Elekta Neuromag® TRIUX

User's Manual

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US6538436 (Interference suppression)
US6876196 (Head position determination)
US7335838 (Magnetic shielding)
US7463024 (Signal Space Separation)
US7502720 (Signal Space Separation)
US7649351 (Interference suppression)
US7933727 (Interference suppression)
US8229540 (Ac and dc signal separation)
US8253036 (Magnetic shielding)

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List of symbols

The following symbols are used in the system and in the manuals. Familiarize yourself with each symbol and its meaning before operating this system.

Caution. Parts of the system are marked with this symbol when it is necessary for the user to draw attention to avoiding a potential hazard or to ensure safe, correct or improved operation and to avoid damage.

Refer to the instruction manual. Parts of the system are marked with this symbol when it is *mandatory* for the user to refer to instructions given in the manuals accompanying the system to in order to ensure safe operation. In the manuals, it also calls attention to these instructions.

Consult instructions for use. Parts of the system are marked with this symbol when it is necessary for the user to refer to instructions given in the manuals accompanying the system. In the manuals, it also calls attention to these instructions. They intend to ensure correct or improved operation and/or increased safety and to avoid damage.

Type BF (body floating) equipment symbol. The applied parts (parts in direct contact with the person being investigated with the system) and the type plate are marked with this symbol to indicate that they fulfill the leakage current requirements of the safety standard IEC 60601-1).

Alternating current (power line) symbol.

Protective ground (earth) terminal symbol. Used to identify terminals which are intended for connection to an external protective conductor for protection against electrical shock in case of a fault, or to the terminal of a protective ground (earth) electrode.

Static electricity symbol. The parts of the system marked with this symbol indicate the presence of components susceptible to static electricity and require the use of special static-electricity preventing techniques.

Non-ionizing radiation, RF transmitter. Marking on equipment or equipment parts that include RF transmitters or that intentionally apply RF electromagnetic energy.

Disposal instruction symbol. Separate collection of waste electrical and electronics equipment (WEEE) necessary (European Union directive 2012/19/EU on WEEE).

Date of manufacture: year (four digits) followed by month and day (if applicable).

Warnings, cautions and notes

WARNING 0.0: Warnings are directions which, if ignored, can constitute a health hazard, cause fatal or serious injury, or lead to erroneous clinical diagnosis and, possibly, to clinical mistreatment.

CAUTION 0.0: Cautions are directions which you must obey to ensure safe and efficient operation and to avoid damage to the system.

Note: *Notes give you advice and recommendations for safe and efficient use of the product as well as highlight unusual points.*

1 Overview of the Elekta Neuromag® TRIUX

2 Safety instructions and precautions

8 Maintenance

1 Overview of the Elekta Neuromag® TRIUX

1.1 Intended use

The Elekta Neuromag® TRIUX is intended for use as a magnetoencephalographic (MEG) device which non-invasively detects and displays biomagnetic signals produced by electrically active nerve tissue in the brain. When interpreted by a trained clinician, the data enhances the diagnostic capability by providing useful information about the location, relative to brain anatomy, of active nerve tissue responsible for critical brain functions.

1.2 Indications for use

The Elekta Neuromag® TRIUX non-invasively measures the magnetoencephalographic (MEG) signals (and, optionally, electroencephalographic (EEG) signals) produced by electrically active tissue of the brain. These signals are recorded by a computerized data acquisition system, displayed, and may then be interpreted by trained physicians to help localize these active areas. The locations may then be correlated with anatomical information of the brain. MEG is routinely used to identify the locations of visual, auditory, somatosensory, and motor cortices in the brain when used in conjunction with evoked response stimulators. MEG is also used to non-invasively locate regions of epileptic activity within the brain. The localization information provided by MEG may be used, in conjunction with other diagnostic data, in neurosurgical planning

1.3 Intended user education level

The Elekta Neuromag® TRIUX is intended to be used by medical professionals trained to use the product.

WARNING 1.1: Only trained clinicians who are capable of judging the relevance and quality of data may interpret the data for clinical purposes.

1.4 General information

Elekta Neuromag® TRIUX (articles NM23900N, NM25000N) allows simultaneous measurement of 306 MEG and, optionally, 32, 64, or 128 scalp EEG signals over the whole head. Activity of several sources all over the cortex can thus be monitored. In addition, 12 auxiliary polygraphic bipolar biopotential signals (a.k.a. bioamplifier channels) can be acquired.

Elekta Neuromag® TRIUX MEG channels are based on 306 superconducting thin-film sensors inside a cryogenic Dewar vessel. The probe unit, which comprises a gantry supporting the Dewar with sensor array, the patient couch, and the patient chair are operated inside a magnetically shielded room. The MEG electronics unit outside the magnetically shielded room reads out the sensor outputs through the filter unit, digitizes the signals, and routes the data to the main data acquisition workstation, which also controls the electronics and data acquisition.

A head position indicator (HPI) subsystem and a three-dimensional digitizer are also included to determine the position of the head with respect to the sensor array.

The subsystem including the bioamplifiers and the optional EEG channels comprises an interface for electrodes, a computer-controlled preamplifier unit, an isolation amplifier with a feedthrough filter, and main electronics. The electrode interface and preamplifier unit are built in the MEG probe unit inside a magnetically shielded room. The rest of the electronics resides outside the magnetically shielded room. The Bioamplifier/EEG subsystem is an integral, permanently built-in part of the Elekta Neuromag® TRIUX designed to be used in conjunction with MEG measurements as an additional optional source of information. It cannot be used as a stand-alone unit outside of the magnetically shielded room.

WARNING 1.2: The Bioamplifier/EEG subsystem is not certified for use with implanted electrodes. It may only be used for recording potentials from the intact body surface.

Elekta Neuromag® TRIUX includes a workstation for performing and controlling measurements and for processing of data. The software includes programs for data acquisition, electronics control, and data display. Typically, another optional workstation is also included for off-line analysis of data. The optional data analysis software includes source modeling, signal processing, magnetic resonance image (MRI) integration, visualization of combined structural and functional data, and reporting tools.

A technical description is found in *Elekta Neuromag® TRIUX Technical Manual*.

1.5 Main components

The Elekta Neuromag® TRIUX typically comprises the following parts:

- Probe unit with 306-channel helmet-shaped dc SQUID (Superconducting Quantum Interference Device) sensor array inside a cryogenic Dewar, housed in a gantry with three fixed measurement positions. If the internal helium recycler is installed, the gantry also has a liquefaction position for reliquefaction of helium. The liquefaction position is not used for measurements.
- Motorized lifting unit for moving the probe unit between the measurement positions
- Patient couch
- Patient chair with optional chair fine-adjustment system and pediatric comfort set
- Filter unit to prevent radio-frequency (RF) interference to the probe unit from the environment and from digital electronics
- Preamplifier electronics for operating the sensor elements
- Radio frequency (RF) shielded cabinet for electronics
- Stimulus delivery interface for auditory stimuli
- Trigger line interface for input and output of synchronization signals (digital)
- RF-shielded cabinet for optional stimulators (third-party items) with appropriate feedthroughs for signal cables and power line
- Main electronics
- Data acquisition workstation with data acquisition software
- Optional data analysis workstation with data analysis software
- Isolation transformers for main electronics and stimulus cabinets
- Head-position indicator with marker coils and drive electronics

- Three-dimensional digitizer, non-magnetic goggles, and a digitizing chair for use in HPI co-registration
- Electronics to measure the liquid helium level, comprising a probe, control electronics, and a local display
- Phantom for MEG calibration and performance verification
- Transfer siphon for refills of liquid helium into the probe unit
- Cryogenic accessory kit
- Internal Active Shielding (IAS) for external ambient noise compensation
- Magnetically shielded room (Third-party item, supplied by Elekta or purchased by customer according to Elekta specification)
- Helium exhaust for venting the Dewar outside of the magnetically shielded room including an emergency vent line (normally part of customer's site preparation)
- Optional intercom and video monitoring (CCTV)
- Optional long-term data storage and backup system
- 12 additional analog inputs for general purpose

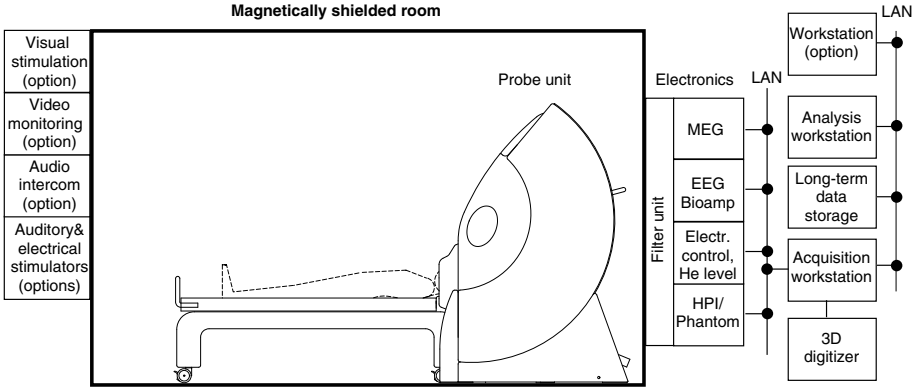


Figure 1.1 Elekta Neuromag® TRIUX system block diagram.

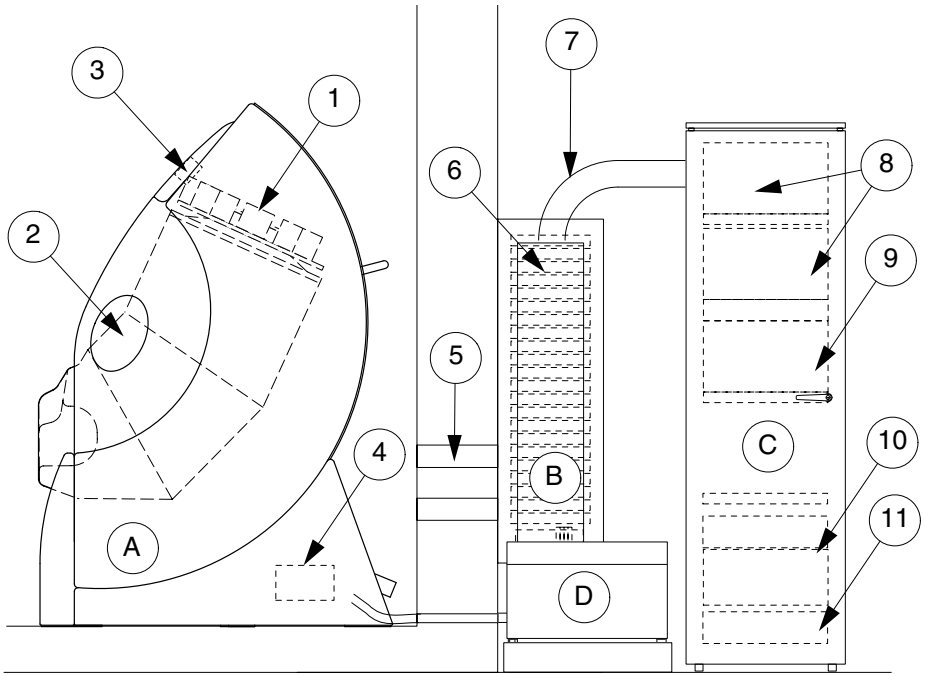


Figure 1.2 *MEG and MEG electronics components. A: probe unit, B: Feedthrough filter unit, C: Main electronics cabinet, D: lifting unit. 1: MEG preamplifiers, 2: interface panel for HPI, electrodes, microphone, and audio stimuli, 3: liquid helium display, 4: EEG and bioamplifier unit, 5: cable feedthrough, 6: feedthrough filter units, 7: cable feedthrough, 8: MEG and bioamplifier main electronics, 9: Optional EEG main electronics, 10: preamplifier power supplies, 11: power control panel.*

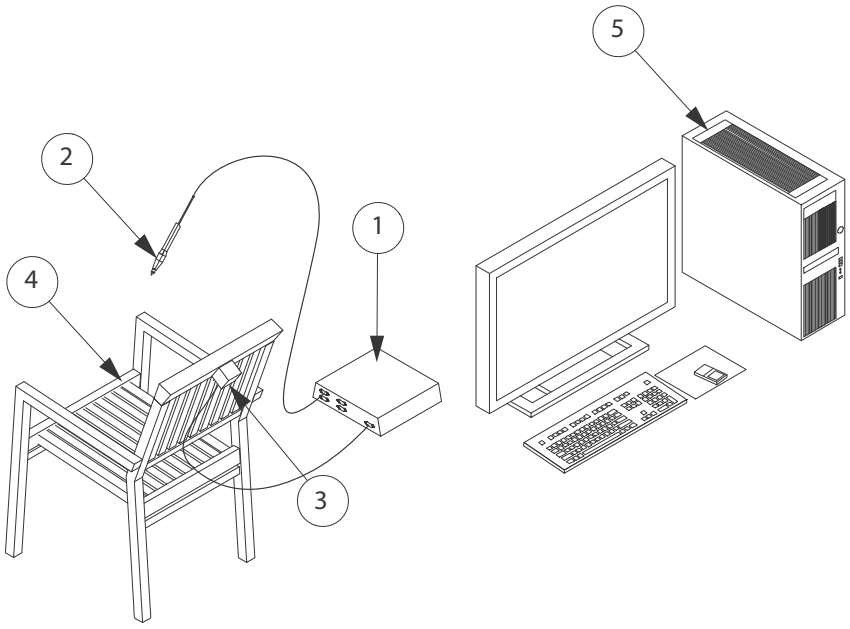


Figure 1.3 *The 3-d digitizer and data acquisition workstation. 1:Digitizer electronics unit, 2: digitizer stylus, 3: digitizer transmitter, 4: digitizing chair, 5: data acquisition workstation.*

The Bioamplifier/EEG subsystem comprises

- 12-channel bipolar (also referred as differential) electrode interface for bioamplifiers and for connection of reference electrode and signal ground electrode
- 12-channel bioamplifier unit, buffered reference channel and current-limited isolated ground electrode driver
- 12-channel bioamplifier optoisolator/filter built in the MEG feedthrough unit
- 12-channel bioamplifier main electronics board
- Optional 32, 64, or 128 channel unipolar (also referred as single-ended) EEG electrode interface
- Optional 32, 64, or 128 channel unipolar electrode cap
- Optional 32-channel unipolar electrode headbox for single electrodes
- Optional 32, 64, or 128 channel preamplifier unit for unipolar EEG channels
- Optional 32-, 64-, or 128-channel optoisolator/filter built in the MEG feedthrough unit
- Optional main electronics boards for 32, 64, or 128 unipolar EEG channels
- Isolated power supply for the preamplifiers and for the preamplifier side of the optoisolator, built in the MEG feedthrough filter unit

A range of other options is also available, see *Elekta Neuromag® TRIUX Technical Manual*.

The main components are summarized in Figs. 1.1, 1.2, and 1.3. An example layout of the components is sketched in Fig. 1.4.

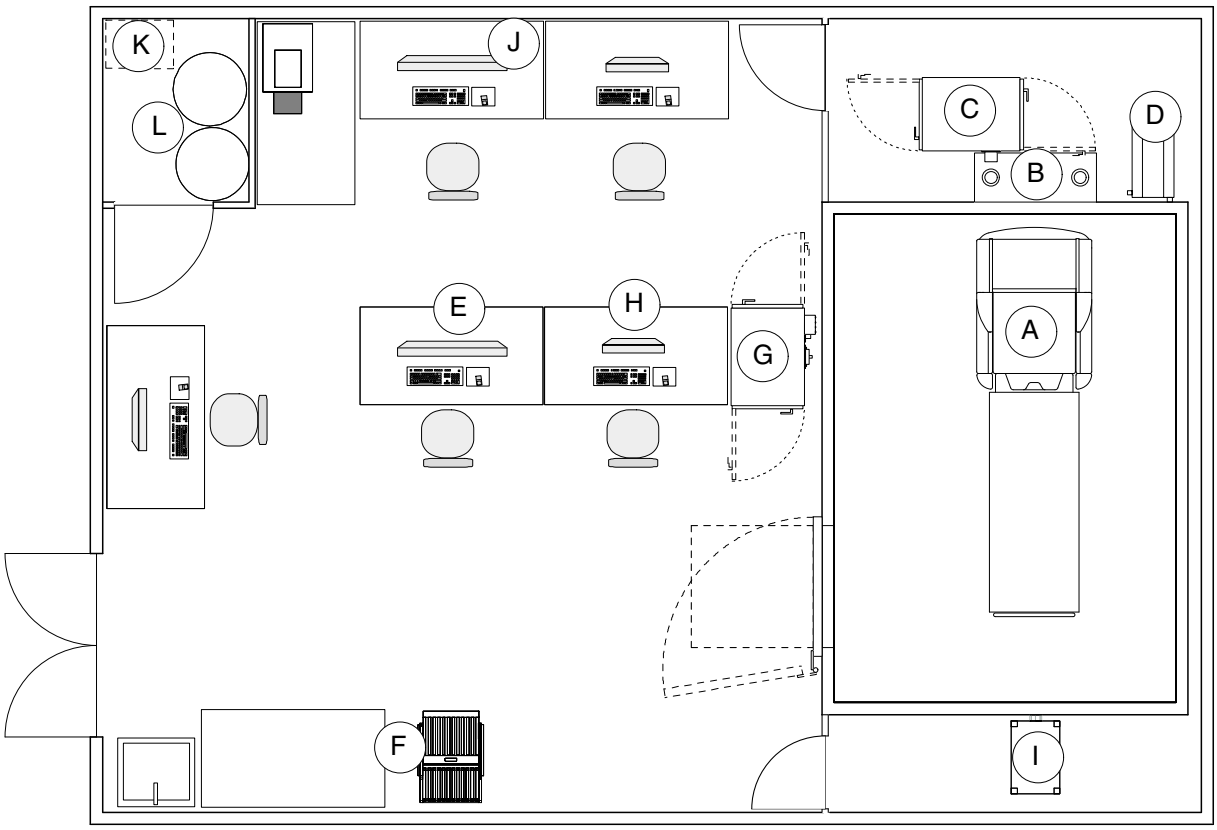


Figure 1.4 *A typical schematic layout of a MEG site. Note: the exact composition and layout is site-dependent. A: probe unit, B: feedthrough filter unit, C: main electronics cabinet, D: lifting unit, E: data acquisition workstation, F: 3D digitizer, G: stimulus cabinet, H: stimulus control (optional) I: video stimulator (optional), J: data analysis workstation (optional), K: isolation transformers, L: storage helium containers (customer-supplied).*

1.6 The probe unit

The Elekta Neuromag® TRIUX probe construction is shown schematically in Fig. 1.5. The 306 sensors measure the magnetic field distribution around the head and convert it to 306 electrical signals. The sensor insert and sensors are immersed in the cryogenic Dewar with liquid helium to keep the temperature stable at 4.2 K. At this temperature the sensors are superconducting. The 306-channel cryogenic insert contains 306 SQUID sensors positioned in a helmet-shaped array and the necessary support structures and cabling. The sensor insert is inside the cryogenic Dewar.

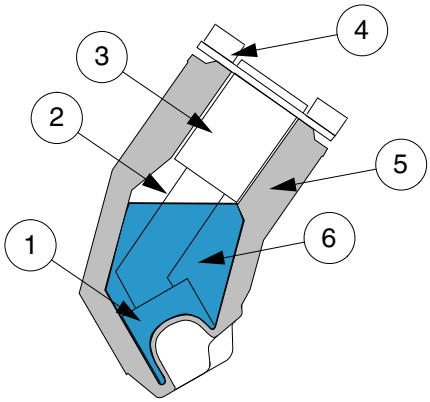


Figure 1.5 *Construction of the probe insert inside the Dewar. 1: Wiring unit with sensor elements, 2: wiring, 3: Neck plug, 4: preamplifiers, 5: Dewar with vacuum insulation, 6: liquid helium.*

The 306 sensors comprise 102 magnetometers that measure the B_z component which is perpendicular to the surface of each detector element, 102 planar gradiometers measuring the gradient $\partial B_z/\partial x$ and 102 planar gradiometers measuring $\partial B_z/\partial y$-component of the gradient. The sensors are arranged in triple sensor elements each comprising two orthogonal planar gradiometers and one magnetometer in the same plane as the planar gradiometers. For geometrical details,

. 1.6.

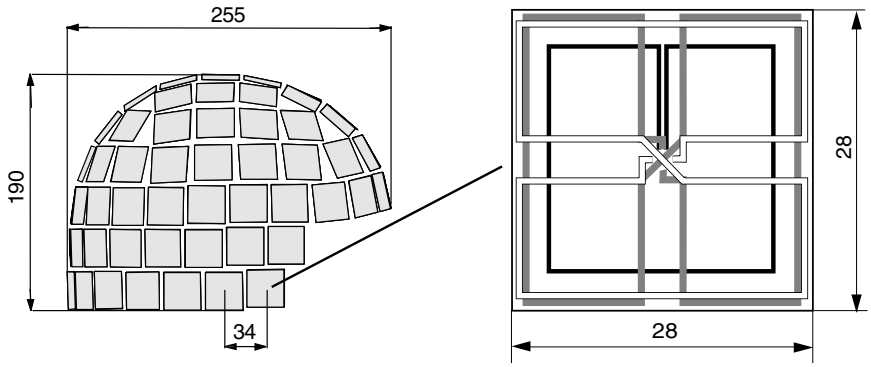


Figure 1.6 *(Left) Detector array, side view. (Right) Triple sensor detector unit. Dimensions are in millimeters. Note: the sensor coils are shown schematically (not to scale).*

The helmet-shaped cryogenic Dewar is a vacuum-insulated vessel to keep the liquid helium necessary for cooling the SQUID sensors to 4.2 K. It is a double-wall structure with vacuum gap and additional thermal radiation shielding in between. The neck plug of the probe unit also provides thermal insulation. The main dimensions of the helmet are shown in Fig. 1.7.

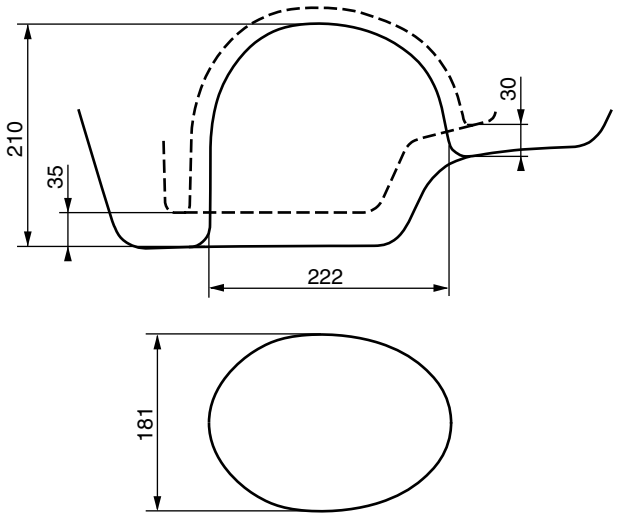


Figure 1.7 Main dimensions [mm] of the helmet-shaped lower end of the Dewar.

1.7 Channel layout

Layout of MEG channels is shown in Fig. 1.8. The naming of individual channels is based on a hierarchical system, see Fig. 1.9. Each channel is identified with a 4 digit number, 'xxyz'. The two most significant digits in a channel number, e.g. '01yz', define a group of channels controlled by a single preamplifier board on the top of the MEG probe.

