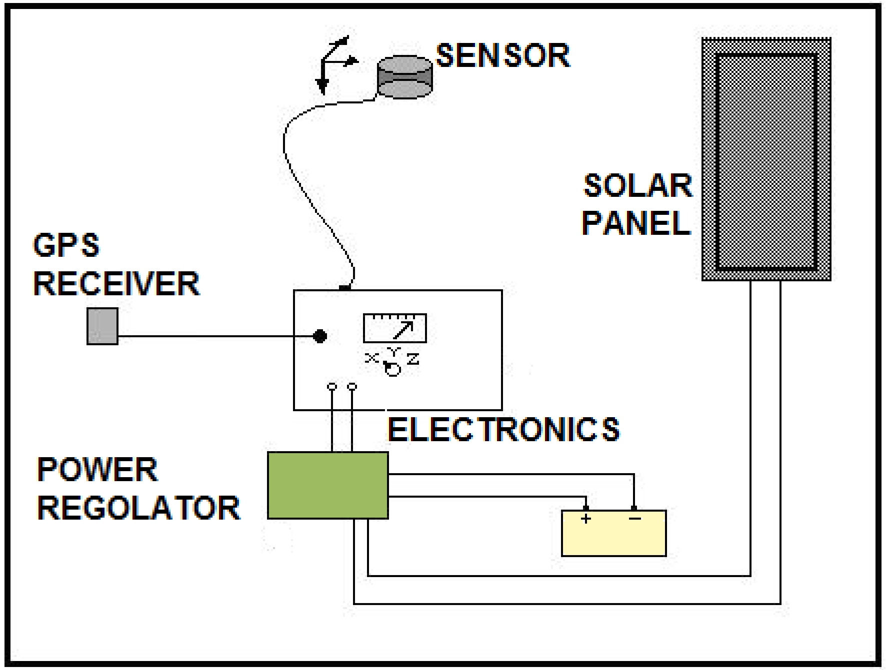
In geomagnetic deep sounding (GDS) the deduction of the internal electrical conductivity distribution is based only on three time-varying geomagnetic field components X, Y and Z (or H, D, and Z).

Basically, the relationship between external and internal magnetic fields, at a range of frequencies, holds information on the radial conductivity distribution. However, the presence of lateral electrical conductivity differences at depth perturbs the flow of induced currents and produces frequency-dependent anomalies in the X, Y and Z components.

The detection of such anomalies can be facilitated by correlating data from closely spaced sites, recorded preferably by an array of simultaneously operating
magnetometers. The detection and interpretation of these frequency-dependent anomalies, related to lateral electrical inhomogeneities, give the basis and objectives of the GDS technique.

In an alternative sense, the GDS combines the principle of both, soundings (depth) and profiling (lateral), to image lateral conductivity inhomogeneities at varying depths.

OPERATIONS ON THE FIELD



EQUIPMENT:

LEMI-018 (manufactured by Lviv Centre of Institute of Space Research

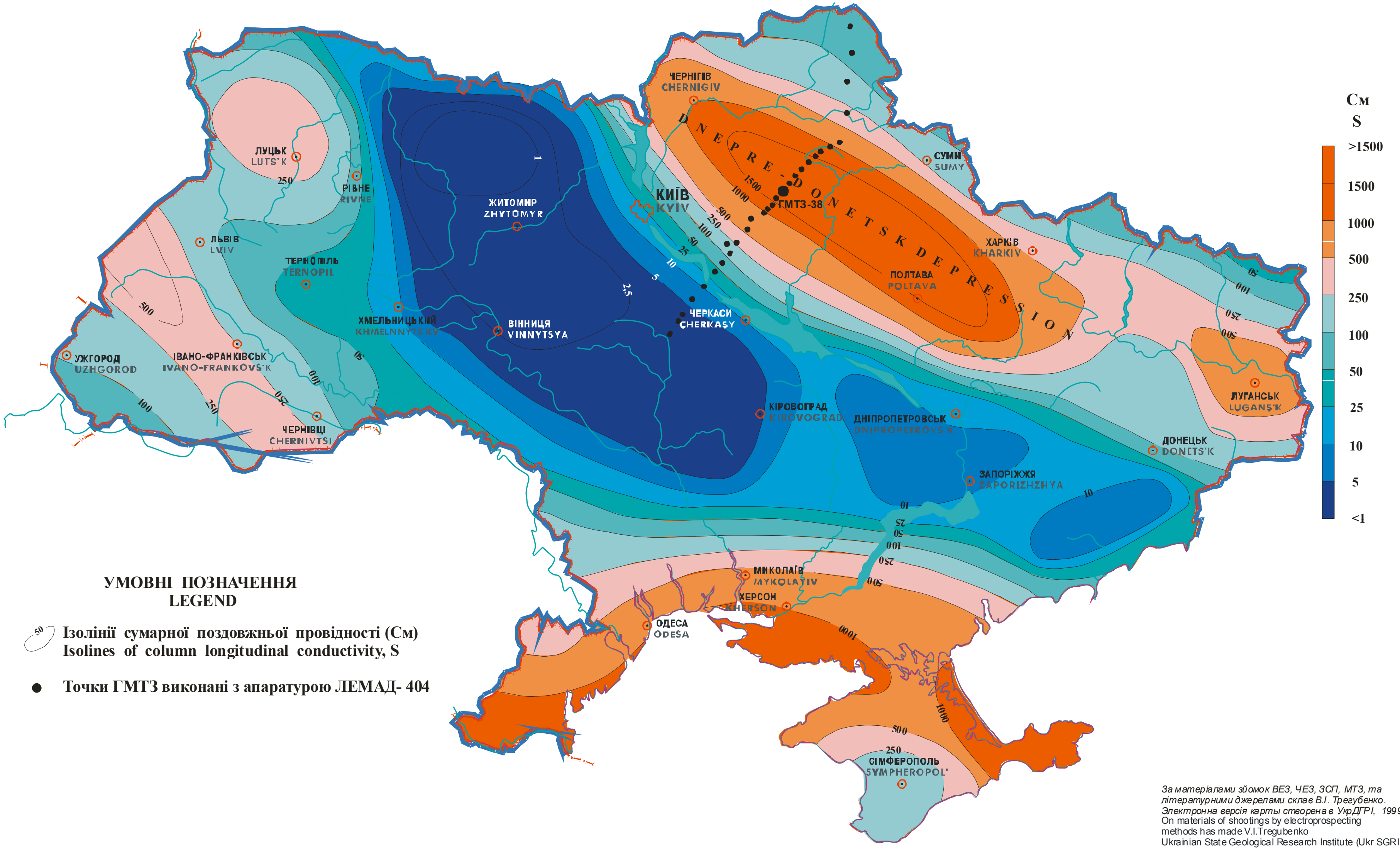
Resolution: 0.1 nT

Noise level (0.01-1)Hz: <10pT rms

Temperature drift: <0.1 nT/°C

Sampling rate: 1 second

ІНТЕГРАЛЬНА ПРОВІДНІСТЬ ОСАДОЧНИХ ВІДКЛАДІВ
COLUMN CONDUCTIVITY OF SEDIMENTARY COVER



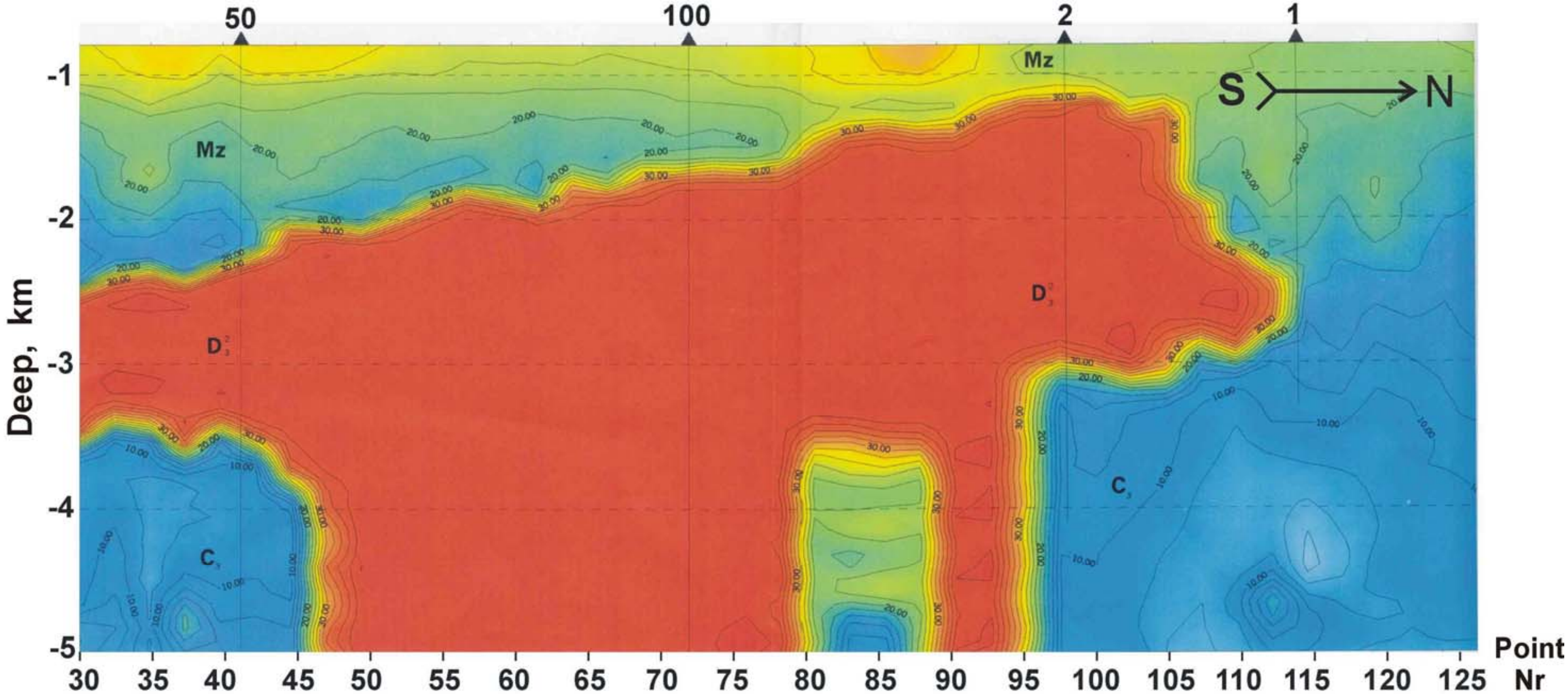
УМОВНІ ПОЗНАЧЕННЯ
LEGEND

Ізолінії сумарної поздовжньої провідності (См)
Isolines of column longitudinal conductivity, S

● Точки ГМТЗ виконані з апаратурою ЛЕМАД- 404

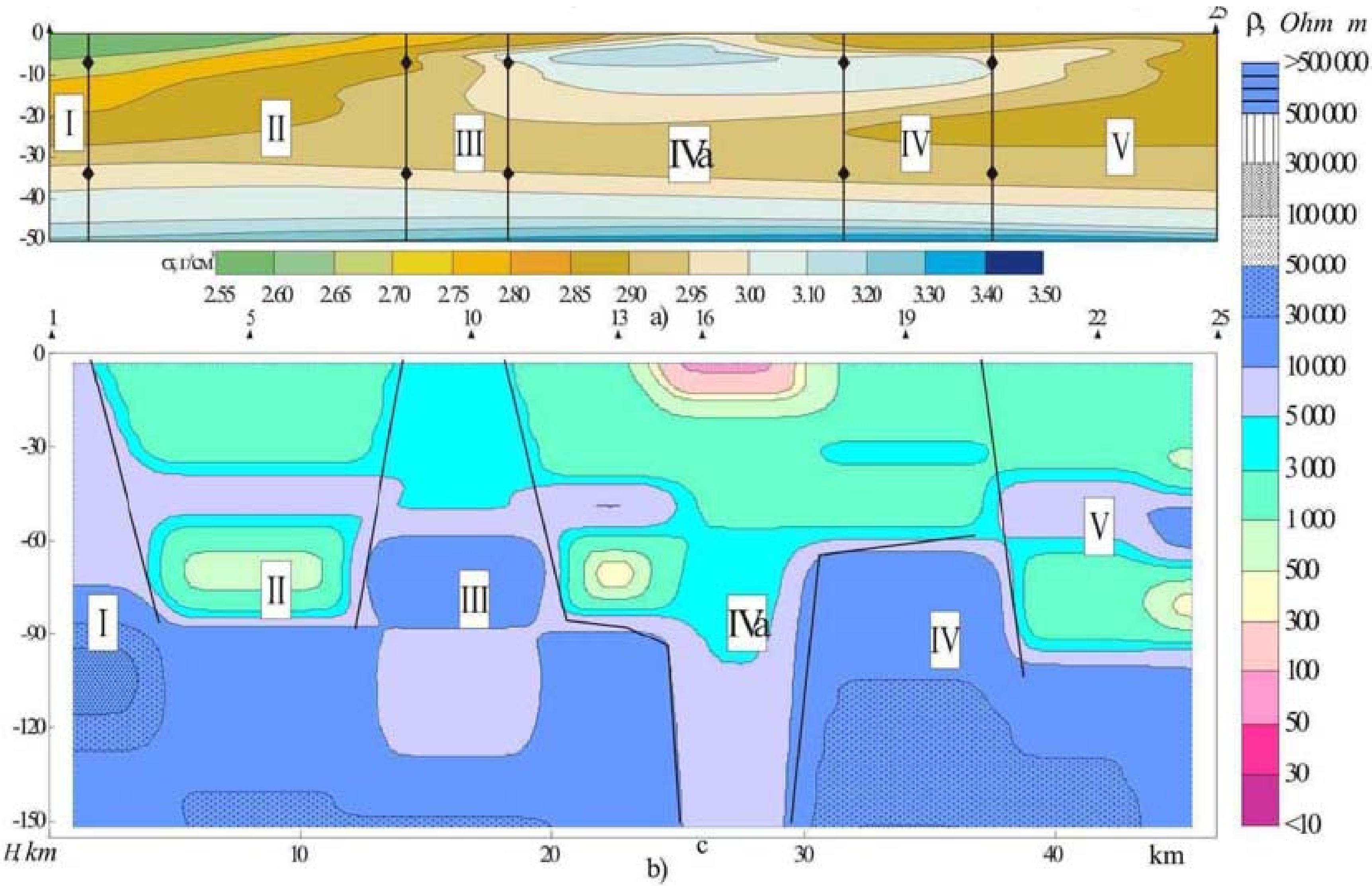
За матеріалами зйомок ВЕЗ, ЧЕЗ, ЗСП, МТЗ, та літературними джерелами склав В.І. Трегубенко.
Электронна версія карты створена в УкрДГРІ, 1999г.
On materials of shootings by electroprospecting methods has made V.I.Tregubenko
Ukrainian State Geological Research Institute (Ukr SGRI)