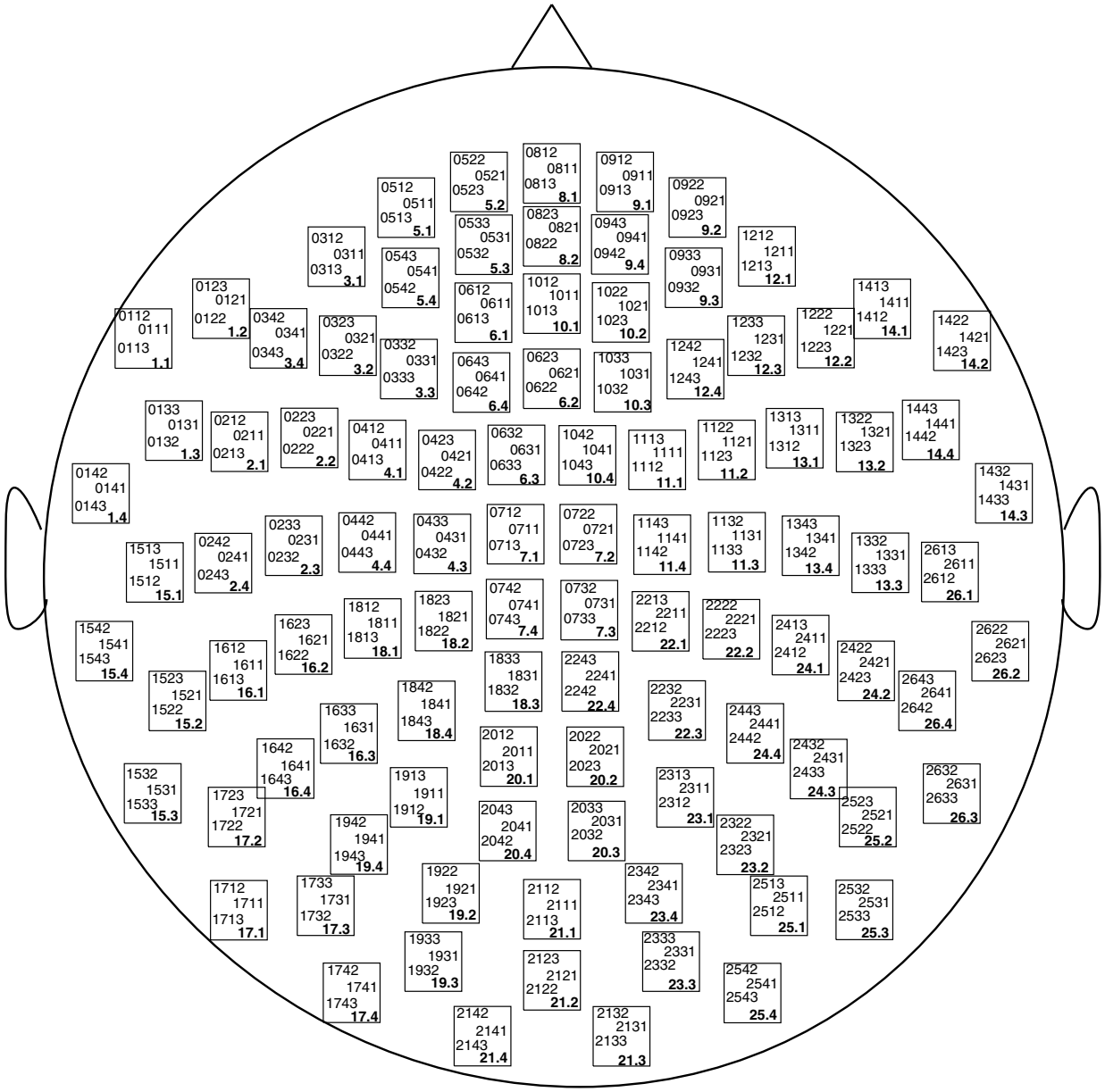


Figure 1.8 Layout of the sensor elements. The helmet shaped sensor array is flattened into a plane. For naming convention and gradient direction, see Fig. 1.9.

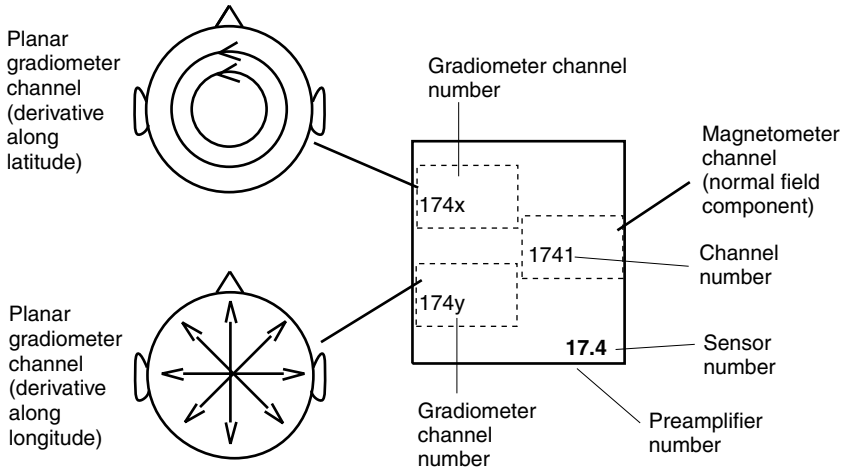


Figure 1.9 Naming convention. Depending on location, x=2 and y=3 or vice versa, refer to Fig. 1.8.

The first group, '01yz', is on the frontal left edge of the array; the last group, '26yz', is on the right edge of the array.

The third digit specifies an individual sensor in a group. Typically four sensors belong into a group. E.g, 'xx2z' is the second sensor in a group.

The least significant digit is used to distinguish between three orthogonal channels of a single sensor element. Value '1' is always used for magnetometer channels. Values '2' and '3' are used for the planar gradiometers. E.g., 'xxy3' is a planar gradiometer channel of a sensor element.

Note: *The value '2' may refer to the derivative along either latitude or longitude depending on the location of the sensor. Same applies to value '3'. For details of the naming convention, see Fig. 1.9.*

Locations of the various sensor groups are illustrated in Fig. 1.10, 1.11, and 1.12.

Note: *The directions (left, right, front, back, top) are referred as to the patient's view.*

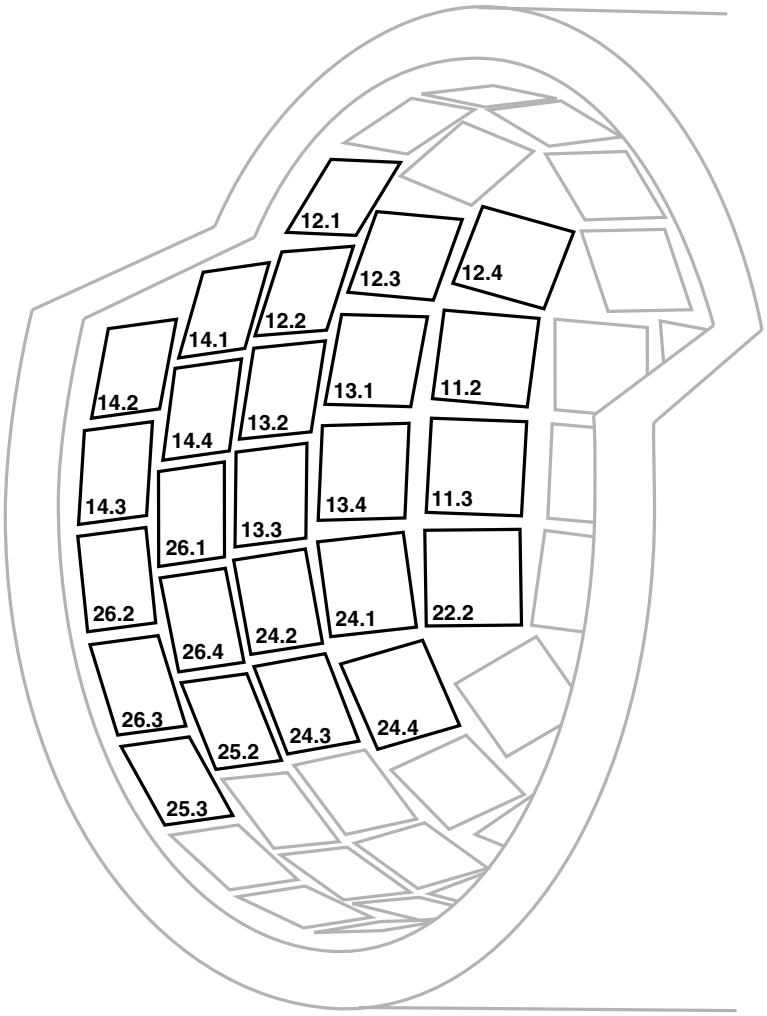


Figure 1.10 Numbering of sensor elements on the right side of the array.

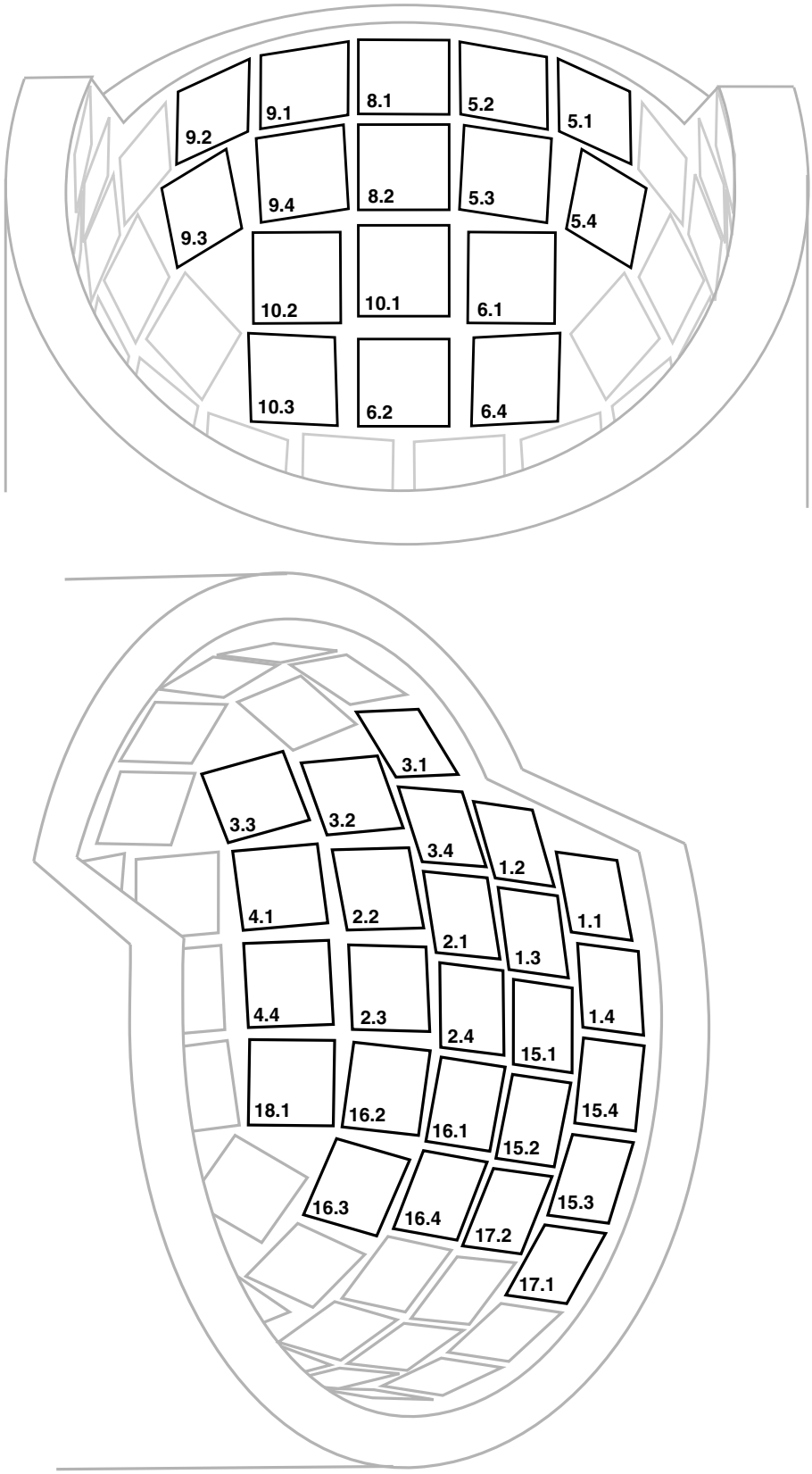


Figure 1.11 Numbering of sensor elements on the front (above) and left side of the array (below).

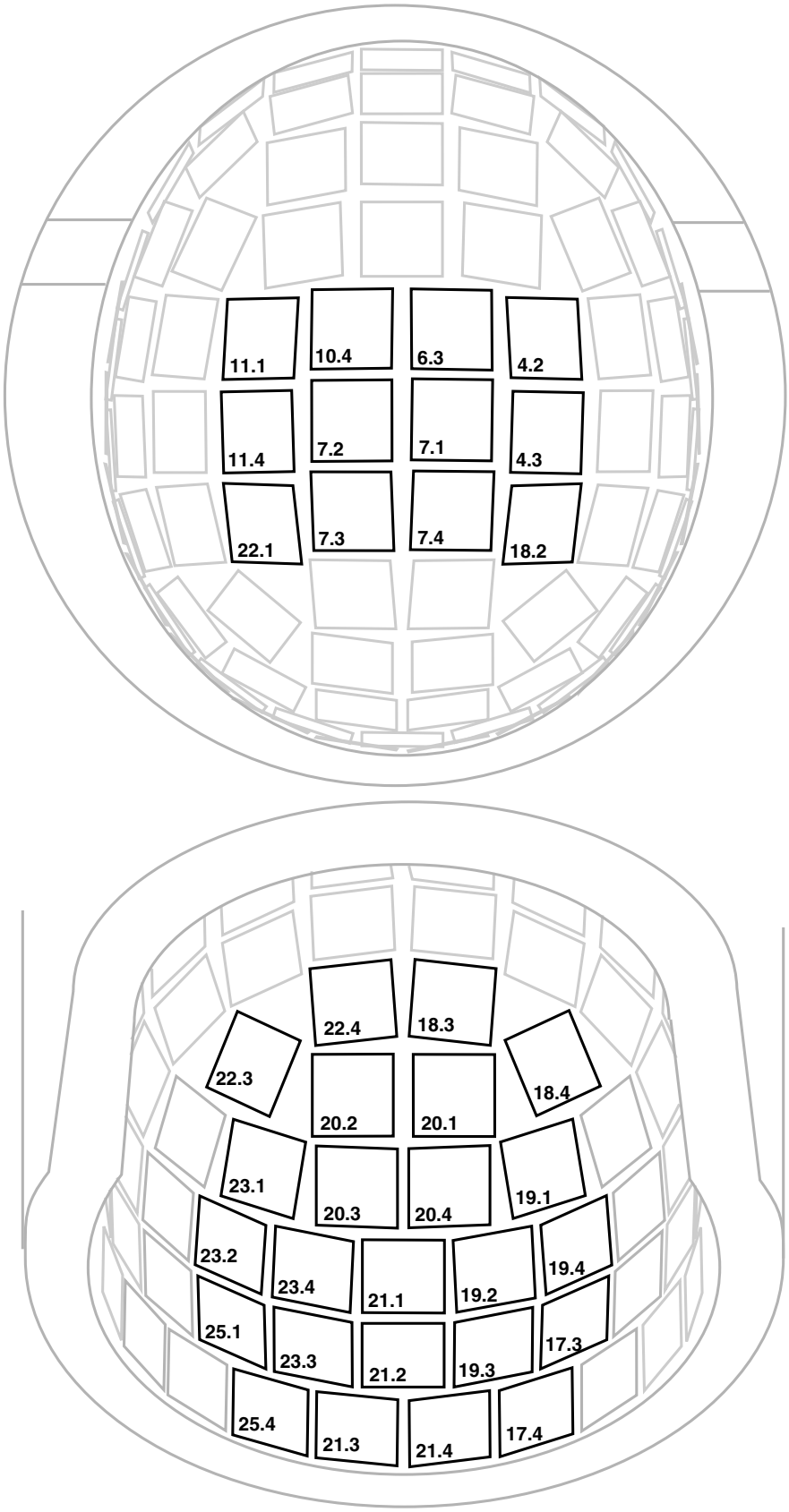


Figure 1.12 Numbering of sensor elements on the vertex (above) and back (below).

1.8 Patient positioning

The patient positioning system consists of a probe unit, couch, chair, chair fine-adjustment system, and pediatric comfort set to position the head of the patient in the sensor helmet. The probe unit is motor driven and enables three different measurement positions for patients and research participants. The patient couch is used for a supine measurement position. The supine position is a preferable position for infants, sleeping patients, and in extended recordings. For the supine position, the probe unit is set to the lowest position with the tilting angle of 0°. The patient chair is used for seated measurement positions, reclined and upright. For the reclined seated position, the tilting angle of the probe unit is set to 60° with respect to the supine position, and the upright seated position to 68°. The optional chair fine-adjustment system is used for horizontal positioning of the patient chair and reclining of the chair backrest. The optional pediatric comfort set enhances the positioning of pediatric patients and research participants. For information on patient positioning, see *Elekta Neuromag® TRIUX Patient Positioning Instructions for Use*.

If the internal helium recycler is installed, the probe unit also has a special liquefaction position, where reliquefaction of helium is optimal. The liquefaction position is not intended to be used for MEG measurements.

Figure 1.13 Measurement in supine position.

Figure 1.14 Measurement with patient seated. The probe unit has reclined and upright seated positions with slightly different tilting angles.

1.9 MEG electronics

The MEG electronics unit is used for reading out and amplifying the electrical signals from the SQUIDs. The electronics boards include preamplifiers for SQUID readout inside the probe unit, and main boards containing analog-to-digital (A/D) converters, digital-to-analog (D/A) converters, and a digital signal processor for feedback loop, as well as adjustable digital anti-aliasing low-pass and high-pass filters, see Fig. 1.15. The main boards (SQC boards) reside inside the main electronics cabinet. The boards are connected to the data acquisition workstation for control and for data forwarding.

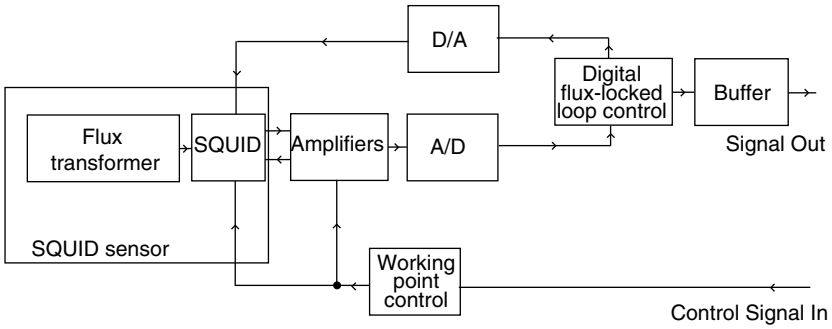


Figure 1.15 Block diagram of the SQUID electronics.

Radio frequency (RF) interference shielding of the SQUID electronics is provided using the filter unit which is an RF-shielded cabinet outside the magnetically shielded room with feedthrough filters for all cables and isolation of power lines. The signal cables between the preamplifier boards on the top plate of the Dewar and the filter unit go through two feedthrough tubes of the magnetically shielded room.

A dedicated fiber-optic link from the main electronics to preamplifiers is used for controlling the preamplifiers.

For block and schematic diagrams of the electronics refer to *Elekta Neuromag® TRIUX Technical Manual*. For explanation of the Internal Active Shielding, refer to *Internal Active Shielding User's Manual*.

1.10 Electrode interface

The electrode interface is located in the side panel of the gantry. The interface panel is shown in Figs. 1.16. and 1.17. It has 24 1.5-mm shrouded safety connectors for single electrodes for connecting the 12 bipolar bioamplifier electrodes. If optional unipolar EEG channels are installed, there are 1, 2, or 4, depending on the number of channels, 32-pin male connectors (32 channels each) for connecting the electrode cap or electrode headbox. Separate sockets are provided for the reference (REF) and ground (GND) electrodes.

Figure 1.16 The electrode interface panel is at the probe unit side. Depending on site, it may also be located on the other side.

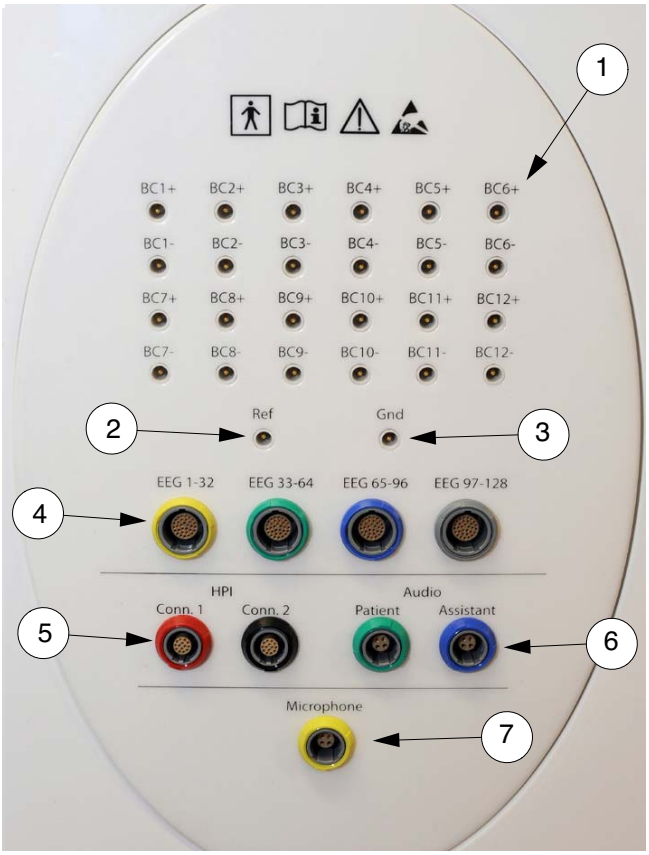


Figure 1.17 *The side panel of the gantry containing the electrode interface. 1:Bipolar single-electrode connectors for bioamplifier channels, 2: reference electrode connector, 3: ground electrode connector, 4: optional multipole connectors (32 channels each) for EEG channels, 5: HPI connectors, 6: audio interface connectors, 7: microphone connector.*

The electrode cap, see Fig. 1.18, allows a convenient way of attaching a large number of electrodes to predefined places. For instructions how to use the cap, see separate manual supplied with the cap. Caps with different electrode configurations are available upon request from Elekta Oy. Alternatively, separate electrodes can be connected into a headbox, see Fig. 1.19. Using the electrode cap or headbox the patient can be prepared outside of the shielded room and the cap or headbox plugged in the electrode interface panel when the actual measurement starts. For discussion on selection and use of electrodes and electrode caps see sections 2.5 and 3.3, and 3.4.

Figure 1.18 The electrode cap.

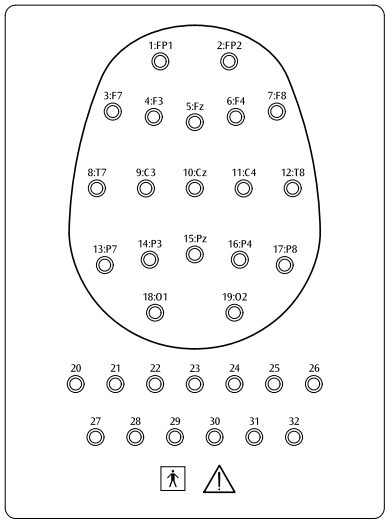


Figure 1.19 The electrode headbox for 32 unipolar channels. Reference and ground electrodes are connected to side panel connectors. Cable (separate) not shown.

1.11 Bioamplifier/EEG electronics

The preamplifier unit for bioamplifier/EEG channels is located inside the probe unit. It is fully software-controlled and it does not contain any switches, connectors, or other parts the operator needs to access.

The 12 bioamplifier (polygraphic) channels are bipolar (differential). Differential channels can be used, e.g., to measure bipolar electrocardiographic (ECG), electromyographic (EMG), electro-oculographic (EOG) auxiliary signals.

The EEG channels (optional 32, 64, or 128 channels) are unipolar (single-ended), using a common reference from reference electrode.

The gain and high-pass frequency can be set from three pre-defined values. A dc mode is also provided. Unused channels can be deactivated by software, eliminating the need of grounding jumpers in input. A built-in test oscillator can also be activated by software to test its operation and to verify the calibration. The interface of the channel control is explained in *Elekta Neuromag Data Acquisition User's Manual*.

For potential equalization between the isolated preamplifier and the patient, it is necessary to connect the patient to the isolated signal ground of the preamplifier over a ground (GND) electrode. However, to limit the patient current to a safe level, the preamplifier signal ground connection is provided through a current-limited ground driver connected to the GND terminal of the electrode interface panel.

The reference (REF) electrode is internally buffered and it is normally selected as the common reference for all the single-ended channels. To facilitate common-mode disturbance rejection, e.g. to reduce line-frequency ripple and drifts, the reference electrode can also be connected as ac input to the ground-driver circuit to provide potential equalization between patient and preamplifier signal ground. This so-called active grounding is effective at frequencies above 5 Hz.

During measurements, both reference and ground electrodes must be connected. The place of the ground electrode is not critical, typically it is placed to some inactive area, like on the cheek. If the reference and ground electrodes are left out, common-mode potential of the patient with respect to the preamplifier common potential may saturate the amplifiers, and active grounding does not work without the reference electrode.

The feedthrough unit isolates the Bioamplifier/EEG front end from the main electronics with optocouplers, i.e., there is no galvanic contact to the rest of the electronics. The feedthrough unit also eliminates RF interference from the data acquisition workstation. The feedthrough unit also houses the isolated power supply for the electrically floating front end. The modules in the feedthrough unit do not contain any parts the operator needs to access nor are there any adjustable parameters.

The Bioamplifier and EEG main electronics contains Signal Acquisition boards (SAM) with analog-to-digital converters and signal processors for filtering and other on-line operations. The boards are connected to the data acquisition workstation for control and for data forwarding. All A/D conversions are started simultaneously, synchronized with MEG channels and the sampling rate is the same as in MEG channels.

The main electronics includes a dedicated fiber-optic link for controlling the preamplifiers.