KRESTISCHY SOLT STOCK,
UKRAINE

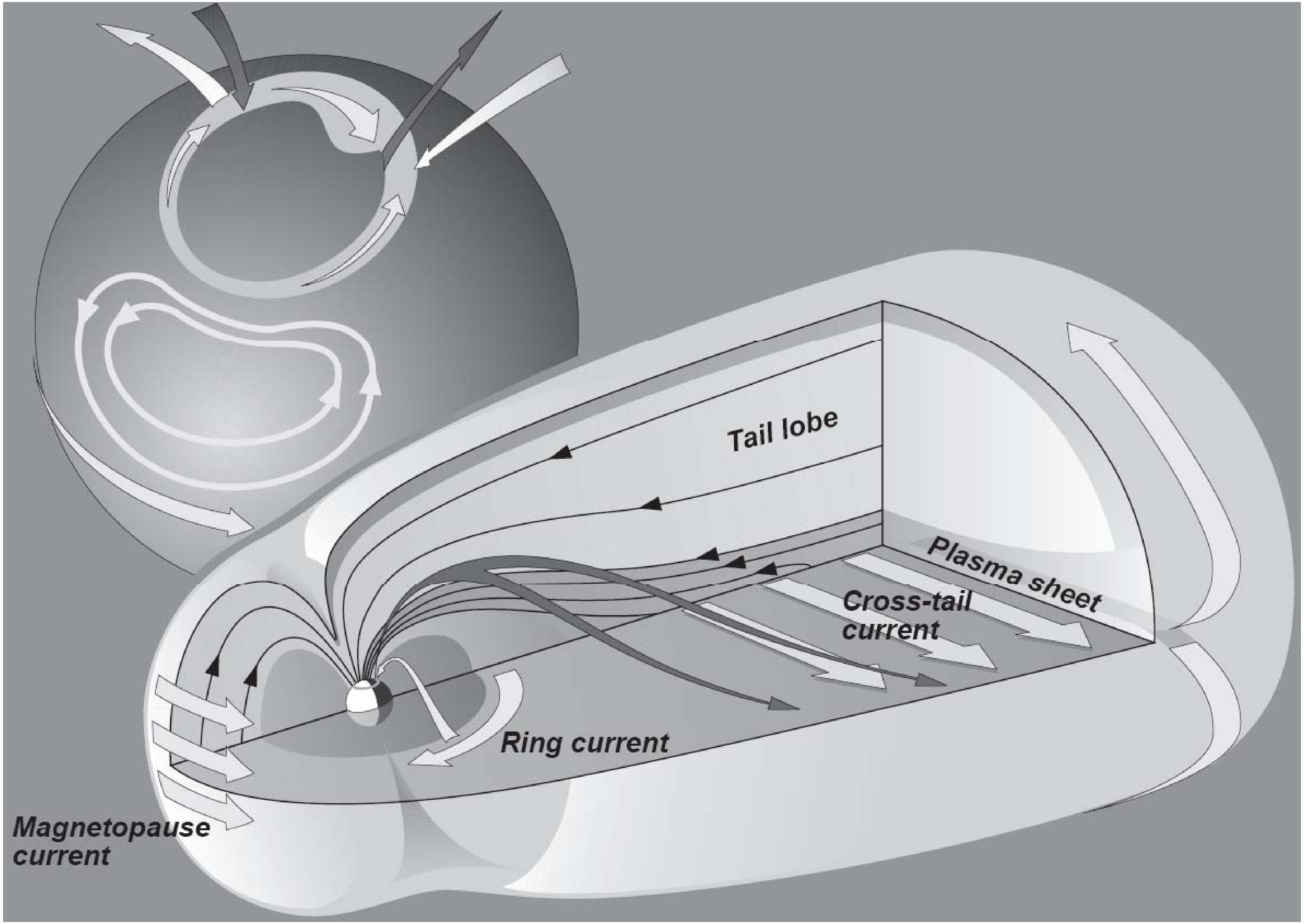


Geoelectric cross-section of discrete interval resistivity. Profile 02.2002. Dniepr-Donetsk basin (H_x component, pulse field formation method)