For block and schematic diagrams refer to *Elekta Neuromag® TRIUX Technical Manual*

1.12 Auxiliary electronics

1.12.1 Head position indicator (HPI)

The head position indicator is based on coils, see Fig. 1.20, Elekta part number NM23880N, placed on known locations on the head. Coils can be energized by a coil driver card with currents of different frequencies. The excitation signal is provided by the main electronics. Color coding of the HPI coil channels is given in Table 1.1.

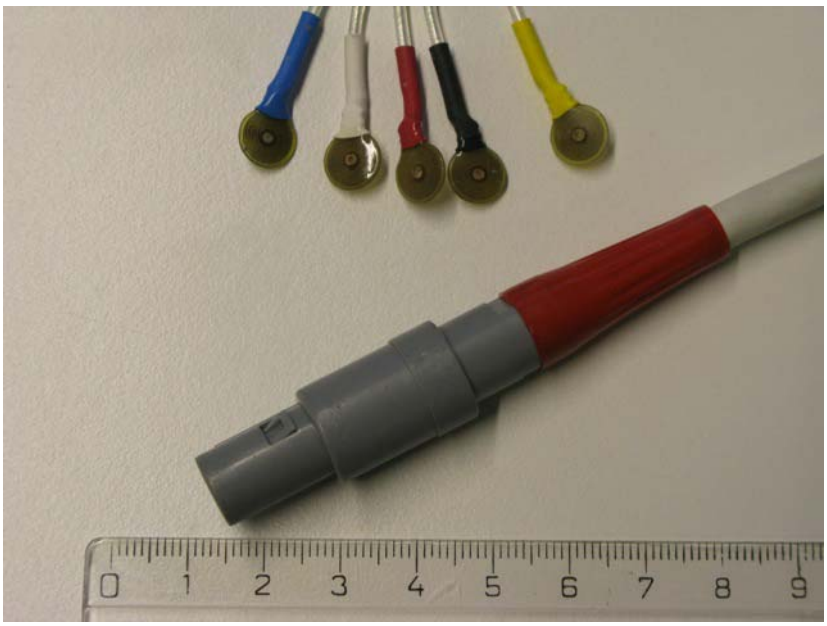


Figure 1.20 Head position indicator coils.

Table 1.1 HPI channel coding

Coil number	Color
1	Blue
2	White
3	Red
4	Black
5	Yellow

A 3-dimensional digitizer (manufacturer: Polhemus, Inc, USA; see Fig. 1.21) is connected to the data acquisition workstation. It is used in the preparation phase before MEG measurement to digitize the positions of the head position indicator coils as well as the landmarks on the head. The locations of the landmarks are used to establishing a coordinate transformation between MEG and MRI (magnetic resonance imaging) data. To allow slight movements of the patient during the digitization, non-magnetic goggles with a separate reference receiver are provided. The transmitter of the 3-D digitizer is attached to the back of the digitization chair, see Fig. 1.23.

Note: *The 3-D digitizer power supply must be connected to mains via the isolation transformer, see Fig. 1.22.*

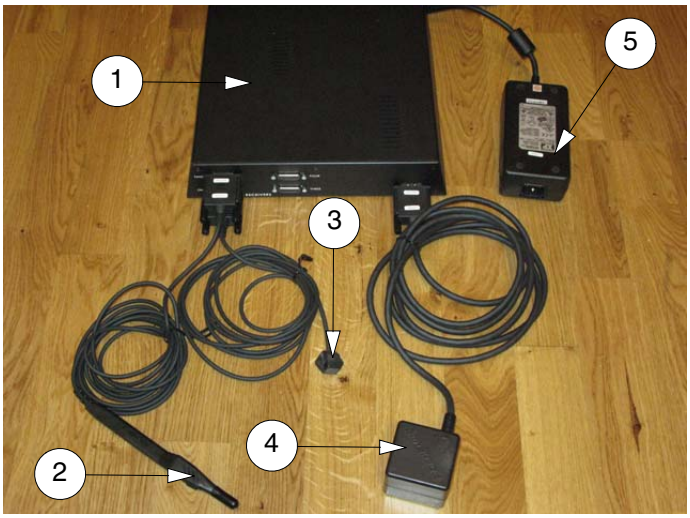


Figure 1.21 *3-D digitizer unit. 1: Main unit, 2: digitizing stylus, 3: separate reference receiver attached to goggles (not shown), 4: transmitter coil, 5: power supply. The stylus is connected to receiver connector labelled "One" and the reference receiver to connector labelled "Two".*

Figure 1.22 *The 3-D digitizer unit power supply (left) must be connected to mains via an isolation transformer (right) supplied with the Elekta Neuromag® TRIUX.*

Figure 1.23 Wooden chair for digitization. Note that the transmitter coil at the back of the chair must be positioned properly to avoid problems in digitization, see section 3.3.4.

1.12.2 Liquid helium level meter

The liquid helium level inside the Dewar is measured with a superconducting probe whose resistance is dependent on the length of the part immersed in liquid. The meter board reads the resistance and converts the reading into digital form which can be transferred to the computer. A local display is under the hatch covering the liquid helium filling port at the up-front face of the probe unit, see Figs. 1.2 and1.24. It is used for monitoring the liquid helium level during helium refilling. For helium refill instructions, see section 4.4.

Figure 1.24 The liquid helium level display is under the hatch covering the liquid helium filling port. The liquid helium measurement can be initiated and stopped with the pushbutton.

1.12.3 Audio electronics interface

Audio electronics interface, see Fig. 1.17, is provided in the side panel of the gantry for the delivery of auditory stimuli. Two sets of headphones (stereo) can be connected, one for the patient and one for the eventual assistant. The microphone connector is for the intercom microphone.

1.12.4 Phantom

A phantom is provided for checking the Elekta Neuromag® TRIUX performance, see Fig. 1.25. It contains 32 artificial dipoles and four head-position-indicator coils. The phantom is based on the mathematical fact that an equilateral triangular line current produces equivalent magnetic field distribution to that of a tangential current dipole in a spherical conductor, provided that the vertex of the triangle is at the origin of the sphere. For phantom measurements, see section 7.2.

Figure 1.25 The phantom.

1.12.5 Patient surveillance

An optional closed circuit TV-monitoring system (CCTV, see section 7.4) is provided for on-line monitoring the patient inside the magnetically shielded room during the measurement. A two-way voice intercommunicator (option, see section 7.3) is used for communicating with the patient inside the magnetically shielded room during the measurement.

1.12.6 Interface to stimulus electronics

A 16-channel trigger pulse (digital) input-output interface, see Section 7.1, is provided for synchronizing the measurement software and stimulators (not supplied in the standard configuration) used for evoked-response studies. The interface unit is optically isolated from the main electronics.

The RF-shielded stimulus electronics cabinet, see Fig. 1.4, is used to prevent possible RF disturbances caused by stimulus devices from entering the magnetically shielded room. RF-filtered feedthroughs are available between the inside and the outside of the cabinet. Active digital circuitry, e.g., a computer inside the stimulus cabinet should be avoided.

1.13 Computers

The standard system configuration typically includes a workstation for performing and controlling measurements and on-line processing (acquisition workstation). An optional second workstation is available for off-line analysis of data (analysis workstation). Additional mass storage and output devices can be added according to need. For schematic and block diagrams, refer to *Elekta Neuromag® TRIUX Technical Manual*. See also Figures 1.1 and 1.4.

1.14 Cryogenic equipment

The liquid helium cooling the SQUID sensors evaporates slowly and, unless the system is equipped with an internal helium recycler, must be refilled regularly, typically once a week. A siphon is used to transfer liquid helium from a storage container to the Dewar when a refill is needed. It is a flexible, vacuum-insulated double-wall tube.

The helium gas evaporating from the Dewar is routed typically via a special exhaust to the outside air or to a gas-recovery system (if available at site).

The Elekta Neuromag® TRIUX is also connected to a safety vent to outside of the building, comprising flexible safety exhaust duct and a helium safety exhaust duct feedthrough. The safety vent line is built on site as part of site preparation.

A block diagram of the cryogenic equipment using liquid and gaseous helium is shown in Fig. 1.26.

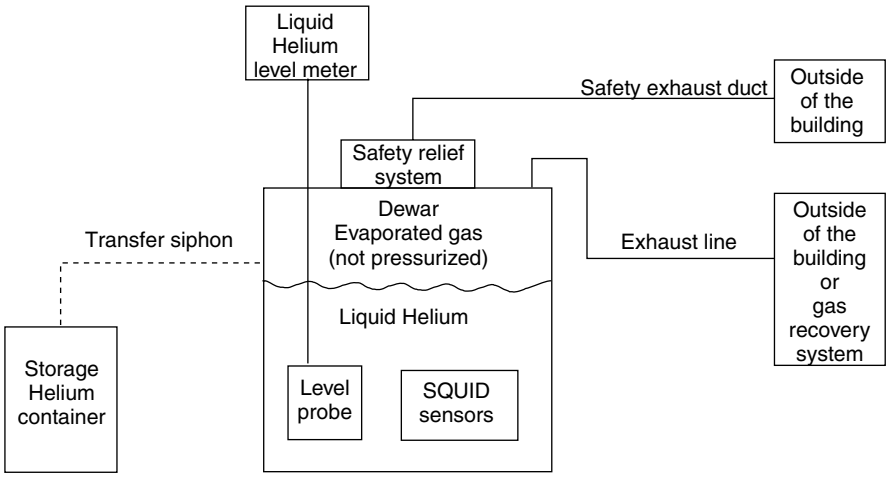


Figure 1.26 Block diagram of the cryogenic equipment using liquid and gaseous helium (without internal helium recycler).

1.15 Internal helium recycler

As an option, Elekta Neuromag® TRIUX can be equipped with an internal helium recycler.

The internal helium recycler is a closed-loop helium reliquefaction system designed to be integrated into and used with an Elekta Neuromag® TRIUX MEG system. The internal helium recycler collects the helium gas that boils off from the MEG system and automatically liquefies it back into the MEG system. To prevent interference to the MEG system during MEG measurements, the internal helium recycler liquefies helium only when MEG measurements are not made, that is, primarily by night. The user plans the daily measurement schedules taking into account the operation times of the internal helium recycler.

With the internal helium recycler, the weekly helium refills can be avoided, as the refill interval changes to, roughly, once a year. However, it is always possible to add liquid helium, if needed.

The internal helium recycler is available both as:

- factory-installed to Elekta Neuromag® TRIUX (NM25000N)
- retrofitted (NM25135N) to Elekta Neuromag® TRIUX (NM23900N).

The internal helium recycler adds modules to the MEG system, but for the most part, the MEG system stays unchanged.

For more information on the internal helium recycler, see *Elekta Neuromag® TRIUX Internal Helium Recycler, Instructions for Use*.

2 Safety instructions and precautions

CAUTION 2.1: This section contains important information concerning the safe use of the product and maintaining reliable operation. Read the instructions entirely before using the product.

For units equipped with the internal helium recycler, see also the safety instructions in *Elekta Neuromag® TRIUX Internal Helium Recycler, Instructions for Use.*

2.1 Use of liquid helium

The Dewar is a vacuum-insulated vessel containing liquid helium at a cryogenic temperature. Since the cold liquid is potentially dangerous, certain precautions must be made in order to assure completely safe operation of the device.

WARNING 2.1: Wear protective gloves to avoid skin contact with liquid helium or exhaust gas or any objects that have recently been in direct contact with liquid or evaporated gas. During transfer, monitor pressure gauges and do not let pressure to rise above limits described in section 4.4.

WARNING 2.2: Beware of the extremely cold, non-life-supporting gas.

2.1.1 Properties of helium

- Helium liquid or gas is nonflammable and nontoxic
- Helium is one of the noble gases (He, Ne, Ar, Kr, Ra)
- Helium gas is odorless and colorless
- Helium gas is seven times lighter than air
- Helium gas is not life-supporting: it may replace air thus reducing the relative oxygen content in closed rooms if evaporated rapidly in large quantities, resulting in a risk of suffocation
- Boiling point 4.2 K (–269°C or -452°F)
- Density of liquid 0.125 kg/liter
- The liquid evaporates very easily (latent heat of evaporation 20.9 kJ/kg = 2.6 kJ/liter).
- One liter liquid corresponds to approx. 750 liters of gas (+20°C, 101,3 kPa).
- Skin contact with liquid or cold gas or cooled objects may cause severe frostbite
- Flow of cold helium gas makes a very good thermal contact with any surface it passes by; unprotected skin cools below freezing point in seconds

- Dangerous pressures may arise as a result of rapid vaporization inside closed vessels
- Liquid helium can cryopump other gases such as nitrogen, oxygen, water vapor, which at liquid helium temperature solidify. This may lead to blocking of the vents and consequently buildup of dangerous pressures in cryogenic vessels. See Sect. 2.1.3.

2.1.2 Structural safety

- The Dewar has a good thermal insulation to minimize helium boil-off.
- The insulating vacuum is properly sealed and all parts are fabricated leak-tight.
- Because of the thermal insulation, all parts of the gantry that may come into contact with the user remain at room temperature at all times during normal operation.
- The cooling capacity of the evaporating cold helium gas is employed to partly minimize the unavoidable heat leak from room temperature to the cryogenic temperature. Therefore, under normal operating conditions the outflowing exhaust gas is warmed up to essentially room temperature before leaving the Dewar. However, during increased outflow occurring normally only during liquid helium refills, the gas exiting from Dewar may be extremely cold. Skin contact with the exhaust line tubings should then be avoided.
- The helium space of the Dewar is vented to prevent buildup of pressure due to evaporating liquid helium.
- The outflowing gas is directed via an exhaust line to open air outside the building or to gas-recovery system (if applicable).
- The dedicated exhaust line together with the sealing of the helium space of the Dewar keeps a slight overpressure to prevent cryopumping of other gases from the atmosphere.
- The top flange of the Dewar is equipped with pressure relief valve and a rupturing membrane which will let gas out, should the pressure inside the Dewar rise for some reason. Also, a pressure gauge is attached on the top flange.
- The safety pressure relief which is based on rupturing membrane vents via a separate safety exhaust duct to outside of the building.
- The gantry is designed to keep the Dewar in proper position.

WARNING 2.3: The structural integrity of the Dewar should not be damaged in any way. Absolutely no holes may be drilled to the Dewar.

- Hard shocks to the Dewar must be avoided.

WARNING 2.4: The Dewar vacuum must not be opened to atmospheric pressure under any circumstances.

- The Dewar is equipped with a vacuum lock valve and is sealed by means of a blind flange to prevent accidental opening and leakage through the vacuum lock. The vacuum lock is operated with a separate vacuum-valve adapter.

CAUTION 2.2: The exhaust line must be open at all times

WARNING 2.5: Do not tilt or tip the storage Dewar.

- The exhaust line should be reasonably leaktight and lead out of the magnetically shielded room to open air or to the recovery system.
- The magnetically shielded room must be properly ventilated. For details, see *Elekta Neuromag® TRIUX Site Planning Guide*.
- The overpressure inside the Dewar (with respect to atmospheric pressure) should be kept below 10 kPa (0.1 bar) even during refill. Should the pressure rise, a safety relief valve will open at 10 kPa (0.1 bar). If for some reason the pressure rises even further, a rupturing membrane will break approximately at 60 kPa (0.6 bar), letting gaseous helium to escape via the safety exhaust duct to the outside of the building.
- The fixed L-siphon, see section 4.4, used in the helium refills and located on top of the Dewar is normally sealed with a plug that has an additional relief valve which effectively vents the cold helium space directly into the atmosphere through the siphon in the unlikely case all other exhaust routes get blocked.
- When transferring liquid helium, transfer instructions should be obeyed, see section 4.4.
- Transfer of liquid helium can be carried out by a single person. For safety reasons it is, however, highly recommended that another person is present to assist or call for help in possible abnormal conditions. This is especially important if the transfer is carried out off-hours.

WARNING 2.6: Do not leave anybody alone inside a closed magnetically shielded room without the presence of another person outside the room!

- The liquid helium level and boil-off rate should be monitored regularly. Substantial increase of boiloff rate may indicate the need to re-evacuate the vacuum. The vacuum pump-out must be left to trained service personnel.
- See also Section 2.1.3 concerning cryopumping.

2.1.3 Cryopumping

At liquid helium temperature all common materials are solid. This means that the vapor pressure of for example the atmospheric gases (nitrogen, oxygen, water) is practically zero in any volume containing liquid helium. This leads to so-called cryopumping of these gases: any helium vessel left open to atmosphere will very effectively suck in large amounts of these gases. Water freezes and may block the helium vessel or a transfer siphon. Oxygen in the probe unit Dewar causes large irregular low frequency drifts of MEG signals because the magnetic susceptibility of the paramagnetic oxygen in its solid form is very high.

CAUTION 2.3: To prevent cryopumping, observe the precautions listed below:

- All helium vessels must be sealed from the atmosphere and properly vented, via a back flow valve or a sufficiently long and narrow exhaust tube.
- Do not leave the fixed L-siphon at the top of the Dewar open. Block the opening with the dedicated plug when not transferring helium.
- Do not leave the boil-off tube vent directly into the room. Use silicon hose to lead the exhaust vent out from the magnetically shielded room. If the hose breaks during transfer, replace it with a new hose as soon as possible
- Do not remove the fixed siphon or the boil-off tube from the top plate. The openings must be plugged with rubber bungs (provided in the Cryogenic Accessory Kit) if the fixed siphon or the boil-off tube are ever removed even for a short while.
- If the safety exhaust rupture membrane accidentally breaks, the opening must be plugged with a large rubber bung and the membrane replaced (provided in the Cryogenic Accessory Kit) .

2.2 Electrical safety

All Elekta Neuromag® TRIUX SQUID sensor electronics is operated using low-voltage (max. 15 V=, 24 V~) power supplies connected to the mains through an isolation transformer. To avoid electrical interference, most parts are shielded and grounded (class I according to IEC 60601-1). The probe unit is operated inside a magnetically shielded room to avoid electromagnetic interference.

2.2.1 Patient environment

Since medical electrical equipment (such as Elekta Neuromag® TRIUX) may be used simultaneously or connected with other equipment (for example with third-party devices like stimulators or auxiliary non-medical devices) forming a medical electrical system, the concept of patient environment is important for electrical safety.

The patient environment is defined as any volume in which intentional or unintentional contact can occur between a patient and the medical electrical equipment or between a patient and other persons touching the parts of the medical electrical equipment. Inside the patient environment, the level of electrical safety of all parts belonging to the medical electrical system must comply with that of medical devices. Outside the patient environment, the level of safety of the system parts must be equivalent to their respective international safety standards, depending on whether the medical electrical system component is medical or non-medical.

Examples of non-medical devices that might be used simultaneously with a medical devices include, for example, computers connected to a drive a stimulator (which itself is a medical device if connected to a patient inside patient environment). The electrical safety of such computers must comply with a level equivalent to standard IEC60950 (normal IT equipment) if located outside of patient environment. However, the safety of all parts inside the patient environment must comply with a level equivalent to the medical standard IEC60601-1.

No exact dimensions for the patient environment are given in the standards. A value justified in practice is an area within 1.5 meters from the patient while positioned for diagnosis. For an MEG system, this means in practice that

- the inside of the magnetically shielded room except for the frontmost wall of the magnetically shielded room is within patient environment
- an area 1.5 meters around the 3-D digitizer is inside the patient environment

2.2.2 Patient connections

All applied parts of MEG equipment connected to the patient are made of electrically insulating materials only. They are classified as BF (body floating) type according to IEC 60601-1.

Helmet-shaped sensor assembly is located inside a double-walled isolating (fiber reinforced plastic, vacuum gap) Dewar vessel, making no electrical contact to the patient. The device does not generate radiation. During the measurement, it is not possible for the patient to get in contact with grounded parts.

Head position coils on small printed circuit boards are spiral-shaped. The coils are driven from an isolated power supply, connected to isolated leads, and cast with isolating epoxy. No electrical contact to the patient is thus made. Current fed to coils is typ. 100 µA, and the resulting field less than 1 nT.

The Bioamplifier/EEG subsystem contains an applied part of BF type (body floating) in galvanic contact with the patient. The applied part has been carefully designed and built to fulfill the safety regulations as set by international standards IEC60601-1 and IEC60601-2-26. The Bio/EEG preamplifiers are optically isolated, and the power supply of the preamplifiers is provided with safety isolation transformer.

WARNING 2.7: To eliminate any risk of electrical shock hazard the Bioamplifier/EEG subsystem must be properly installed by authorized service personnel and used as part of the Elekta Neuromag® TRIUX according to manuals and assembly instructions. Internal cabling must not be changed.

WARNING 2.8: The Bioamplifier/EEG subsystem is not certified for use with implanted electrodes. It may only be used for recording potentials from the intact body surface.

WARNING 2.9: After electrodes have been attached onto the patient's head, avoid contact of conducting parts of the electrodes, including reference (REF) and isolated preamplifier signal ground (GND) electrodes, to actual ground or other conducting parts which may be grounded or become live at mains voltage. Do not ground patient to actual ground (e.g. the wall of the magnetically shielded room). Do not place conducting grounded objects near the patient that he/she may touch while connected to the equipment.

Note: *The Bioamplifier/EEG subsystem cannot be used as a standalone unit outside of the magnetically shielded room.*

WARNING 2.10: Do not use conducting EEG paste to attach HPI coils.

There are no internal operator-serviceable parts inside. Head position indicator coils, electrode caps, headboxes, and electrode interface in the side panel of the gantry are the only operator-accessible parts of the Bioamplifier/EEG subsystem. Use only headboxes and electrode caps supplied with the product or available as options.

2.2.3 Power supplies and grounding

The main electronics is powered through medical safety-isolating transformer connected to electronics cabinet outlets. These sockects are intended only for main electronics equiment located inside the cabinets. Connecting other electrical equipment to them effectively forms an medical electrical system, see also 2.2.5, and can result in reduced level of electrical safety. Also, internal power cabling must not be changed. For schematic diagrams of the powering, refer to *Elekta Neuromag® TRIUX Technical Manual*.

CAUTION 2.4: The power supply of the electronics must be connected only to the power outlets inside the electronics cabinet which are connected to mains via an isolation transformer. Do not connect other electrical equipment to these sockets as this may result in reduced electrical safety. Also, internal power cabling must not be changed.

CAUTION 2.5: The 3-D digitizer power supply unit must be connected to mains via an isolation transformer supplied with the Elekta Neuromag® TRIUX.

CAUTION 2.6: The isolation transformers also provide step-up or step-down voltage conversion if needed. Inside the main electronics cabinet the mains voltage is 230 V~.

CAUTION 2.7: The RF line filters in stimulus cabinet contain capacitors with large capacitance. Thus voltage may remain across terminals even after the power has been switched off from the filter. The filters have built-in resistors which discharge the terminals in less than 10 seconds. All shielding covers must be in place before applying power to the filter. The filters may only be installed permanently; mains plug connection of the filter is prohibited.

CAUTION 2.8: There are no operator serviceable parts inside the power supply units. Do not open the covers.

The Elekta Neuromag® TRIUX, except for the Bioamplifier/EEG and HPI applied parts discussed below, is permanently grounded (class I equipment according to IEC 60601-1) at a single point (main grounding point) located at the filter unit cabinet between the electronics cabinet and the magnetically shielded room, see Fig. 2.1.

CAUTION 2.9: The grounding cables must not be disconnected.

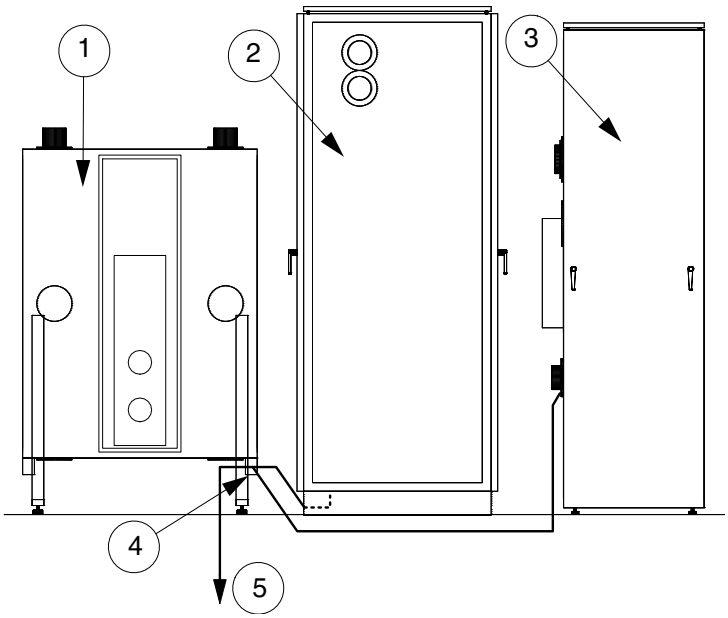


Figure 2.1 *Grounding principle. 1: RF feedthrough filter cabinet, 2: main electronics cabinet, 3: stimulus cabinet, 4: main grounding point, 5: to main gound at electric switchboard (building transformer ground).*

CAUTION 2.10: The Elekta Neuromag® TRIUX must not be grounded to any other place than the main grounding point. This is very important since otherwise ground loops will be formed resulting in artefacts in the measurements.

The grounding of Elekta Neuromag® TRIUX has been carefully designed. Do not add any equipment to the system or change any cabling without considering the possible side-effects. If in any doubt, contact Elekta.

The applied parts of HPI coils, bioamplifiers, optional EEG channels are electrically floating, i.e., isolated from ground. They must not be grounded in any circumstances. For potential equalization between the isolated preamplifier and the patient it is necessary to connect the patient to the isolated signal ground of the preamplifier. For that purpose, a terminal labelled ”GND” is available in the electrode interface panel. To limit the patient current flowing through that terminal to a safe level, the preamplifier signal ground connection is provided through a current-limited ground driver of the preamplifier, see section 1.11 and Appendix. The isolated preamplifier signal ground is not directly accessible when headboxes and electrode caps supplied with the product or available as options are used. The isolated preamplifier signal ground, which is only available internally, must not be connected directly to patients as the maximum allowable current may be exceeded in a fault condition.

2.2.4 Fire safety

The power supply units are protected by mains (primary) fuses. All fuses are accessible at the back plane of the MEG preamplifier power supply unit with the correct values of the fuses marked in the immediate vicinity. A “T” before the rated current in amperes indicates slow (time-lag, slow blow) type and a “F” fast type. If no type has been indicated, use fast type fuses.

CAUTION 2.11: To avoid risk of fire and of electric shock ALWAYS use only correct-rated fuses as replacement.

The Elekta Neuromag® TRIUX is also equipped with temperature sensors in power supplies to detect over-heating.

CAUTION 2.12: Overheating is normally a symptom of a fault. To reduce risk of fire the reason must be resolved if the thermal shutdown repeats.

The Elekta Neuromag® TRIUX is not category AP or APG (for definition, see Appendix). It is not intended, designed, nor certified for use within an environment containing flammable anaesthetic mixture with air, oxygen, or nitrous oxide.

WARNING 2.11: Do not bring flammable anaesthesics into the magnetically shielded room or into the equipment area of the Elekta Neuromag® TRIUX.

2.2.5 Third-party devices and other auxiliary user-supplied equipment

As described above in section 2.2.1, other equipment connected simultaneously to the patient or to the Elekta Neuromag® TRIUX form a medical electrical system. Such combination may compromise the electrical safety without proper precautions. Also, the electromagnetic compatibility, see section 2.6.1, may be jeopardized.

Elekta assumes responsibility only for third-party equipment or components that are expressly recognized as compatible by Elekta. Elekta assumes no responsibility for the compatibility, fitness for use, or safety of third-party equipment not expressly recognized as compatible by Elekta.

WARNING 2.12: The use of unapproved third-party equipment, may lead to serious injury and/or damage to the equipment.

To avoid risk of electrical shock, equipment supplied by the user and connected to patients must comply with isolation requirements similar to or better than this system. For connection of these devices, isolated and filtered power outlets are provided in the stimulus cabinet. Maximum current available is 10 A (total).

WARNING 2.13: Parts of user-supplied equipment inside the patient environment, see section 2.2.1, must fulfill leakage current requirements according to the norms IEC 60601–1 for medical electrical equipment with BF type applied parts or better. Although the individual devices fulfill the leakage current requirements set forth in standards, a possible hazard exists caused by the summation of leakage currents when several pieces of equipment are interconnected.

CAUTION 2.13: If any of the equipment connected to the the stimulus trigger interface unit is patient-connected, all other equipment connected to the same interface unit must fulfill the safety requirements of IEC 60601-1 for medical electrical equipment.

Note: *The power outlets in the electronics and stimulus cabinets may only be used for the connection of system components or equipment needed during service and maintenance operations (electronics cabinet) or for compatible user-supplied auxiliary equipment (stimulus cabinet).*

2.2.6 Defibrillators

Note: *The Bioamplifier/EEG subsystem is not protected against cardiac defibrillator discharge. Damage to the front end may result if a defibrillator is used on a patient connected to the electroencephalograph. In case of a need for defibrillation, disconnect the electrodes if possible. This is carried out quickly by unplugging the electrode cap or headbox connectors and the eventual single electrodes from the electrode interface panel.*

The Elekta Neuromag® TRIUX cannot be used with treatment devices feeding energy to the patient such as high-frequency surgical equipment.

2.2.7 Changes to the product

Any changes to the equipment provided by Elekta may only be performed by persons expressly authorized to do so by Elekta. Such changes must comply with best engineering practices, effective laws, and regulations that have the force of law within the applicable jurisdiction.

CAUTION 2.14: Changes, additions, or maintenance to the equipment performed by persons without appropriate qualifications, and training, may introduce risks of serious injury and/or damage to the equipment. Furthermore, such alterations may void the warranty of the Elekta Neuromag® TRIUX. No modification of this equipment is allowed without authorization from the manufacturer. If this equipment is modified, appropriate inspection and testing must be conducted in order to ensure safe use of the equipment.

2.3 Mechanical safety

The weight of the fully loaded Dewar including liquid helium and the Dewar supporting gantry cradle moving with the sensors is approximately 200 kg. To ensure that the gantry is prevented from falling down from the seated measurement positions or liquefaction position under any circumstances, it is equipped with two completely separate and parallel support mechanisms. The lifting motor and the safety latches on both sides of the cradle, engaged in the seated measurement and liquefaction positions, can both withstand alone a four-fold overload compared with the normal working condition. In supine position, the end stoppers prevent the cradle from coming out even if a fault occurs, e.g. the lifting rope breaks. To ensure safety even in case of a single fault the gantry must be in one of the three secured measurement positions with latches engaged while a patient is positioned under the gantry. For information on patient positioning, see *Elekta Neuromag® TRIUX Patient Positioning Instructions for Use*.

WARNING 2.14: The measurement position must not be changed while the patient is under the gantry.

WARNING 2.15: Do not place the patient under the gantry except when the green *OK* light is lit on the position indicator display.

The patient is released from the helmet in the reclined or upright seated measurement position by releasing the brake and the elevation mechanism of the chair and pulling the chair from under the gantry. For instructions, see *Elekta Neuromag® TRIUX Patient Positioning Instructions for Use*.

In the supine measurement position release the upper patient bed and pull it out. For instructions, see *Elekta Neuromag® TRIUX Patient Positioning Instructions for Use*.

CAUTION 2.15: Care should be excercised to prevent limbs, fingers, or toes being left between moving parts of the chair or couch and the gantry or doorway. Instruct the patient to keep hands on the table, armrests or on his/her lap.

Have the unit regularly serviced according to the maintenance program, see section 8.1. This must be accomplished by trained service personnel only.

2.4 Trapped flux in the sensors

Strong magnetic fields in the vicinity of the sensors may cause magnetic flux to be trapped in the superconducting thin films due to their limited capability of repelling magnetic flux completely. In particular, if magnetized objects like magnetic electrodes or hairpins are brought inside the helmet against the surface, flux trapping may occur.

Trapped magnetic flux in the dc SQUID manifests itself as a greatly reduced modulation depth of the flux vs. current characteristics. The point of operation also changes. As a result, the SQUID feedback loop may not lock any more after flux trapping or the noise level may be increased, resulting in deteroriated signal quality. Flux trapped in the flux transformer structures may manifest itself as discrete jumps in the output level causing rejections of evoked data.

Normal performance may, however, be recovered by detrapping, see section 2.4.2. In the detrapping procedure, the trapped flux is removed by increasing the temperature above superconductive transition temperature using heaters mounted on each triple sensor element. In order to minimize the delay due to the flux detrapping in a measurement certain precautions should be noticed.

2.4.1 Preventive measures

The only way of avoiding trapped flux is to avoid bringing permanently magnetized objects in the vicinity of the Dewar. Therefore:

- Items unnecessary for the measurement should be removed (hairpins, jewelry, eyeglasses etc.)
- Test the objects worn by the patient, particularly on the head like electrodes, before the patient goes under the gantry. In particular, test a new batch of electrodes before they are taken into use.
- To test whether an object is magnetic or not: First, test whether the object attaches to an ordinary bar magnet. If it does, the object is magnetic and it should absolutely be kept out of the magnetically shielded room. If the object is not attracted to the bar magnet, do a test with the Elekta Neuromag® TRIUX. Ask for someone to assist you in the test. First, carefully remove everything possibly magnetic from your pockets, wrist watch, belt, eyeglasses etc. Go with the object to be tested inside the magnetically shielded room and close the door. Ask the assisting person to start acquisition of data and watch the raw data display as described in the *Elekta Neuromag Data Acquisition User's Manual*. Wave your bare hand under the magnetometer helmet to verify that it does not cause any noticeable signals. Then, take the object under test in your hand and wave it first 1 m away from the helmet to see whether it causes any disturbances. If not, move it closer and finally under the helmet if still no disturbances are see. If, however, disturbances are seen the object is too magnetic for MEG and it should be avoided in measurements.

Note: *Do not bring the bar magnet inside or even close to the magnetically shielded room. Do not attach the bar magnet to the magnetically shielded room wall as it will magnetize the wall material to saturation, severely degrading the shielding performance.*

- Avoid bringing magnetic objects and devices (e.g. heavy tools or devices with electric motors) into the magnetically shielded room. If it is absolutely necessary, keep them as far as possible from the sensors and their power cables as far as possible from the probe unit. Nonmagnetic tools are also commercially available.
- Do not use electronic flash inside the magnetically shielded room.
- Avoid discharges of static electricity on any part of the probe unit. The humidity in the magnetically shielded room should be controlled according to *Elekta Neuromag® TRIUX Site Planning Guide*.
- The electrodes and electrode caps should be stored carefully, preferably hanging in dry room air. Do not keep the electrodes and the caps on a table where they might be contaminated with magnetic particles. Wash them carefully after each use (see cleaning instructions in section 8.7 and instructions supplied with the electrode cap).

Note: *The connectors used in the headbox may contain a thin intermetallic layer of magnetic material. To avoid magnetic artefacts during MEG measurements, do not bring the headbox close to the helmet and keep it steady. Put it on the couch or on the removable table of the chair at least 0,5 m away from the helmet. Do not put it in the patient's lap or on the chest as movement caused by respiration may produce an artefact. A detchable headbox support attached to the probe unit is also provided.*

2.4.2 Detrapping

The Elekta Neuromag® TRIUX triple sensors are equipped with heaters. To detrap a sensor, invoke program *Tuner* from the *Tools* Menu of the Data acquisition program. Then, activate the heater from the program. You can heat any sensor element (three channels) at a time or all sensor elements sequentially (*Heat all* command). Detrapping all channels takes about one minute. Measure the noise level of the sensor, and, if necessary retune the sensor. For further details, refer to *Sensor Tuner User's Manual*.

2.5 Electrodes

In combined MEG/EEG measurements, the choice of proper electrode materials and paste/gel is very important.

As the electrodes and the electrode cap are very close to the magnetometer sensors, they are particulary prone to cause magnetic artefacts. Even a thin layer of magnetic material or a small particle of ferromagnetic dust can cause magnetic artefacts to one or more MEG channels.

When operated in dc-coupled mode electrochemical battery potentials generated in electrodes are amplified by the preamplifier. This causes a risk of saturating the amplifiers. In fact, even in ac coupled mode saturation may occur if the electrochemical potential exceed specified limits (see *Elekta Neuromag® TRIUX Technical Manual*) since frontmost amplification stage is internally always dc coupled. Furthermore, if the connection between the electrode and skin is not stable movements tend to change the electrode potential and cause severe low frequency noise or drift.

Note: *The use of sintered Ag/AgCl electrodes is recommended since they are known to minimize the electrochemical battery potentials, they are non-magnetic, see section 2.4, and relatively easy to obtain. It is best to have all electrodes made of same material and to use the same electrode paste/gel. Specifically, all the electrodes of the unipolar channels and the reference channel must be of same material and use the same electrode paste/gel. In order to maintain good performance, the AgCl coating must cover the whole electrode surface; worn or scratched coating may result in electrochemical battery potentials saturating the amplifier. Sintered Ag/AgCl, because of their construction, resist mechanical wearing much better than coated solid metal electrodes*

Note: *Gold-coated electrodes are not recommended since most often they contain a magnetic intermetal layer making them incompatible with MEG measurements. Also, some commercially available Ag/AgCl electrodes contain nickel or other magnetic material; all electrodes must therefore be tested before using them with MEG, see section 2.4.1.*

The electrodes in caps supplied with the Elekta Neuromag® TRIUX as an option are made of sintered Ag/AgCl and tested to be non-magnetic.

Note: *Electrode caps available commercially elsewhere may be incompatible with MEG*

For cleaning, disinfecting, and maintenance of the electrodes, refer to Section 8.7 and electrode cap documentation.

WARNING 2.16: Avoid getting the electrode paste or gel to the eyes or mouth. Use only non-toxic pastes approved for clinical use.

2.6 Electromagnetic compatibility

CAUTION 2.16: Medical electrical equipment needs special precautions regarding electromagnetic compatibility (EMC). It needs to be installed and put into service according to the EMC information provided in this manual and *Elekta Neuromag® TRIUX Technical Manual*.

CAUTION 2.17: Portable and mobile RF communications equipment (e.g. mobile phones) can disturb medical electrical equipment.

WARNING 2.17: Do not use stimulators or other equipment containing magnetic material in parts in the immediate vicinity of the probe unit or which produce high electromagnetic fields inside the magnetically shielded room as this may deteriorate signal quality and lead to incorrect results.

Note: *Elekta assumes responsibility only for electromagnetic compatibility of such third-party equipment or components that are expressly recognized as compatible by Elekta. Elekta assumes no responsibility for the electromagnetic compatibility of third-party equipment not expressly recognized as compatible by Elekta.*

2.6.1 Electromagnetic interference

The probe unit including the Bio/EEG preamplifiers and the electrode interface is placed inside a magnetically shielded room, and all cables to the inside of the room have been carefully filtered. This immunity can, however, easily be corrupted by careless setups of additional equipment. This is especially important for MEG recordings.

WARNING 2.18: Radiofrequency (RF) electromagnetic intereference may deteriorate signal quality and lead to incorrect results. Do not use any own wiring leading from outside to inside of the magnetically shielded room without proper RF filtering.

To maintain high level of electromagnetic interference immunity, all cables coming to the magnetically shielded room must be properly filtered. Radiofrequency transmitters, like mobile phones as well as mains operated devices and active digital electronics inside the magnetically shielded room, must be avoided altogether. Use of the stimulus cabinet outside of the magnetically shielded room is highly recommended for other equipment. There is a direct access from the stimulator cabinet to the inside of the magnetically shielded room, and the stimulus cabinet is equipped with signal and mains feedthrough filters. Place, for example, the isolation units of somatosensory stimulators inside the stimulus cabinet. To avoid radiated intereference via cabling, digital electronics which is active during measurement should, however, be avoided also inside the stimulus cabinet.

2.6.2 Electrostatic discharges

Note: *The probe unit and the electronics contain static electricity sensitive components. To prevent flux trapping or permanent damage certain precautions are necessary. Pins or connectors marked with the ESD symbol should not be touched and connections should not be made to these connectors unless ESD precautionary procedures are used.*

Note: *It is recommended that the meaning of the ESD symbol should be explained to all staff involved in the use of the Elekta Neuromag® TRIUX. They should also receive training covering the precautionary procedures described below.*

Precautions to avoid damage to equipment due to static electricity:

- The properly grounded and shielded cabinets and racks are the most effective shield against damage. In normal operation, there are no parts inside the main electronics cabinet or the probe unit the user needs to access. Do not remove any covers and do keep the cabinet doors closed.
- Do not touch the pins of connectors or cables, the electronics backplane, or the electronics boards before grounding yourself properly.
- Ground yourself with a grounding wrist strap or by touching any metallic parts of the magnetically shielded room or inside the electronics cabinets. To minimize the danger of electric shock it is recommended to use a grounding strap specially made for this purpose that contains a built-in series resistance. Connect it to the cabinet frame or wall of the magnetically shielded room.
- To prevent static electricity discharge to preamplifiers while connecting or disconnecting head position indicator coils, electrodes or electrode caps, the relative humidity of the air inside the magnetically shielded room should be over 30%, preferably between 40% and 70% (see *Elekta Neuromag® TRIUX Site Planning Guide*).
- Leave electronics service to trained service personnel.
- Do not disconnect the electronics cables or boards from the top flange of the probe unit or electronics cabinet or any other internal cables.
- Handle electronics boards only on static-electricity-free surfaces
- All strain relievers and covers must be in place before connecting power to the electronics. Follow proper power-up instructions, see section 6.3.

2.7 Information security

All workstations delivered by Elekta are factory-configured with predefined user accounts and default passwords. Upon commissioning, all user passwords must be immediately changed to secure ones in order to protect the workstations against intrusions and malware.

CAUTION 2.18: Not following the instrucions presented here may cause incorrect operation of the system which can lead to an incorrect diagnosis, or disclosure of sensitive patient information.

To maintain information security, all users should change their passwords at frequent intervals and to keep the password in a safe place.

- Choose a password with at least 8 characters and a mix of different character types.
- Never use names, words found in a dictionary, phone numbers, dates, or simple combinations of the same.
- Never use a keyboard pattern, such as lines of keyboard keys or sequences of digits.
- Use a sequence of random characters, including a mix of upper and lower case letters, and punctuation marks.
- An easy way to generate a secure password is to start with a phrase, verse, or line from a song. Take first letters of words and transform some characters into numbers or punctuation marks resembling the original letter, also inserting additional punctuation and/or digits if appropriate. Use also a mix of upper and lower case.

Furthermore, the entire data acquisition system as well as all data analysis workstations must always be protected against intrusions by means of a firewall. Consult your Elekta service representative for further information on configuring the firewall hardware to protect the Elekta Neuromag® TRIUX.

Do not connect other devices to the data acquisition network, disconnect devices, or alter the data acquisition network or its configuration in any way.

When connecting other devices, except those that are explicitely allowed by Elekta, to the MEG laboratory side network, or changing the laboratory network configuration, the possible risks must be analyzed and handled, by the user organization.

If any other programs, except those explicitely approved by Elekta, are installed on the data acquisition workstation, including possible patches to operating system and other updates or upgrades, they must be validated by the user organization.

The web browser in the workstation installation is intended to be used only to browse files stored in the workstation and other safe locations. Though the operating system (Linux) is relatively safe, browsing files in Internet is still dangerous and not allowed. If you can browse the internet, please consult your IT or Elekta service since this means that your firewall is not properly configured.

Login access to the data acquisition workstation should be given only to persons who have right to access the patient information stored on the workstation. Although restricted visibility of the patient information is provided between project groups, the system architecture does not prevent unauthorized access to patient-specific information. To avoid exposure of patient information, do not include the name or other explicit identification information in any field of the patient record.

Note also that the workstations must be physically protected. The data on the disks is not encrypted and thus in principle accessible by anyone who has access to the physical disks. In addition to loosing sensitive information stored in the workstation, it opens may possibilities for several different kinds of attacs against the security, which may compromise also other systems which share user credentials like passwords.

2.8 Other warnings

MEG data can be inherently be explained by many different source distributions, and measurements often contain various kinds of artefacts. Data used for clinical purposes must be interpreted by a trained clinician who is capable of judging the relevance and quality of data.

WARNING 2.19: Only trained clinicians who are capable of judging the relevance and quality of data may interpret the data for clinical purposes.

Errors and artefacts in the data may, e.g., result from external interference or from patient head movements or inoptimal placement inside the probe unit helmet, especially for persons with small heads or for children.

WARNING 2.20: Excercise care when measuring and interpreting data from small infants or persons with small heads.

WARNING 2.21: Data quality should always be monitored during acquisition. Also, eventual interference should be checked before acquisition.

WARNING 2.22: Large metallic objects located near the 3D-digitizer may adversely affect the accuracy of the readings and thus the accuracy of source localization.

Note: *In case of studying patients or small children an accompanying person in the magnetically shielded room is highly advisable, particularly if it is likely that the patient cannot call for help or get out in case of emergency. Audio and video monitoring is also recommended. Test the audio and video monitoring before use.*

3 A typical measurement

3.1 MRI scan

If the anatomical magnetic resonance imaging (MRI) scan is required to overlay display of the MEG localization results, the MRI of the patient should be acquired and transferred into the Elekta Neuromag® TRIUX. This can be carried out after a measurement as well; MR imaging after measurment is even recommended if the patient has dental braces, fills or the like that could be permanently magnetized during MRI scanning.

3.2 Measurement preparations

Open the door of the magnetically shielded room. Check the inside of the room and remove unnecessary items. Large metallic and especially ferromagnetic objects should be avoided. Keep the room, and especially the chair, couch, and probe unit clean. Adjust the gantry to a secured measurement position as described in *Elekta Neuromag® TRIUX Patient Positioning Instructions for Use*.

Log in to the computer and start the measurement session as described in *Elekta Neuromag Data Acquisition User's Manual*. Check the liquid helium level from computer if needed. If applicable, set up the stimulation equipment for the particular measurement and test the stimuli. Test also audio and video monitoring.

Note: *If stimulation is used, it is important to test the stimuli before the actual acquisition. To prevent sensory damage or miscomfort to the patient and incorrect interpretation of measurement results, it is important to verify that the delivered intensities are correct and that the physical stimuli and their planned trigger line assignments match, e.g. there are no swaps or mixups.*

Set up appropriate values for the acquisition parameters like sampling rates and passbands on the acquisition program. Enter the patient data and measurement data. Set up on-line averaging if applicable. Verify that correct gantry position is shown on the main control panel.

The active MEG and bioamplifier/EEG channels and the sampling rate as well as the low-pass filter are selected from the acquisition setup dialog. MEG and bioamplifier/EEG signals are recorded synchronously, using the same low-pass and sampling rate settings. The acquisition program also controls digital high-pass filters of MEG signals as well as analog high-pass filters and gains of the bioamplifier and EEG channels. The gain and high-pass filter of bioamplifier and EEG channels are set in group. For biamplifier channels, it is also possible to set the gains and high-pass filters individually, and it is possible to assign each bioamplifier channel a specific type (such as EOG). Select also EEG/BIO active ground, see section 1.11, or Internal Active Shielding if they are used, see *Internal Active Shielding User's Manual*.

Note: *To prevent noisy signals from disturbing the analysis, switch noisy as well as unused bioamplifier/EEG channels off from data acquisition. Several unused but active bioamplifier/EEG channels may cause spurious oscillations of isolated signal ground of the preamplifier, which propagate to all bioamplifier/EEG channels. The bio/EEG pre-amplifiers have built-in circuitry to deactivate unused channels. The acquisition control software automatically controls this circuitry.*

Note: *It is recommended to switch the EEG/BIO active gnd temporarily off when the patient electrode leads are connected/disconnected to the system. If there is a low level of mains interference in the signals active gnd may be left out even during the measurements. Make sure that the impedance checking should be enabled only when all connections including the ref and gnd connections have been made.*

For details of the data acquisition software, see *Elekta Neuromag Data Acquisition User's Manual*.

3.3 Preparation of the patient

To avoid magnetic artefacts, ask the patient to remove all metal objects he/she is wearing. Remember especially hairpins, the watch, and jewelry worn on the head. Wearing special clothing without any hooks etc. may be necessary since all ferromagnetic materials cause magnetic artefacts. Attach head position indicator (HPI) coils and eventual EOG and EEG electrodes or caps as described below.

After electrodes have been attached onto the patient's head, avoid contact of the electrodes, including reference (REF) and isolated preamplifier signal ground (GND) electrodes, to actual ground or other conducting parts which may be grounded or become live at mains voltage.

WARNING 3.1: Do not ground patient to actual ground (e.g. the wall of the magnetically shielded room). Do not place conducting objects near the patient that he/she may touch while connected to the equipment.

3.3.1 Attaching the head position indicator coils

Take a head position indicator (HPI) coil set and verify visually that the coil surfaces are not damaged. If necessary, replace the HPI coil set with a spare part available separately (part number NM23880N).

Attach the HPI coils to the patient using skin tape (such as 3M™ Micropore™ Tape or 3M™ Tegaderm™ dressing, 3M Corporation, St. Paul, MN, USA, or equivalent) or adhesive washers (such as Gereonics 450097, Gereonics Inc, Escondido, CA, USA, or equivalent). Two of the coils are placed frontally on both sides near the hair line while two others behind the ears as high as possible near the hair. The fifth coil can be placed in the upper parietal region, preferably somewhat off midline. See also Fig. 3.1 and Table 3.1. Do not place the fifth coil directly on vertex as it may interfere with the Internal Active Shielding if used. Avoid the locations of the zero detectors when placing the head position indicator coils in order to prevent this problem. Refer to *Internal Active Shielding User's Manual* for zero detector locations. Usually, the coils should be placed high enough that they will be well inside the sensor array area.

WARNING 3.2: Do not use conducting EEG paste to attach HPI coils.

Figure 3.1 HPI coils.