Comparison of the results of gravity (a) and electromagnetic (b) prospecting

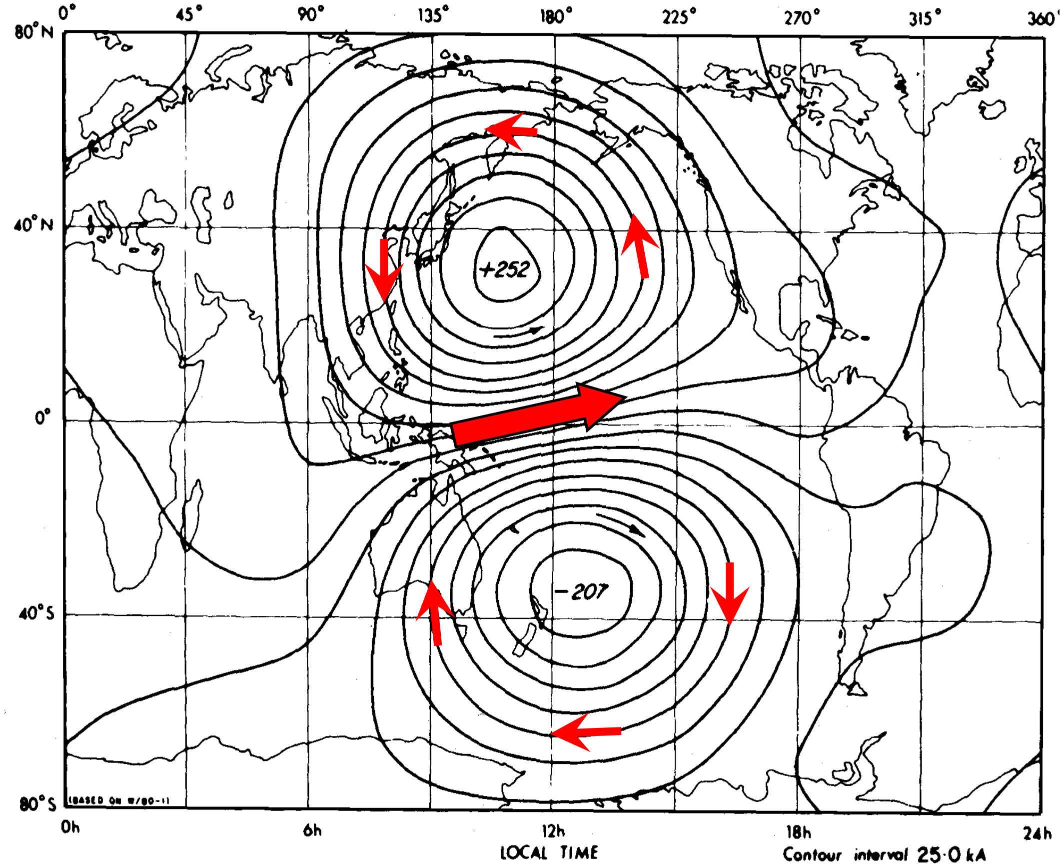


SPACE GEOPHYSICS

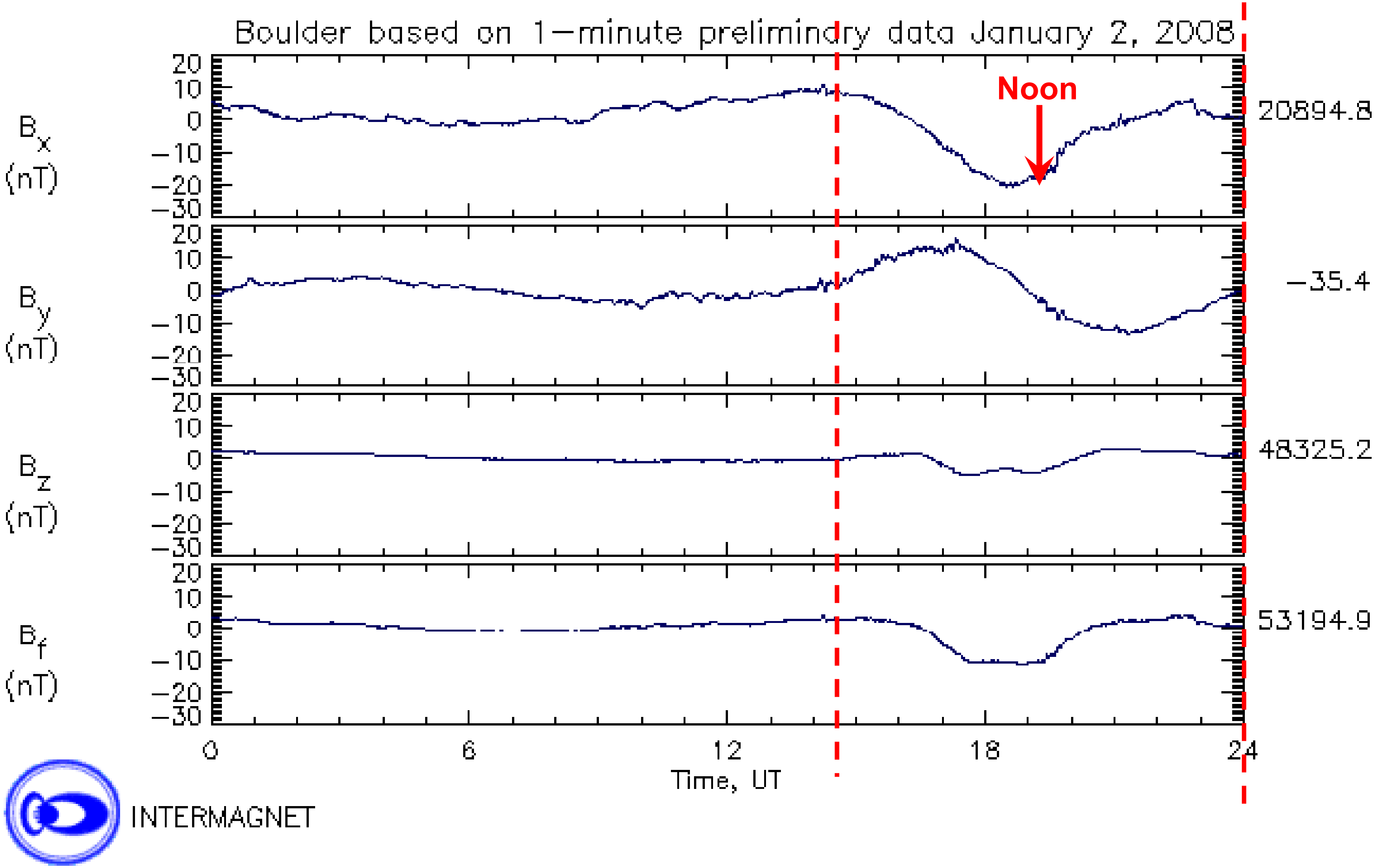

Tail lobe
Plasma sheet
Cross-tail
current
Ring current
Magnetopause
current

The Ionospheric Dynamo - Sq

- Solar illumination creates a hot spot in ionosphere near local noon
- Ionized atmosphere flows away from region of high pressure across the magnetic field
- Moving a conductor in a magnetic field produces a current (dynamo)
- The current produces the quiet day magnetic variation Sq
- The pattern of this current is shown in the diagram



Example: Quiet Day Variation



The Magnetopause Current

- Electrons and protons in the solar wind turn in the dipole field producing a sheet of current in space called the magnetopause
- The current opposes the Earth's field outside the current sheet and increases it inside completely enclosing the Earth's field
- The current circulates CCW in northern hemisphere and has effects similar to Sq