Table 3.1 HPI coil identification

Coil number	Color
1	Blue
2	White
3	Red
4	Black
5	Yellow

If an electrode cap is used and the coils are put on the cap, care should be excercised that the coils do not detach or move with respect ro head. Make sure that the textile in the cap is tight enough to keep the coils in place.

3.3.2 Attaching the electrode cap

For attaching the optional electrode cap on the head, refer to instructions supplied with the cap. Refer also to the instructions given by the electrode/gel manufacturers.

After preparing the cap, attach the reference (REF) and ground (GND) electrodes (single electrodes) as explained in the next section.

3.3.3 Attaching single electrodes

Instead of the electrode cap, single electrodes can be used, especially if only a few are required. In addition, single electrodes are used for bioamplifier channels and for the reference and ground electrodes, also when an electrode cap is employed.

The reference electrode acts as a reference for all the unipolar channels of the cap, and the ground electrode is used to set the patient to common potential with the preamplifiers to reduce common-mode interference. Line frequency ripple and drift may be further reduced by using active grounding as explained in section 1.11. Both the reference and ground electrodes must be connected. Place the reference electrode according to the electrode derivation used. The place of the ground electrode is not critical, typically it is placed to some inactive area, like cheek. In SEF measurements, place the ground electrode close to the stimulating electrode to minimize artifacts.

For reference and ground and most bioamplifier channels, single-use electrodes (included in the delivery) are suitable. Clean the skin e.g. with alcohol, peel off the protective film and attach the electrode.

If single electrodes are used for EEG channels, multi-use electrodes (not supplied with the system, see also section 2.5) are preferred. Prepare the skin with an abrasive skin cleaner such as OmniPrep® Skin Preparation (D. O. Weaver & Co., Aurora, CO, USA) or with alcohol using a cotton swab. Apply electrode paste (e.g. Grass EC2, Grass Instruments, Quincy, MA, USA, or equivalent) to the electrode and put it in place. Press the electrode with a small piece of paper tissue until the paste is hard enough to keep the electrode in place. Special adhesive washers, such as Gereonics 450097 (Gereonics Inc, Escondido, CA, USA) or skin tape such as 3M™ Micropore™ Tape or 3M™ Tegaderm™ dressing (3M Corporation, St. Paul, MN, USA) can also be used if applicable. After use, the electrodes can be cleaned following the instructions given by the electrode manufacturer.

WARNING 3.3: Avoid getting the electrode paste or gel to the eyes or mouth. Use only non-toxic pastes approved for clinical use.

The single EEG channels are plugged in the headbox during the preparation. Reference and ground electrodes as well as bioamplifier channel electrodes such as for EOG and EMG are connected to the electrode interface panel on the side panel of the gantry inside the magnetically shielded room.

3.3.4 Digitization of head position indicator coils

Determination of the position of the head position indicator coils and optionally the head shape digitization is performed with the help of 3-D digitizer included in the Elekta Neuromag® TRIUX. Digitization is performed outside of the magnetically shielded room.

CAUTION 3.1: The 3-D digitizer power supply unit must be connected to mains via an isolation transformer supplied with the Elekta Neuromag® TRIUX.

Have the patient seated in the dedicated digitization chair. Place the goggles firmly on the patient's head and tighten the strap, see Fig. 3.2. Alternatively, the digitization may be performed while lying on the couch. For using the couch for digitization, the transmitter unit of the digitizer, see Fig. 3.3, must be moved from the chair to the auxiliary table, see Fig. 3.4, with transmitter holder delivered with the product. The transmitter is released by sliding it off from its plastic holder. Under the table there is a similar plastic holder. Slide the transmitter to the holder and move the table under the couch so that the transmitter is approximately under the patient's shoulders with the cable pointing towards the feet.

Note: *The cable of the transmitter should point downwards (chair) or towards the feet of the patient (couch).*

Note: *Make sure that the digitizer pen and additional receiver cables are not close to the transmitter to avoid cross-talk which may lead to imprecise readings.*

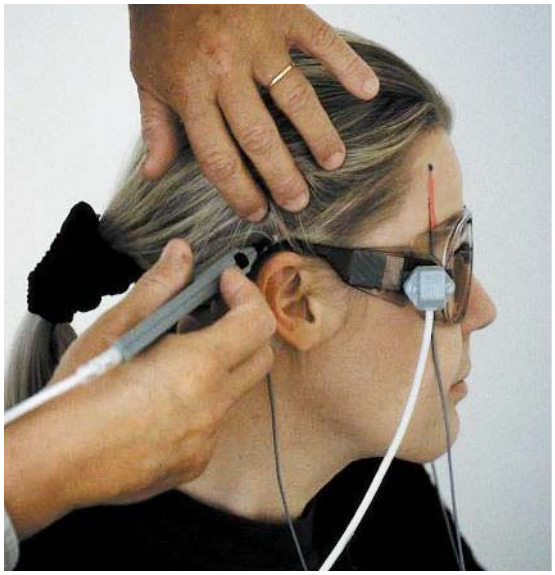


Figure 3.2 The head digitization goggles with additional receiver.

Figure 3.3 The transmitter attached to the chair. The cable must point downwards.

Figure 3.4 Auxiliary table for HPI coil digitization with the patient couch. The HPI coil transmitter (not shown) cable must point towards patient's feet.

Digitize first the cardinal points (landmarks) and then the midpoints of the HPI coils. The coils have a small recess in the middle to which the stylus tip should be put. EEG electrode positions must be digitized if modeling of the EEG signals is required in the analysis phase. It is recommended to digitize also additional points. These can be used to record, e.g., the head shape.

Refer to *Elekta Neuromag Data Acquisition User's Manual* for detailed digitization instructions.

CAUTION 3.2: Be careful not to hurt the patient with the stylus tip.

Large metallic objects, such as desks, cabinets, or the magnetically shielded room located near the transmitter or receivers of the 3D-digitizer may adversely affect the accuracy of the readings and thus the accuracy of source localization. Many walls, floors, and ceilings also contain significant amounts of metal.

WARNING 3.4: Large metallic objects located near the 3D-digitizer may adversely affect the accuracy of the readings and thus the accuracy of source localization.

To test whether the surroundings affects the accuracy of the readings digitize an object with known dimensions. For example, digitize the centers of the HPI coils permanently attached to the phantom and compare the readings with the known values, see Table 7.1 in section 7.2.

Note: *Handle the stylus tip carefully. The tip of the stylus is easily damaged if too much force is applied on it, leading to inaccurate digitization. Be careful not to drop the stylus. If in doubt, test the accuracy as described above.*

3.4 Recording

Prior to positioning the patient's head in the gantry make sure that the green 'OK' light of the position indicator display is lit. For details, see *Elekta Neuromag® TRIUX Patient Positioning Instructions for Use*.

Guide the patient in the magnetically shielded room and assist him/her on the couch or into the chair. For instructions, see *Elekta Neuromag® TRIUX Patient Positioning Instructions for Use*.

Plug the head position indicator coil connector to the HPI connector on the interface panel on the side of the gantry, see Fig. 1.17, and the eventual electrode cap, bioamplifier electrodes, and reference and ground electrodes to corresponding connectors on the electrode interface panel on the side panel of the gantry. The connectors on the panel have color codings that must match with the mating cable connector. If active gnd is used in order to increase the common mode rejection ratio against mains interference it is, however, recommended to switch the active gnd off temporarily when the patient electrode leads are connected or disconnected to the system. Check also that the impedance checking is be enabled only when all connections including the ref and gnd connections have been made.

If a headbox is used, connect it into the appropriate connector of the side panel. Note that both reference and ground electrodes must be connected to the side panel.

Do not ground patient to actual ground (e.g. the wall of the magnetically shielded room). The GND terminal refers to isolated signal ground of the preamplifier, connected through a current-limiting driver circuit. Do not place conducting parts near the patient that he/she may touch while connected to the equipment.

CAUTION 3.3: Do not ground patient to actual ground. Do not place conducting parts near the patient that he/she may touch while connected to the equipment.

Note: *Instruct the patient to keep the head steady during the recording.*

The operator exits the room. Close the door of the magnetically shielded room.

Note: *In case of studying patients or small children, an accompanying person in the room is highly advisable, particularly if it is likely that the patient cannot call for help or get out in case of emergency. Audio and video monitoring is also recommended. Test the monitoring before measurement.*

WARNING 3.5: Data quality should always be monitored during acquisition. Also, eventual interference should be checked before acquisition.

If an intercom is installed ask the patient if the he/she is ready. Start the data acquisition. If EEG or bioamplifier channels are selected, an electrode impedance check window is displayed. Check the impedance levels and correct if necessary, see section 3.3. For optimum performance, impedances below 10 kΩ are recommended.

Check the data quality of all channels. Try heating noisy channels if necessary, see section 2.4.2. Resetting of all channels may not be effective in some special situations. Occasionally, the system may require multiple subsequent reset cycles or initiation of tuning to recover. Measure the HPI coil locations with the respect to the sensor array. If the HPI fails, check the leads and ask the patient to move the head in a slightly different position and try again. Start stimulation if using any. During the acquisition, the raw data and averaged data should be constantly monitored, watching for any artefacts. Magnetic impurities left on the patient may cause severe artefacts; they should be removed.

The measurement of the positions of the head position indicator coils (HPI) may not be reliable when one or more of the coils are placed directly beneath the zero detector channels of the internal active shielding system. This is typically not the case in patient measurements but may occur in phantom measurements. Avoid the locations of the zero detectors when placing the head position indicator coils in order to prevent this problem. Refer to *Internal Active Shielding User's Manual*.

Note: *The accuracy of the head position estimate may be slightly reduced by non-functional or noisy MEG channels. When suspecting poor quality of the HPI fit, verify that no nonfunctional or noisy channels are in the vicinity of the head position indicator coils.*

If EEG or bioamplifier signals are selected, you have the possibility to record a square-wave calibration signal (±100 μV) to the data file.

When enough data has been collected, stop acquisition and stimulation. Determine if additional recordings using, e.g. a different stimulation condition, are necessary. Keep a log of recordings, stimulation conditions, and trigger line assignments etc. For details of the data acquisition software, see *Elekta Neuromag Data Acquisition User's Manual*.

When the measurements have been finished, open the door of the magnetically shielded room. Disconnect the HPI coil set and electrodes or electrode caps from the corresponding connectors by gently pulling from the thickest cylindrical part of the cable connector. Do not pull from the cable. Remove stimulator leads as needed.

If reclined or upright seated measurement position was used, release the brake and the elevation mechanism of the chair and pull the chair from under the gantry. In supine measurement position, release the lock of the upper bed and pull the upper bed away from the probe unit. Support the patients head if appropriate. Lock the upper bed again. For instructions, see *Elekta Neuromag® TRIUX Patient Positioning Instructions for Use*.

Help the patient to come out of the magnetically shielded room.

Remove the head position indicator coils and electrodes and clean them, see section 8.7. For cap cleaning, refer to the instructions delivered with the cap.

4 Cryogenics

4.1 Precautions

WARNING 4.1: As to potential hazards and necessary precautions for handling liquid and gaseous helium, refer to Section 2.1 in addition to this Section. Before attempting to transfer liquid helium read first that section and these instructions entirely.

When refilling the Dewar with liquid helium one must be aware of and respect the following physical facts:

- Liquid helium is very cold and the latent heat of evaporation is very low. Therefore, helium stays in liquid form only in specially designed vessels or transfer tubes. If the liquid gets in contact with objects at temperatures higher than 4 K it will immediately evaporate and expand. At room temperature the volume of the gas is 750 times larger than the liquid volume. This means that a potential for dangerous pressure rise always exists if this cryogenic liquid is handled carelessly or left to warm up in a completely closed volume.
- At liquid helium temperature all common materials are solid. This means that the vapor pressure of for example the atmospheric gases (nitrogen, oxygen, water) is practically zero in any volume containing liquid helium which leads to cryopumping, see 2.1, of these gases: any helium vessel left open to atmosphere will very effectively suck in large amounts of these gases. Water freezes and may block the helium vessel or a transfer siphon. Oxygen in the probe unit Dewar causes large irregular low frequency drifts to MEG signals because oxygen in its solid form is very paramagnetic. Because of the above, all vessels containing liquid helium must be sealed from the atmosphere and properly vented, via a back flow valve or a sufficiently long and narrow exhaust tube.
- Flow of cold helium gas makes a very good thermal contact with any surface it passes by: unprotected skin cools below freezing point in seconds.
- Even after warming up to room temperature the odorless and colorless gas may cause a risk of suffocation if ventilation is not taken care of. Breathing helium gas does not bring about any physiological unpleasent symptoms before dizziness. The pitch of the voice of the person characteristically raises when a large fraction of air is replaced with helium gas.

You should avoid using magnetic tools and electrical equipment, like hot air guns inside the magnetically shielded room. If absolutely necessary, they must be kept more than one (1) meter away from the sensor array. For sensor detrapping, see section 2.4.2.

4.2 Refill schedule

The recommended liquid helium refill interval of Elekta Neuromag® TRIUX is 7 days. It is recommended that a fixed weekly schedule is set up for helium transfer. In addition to the person responsible for the transfer, backup personnel should be assigned.

If the internal helium recycler is installed, the weekly refills are not needed.

It is highly advisable to monitor the helium level regularly, see sections 4.3 and 8.6, to avoid accidental warming up of the Elekta Neuromag® TRIUX. Should the level be very low, an extra refill should be performed. One should not, however, bypass the regular filling schedule even if additional refills are performed. After the helium level has reached zero percent reading in supine position, there is still a reserve for about 24 hours left. Note that in reclined or upright seated positions the reserve corresponding to zero percent reading is less. However, system performance deteriorates if the helium level is near or below zero percent. Therefore, a refill should be performed before proceeding to the next measurement. The Elekta Neuromag® TRIUX should not be left to warm up by itself, otherwise system might be damaged, especially if power is left on. Warmup of the system using a special procedure must be left to authorized service personnel.

The helium transfer takes about one hour. After the transfer, it is recommended to allow the temperature in the Dewar to stabilize for about an hour before starting new measurements and check the performance of the Elekta Neuromag® TRIUX as described in section 8.3.

4.3 Monitoring the helium level

Note: *Helium level must be followed regularly.*

Helium-level readings are automatically taken and logged approximately once in an hour. Readings are not taken during data acquisition.

The location of the He-level gauge probe is shown in Fig 4.1.

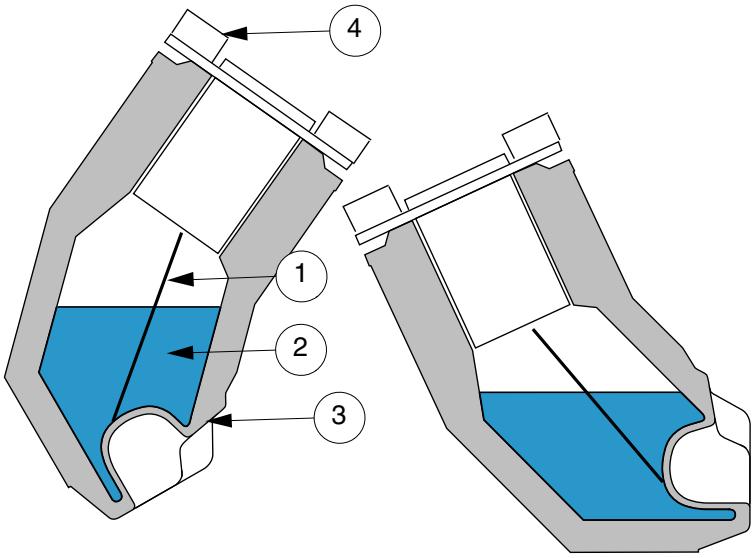


Figure 4.1 *Location of the helium level gauge probe. 1: Liquid helium probe, 2: liquid helium, 3: Dewar, 4: gauge electronics board. The local helium level display (not shown) is mounted on the gantry, see Fig. 4.3.*

The helium level log file can be studied with the *Helium level* command from the Tools menu of the data acquisition program. You can view a graphical display of the helium level and obtain an estimate of the time when zero-percent level is reached.

The helium level can also be checked from the local helium display in the probe unit, see Fig. 4.3. The helium level probe is switched on and off by pressing the toggle button on the local display. The reading stabilizes in about 20 — 30 s. The reading is shown in percent of the gauge length immersed in liquid helium.

Note: *Make sure to switch off the probe after taking a reading by pressing the toggle button again. If the probe is on, extra noise will appear and the boiloff will increase.*

The helium level probe does not cover the whole helium space. A zero reading in reclined or upright seated position corresponds to a level where all the sensors are barely immersed in liquid helium while the 100-percent reading level in reclined or upright seated position the He-level is close to the lower edge of the neck plug. Refer to Table 4.1 for actual values in reclined seated and supine positions. It is recommended to keep the gantry in upright seated position only when needed.

Table 4.1 Liquid helium level data. Reclined seated = 60° from horizontal.

% (supine)	% (reclined seated)	Liters liquid helium	% (supine)	% (reclined seated)	Liters liquid helium
1	12	9	51	54	44
3	14	10	53	55	45
4	15	11	55	57	47
6	17	12	56	58	48
8	18	13	58	61	50
9	19	14	60	62	51
11	21	14	61	63	52
12	23	15	63	65	54
14	24	16	64	67	56
16	25	17	66	68	57
17	26	18	68	69	58
19	27	19	69	70	59
21	28	20	71	72	61
22	29	21	73	74	62
24	30	22	74	75	63
25	31	23	76	76	64
27	32	24	77	77	65
29	34	25	79	77	66
30	35	27	81	78	67
32	37	28	82	79	68
34	38	29	84	81	69
35	39	30	86	82	70
37	41	32	87	84	72
38	43	33	89	85	73
40	44	34	90	86	74
42	45	36	92	87	75
43	46	37	94	88	75
45	48	38	95	90	76
47	50	40	97	91	77
48	52	42	99	92	78
50	53	43	100	94	79

The normal boil-off rate corresponds to a transfer interval of one week. When the helium probe reading in supine position is zero percent there is still about 8 liters of liquid in the helmet shaped part of the Dewar; in reclined or upright seated positions a reading of zero percent corresponds to a smaller amount. A refill should soon follow.

Note: *In the upright seated position (68°) the boiloff may be slightly increased if kept there for a prolonged time. It is recommended that the gantry is kept in the upright seated position only when needed. To minimize helium boiloff, set the gantry to supine position if the Elekta Neuromag® TRIUX is not used for some time (e.g. during weekend).*

When you have checked the helium level, estimate whether zero level is reached before the next scheduled refill. If this is the case schedule an extra refill.

The liquid helium level and boiloff rate should be monitored regularly. Substantial increase of boiloff rate may indicate the need to re-evacuate the vacuum. The vacuum pump-out must be left to trained service personnel.

4.4 Helium transfer procedure

If the internal helium recycler is installed, this section is not applicable. See *Elekta Neuromag® TRIUX Internal Helium Recycler, Instructions for Use*.

Familiarize yourself with safety instructions before transferring helium.

WARNING 4.2: Wear protective gloves to avoid skin contact with liquid helium or exhaust gas or any objects that have recently been in direct contact with liquid or evaporated gas. During transfer, monitor pressure gauges and do not let pressure to rise above limits described below.

This section gives instructions how to transfer liquid helium using the manual pressurizing unit. For instructions how to transfer with pressurized helium from a gas cylinder (pressurizing unit available as an option), refer to *Liquid Helium transfer with pressurized Helium gas User's Manual*.

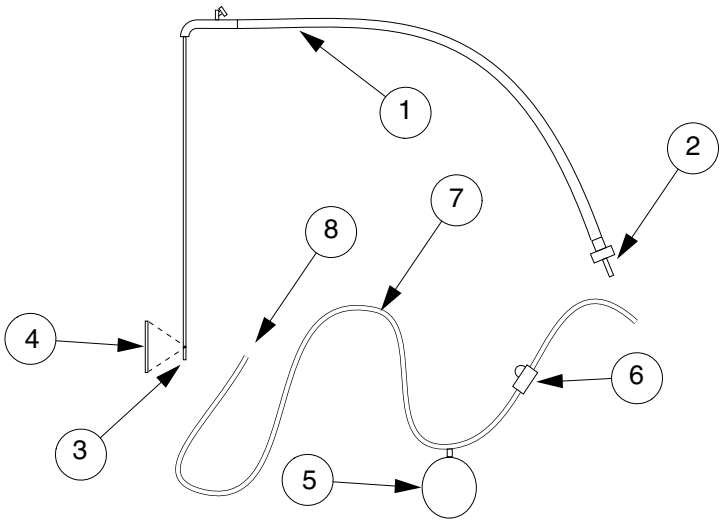


Figure 4.2 *Parts needed in liquid helium transfer. 1: Flexible siphon, 2: siphon tip, 3: filter unit, 4: extension tube (optional), 5: manual pressurizing unit, 6: hose clamp, 7: transfer exhaust silicon hose, 8: connection to storage Dewar venting port. The other end of the silicon hose may be left free or connected to helium recovery system (if installed).*

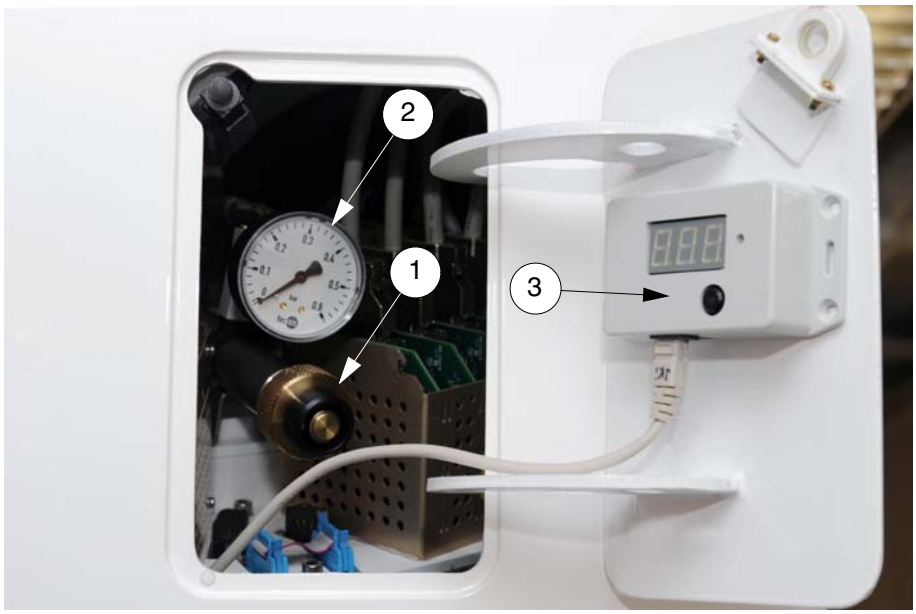


Figure 4.3 The liquid helium filling port on the upper part of the probe unit front face. 1: Fixed L-siphon port with plug, 2: pressure gauge, 3: liquid helium level local display.

Figure 4.4 The plastic cap for flexible siphon.

Figure 4.5 Inserting the flexible siphon into fixed siphon.

1. For helium refill, at least 90 liters of liquid helium is needed in a nonmagnetic storage container is needed. When scheduling liquid helium orders from the supplier (100 liter containers recommended) please note that the amount of liquid in storage dewars will boil off with a rate of typically 1-2 liters per 24 hours.

2. If the exhaust line is equipped with an electrical helium gas flow meter (outside of the MSR, not installed on most sites), bypass the meter by opening the bypass valve.

3. Move the gantry to the supine position.

4. Move the storage container to the magnetically shielded room entrance and connect the exhaust of the storage container to the transfer exhaust hose. The hose includes a rubber balloon pump (manual pressurizing unit) and a plastic hose clamp valve, see Fig. 4.2. Close the hose clamp, then open the exhaust valve on the storage container and let the pressurizing unit balloon fill up. Then close the exhaust valve, open the hose clamp, and squeeze the balloon. Repeat this procedure 2–3 times, it will flush air out of the transfer hose and balloon. Close the hose clamp and the safety relief valve of the storage container.

5. Clean your hands. Check that the filter unit at the tip of the thin, stiff part of the transfer siphon is in place, see Fig. 4.2. The siphon extension tube can be used if needed. The extension tube is mounted between the filter unit and the vertical part of the siphon.

6. Check that the helium exhaust line is unobstructed.

7. Put thick protective gloves supplied in the Cryogenic accessories kit on. Lower the transfer siphon very slowly into the storage container. Block the transfer exhaust hose with the plastic hose clamp valve. Close the relief valve of the storage container. helium gas should be let flow through the siphon in order to get air out of it and to precool it. *Beware the extremely cold gas stream*. When the helium gas flow starts to resemble a white flame open the hose clamp and temporarily plug the open end of the transfer siphon with a plastic plug supplied, see Fig. 4.4. Continue to lower the siphon to the bottom of the storage container.

8. Move the storage container into the magnetically shielded room. Leave the door open. If you have a long siphon (can be ordered separately) the storage container can be left outside of the room. If you have a long siphon with the storage container outside of the room, ground the braided cover of the siphon to the magnetically shielded room wall and support the long flexible tube at least at one point; the exact realization of such arrangements is site-dependent.

9. Use thick protective gloves and beware of the cold helium flowing out. Remove the plastic cap covering the siphon tip. Loosen the plug at the fixed L-siphon port of the probe unit of the Elekta Neuromag® TRIUX. Replace the plug *as quickly as possible* with the tip of the flexible siphon, see Fig. 4.5. During the short interval when the fixed siphon on the probe unit is unplugged there should be helium flowing out of the fixed siphon as well as from the flexible siphon. If this is not the case there might be a plug of frozen air in the siphon, see Section 4.5. Secure the siphon in place by tightening the knurled sleeve nut on the siphon. Place the plug of the fixed siphon to a place where it is readily available, e.g., the plug holder at the cover of the refill opening.

10. Block the transfer balloon exhaust hose with the plastic clamp again and pump gently with the rubber balloon. Follow the pressure from the probe unit of the Elekta Neuromag® TRIUX pressure gauge, see Fig. 4.3; *do not let the pressure rise over 0.1 bar (10 kPa)*. The pressure rises quickly at first. When the flow of liquid starts after a few minutes the pressure goes down for a moment and then rises again to approximately 0.04 — 0.07 bar (4–7 kPa) depending on the flow impedance of the exhaust line. After the liquid starts flowing you can usually pump the balloon continuously until the transfer is complete. Follow the liquid helium transfer progress with the local liquid helium level display. When the desired helium level is reached, release the transfer exhaust hose clamp valve and let the pressure stabilize for a couple of minutes.

11. Detach the siphon from the probe unit when the pressure has decreased. Have the plug ready. Pull the tip of the siphon out and insert the plug as quickly as possible. Tighten the plug. Move the storage container out of the magnetically shielded room and lift the siphon out. Use gloves to avoid frost bite. Close the exhaust valve on the storage container. Disconnect the transfer hose and open the relief valve on the storage container.
12. Close the bypass valve (if installed) of the electrical gas flow meter.
13. Return the storage container to its place.

Note: *After finishing transfer, check that all valves are in their normal positions, that is, vessels containing liquid helium are vented through their proper return lines and all the other valves are closed.*

Note: *Make sure to switch off the local liquid helium level display.*

Note: *Do not change the gantry position immediately after transfer as the thermal insulation on the exhaust lines is very cold and might break easily. Allow 1 hour before changing position.*

4.5 Troubleshooting transfer problems

Use caution and care when handling the helium storage containers. One liter of liquid helium corresponds to approximately 750 liters of helium gas at 20°C, 101.3 kPa (NTP, Normal Temperature and Pressure). Cold helium may cause frost bites and it may replace breathing air. However, there is no need to be alarmed when liquid helium is properly handled.

WARNING 4.3: Beware of the extremely cold, non-life-supporting gas.

The following hints may help you in solving problems which may arise during a transfer:

4.5.1 Overpressure

- The pressure in the probe unit of the Elekta Neuromag® TRIUX goes high.

  Release the hose clamp valve blocking the transfer exhaust hose, see Fig. 4.2. If the pressure still keeps increasing, open the relief valve on the storage container and the siphon precooling valve. Watch out for the eventual stream of extremely cold gas.

  The relief valve of the probe unit will open when the pressure inside the Dewar is 10 kPa (0.1 bar). If the pressure goes up further to approximately 60 kPa (0.6 bar), the safety rupture membrane on the top plate breaks and helium gas will flow though the emergency duct. Should this happen or if the membrane breaks by itself, plug the safety duct with a rubber bung contained in the Cryogenic accessory kit after the pressure has decreased. To plug the duct, release the hose clamp attaching the flexible duct to the fiberglass feedthrough tube at the back of the gantry, remove the duct from the feedthrough and plug the duct end. Try to identify the cause of the pressure rise, and have the safety rupturing membrane replaced by Elekta service.

4.5.2 Leaks

- The frozen silicon exhaust hose of the probe unit breaks because of thermal stresses and helium leaks into the magnetically shielded room.

  This may be associated with a loud popping sound and a greyish cloud of gas caused by condensing moisture. This may sound and look dramatic but *do not panic.*

  Should this happen, open the hose clamp valve at the transfer exhaust hose of the storage container and let the pressure drop. *Beware of the extremely cold, non-life-supporting gas.*

  You may wish to step out of the magnetically shielded room while waiting for the pressure to drop. Replace the broken silicon hose when it has warmed up sufficiently. There is a spare hose and plastic connection pieces in the Cryogenic Accessory Kit provided with the Elekta Neuromag® TRIUX.

- The joint between the storage container and flexible siphon stiff part leaks.

  The stiff part of the flexible siphon is sealed with an o-ring which can be tightened. If the seal starts to leak, the o-ring will be cooled and become very hard whereby it will not be able to tighten the joint properly. Release pressure from the storage container and let the joint warm up. Try tightening the o-ring seal or replace the o-ring (can be found in the cryogenic accessory kit) if necessary. The flexible siphon stiff part has an outer diameter of 12 mm, and the storage container o-ring should have correspondingly an inner diameter of 12 mm. A half-inch inner diameter will not be tight enough. Use vacuum grease (also in the Cryogenic accessory kit). See also next paragraph for instructions how to dry the flexible siphon if it is taken out.

4.5.3 Transfer does not proceed, helium flow blocked

- There is not enough helium to complete the transfer.

  This shows up as difficulties in maintaining the pressure in the storage container, and the local level indicator also stops rising. If the transfer is far from complete get a new storage container and start again. Dry the inside of the flexible siphon, for example, by blowing warm gas through the siphon. If you leave the transfer incomplete ensure that the transfer schedule is modified accordingly.

- There is no flow of liquid and the pressure in the storage container does not go down even if pumping is stopped.

  This may be caused by frozen air or moisture obstructing one or both of the siphons.

  Stop transfer, depressurize the storage container, remove the flexible siphon, observe the outflow of helium, and plug the fixed siphon. Some helium should emerge out of the fixed siphon head. If no helium flow appears at the end of the flexible siphon even if the storage container is slightly pressurized, there is a obstruction in the flexible siphon.

  If the solid air or moisture obstruction is in the flexible siphon, stop transfer, warm the siphon up, let it dry as described above and start again.

  If this does not help check the flexible siphon filter by unscrewing the cap of the filter unit. Replace the filter cartridge if necessary (can be found in the Cryogenic accessory kit, see Fig. 4.6).

  If there is no helium flowing out from the fixed L-siphon mounted to the probe unit of the Elekta Neuromag® TRIUX when the plug is removed, the solid air or moisture obstruction is within the fixed siphon. Call an Elekta service representative.

Figure 4.6 The flexible siphon filter unit. 1: Filter body, 2: end cap, 3: filter cartridge. Please note the correct orientation of the filter cartridge: the closed end must be facing towards end cap 2.

4.5.4 Transfer does not proceed, siphon or helmet cold

- There is excessive flow of helium gas but no liquid is transferred and the siphon (flexible or fixed) feels cold or has ice on it.

  The insulating vacuum of the siphon is bad, and it needs to be re-evacuated by service personnel. Use another siphon if available.

- Transfer does not succeed and the helmet of the probe unit feels cold or has ice on it.

  This may happen due to poor insulating vacuum. The vacuum has to be re-evacuated, which is a normal procedure during annual maintenance. Call an Elekta service representative.

5 Patient positioning

For information on patient positioning, see *Elekta Neuromag® TRIUX Patient Positioning Instructions for Use*.

6 Electronics

6.1 Precautions

CAUTION 6.1: For precautions concerning electrical safety refer to section 2.2.

Note:

The electronics contains components susceptible to static electricity. Read precautions of section 2.6.2 first.

6.2 General

6.2.1 Rack installation

The main electronics cabinet comprises two MEG subracks, one EEG subracks and preamplifier power supply racks. The mounting of the units inside the cabinets is shown schematically in Fig. 6.1.

Note:

The electronics is designed to be operated in proper RF-shielded cabinet mounting only. Do not disconnect any cables. In particular, the unit must be operated with cooling fan units on. Their cables must not be disconnected. Keep the doors closed.

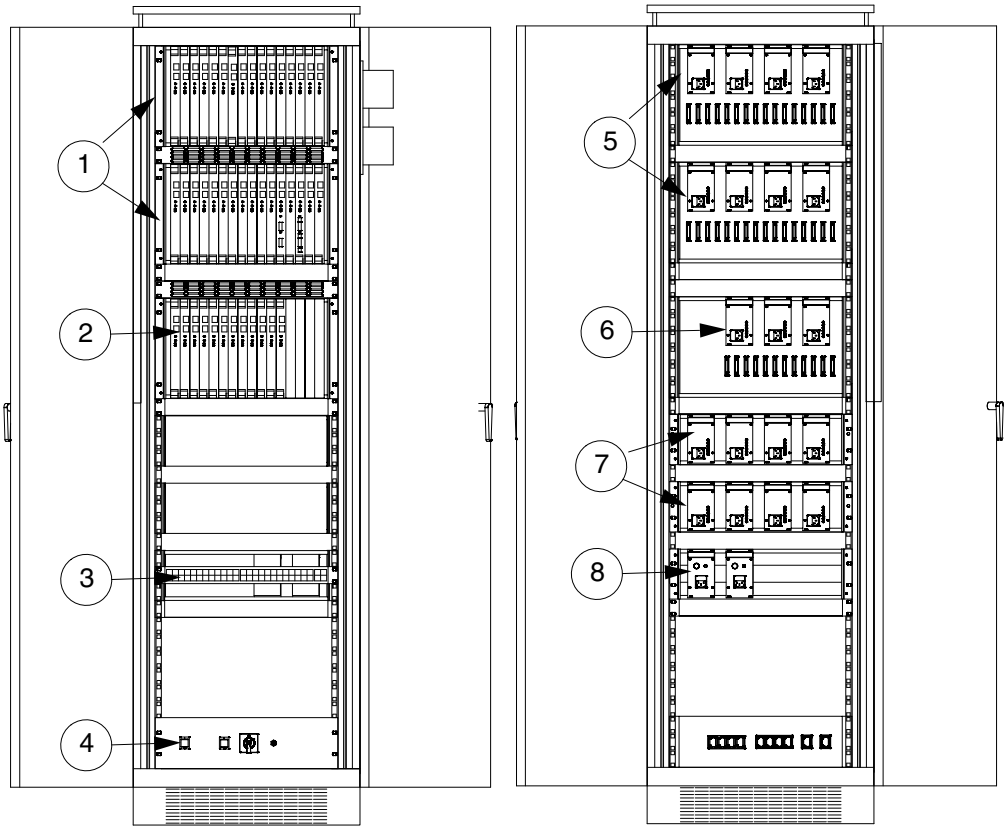


Figure 6.1 *Mounting of the electronics units inside the main electronics cabinet. Left: front view, right: back view. 1: MEG and bioamplifier electronics racks, 2: EEG electronics rack (optional), 3: ethernet switch for internal dedicated data acquisition subnet, 4: mains control panel, 5: MEG electronics rack power supplies, 6: EEG electronics rack power supplies, 7: MEG preamplifier power supplies, 8: isolated EEG preamplifier ac power supplies.*

6.2.2 Electronics control

Normal operation of the electronics requires no user action except power-up and shutdown, see section 6.3. All settings of the electronics are computer controlled. For further details, refer to *Sensor Tuner User's Manual* and *Elekta Neuromag Data Acquisition User's Manual*.

6.2.3 Power supplies

The main electronics subracks have several dc power supply units as shown in Figs. 6.1 and 6.3.

CAUTION 6.2: There are no operator serviceable parts inside the power supply units. Do not open the covers.

6.2.4 Isolated Power Supply

The actual Isolated power supplies for the Bio/EEG preamplifiers are located in the feedthrough unit. They are powered by 24V~ ac power supplies (transformers) in a separate rack inside the main electronics cabinet, see Figs. 6.1 and 6.3.

6.3 Powerup and shutdown instructions

6.3.1 Cold start powerup after mains failure

Note:

The main electronics cabinet has been equipped with a power failure release main switch to ensure proper boot-up sequence of the computers. Please follow these instructions after the mains power coming to the main electronics cabinet has been off due to mains failure or because of disconnecting the power from the isolation transformer for e.g. service operations.

1. Boot the acquisition workstation if it has not started automatically. Wait until it runs normally.

2. On the mains control panel of the main electronics cabinet, see Fig. 6.2, ensure that the green rocker switches (Preamplifiers, main electronics) are in *Off* position.

3. Inside the main electronics cabinet, the individual power supply units are connected to outlet socket strips located in the rear of the cabinets. Ensure that the power cords are in place.

4. Switch on the main electronics cabinet power by turning the main switch (1) on the mains control panel to *On* position. The switch will automatically turn back into *Off* position if mains voltage is too low.

5. Proceed with normal powerup instructions (6.3.2) presented below.

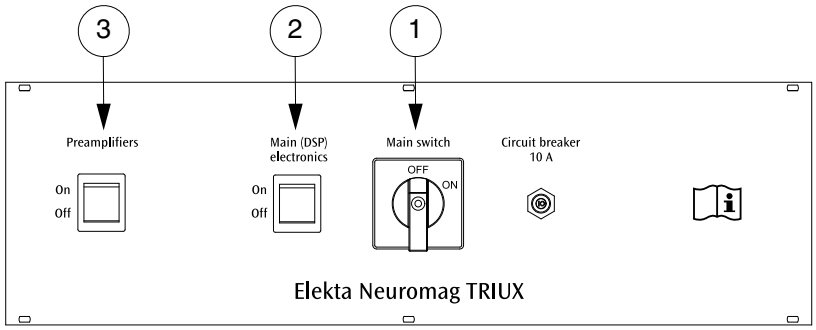


Figure 6.2 The mains control panel of the main electronics cabinet. 1: Main switch with no-mains release, 2: MEG and Bioamplifier/EEG main electronics rocker switch, 3: MEG and Bio/EEG preamplifier rocker switch.

6.3.2 Normal powerup

1. Make sure that the main switch (1) of the mains control panel is in the *On* position.

2. After turning the main switch (1) to *On* position, wait until the ethernet switch has started up, indicated by the *Self test* and *Fail* indicators going off. Bootup takes about one minute.

3. Switch on the main electronics rocker switch (2) from the mains control panel. Wait until all electronics boards of the MEG and EEG racks show steady green *Run* lights and the *Fail* lights are off. Boot-up takes about 30–60 seconds. If the bootup fails, open the back door of the main electronics cabinet and check the indicator LEDs of individual power supplies, see Fig. 6.3. The main electronics racks must be booted before preamplifiers becausee the preamplifiers are controlled by one of the main electronics boards.

4. Switch on the preamplifier rocker switch (3) from the mains control panel to *On* position.

5. Run Restart acquisition programs by double-clicking its icon in the Maintenance toolbox on the acquisition workstation

Note: *Each time the MEG front end is powered it must be initialized by invoking the restart acquisition programs as above. Also, tuning settings must be loaded as instructed in the Sensor Tuner User's Manual.*

Note: *For optimum noise performance, let the preamplifiers stabilize for approximately 1-2 hours before commencing MEG measurements. You can keep the preamplifier power supply normally always on.*

Note: *Individual main electronics power supply units will not start up if any of their red/yellow indicator LEDs on the back, see Fig. 6.3, is lit. This may happen if a powerup is made immediately following power-down of the unit.*

6.3.3 Power shutdown

Before any electronics service operations, main power must be switched off.

1. Switch off preamplifier and main electronics rocker switches (2) and (3) from the mains control panel.

2. Switch the main switch (1) on the mains control panel to *Off* position. This will turn off the ethernet switch, the roof fans and eventual equipment connected to the auxiliary sockets, e.g. the optional intercom.

Note: *It may take a while before the LED indicators go off. A main electronic power supply unit will not restart before all indicators are off.*

6.4 Protection

6.4.1 Fuses

CAUTION 6.3: To avoid risk of fire and of electric shock use only correct-rated fuses as replacement.

All mains (primary) circuits of the power supply units are fused. All fuses are accessible at the back planes of the power supply units with the correct values of the fuses marked in the immediate vicinity, for details see Figs. 6.3 and 6.4. A "T" before the rated current in amperes indicates slow (time-lag) type and an "F" fast type. If no type has been indicated, use fast type fuses. The power supply units have a spare fuse in the fuse holder.

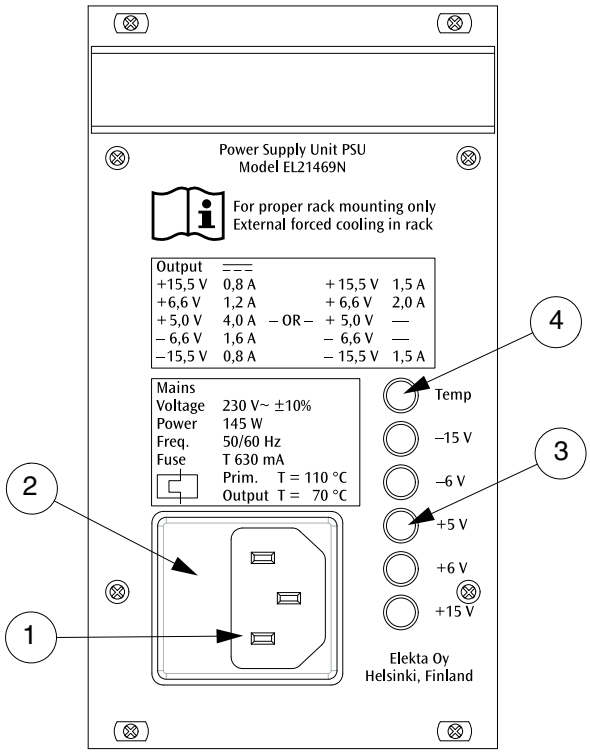


Figure 6.3 Back panel of a dc power supply unit used for MEG and Bioamplifier/EEG electronics and MEG preamplifiers. 1: Mains inlet, 2: primary fuses, 3: output voltage indicators, 4: overtemperature indicator. The output indicators (4) have three colors: green for normal operation, red for overcurrent shutdown, and yellow for undervoltage indication.

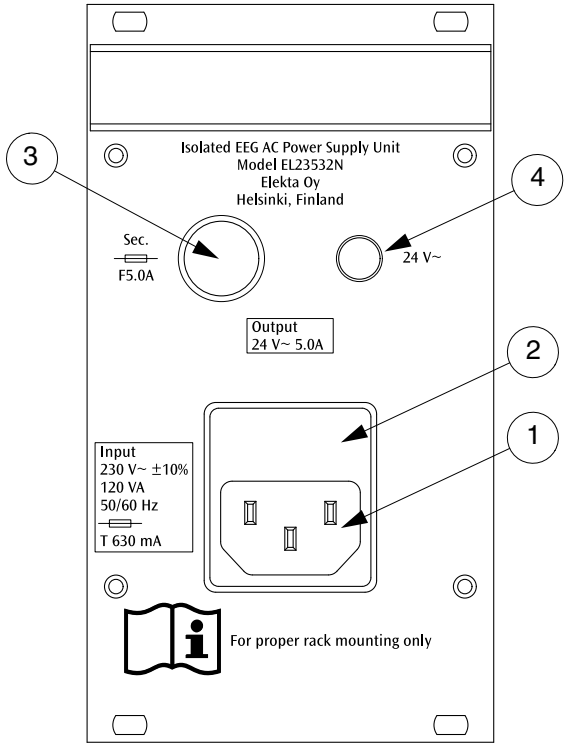


Figure 6.4 Back panel of the ac power supply used for Bio/EEG preamplifier isolated power. 1: Mains inlet, 2: primary fuses, 3: secondary fuse, 4: ouput indicator.

6.4.2 Limiting circuits

The dc power supply units have resettable current-limiting circuits on the low-voltage side. The ac power supplies have secondary non-resettable fuses.

Note:

If any output current of a dc electronics power supply unit exceeds its limit, the unit will turn off all its output voltages, and the indicator LED (3) of Fig. 6.3 for that voltage will turn red.

If a current-limit shutdown occurs, try restarting the unit by detaching its power cord, wait unit the red indicator LED goes off and re-connect the power cord. During startup, all indicators are lit briefly in a sequence first red and then green. If the problem persists or repeats often, call a service representative.

6.4.3 Undervoltage detection

The dc power supply units have undervoltage detection circuits on the low-voltage side.

Note:

If any output voltage of a main electronics power supply unit falls below its limit, the indicator LED (3) of Fig. 6.3 for that voltage will turn yellow as long the problem persists.

If the undervoltage indication persists or repeats often, call a service representative or have the mains supply voltage checked by a electrician.

6.4.4 Overtemperature protection

The main electronics power supply units have two temperature-protection mechanisms. If the internal temperature of the low-voltage side exceeds the limit marked on the cover (secondary), the unit will turn off all its output voltages, and the indicator LED (4) of Fig. 6.3 for the temperature will turn red. If the temperature of the power supply unit transformer exceeds the limit (primary) marked on the cover, a thermal switch will shut off the mains supply to the unit and all indicators (3) and (4) of Fig. 6.3 will be dark.

If a secondary thermal shutdown occurs, wait at least 30 minutes to cool down the unit. Check that the fans operate normally. Try restarting the unit by detaching its power cord, wait unit the red indicator LED goes off and re-connect the power cord. During startup, all indicators are lit briefly in a sequence first red and then green. If the problem persists or repeats often, call a service representative.

If the transformer primary thermal shutdown occurs, disconnect the power cord of the unit and wait at least 30 minutes to cool down the unit. The primary winding thermal switch will reset automatically. Try restarting the unit by reconnecting its power cord. If the problem repeats, call a service representative.

CAUTION 6.4: Overheating is normally a symptom of a fault. To reduce risk of fire the reason must be resolved if the shutdown repeats.

6.5 Cooling fans

The cooling airflow in the cabinet enters through a dust filter below the cabinet floor and exits through the top of the cabinet. In addition, there are individual local fan units, connected to mains supply so that they operate simultaneuosly with the unit they are cooling. Power cords of these fan units must not be removed or replaced. The roof fans operate always when the cabinet main switch is on.

Note: *For proper airflow in the cabinet, keep the doors closed. This also helps to reduce the acoustic noise from the fans.*

6.6 Resetting the electronics

The Elekta Neuromag® TRIUX has four different main electronics boards:

- SQUID controller (SQC) board, used for MEG channels, HPI and Internal Active Shielding
- Signal acquisition module (SAM) board, used for bioamplifiers, EEG, and analog signal input
- System controller (SCC) board, a master board for the main electronics
- Front end controller (FEC) board, used for controlling the preamplifiers

Each main electronics board has a recessed *Reset* switch on its front panel, see Fig. 6.5. If the board becomes locked up (e.g. showing red fail light or it is reported by the data acquisition software as been dropped from acquisition) press the *Reset* switch. Boot-up of the boards starts automatically. Wait until the board shows steady green *Run* lights and the *Fail* lights are off. Boot-up takes about 30–60 seconds. If the bootup fails, open the back door of the main electronics cabinet and check the indicator LEDs of individual power supplies, see Fig. 6.3. Reset the power supplies as instructed in sections 6.4.2 and 6.4.4 if necessary.

If several boards fail simultaneously, all boards can be reset simultaneously by pressing the reset switch of the System Controller Board (SCC) which is located on the second rightmost slot of the second MEG rack.

After resetting the boards, run *Restart acquisition programs* by double-clicking its icon in the *Maintenance* toolbox on the acquisition workstation.

The SCC and FEC boards have status lights for the optic links of stimulus trigger interface units and MEG and Bio/EEG preamplifiers. The link lights should normally be on.