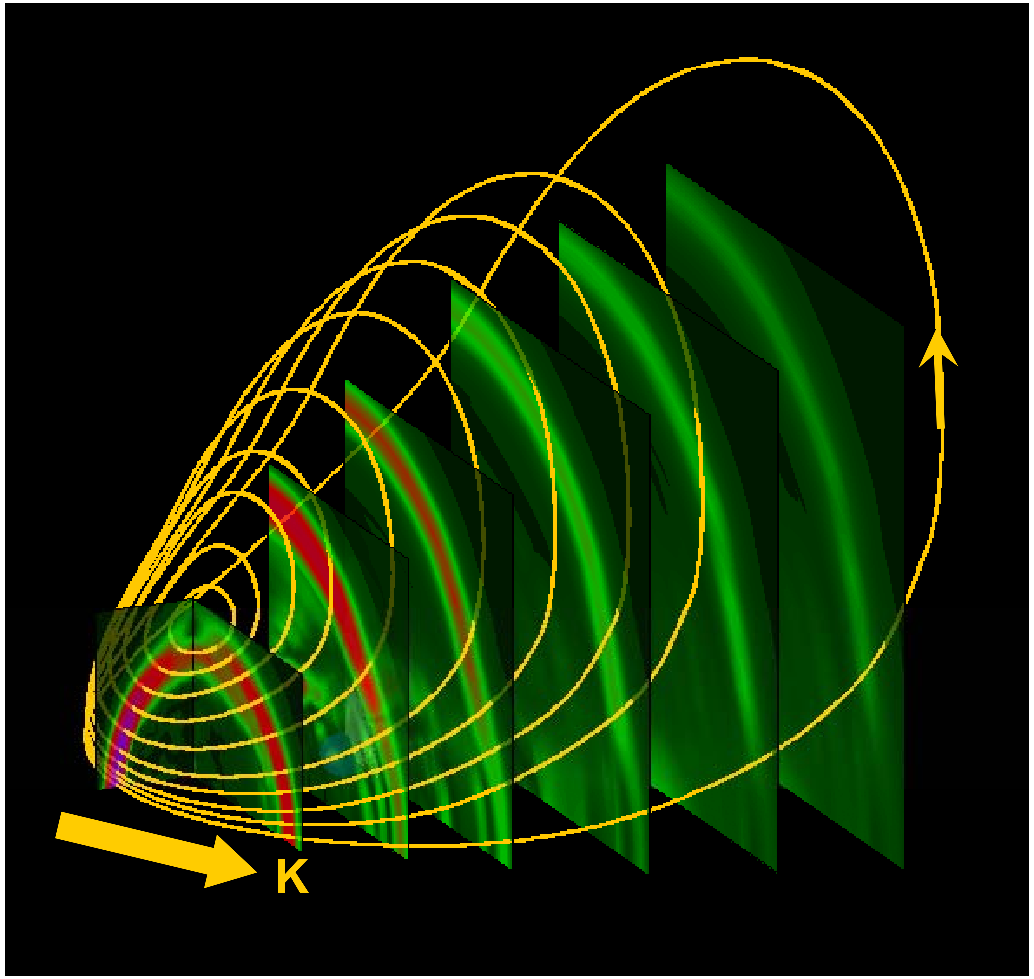
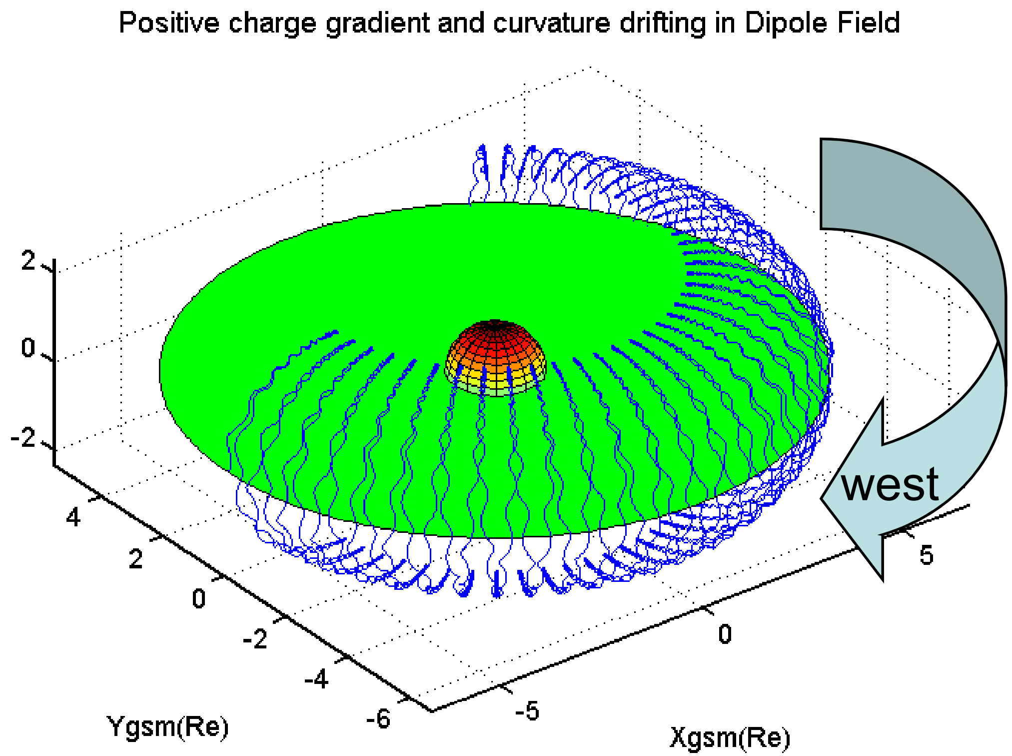


Image from Siscoe

The Ring Current - Dst

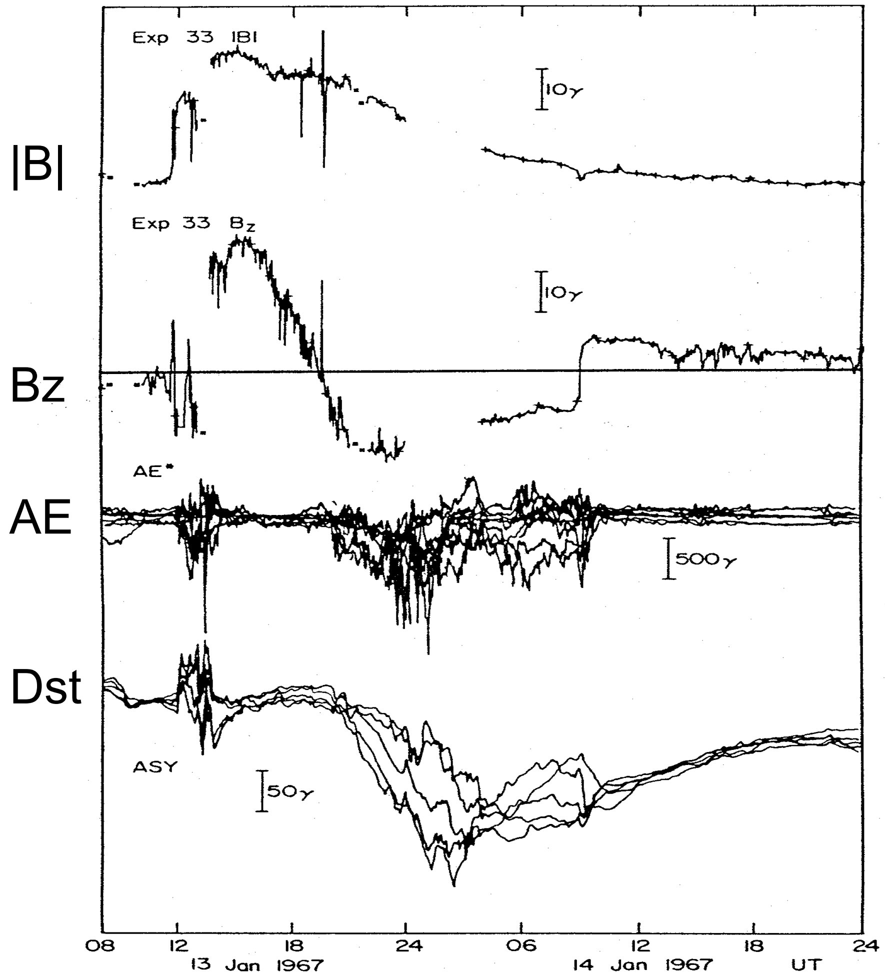
- The ring current is produced by ions drifting westward and electrons drifting eastward in dipole field about 4 Re from Earth
- Their effect on ground is a southward magnetic field that decreases the intensity of main field
- The magnitude of the disturbance is proportional to total energy of drifting particles



Positive ions drift westward and electrons drift eastward creating a westward current

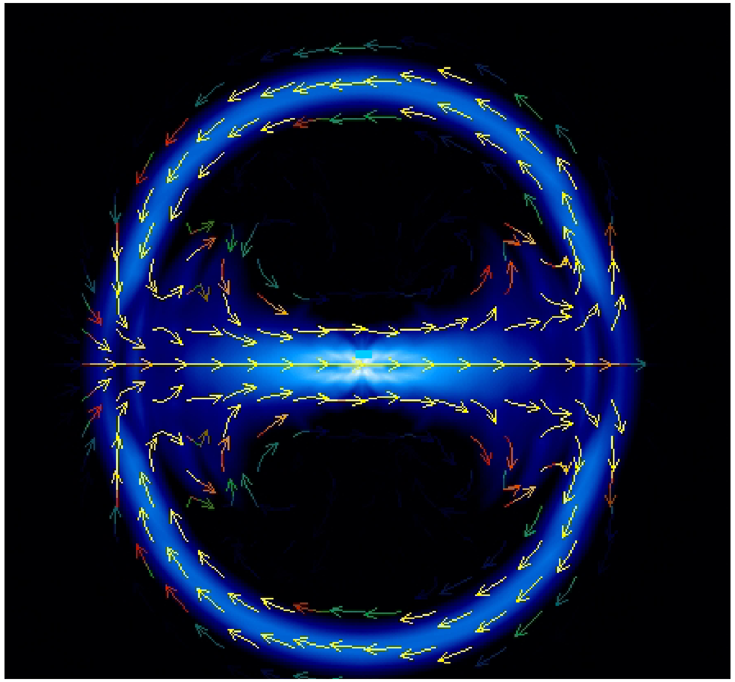
Example of Ring Current Effects

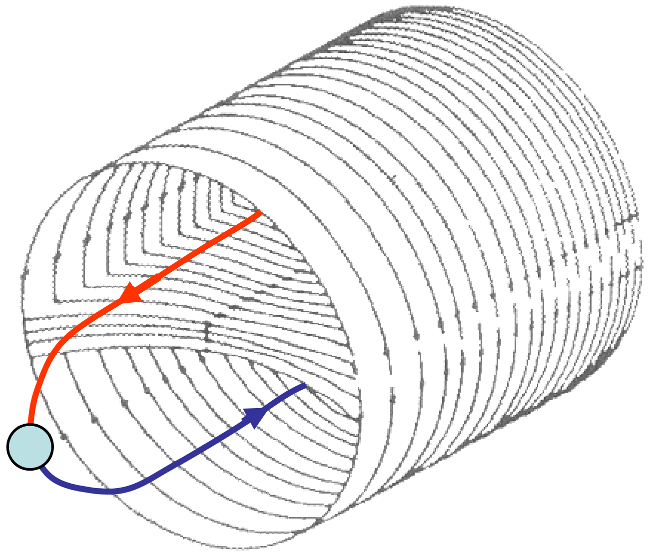
- Coronal mass ejection produce intervals of strong southward Bz at the earth
- Magnetic reconnection drives magnetospheric convection
- Convection drives currents along field lines and through ionosphere
- Ground magnetometers record effects of ionospheric and magnetospheric currents in H and other components
- H traces are used to construct the AE and Dst index



The Tail Current

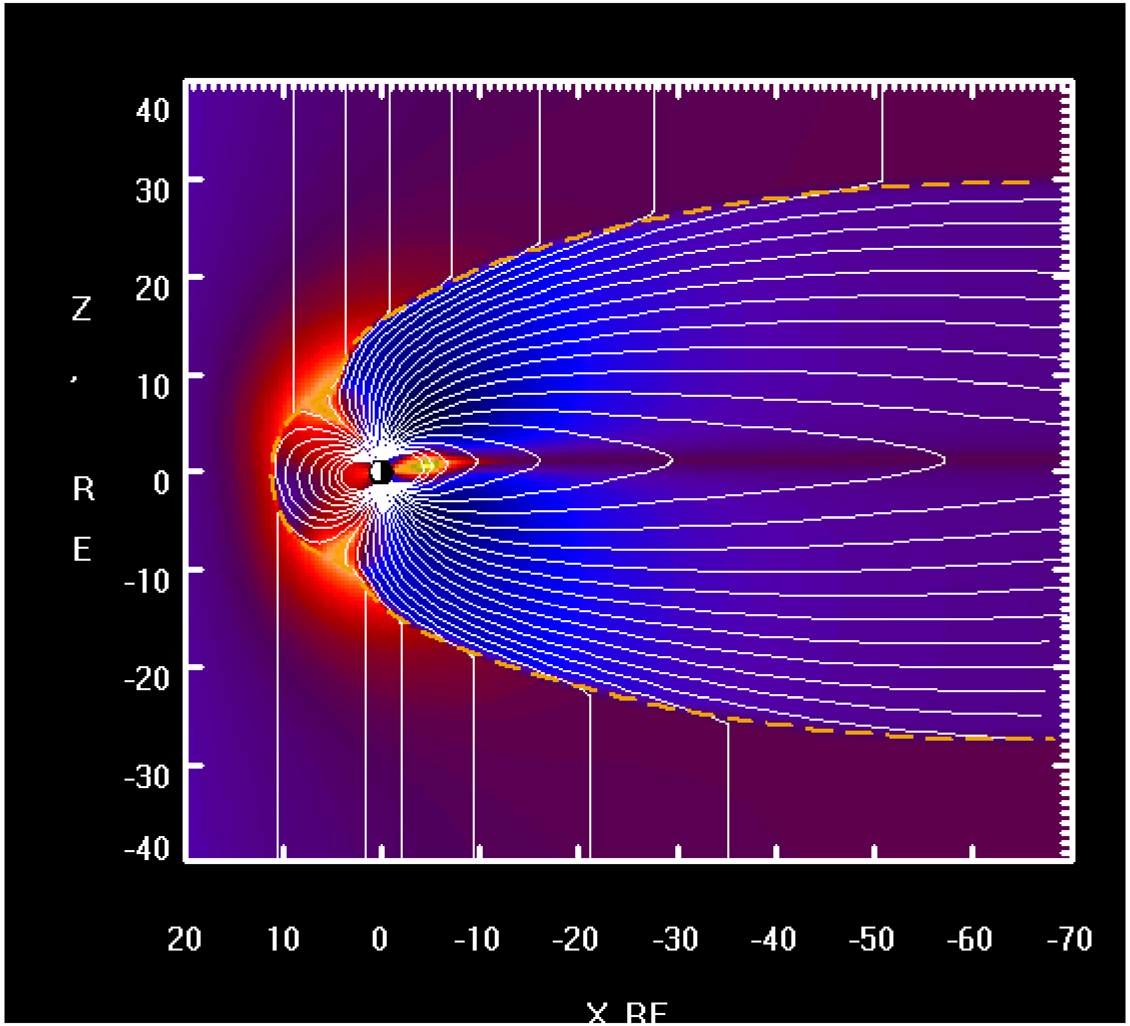
- The tail current is produced by two solenoids downstream of Earth with current flowing in opposite sense in each solenoid
- The effect is a fringing field in the vicinity of the Earth that reduces the horizontal component
- The effect is stronger on night and evening side creating an asymmetry in the surface field