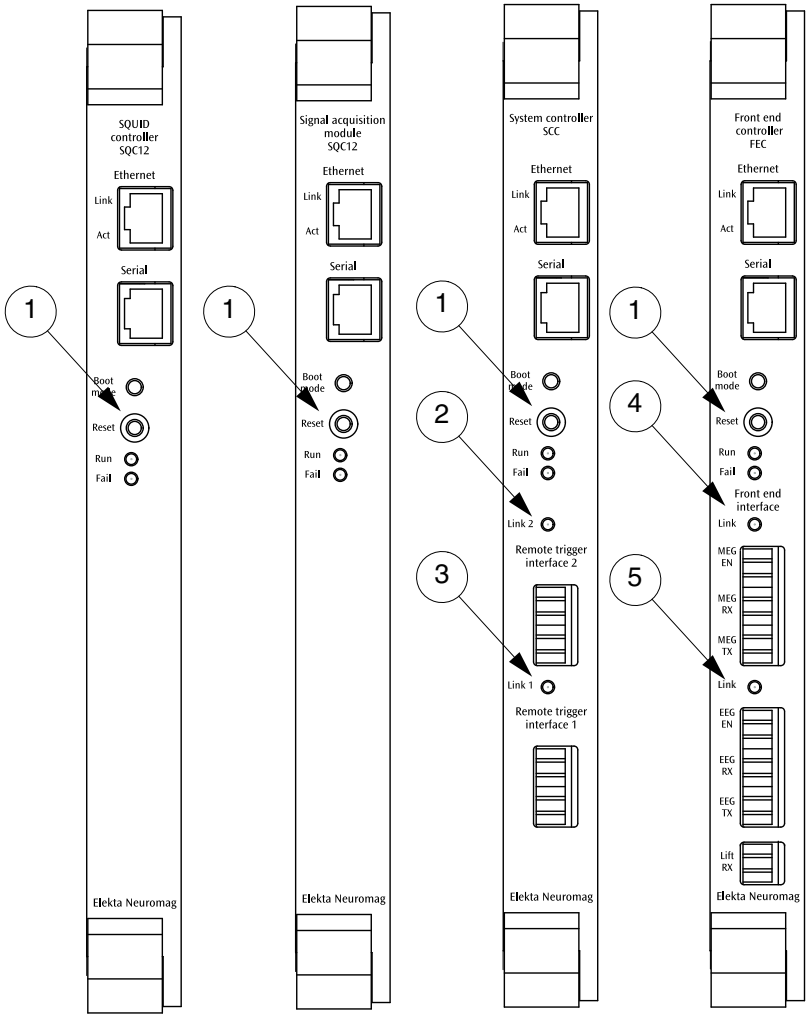


Figure 6.5 The main electronics boards, from left to right: SQUID controller (SQC), signal acquisition module (SAM), system controller (SCC), and front end controller (FEC). 1: recessed reset switch, 2, 3: stimulus trigger interface unit optical link status lights, 4, 5: front end optical link status lights.

7 Auxiliary electronics

7.1 Interface to stimulus electronics

7.1.1 General

The stimulus I/O interface, see Fig. 7.1, is used to synchronize external stimulators and MEG signal averaging.

Two modes of synchronization are possible:

- Internal triggering: Averaging is triggered using pulses generated internally by the Elekta Neuromag® TRIUX data acquisition hardware; these pulses are output via the stimulus I/O units for triggering external stimulators
- External triggering: External stimulators are used in a self-paced mode, and the stimulus synchronization pulses are input via the stimulus I/O units to main electronics hardware.

The stimulus I/O interface has two interface units connected to the main electronics System controller (SCC) boards over optical fibre links. The trigger I/O interface boxes are placed near the stimulators, one in the stimulus cabinet and the other close to the data acquisition workstation.

Each of the trigger I/O interface boxes has 16 lines. Stimulators can be connected using individual BNC connectors or a parallel 37-pin multipole connector, see Fig. 7.2.

Note: *The BNC connectors and the parallel multipole connector are internally connected together. Do not connect the parallel connector simultaneously with the BNC connectors.*

The two interface boxes are operated by default in parallel, i.e., input 1 and output 1 on *both* interface units correspond to trigger line 1 on the combination trigger channel (STI101) associated with the 1st interface unit. However, the two interfaces can also be treated separately by turning on (selecting for acquisition) the trigger channel (STI102) associated with the 2nd interface unit. This is done using the acquisition setup dialog as explained in *Elekta Neuromag Data Acquisition User's Manual*.

In parallel operation with a total of 16 trigger lines the signals on the first unit are also duplicated on the second unit which may at a physically separate place. This default mode may be useful in complex stimulus setups where stimulus-generating equipment may be located at distinct places.

The optional separate mode provides a total of 32 trigger lines. However, internal trigger pulse generation is only supporting 16 lines.

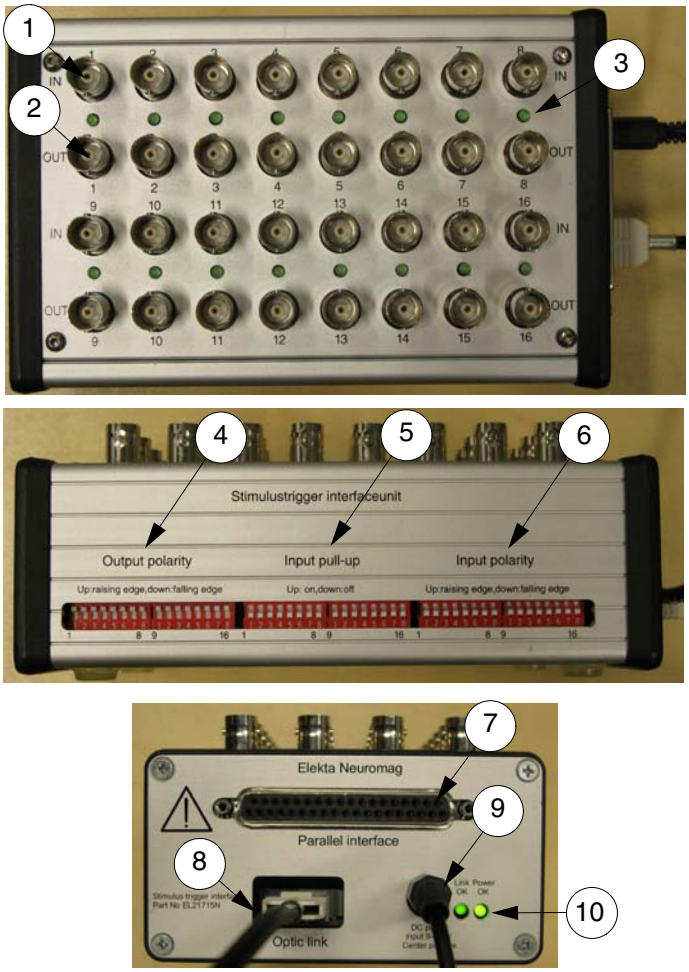
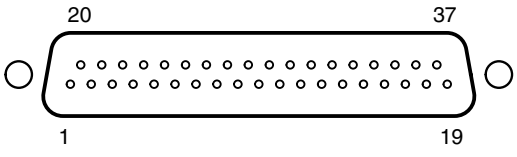


Figure 7.1 *The stimulus trigger interface unit. 1: Trigger inputs, 2: trigger outputs, 3: trigger pulse indicator lights, 4: Output polarity switches (raising edge up, falling edge down), 5: Input pull-up selectors (on up, down off), 6: input polarity switches (raising edge up, falling edge down), 7: parallel multipole connector, 8: optic link fiber to System controller SCC, 9: power supply cable, 10: status indicators.*



1: In 1	10: In 10	20: Out 1	29: Out 10
2: In 2	11: In 11	21: Out 2	30: Out 11
3: In 3	12: In 12	22: Out 3	31: Out 12
4: In 4	13: In 13	23: Out 4	32: Out 13
5: In 5	14: In 14	24: Out 5	33: Out 14
6: In 6	15: In 15	25: Out 6	34: Out 15
7: In 7	16: In 16	26: Out 7	35: Out 16
8: In 8	17: Common	27: Out 8	36: Common
9: In 9	18: Common	28: Out 9	37: Common

Figure 7.2 *The pinout of the parallel multipole 37-pin connector. Front view.*

The trigger interface manages both internal and external triggers. Irrespective of the triggering mode (internal/external) the trigger pulses always appear at the corresponding trigger outputs of both interface units. Internally generated trigger pulses and the pulses acquired from external sources are logically OR'ed line by line. The pulse is fed to the acquisition software and to the trigger outputs. Thus the system automatically 'chooses' the right source for each trigger channel provided that a trigger channel is not receiving pulses both from internal and external sources at the same time. Should this happen, pulses from those two or three sources will be intermixed and indistinguishable at further processing stages.

For further details of triggering, refer to *Elekta Neuromag Data Acquisition User's Manual*.

7.1.2 Usage

CAUTION 7.1: If any of the equipment connected to the the stimulus trigger interface unit is patient-connected, all other equipment connected to the same interface unit must fulfill the safety requirements of IEC 60601-1 for medical electrical equipment.

Verify correct voltage and polarity and connect the power supply to the DC connector (9) on the side of the interface box, see Fig. 7.1. Connect the fiber-optic link (8) between the interface box and the main electronics cabinet. The green lights *Power* and *Link* (10) on the unit should be lit.

For using internal triggering, select a stimulus channel and connect a BNC cable to the appropriate stimulator trigger output BNC connector (2) of the stimulus I/O interface unit and to the stimulator trig-in connector. In the data acquisition program, select internal triggering and set the trigger channel, and interstimulus interval. Refer to the *Elekta Neuromag Data Acquisition User's Manual*. If you are using several stimulators, repeat the above steps as many times as necessary.

Correspondingly, for using external triggering, select a stimulus channel and connect a BNC cable between the appropriate stimulator trigger input BNC connector (1) of the stimulus I/O interface unit and the stimulator trig out connector. In the data acquisition program, select external triggering. Refer to *Elekta Neuromag Data Acquisition User's Manual* for further details. If you are using several stimulators, repeat the above steps as many times as necessary.

In both cases, the LEDs (3) in the interface box will be lit when a trigger pulse is detected in input or output.

The input channels are factory set to trigger on rising edge of TTL-level pulses. Select the polarity of a particular channel from the corresponding *Input polarity* switch (6) (located on the longer side of the unit). The inputs can also be used with passive switches. Therefore, an internal pull-up resistor is supplied. It is selected by sliding the corresponding *Input Pull-up* switch (5) to *On*. Normally, the input polarity should also be changed to falling edge if pull-up is used. The polarity of the output pulses can also be selected by from the corresponding *Output polarity* switch (4).

For specifications of the trigger input/output signals, see *Elekta Neuromag® TRIUX Technical Manual*.

The stimulus cabinet is available for placing various stimulator devices, providing isolated power and RF-filtered feedthroughs. The feedthroughs are specified and explained in greater detail in *Elekta Neuromag® TRIUX Technical Manual*. Active digital circuitry, e.g., a computer inside the stimulus cabinet should be avoided.

7.2 Phantom

A phantom is provided for checking the system performance. It contains 32 artificial dipoles and four fixed head-position-indicator coils. The phantom is based on the mathematical fact that an equilateral triangular line current produces equivalent magnetic field distribution to that of a tangential current dipole in a spherical conductor, provided that the vertex of the triangle and the origin of the conducting sphere coincide. The phantom dipoles are energized using an internal signal generator which also feeds the HPI coils. An external multiplexer box is used to connect the signal to the individual dipoles. Only one dipole can be activated at a time.

The phantom is shown in Fig. 7.3, and the locations of the fixed HPI coils and dipoles are given in Tables 7.1 and 7.2, respectively. The radius of the hemispherical plastic cover is 87.5 mm.

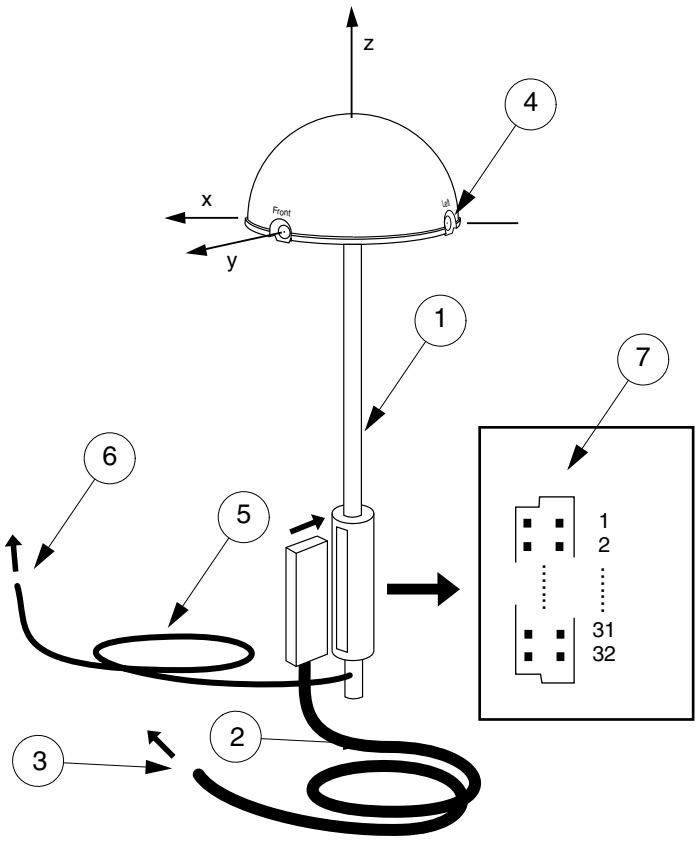


Figure 7.3 *The phantom. 1: Phantom, 2: phantom cable, 3: connection to phantom driver connector located at the back of the probe unit base (grey), 4: HPI coil (left), 5: HPI cable, 6: connection to the side panel of the gantry, 7: pin arrangement for dipoles 1...32.*

The fixed head position coils can also be used in checking the operation of the 3D-digitizing unit.

A phantom measurement is basically similar to an ordinary evoked-response measurement with HPI coil digitization etc. This is to check the accuracy of the whole measurement chain, comprising HPI coil digitization, data acquisition, and dipole source analysis.

Refer also to *Elekta Neuromag Data Acquisition User's Manual* for further instructions on data acquisition software.

Note: *If Internal Active Shielding (IAS) is used, the phantom fixed hpi coils may interfere with the IAS reference sensors. See step 9 below.*

Figure 7.4 *The phantom holder on the patient chair. The white plastic part below the phantom hemisphere is an adapter to attach the goggles during digitization.*

1. Attach the phantom to the phantom holder, see Fig. 7.4, and set the holder and the phantom to the digitization chair. Attach the digitization goggles to the phantom.

2. Start the acquisition software and set the project name and the subject name, e.g. *Test* and *Phantom*. Use 1 kHz sampling frequency and 330 Hz low-pass. Select Internal Active Shielding (IAS) if needed.

3. Open the phantom control dialog by selecting *Phantom…* from the *Tools* menu of the main window. Press *Load settings*.

4. Start digitization by pressing the digitization *Change* button next to the "HPI not digitized" indicator.

5. Press *Coordinate frame alignment* button.

6. Digitize three landmarks from the phantom using the front coil, the left coil, and the right coil. Press *Align frame*.

7. Digitize the four coils of the phantom and end the digitization process by pressing digitizer pen button somewhere far from the phantom. Check that distances of the coordinates of the coils from the expected positions given in Table 7.1 are less than 1 mm. If the step fails, try to repeat the alignment and digitization. If the problem persists, see if the phantom is damaged, the stylus tip is damaged (e.g. the stylus has been dropped on floor and the tip damaged) or if there are large metallic objects in the vicinity of the digitizer that might affect the accuracy. Do not proceed without finding out the reason.

8. Close the digitization dialog by clicking OK once complete.

9. Move the phantom and the phantom holder to the magnetically shielded room, and setup the phantom inside the Dewar helmet so that the back of the phantom touches the back of the Dewar. If Internal Active Shielding (IAS) is used, rotate the phatom slightly (about 10-20 degrees) so that the front coil is not exactly vertical as it might interfere with the IAS sensor channels. Connect the 32-pair cable of the phantom to the connector at the back of the gantry and the HPI coil connector to the gantry side panel HPI connector.

10. Start the measurement by pressing *GO!* button in the main window. Start HPI measurement by pressing *Measure* button of the confirmation dialog. Observe that the g-values of three best fitting coils are better than 98% and that the differences of fitted coil coordinates to digitized coordinates are within 5 mm. Press *Accept* if ok. If the fitting fails, retry HPI measurement. If the problem persists, try adjusting the phantom position or orientation.

11. Select dipole 1 from the phantom control dialog, set amplitude 1000 nAm, and select *Activate sequentially*.

12. Press *Activate*. Check that the phantom excitation signal on MEG channels (sine wave cycles) and triggers appear on the raw data display. Select *Average* from the main window. Data acquisition starts averaging data: the average count increases, and after a short while you see the averaged data in plotter window. If bad channels prohibit operation (indicated in the Acquisition control window status lines), mark them manually bad with *Mark bad channels* command in the *Online* menu. After every 100 averages, the phantom controller changes to activate the next dipole sequentially. Phantom controller stops activation when all the 32 dipole signal averages have been collected.

13. Once the data for all dipoles has been collected, stop the measurement by pressing *Stop*, and save the data to a file called alldipoles.fif. This file contains the responses of all measured dipoles, stored as different categories.

14. If the Internal Active Shielding was on during recording, open a terminal window and issue the command

```
/neuro/bin/util/maxfilter -v -frame head -origin 0 0 0 -f all-
dipoles.fif
```

where filename is the name given in previous step. Note that the command has to be entered on a single line. This will produce a processed file alldipoles_sss.fif.

15. Start the Source Modelling Program. Open the original file alldipoles.fif (without Internal Active Shielding) or processed file alldipoles_sss.fif (with Internal Active Shielding) and load, one at a time, averaging category n (where n=1,…,32) data from file.

16. Set the sphere model origin to (0, 0, 0) in the head coordinate system, and set the baseline from -50 to 0 ms.

17. Open *Full view* from *View* menu, and mark all the possible bad quality channels as bad, by clicking them with middle mouse button.

18. Select *accurate coil definition*: from the *File>Preferences>Fitting...* dialog: Enter "*Accurate*" from drop-down menu "*Coil accuracy*". Do not use low-pass filter unless there is clear high-frequency noise that needs to be filtered. If filtering is needed, open dialog *Process>Filter...* and adjust low-pass filter parameters so that extra noise is eliminated but the dipole waveform is not distorted. Observe carefully the effect by looking at the "*Original response*" and "*Filtered response*" displays. The two cycles of phantom waveforms should be of equal amplitude.

19. Right-click the *Signal waveform* display. Select *Dipole at max. amp* in the pop-up menu. Drag the mouse, left button+shift pressed down, over the first positive peak in the *Signal waveform* display. Repeat the fitting for the first negative peak.

20. Repeat the fitting or all other dipoles 2-32. For further instructions on how to fit the dipoles, refer to *Source Modelling Software User's Guide*.

21. Go to *Dipole fitting* window, select all fitted dipoles, press the right button of the mouse and select *Print -> File*. In the saving options dialog, select column titles, Cartesian dipole coordinates, distance from origin, dipole moment and tab delimited output. If you intend to do further processing (see next step) on a spreadsheet using a computer using a decimal comma, you may also want to select *decimal part separated by comma*.

22. Compare the localization results with the positions given in Table 7.2. Calculate the position differences of individual dipoles and their average as

$$\Delta r = \sqrt{(x_{meas} - x_{known})^2 + (y_{meas} - y_{known})^2 + (z_{meas} - z_{known})^2}$$

23. The maximum error should be less than 5 mm. Check that the amplitudes roughly match with the dipole moment selected at step 11 (due to the finite precision of the physical dipole length, the measured dipole moments typically differ slightly from the nominal value). Note that the Source modelling program displays the dipole moments (Q) as zero-to-peak values whereas phantom dipole select uses peak-to-peak values, calculated by subtracting the fitted peak amplitudes corresponding to the first positive and negative peaks of the waveform as in step 19.

Table 7.1 Phantom fixed coil locations

Coil	x [mm]	y [mm]	z [mm]	Dist. from center [mm]
Right	79.5	0.0	0.0	79.5
Front	0.0	79.5	0.0	79.5
Left	-79.5	.0	0.0	79.5
Back	0.0	-79.5	0.0	79.5

Table 7.2 Phantom dipoles (length = 5.0 mm)

Dipole	x [mm]	y [mm]	z [mm]	Dist. from center [mm]
1	59.7	0.0	22.9	64.0
2	48.6	0.0	23.5	54.0
3	35.8	0.0	25.5	44.0
4	24.8	0.0	23.1	34.0
5	37.2	0.0	52.0	64.0
6	27.5	0.0	46.4	54.0
7	15.8	0.0	41.0	44.0
8	7.9	0.0	33.0	34.0
9	0.0	-59.7	22.9	64.0
10	0.0	-48.6	23.5	54.0
11	0.0	-35.8	25.5	44.0
12	0.0	-24.8	23.1	34.0
13	0.0	-37.2	52.0	64.0
14	0.0	-27.5	46.4	54.0
15	0.0	-15.8	41.0	44.0
16	0.0	-7.9	33.0	34.0
17	-46.1	0.0	44.4	64,0
18	-41.9	0.0	34.0	54,0
19	-38.3	0.0	21.6	44.0
20	-31.5	0.0	12.7	34.0
21	-13.9	0.0	62.4	64.0
22	-16.2	0.0	51.5	54.0
23	-20.0	0.0	39.1	44.0
24	-19.3	0.0	27.9	34.0
25	0.0	46.1	44.4	64.0
26	0.0	41.9	34.0	54.0
27	0.0	38.3	21.6	44.0
28	0.0	31.5	12.7	34.0
29	0.0	13.9	62.4	64.0
30	0.0	16.2	51.5	54.0
31	0.0	20.0	39.1	44.0
32	0.0	19.3	27.9	34.0

7.3 Voice intercom (option)

7.3.1 General

The intercom makes it possible to communicate with the patient between and during the measurements. It has been designed not to cause any interference to the Elekta Neuromag® TRIUX. However, in order to avoid disturbances, the microphone should be kept further than 30 cm away from the helmet.

Figure 7.5 illustrates the intercom. It is composed of a table station (1) and main station with power supply (2). The microphone (3) of the main station is inside the magnetically shielded room, connected to the side panel of the gantry. The microphone cable runs to the main station via the feedthrough filter. The loudspeaker for main station is outside of the magnetically shielded room attached on a separate feedthrough tube on the magnetically shielded room wall (4).

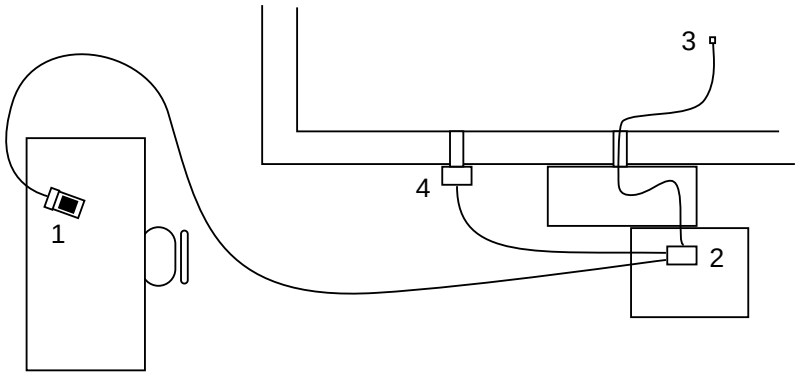


Figure 7.5 The intercom. 1: Table unit, 2: main unit inside the main electronics cabinet, 3: microphone connected to probe unit, 4: loudspeaker.

Figure 7.6 The intercom table unit.

7.3.2 Usage

To open the connection to the magnetically shielded room, dial *11* on the table station, see fig. 7.6. A short tone, a green light and number *11* on the display of the table station indicate that the connection is established. By default, the unit operates in automatic speech direction control. Note that the patient can hear what is spoken in the control room.

The volume of the loudspeaker to the magnetically shielded room is adjusted inside the main station. For more information, see the intercom instruction booklet.

7.3.3 Simplex mode

It is possible to switch the unit to a simplex mode with manual speech direction control by pressing the *T* button on the table unit. Then it is possible to listen to the patient, but the patient cannot hear what is spoken in the control room. To give instructions to the patient, press *T* and speak close (<50 cm) to the device. The button has to be kept down as long as you speak. During that time you cannot hear what the patient says. When the button is released, the intercom returns to the listening mode. To close the connection, press the *X* button.

To return to the automatic speech direction control mode, close and re-open the connection by pressing *X* and dialing *11* or press *T* for a fraction of a second.

Note: *There is no indication of the speech direction control mode on the table unit. If in doubt, close and reopen the connection to restore known (automatic) speech direction control.*

7.3.4 Low-speaking mode

The system has a low-speaking mode, also called the soft-speaking mode. This mode sets the volume of the speaker to a very low level, thus making it difficult to hear the voice of the patient. Switch the unit to the low-speaking mode by pressing the handset button in the middle of the upper row on the intercom table unit, see fig. 7.6. The handset button works as a toggle. Press the button again to revert to the loud-speaking, normal mode.

Note: *The only indication that the low-speaking mode is activated is a small dot, one pixel, in the middle of the LCD display of the table unit.*

Figure 7.7 *The small dot in the middle of the LCD display indicates that the low-speaking mode is activated.*

7.4 Video monitoring (option)

The schematic diagram of the optional video monitoring (CCTV, closed-circuit television) is shown in Fig. 7.8. The camera (1) is placed inside a separate RF-shield inside the magnetically shielded room. The camera is powered through a power supply inside the stimulus cabinet (2). An optic video link (3) connects the camera to the monitor (3). For more details and operating instructions refer to *Elekta Neuromag CCTV Camera System User's Guide*.

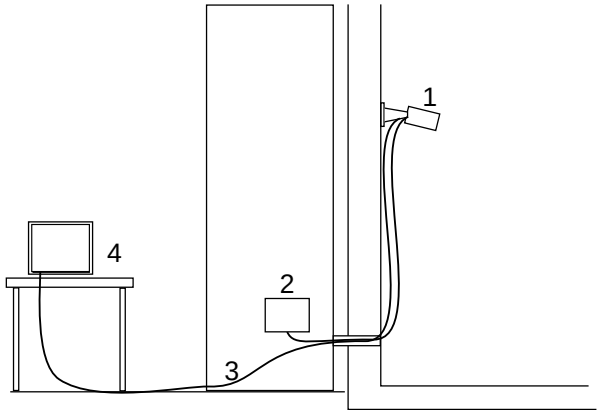


Figure 7.8 *Video monitoring. 1: Camera inside the magnetically shielded room, 2: camera power supply inside stimulus cabinet, 3: optic video link, 4: monitor on operator's desk*

7.5 Audio interface

The connection of the audio interface in the side panel of the gantry is shown in Fig. 1.17 of Section 1.10. The electronics has audio output connector for the patient's and, optionally, for the assistant's earphones, see Fig. 7.9. Replace the foamtips for each patient, they are single-patient use only. Connect the audio source to the cables (4 pcs, patient left and right channel, assistant left and right channel) coming out of the feedthrough cabinet. Before measurements, verify by testing the correct order of cables so that left and right channels are not intermixed. Test also audio intensity.

CAUTION 7.2: Adjust and test the audio intensity before connecting the earphones to the patient to avoid damage to hearing. Verify also left/right channel assignment.

Note: *The transducers are slightly magnetic, and generation of sounds produces also some magnetic artefacts. Place the transducers as far as possible from the sensor helmet.*

The probe unit also includes a microphone input connector and a microphone for the optional intercom unit.

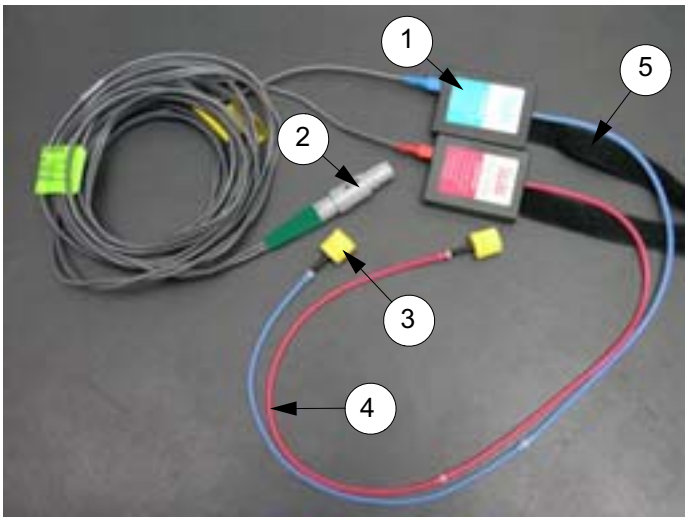


Figure 7.9 The tubal insert earphones. 1: Transducer, 2: audio connector, 3: foam eartips, 4: silicon tubing, 5: velcro fasteners.

7.6 Analog input

Twelve analog inputs for miscellaneous analog signals (maximum voltage ±10 V) are available. The inputs are connected to BNC connectors of a separate interface box shown in Fig. 7.10. The interface box is located outside of the main electronics cabinet. The interface box is intended to connect auxiliary third party devices outside the magnetically shielded room to Elekta Neuromag® TRIUX system.

Note: *The analog inputs are not intended for use inside the patient environment.*

Note: *The connection between analog input interface and main electronics cabinet is not RF-shielded, and therefore EMC susceptibility of the MEG system may be jeopardized if analog input interface box, cables, or devices attached on to it, are brought inside the magnetically shielded room.*

If devices attached to the analog input are used inside the magnetically shielded room, the cabling entering the magnetically shielded room must be properly RF filtered. Connect the signal cable via the RF-filter in the stimulus cabinet or use an optic link.

Figure 7.10 Analog input interface unit.

8 Maintenance

8.1 Maintenance program

The following maintenance program is recommended:

- Before every measurement: check artefacts and noise (check made by user)
- Every morning: check helium level, check MEG noise by recording signals without patient, determine need for tuning, tune if necessary (made by user). For bioamplifier and EEG channels verify the operation by using the internal calibration signal (test made by user).
- After every Bioamplifier/EEG measurement: cleaning of electrodes and electrode caps, check for wear (made by user)
- According to a site-specific user-derived schedule, about once a week: liquid helium refill (made by user). A fixed weekly schedule is recommended.
- Regular: phantom measurements, daily or at least once a week, are recommended (made by user). See section 7.2.
- Weekly: free disk space monitoring and cleanup. See section 8.8.
- Once every year: annual preventive maintenance service (made by authorized service personnel)

8.2 Checkup before every measurement

Before each measurement session, it is advisable to set up the measurement fully and make at least part of the measurement first with empty room, then with possible stimulators connected but with no patient, and finally with a test subject in the measurement position if possible. Check visually both in Bioamplifier/EEG and MEG channels for

- Stimulus artefacts
- Line interference
- Noise
- Bad channels
- Stimuli coming (if used)

The “responses” in an empty room measurement should be virtually flat lines showing only normal average noise. If you encounter a problem, try to remove the problem by simplifying the setup as long the problem has been identified. Especially try to determine which issues have changed since the system last time operated without trouble.

Note: *Excessive noise on the channels may deteriorate signal quality and lead to incorrect measurement. Usually, a few noisy channels does not, however, cause problems as this can be taken into account by rejection settings in data acquisition in the in source localization (refer to corresponding software manuals).*

8.3 Noise level follow-up and MEG channel tuning

Every day, preferably in the morning, the noise level of all channels should be checked by making an empty-room measurement. Bad channels, if any, are tuned according to *Sensor Tuner User's Manual*.

Let the Tuner program run always when appropriate. See *Sensor Tuner User's Manual*. It is recommended to save a good basic setup (having low overall noise) which is always used as the starting point for the auto program.

8.4 Bioamplifier/EEG channel checking

To check the operation of bioamplifier or optional EEG channels do a dummy measurement (no subject) with bioamplifier and EEG channels switched on. Select *Send calibration signal* from data acquisition software. Select the bioamplifier and EEG channel sets in the raw data display and verify that the calibration signal (±100 μV) is seen, there are no channels whose noise level clearly exceeds that of other channels or shows a completely flat line.

If necessary, record a short period of test signal and verify that the amplitude is same for all channels using, e.g., the signal processor program. Adjustment of calibration must be left to an authorized service engineer.

8.5 Troubleshooting

Try to remove the problem by simplifying the setup until the problem has been identified. Especially try to determine which issues have changed since the last time the system operated without a trouble. Possible, quite common causes of artefacts, noisy and flat channels are, e.g.,

- Improper grounding of stimulators or other peripherals, causing currents to flow in the walls of the magnetic shield (stimulus artefacts, line interference, computer data transfer artefacts). → Check that grounding is single-point. Consult Elekta's representative if in doubt how to connect the equipment.
- Multiple grounding points because of improperly added equipment (line interference). → Check that grounding is from a single point only.
- RF interference from external sources caused by extra unfiltered cables drawn into the magnetically shielded room (increased noise, level shifts). → Check all the leads inside the magnetically shielded room. Check that the cables are RF-filtered properly.
- Active digital equipment in stimulus cabinet, inducing interference to leads going inside the magnetically shielded room. → Shield the digital device or, preferably, have it outside the stimulus cabinet and feed the signals through a feedthrough filter
- Stimulus cables improperly connected (stimuli not coming, artefacts, line interference or RF interference). → Check cabling.
- Incorrect tuning (noise, some channels saturated). → Tune.
- Too low liquid helium level (noisy channels, saturated channels). → Transfer Helium
- Magnetic contamination on the patient (big artefacts). Remove patient and check with empty room. → Check patient and try to demagnetize.

- In the worst case magnetic objects near the sensor array lead to trapping of flux in the sensors, causing flat or noisy channels which are not recovered by taking the patient out. → Detrapping using the sensor heaters is needed, see Section 2.4.2.
- Loose electrode or bad connection to skin → Check connection. Clean skin and re-attach electrode
- Bad cable connections → Check electrode cap or headbox cable connections.
- Reference or active ground electrodes badly connected or left open → Check connection.
- Unused Bioamplifier/EEG channel left active → Unused channels should be switched off from data acquisition, see section 3.2 and *Elekta Neuromag Data Acquisition User's Manual*.
- Data acquisition lock-up (e.g. red fail lights on main electronics boards, stops responding, connection lost) → reset, see section 6.6.

8.6 Monitoring the liquid helium level

As part of the standard maintenance, the helium level should be checked regularly. There are three different ways to accomplish this:

- Push the toggle switch of the local display inside the magnetically shielded room to turn the display on and wait for 20–30 seconds for the display to stabilize. Remember to switch the display off by pushing the toggle switch again. See section 4.3.
- Select *Helium* from the *Tools* menu of the data acquisition program
- Double-click the icon of the *Helium* utility from the *Maintenance* folder

The level is automatically recorded in file on the data acquistion workstation, and the current level and recent history can be read from the workstation screen using the separate *Helium* utility. The boiloff rate should also be occasionally checked. A substantial increase of the boiloff rate usually signifies need for service (regenerating the vacuum which must be left for trained service personnel).

When the liquid helium level has reached near or to 0%, new liquid must be transferred. A regular weekly transfer schedule is recommended.

Note: *Do not leave the Elekta Neuromag® TRIUX warm up by itself.*

Usually, however, after the level has reached 0% it takes approximately one day before all the liquid is evaporated from the system. Carrying out measurements during this period is possible but disturbances due to low level of helium may occur. It is good practice to ensure beforehand that replacement liquid helium is available when needed by having a spare storage container always at hand or at least having a second, independent supplier of liquid.

See section 4.4 for helium transfer instructions.

8.7 Cleaning

The HPI coils and the painted parts of the Elekta Neuromag® TRIUX and the HPI coils can be cleaned and disinfected with pure alcohol. Acetone is not recommended as it may damage the insulating surface.

The upholstering of the patient couch and chair, and the wooden digitization chair are cleaned with soap water or ordinary mild dish care detergent.

For cleaning the electrode caps, refer to the instructions delivered with the caps.

The white cover of the phantom can be cleaned with with soap water or ordinary mild dish care detergent.

The workstation and its display included in the Elekta Neuromag® TRIUX must be cleaned with agents and wipes specifically designed for this purpose. Do not spill liquids inside the keyboards or other devices where they can cause short-circuits and damage to the devices.

Note: *When cleaning the probe unit, especially the interior of the helmet (= outer surface of the helmet), observe that risk of flux trapping to sensors exists, resulting in artefacts. Therefore, magnetic objects like wristwatches, belt buckles, magnetic buttons on sleeves etc. must not be brought in the vicinity of the Dewar. Refer to section 2.4.*

8.8 Disk space monitoring

The available disk space should be checked periodaically (e.g. once a week) in order to prevent disk space to run out unexpectedly, which can lead to measurement system refusing to run or cause some unexpected errors. The disk usage can be shown using the command issued at a terminal window:

```
df -h
```

The usage in percent and the directory names can be seen in the two rightmost columns. If any filesystem is nearly full, please study the associated directories and check if you can move some files elsewhere or delete them.

Note: *Please be careful when deleting files, and do not delete files the purpose of which you don't understand.*

In unclear situations please consult Elekta service. Note that if you have read-only devices (e.g. CDROM) present, their usage is normally reported to be 100%, which is not a problem.

8.9 Annual maintenance

The annual maintenance service must be left for trained service personnel. The service includes:

- Overall system performance test (noise, phantom measurement)
- Identifying causes of unresolved reported problems
- Checking of the magnetically shielded room (grounding, installations, door mechanisms etc.)
- Checking and cleaning of the Dewar (boiloff rate)
- Re-evacuating the Dewar vacuum, if necessary
- Performing detrapping, if necessary
- Checking of siphons, re-evacuating, if necessary

- Checking the mechanisms of the gantry, including the rope, replacing worn-out parts, lubricating mechanisms if necessary and cleaning the unit. The ropes are changed every five years.
- Checking the couch and chair mechanisms and cleaning both of them, top up of the hydraulic liquid of the chair and the chair fine-adjustment system, if installed, and inspection for leaks
- Checking the feedthrough filter unit and the main electronics cabinet, including checking all cabling and replacement of dust filters if necessary
- Checking of grounding and isolation arrangements
- Cleaning
- Checking workstations and peripherals, including checking software versions
- Checking liquid helium gauge
- Checking and changing defective and worn-out parts
- Checking intercom and video monitor operation (if installed)
- Checking the accessories
- Tuning of the system
- Overall system performance test (noise and phantom measurement, calibration) after the service

APPENDIX A Basic concepts, terminology

A/D conversion

Conversion of an analog signal to digital form, digitalization.

Amplifier deactivation

Ensuring that an unused amplifier with open inputs does not cause interference by forcing the output to a known stable state.

Anti-aliasing filter

A low-pass filter designed to limit the signal bandwidth to less than half of the sampling frequency. If the signal being digitized contains frequency components higher than half of the sampling frequency, a phenomenom known as aliasing occurs, whereby higher frequency components are folded back to lower frequencies, introducing spurious signal components.

Applied part

Parts of the system in direct contact with the person being investigated with the system.

Balance

See gradiometer balance.

BF type

Body floating. An applied part providing enhanced protection against electrical shock. An applied part of BF type must fulfill leakage current requirements specified in the standard IEC 60601-1 even in the case that the patient is unintentionally connected to an external mains voltage.

Bioamplifier

An instrument for measuring bioelectrical signals from body surface potentials., e.g. electro-oculogram etc. Also known as polygraphic amplifier.

Biomagnetism

The phenomenon of magnetic fields produced by living organisms, including the magnetic fields produced by the human brain and measured by means of magnetoencephalography.

Category AP

Rating for medical electrical equipment or medical electrical equipment part complying with specified requirements on construction, marking, and documentation in order to avoid sources of ignition in a flammable anaesthetic mixture with air.

Category APG

Rating for medical electrical equipment or medical electrical equipment part complying with specified requirements on construction, marking, and documentation in order to avoid sources of ignition in a flammable anaesthetic mixture with oxygen or nitrous oxide.

cHPI

See continuous HPI.

Class I device

A device whose protection agains electrical shock does not rely only on basic insulation but also has a permanently connected protective earth connection so that accessible metal parts cannot become live if basic insulation is damaged.

Continuous HPI

Head position indicator signals that are activated continuously and that allow tracking the head movement. Currently, the head position tracking is made off-line.

Cortical dipole

A dipole located in the cerebral cortex.

Cryopumping

Adsorption of gases on surfaces on cryogenic temperatures. See detailed description in Section 2.1.3.

Current dipole

A model of an elementary current element with equal and opposite current source and sink. See also magnetic dipole.

D/A conversion

Conversion of a digital signal into analog form.

Data acquisition

The process by which signals detected by the measurement system are digitized, transferred to the workstation, and displayed.

Data recording

The process by which acquired signals are stored on disk for later off-line review and analysis.

Dewar

A thermally insulated vessel for cryogenic liquids. It has a vacuum-insulated double-wall structure. The vacuum space also houses thermal radiation shields.

Dipole

See current dipole and magnetic dipole.

EEG

See electroencephalography.

EEG active ground

See EEG Ground terminal.

EEG bipolar channels (Differential channels)

Channels with terminals for both the positive (+) and negative (-) amplifier inputs separately for each channel. The reference is irrelevant for differential channels but may still be required for active grounding, see EEG ground terminal.

EEG ground terminal, Active ground

A terminal for attaching an electrode to equalize the potential of the patient with respect to the preamplifier signal ground. As described above, the pre-amp unit is floating. Thus, there has to be a way to set it to a common potential with the patient in order to keep the input amplifier at linear operating range over extended periods of time and to minimize the common mode voltage between the patient and the amplifier.

Traditionally, this has been accomplished by connecting the isolated preamplifier signal ground directly to the patient with an EEG electrode. However, in a fault condition, the maximum patient leak current allowed by patient safety regulations may be exceeded. Also, the amount of common-mode interference is affected by changes in the impedance of the reference electrode.

To work around this, the patient is connected to isolated preamplifier signal signal ground by means of a current-limited amplifier (driver) that even in a fault condition keeps the current of the ground electrode within acceptable limits. In addition, the ground driver can also be actively controlled so that the ac signal components (above approximately 5 Hz) seen on the reference electrode input are compensated for by the active ground driver. Consequently, the potential difference between the patient and isolated preamplifier signal ground is smaller than without the active grounding circuit, and results in a better common-mode interference rejection. Another way to understand the operation of the circuit is that active ground reduces the impedance of the ground electrode by a factor of 10.

The active ground driver socket on the side panel of the gantry and headbox is labelled "GND" as is customary in the EEG practice although the term strictly speaking refers to isolated preamplifier signal ground potential. Ground electrode should always be connected to the terminal labelled "GND" on the side panel or headbox when making measurements.

EEG isolated preamplifier signal ground (GNDi))

Ground potential (signal zero-level) of the Bio/EEG preamplifier subsystem. As patient safety regulations require, this ground is isolated from all other grounds in the Elekta Neuromag® TRIUX, including the magnetically shielded room. Thus, the Bio/EEG preamplifier unit is floating.

Internally, the preamplifiers see all signals with respect to GNDi. Technically speaking, isolated ground refers to the center tap of the secondary of the safety isolating transformer of the EEG preamplifiers.

Because of safety principles, isolated ground should never be connected directly to patients (see EEG ground terminal). In the headbox and electrode caps supplied with the Elekta Neuromag® TRIUX or available as options, isolated ground is not accessible.

EEG reference

Signal subtracted from all the single-ended channels. In normal EEG measurements, the reference signal is derived from the reference electrode. For ECG measurements, the Wilson Central Terminal (WCT, see below) reference can be used. For testing and calibrating the EEG subsystem, the reference signal can be connected to the isolated ground of the preamplifiers.

EEG reference electrode

An electrode, placed usually at an inactive area, monitoring the potential of the patient. This can serve for two purposes, depending on the mode of the preamplifier: 1) it gives the signal ('reference') which is subtracted from the single-ended (unipolar) EEG channels when selected as the reference source, and 2) it acts as a sensor for the active ground driver. Because of 2), the reference electrode needs to be connected even when using only differential EEG channels with the active ground switched on.

EEG unipolar channels (Single-ended channels)

Channels with just one electrode per channel (+), and sharing a common reference signal (-). The reference signal can come from various sources, see EEG reference.

Electroencephalograph

An instrument for performing electroencephalography.

Electroencephalography

The recording of electrical activity along the scalp produced by the simultaneous firing of neurons within the brain.

Evoked response

Magneto- or electroencephalograhic signal produced by the simultaneous firing of neurons within the brain in response to a stimulation, e.g., to a short tone.

Feedback loop, Flux-locked loop

A readout method for the SQUID sensor where the output of the preamplifier is fed magnetically back to the sensor. In this configuration, the sensor acts as a null-detector while the feedback effectively compensates for the input magnetic field. The feedback signal is thus equal to the input magnetic field; a copy of the feedback signal is then used as the output. Flux locked loop provides a linear input-output relation whose calibration is to a large amount independent of individual component gain variations.

Flux transformer

A superconducting circuit comprising at least two coils connected in series. Because of superconductivity, magnetic flux is conserved. Thus, a magnetic field imposed on one of the coils will induce a shielding current to flow in the circuit, cancelling the effect of externally imposed flux. Since the shielding current will induce a magnetic field in other coils belonging to the circuit, a flux transformer can be used to scale magnetic field intensity by varying the coil parameters.

Gantry

A scanner assembly used to hold the Dewar and sensor array inside the Dewar.

Gradiometer

A flux transformer coupling external magnetic signal to the SQUID detector, making the SQUID to respond to spatial variations of the external magnetic field. A gradiometer comprises multiple pickup coils and a signal coil which couples the signal to the SQUID. The gradiometer is insensitive to uniform magnetic fields.

Gradiometer balance

A measure of the nonideality of a gradiometer, relative area difference of the actual individual gradiometer pickup loop areas. For a first-order gradiometer with individual pickup loop areas A and A+δA, the balance is given by δA/A.

HPI

See Head Position Indicator.

Head position indicator

A set of marker coils attached on the head which are then activated with a small current, and the location of the coils relative to the sensor array is then determined, based on the measured magnetic field distribution. The positions of the coils with respect to landmarks on the head are determined with a 3D digitizer prior to the measurement, and the HPI determination is made at the beginning of each recording.

IEC60601

A family of international standards concerning the safety of medical electrical equipment and systems.

Interelectrode impedance

A measure of the total opposition to current flow between two EEG or bioamplifier electrodes.

Internal Active Shielding (IAS)

A means to suppress external disturbances in a magnetically shielded room. Internal Active Shielding uses the sensor array in the probe unit to sense the residual ambient field variations inside the magnetically shielded room. These signals are fed back to the coils inside the magnetically shielded room, forming a closed control loop that effectively minimizes the external disturbances at the sensor area. An integrated part of the Elekta Neuromag® TRIUX. It can, however, also be turned off from data acquisition software.

Leakage current

Current that is not intended (not functional). For example, patient leakage current is the unintentional current that flows from equipment via patient to ground.

Magnetically shielded room (MSR)

A special enclosure whose walls, floor, and ceiling made of plates of high-permeability alloy and of high-conductivity metal (typically Aluminium). Typically, the magnetically shielded room has 2-3 such concentric shells, separated by a few hundred mm. The room distorts the external magnetic field in such a way that the magnetic field inside is substantially weaker. The shielding efficacy increases with frequency.

Magnetic dipole

A model of an object that generates a magnetic field in which the field is considered to emanate from two opposite poles much. See also current dipole

Magnetoencephalograph

An instrument for performing magnetoencephalography.

Magnetoencephalography

An imaging technique used to measure the magnetic fields produced by electrical activity in the brain.

Magnetometer

A flux transformer coupling external magnetic signal to the SQUID detector, making the SQUID to respond to the external magnetic field. A magnetometer comprises a single pickup coil and a signal coil coupling the signal to the SQUID.

MEG

See magnetoencephalography.

MSR

Magnetically shielded room.

Planar gradiometer

A gradiometer where the multiple pickup coil is made of two adjacent loops. The planar gradiometer is sensitive to spatial changes of the magnetic fields in a direction along the line joining the centerpoints of the lines. A planar gradiometer has a focused, directional sensitivity pattern and couples strongly to currents right underneath it.

Recording

See data recording.

Sensor array

An assembly of two or more sensors. See also sensor helmet.

Sensor helmet

A room-temperature surface that covers the sensor array in a magnetoencephalograph.

Signal space projection (SSP)

A mathematical method for compensation of external interference and sensor artifacts especially in magnetoencephalography, based on projection of different spatial signal distributions characterized by multi-dimenstional signal vectors. The SSP projects out signal space components in pre-defined signal space orientations determined on site which are characteristic for external interfererence.

Signal space separation (SSS)

A mathematical method for compensation of external interference and sensor artifacts esp. in magnetoencephalography, based on series expansions of signal sources and their different convergence characteristics with respect to the sensor array. The *MaxFilter* software is based on this method.

Siphon

A vacuum-insulated tube for transferring liquid helium from storage vessel to the probe unit. The Elekta Neuromag® TRIUX transfer siphon comprises a flexible part and a fixed part.

SQUID

Superconducting QUantum Interference Device: The SQUID is an ultrasensitive magnetic flux detector based on superconductivity and so-called Josephson effect. It operates at cryogenic temperatures.

SSP

See Signal Space Projection.

SSS

See Signal Space Separation.

Stimulus channel

A combination of trigger lines composed in a single multi-bit virtual channel, e.g., 16 bits. Each sample contains the state of the individual trigger lines.

Subcortical dipole

A dipole located below the cerebral cortex.

Superconductivity

A state where electric resistance equals zero. Present in several substances, e.g. in Niobium and Lead. A superconductor also repels magnetic flux, i.e., magnetic field lines cannot penetrate the superconductor.

Trapped flux

A phenomenom where magnetic flux is trapped in superconducting structures, e.g., thin films. A superconductor normally repels magnetic flux. However, if regions of the superconcutor become non-superconducting as a result of being exposed to strong magnetic fields, magnetic field lines can enter the superconductor and become trapped inside superconducting areas. May lead to deteriorated operation and increased noise of the SQUID sensor. Movements of the trapped flux are seen as magnetic signal jumps. Trapped flux can be released by heating the superconductor above its superconducting transition temperature, typically over 10 K.

Trigger channel

Same as stimulus channel.

Trigger line

A binary trigger signal for an individual sensory stimulator typically used for synchronization of stimulator activity and MEG/EEG data stream. Can be used as input (self-paced stimulators) or output (externally controlled stimulators). Activity of patient-response devices, such as push-buttons, may also be encoded in trigger lines.

Wilson central terminal (WCT)

Average of limb electrode potentials, normally connected to both arms and left leg. When Wilson central terminal is selected as reference, the average of the signals of the channels BIO1–BIO3 is subtracted from all the single-ended channels. This mode is used only in some ECG measurements when electrodes BIO1–BIO3 are attached to limbs.

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