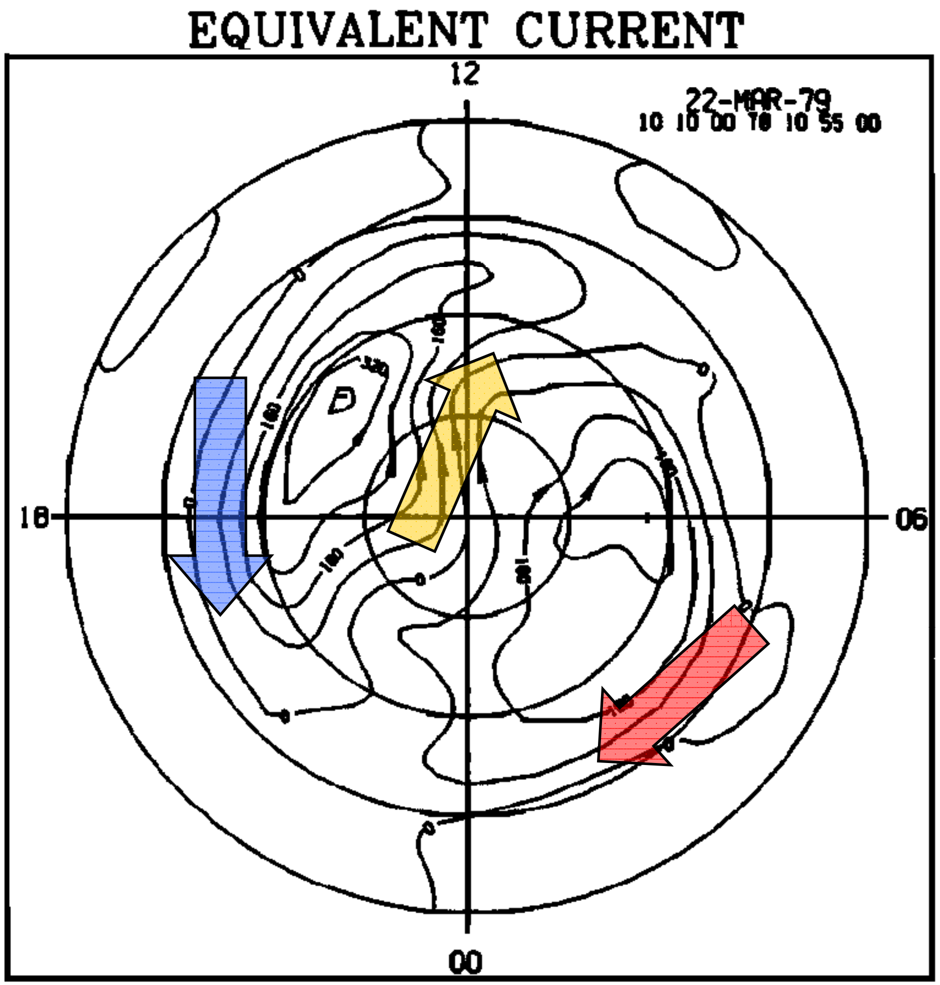
An Empirical Fit to Magnetic Field Data

- Use the entire history of observations of the magnetospheric magnetic field
- Create a spherical harmonic fit to the observations
- Include dipole tilt as function of season
- External field is reconnecting with dipole field



The DP-2 Equivalent Current System

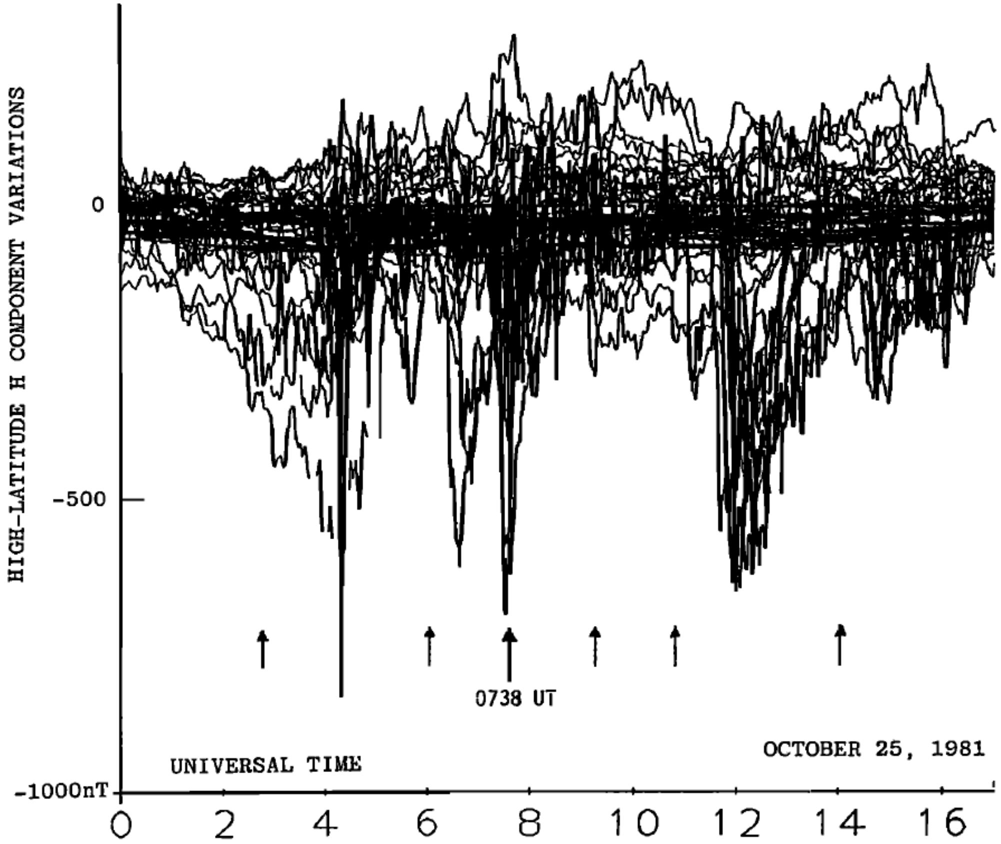
- Magnetospheric convection in a 2-cell pattern produces a closed circuit of sheet current in the ionosphere called DP-2
- The current flows from midnight (bottom) towards noon (**yellow**) and returns along the auroral oval
- High conductivity in the auroral oval concentrates the current into the eastward (**left**) and westward (**right**) electrojets



Clauer, C. R., and Y. Kamide (1985), DP 1 and DP 2 current systems for the March 22, 1979 substorms, J. Geophys. Res., 90(A2), 1343-1354.

Effects of the Auroral Electrojets

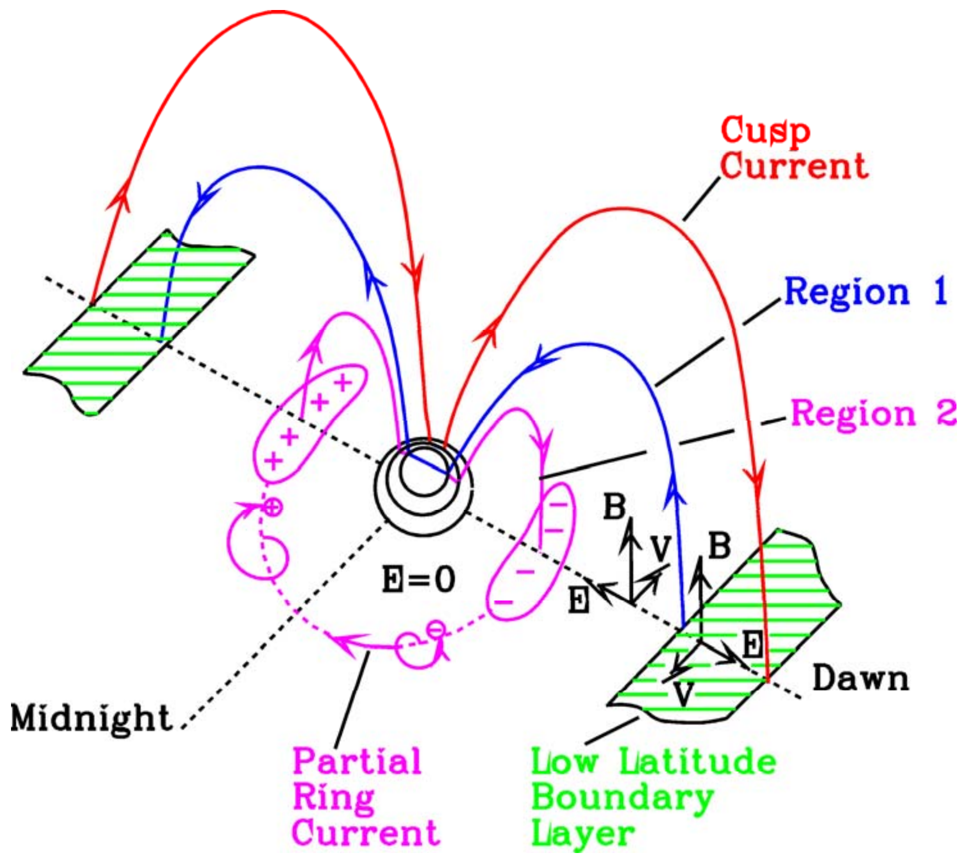
- Magnetometers below the eastward electrojet measure positive (northward) perturbations
- Below the eastward electrojet they measure negative (southward) perturbations
- The time scale of the electrojet disturbances is about 3 hours and repeats several times per day



Kamide, Y., ET AL., Ground-Based Studies of Ionospheric Convection Associate with Substorm Expansion, J. Geophys. Res., 99(A10), 19451-19466.

Generation of Region-2 Field Aligned Currents

- The low latitude boundary layer moves tailward just inside the magnetopause
- The electric field within the dawn side layer points outward
- Just inside the boundary layer the plasma flows Sunward so the electric field is inward
- Magnetic field lines map the magnetospheric electric fields to the ionosphere
- On the dawn side the E field point poleward across the polar cap and equatorward
- The electric fields drive currents in the ionosphere that diverge at the point where the inner edge of the boundary layer maps
- The current divergence is fed by a field-aligned current called the Region 1 current



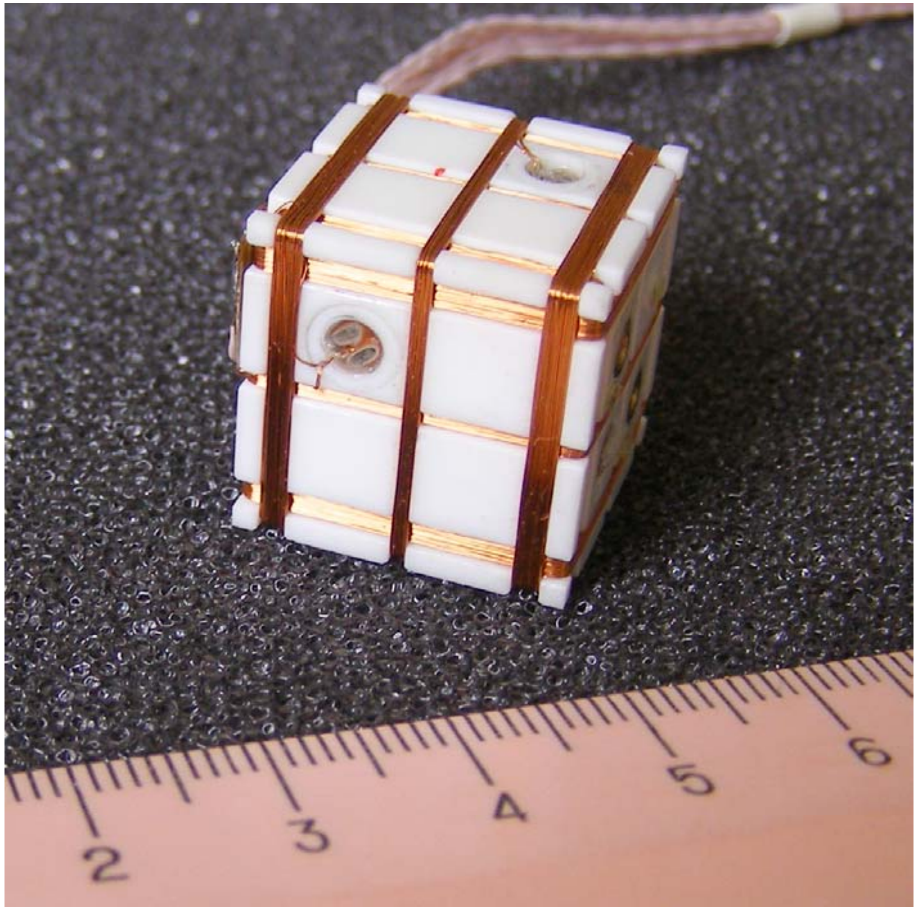
SPACE INSTRUMENTATION

DUAL THREE-COMPONENT MICROSATELLITE FLUX-GATE ATTITUDE CONTROL MAGNETOMETER LEMI-016

TECHNICAL SPECIFICATIONS

Measurement range, nT	> ± 65000
Maximal sample rate, Hz	12
Resolution, bits	16
Axial alignment precision calibrated)	± 5 min of arc
Maximal offset, nT	50
Gain error, % of reading	< 0.1
Zero drift over temperature, nT/°C	< 1.5
Gain drift over temperature, % of reading /°C	< 0.005
Operation temperature range, °C:	40...+80
Power consumption (galvanically insulated power converter utilizes onboard power supply voltage 24..34V), W	< 0.25
Overall dimensions	130x80x80 mm,
Weight	1,2 kg
Shockproof, till, g	300

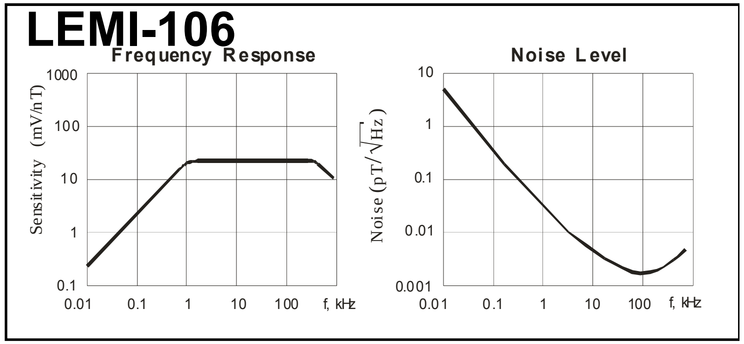
MINIATURE LOW NOISE SENSOR FOR "NANOSPACE" (SWEDEN)



TECHNICAL SPECIFICATION

Measurement range	± 65000 nT
Noise	50 pT/Hz^1/2 at 1 Hz
Zero offset	± 20 nT
Excitation frequency	8-16 kHz
Non-orthogonality	< 30 "
Temperature range	-50ºC - +80ºC
Power consumption	< 200 mW
Dimensions	20x20x20 mm
Weight	25 g

SEARCH-COIL MAGNETOMETERS FOR SPACE APPLICATIONS - LEMI-106, LEMI-106H



TECHNICAL SPECIFICATIONS

	LEMI-106	LEMI-106H
Full frequency range	10...600000 Hz	1…20000Hz
Sensitivity, linear part	0.02 mV/nT*Hz	0,1 mV/nT*Hz
Sensitivity, flat part	20 mV/nT	100 mV/nT
Length	510 mm	300 mm
Weight	75 g	95 g
Power consumption	2 mA at ±12 V	10 mA at ±12 V


THANK YOU FOR
ATTENTION!