EYE TRACKING SYSTEM

CS681

EIGHT CHANNEL SEARCH COIL SYSTEM
WITH REAL-TIME DIGITAL SIGNAL PROCESSING

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Swiss Quality Products

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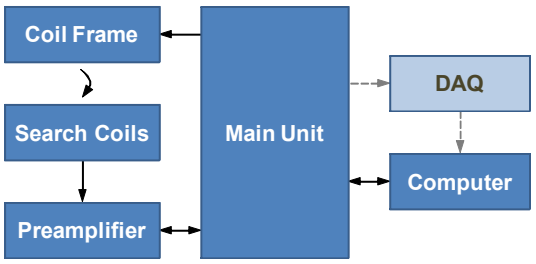
SHORT DESCRIPTION

The CS681 is the third generation of Primelec's search coil systems for the linear detection of 3D eye and head movements.

The system's ultra high accuracy and bandwidth guarantees effortless recording of not only saccades, vergence, smooth pursuit, vestibular and optokinetic eye movements but also of miniature eye movements such as drift, tremor and microsaccades.

A typical system setup consists of the main unit, the coil frame, up to eight search coils, the pre-amplifier and a computer. The use of an external analog data acquisition system is optional thanks to the digital output data of the CS681.

Applications of the CS681 include neurophysiological, ophthalmological, psychological, visual and psychiatric studies.



MAIN FEATURES

- 8 recording channels, digital processing of up to 8 search coils in real-time
- Digital and analog output data (USB interface and 24 analog outputs)
- Linear angular output data (horizontal and vertical) and raw output data (X, Y and Z)
- Output data rate up to 8000 readings per second
- Recording range 360° in the horizontal plane, ±80° in the vertical plane
- Linearity error ±0.3° max. (within specified recording range)
- Noise < 0.0028° RMS (< 0.01° RMS within specified recording range)
- Resolution < 0.0002° (digital output data)
- Drift < 0.1° within 30 minutes after power-on (warm-up), negligible after warm-up
- Automatic tuning of gain- and offset settings
- User friendly configuration (LCD with touch screen, USB interface)
- Nonvolatile memory for 10 user specific system configurations
- ActiveX control and application software included (MS Windows)
- Comprehensive customer support by Primelec
- Two years full warranty

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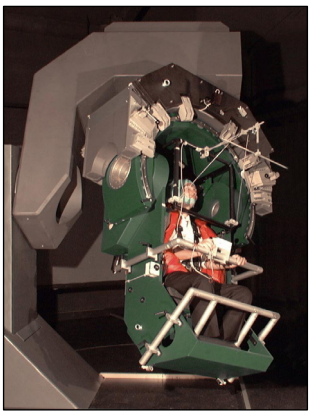
APPLICATION



The CS681 is intended for research use only and has not been reviewed, certified or approved for clinical purposes. All use of the system must be in compliance with appropriate procedures.

The typical application of the CS681 is the measurement of three-dimensional (horizontal, vertical and torsional) eye and head movements in neurophysiological, ophthalmological, psychological, psychiatric and visual studies.

The picture shows a motorized multi-axes turntable, equipped with our search coil system (by courtesy of Prof. D. Straumann, Neurology Department of the University Hospital Zurich).

SYSTEM CONFIGURATION

The CS681 provides versatile configuration options, such as

- Automatic tuning of all gain- and offset settings
- Separate gain- and offset correction (X, Y and Z) per channel
- Selectable preamplifier gain per channel
- Selectable digital low pass filter per channel
- Selectable phase reversal per field signal and per channel
- Selectable voltage swing for the analog outputs

The system configuration is done very user friendly with the touch screen of the display and / or via the USB interface. Up to ten user-specific system configurations may be saved in the non-volatile memory of the CS681.

OUTPUT DATA

The CS681 provides digital and analog output data (USB interface and 24 analog outputs).

The analog outputs of the CS681 may be used in conjunction with an external data acquisition system, e.g. an analog data acquisition board for a PC. The user may select the format of the analog output data: linear angular data (horizontal and vertical orientation of the search coils, i.e. no additional trigonometric calculations required) or detected signals X, Y and Z (raw data). The voltage swing of the analog outputs is user selectable.

USB UNIVERSAL SERIAL BUS

The USB interface of the CS681 eliminates the need for an external analog data acquisition system, which improves system performance and saves costs. The USB interface continuously transmits data packets consisting of all output data (linear angular data and raw data, 21 bit resolution), a time stamp and a sequential packet number.

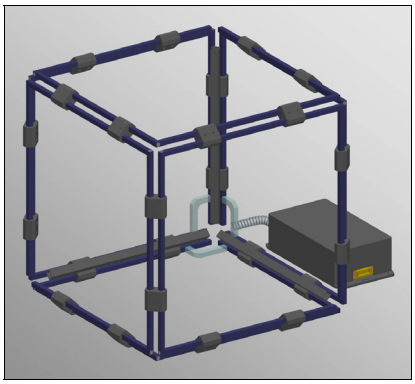
The output data rate of the CS681 depends on the number of processed channels. The user may select the processing of two, four or eight channels, depending on the number of search coils used for the experiment. If two channels are processed, the CS681 provides a very high-speed output data rate of 8000 readings per second. Processing all eight channels still ensures a high speed output data rate of 2000 readings per second.

SOFTWARE

Included with the CS681 is an application software (MS Windows). The software may be used to control the system configuration, to analyze and capture the digital output data and to upgrade the system firmware over the USB interface.

Also included is an ActiveX control for MS Windows. The ActiveX control allows a user application software (e.g. a LabVIEW VI) the straightforward communication with the CS681 over the USB interface. The ActiveX control comes with detailed documentation (help file) and examples (Visual Basic source code and LabVIEW VI).

COIL FRAME



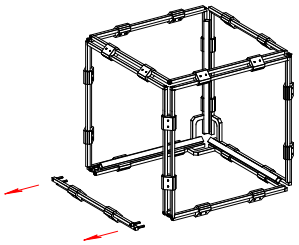
The coil frame consists of three field coils (X-, Y- and Z-axis), composed of aluminium bars with a cross section of 8 mm. Thus, the restriction of the visual field is minimal.

An external Matching-Box contains the required capacitor networks for resonance tuning.

The entire coil frame may be dismounted if required for easy integration into user specific setups.

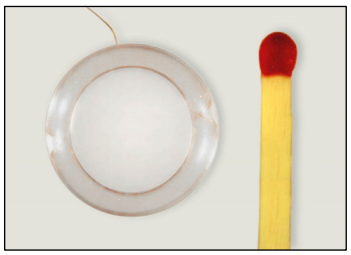
Primelec offers coil frames in various colors, arranged as a cube with an edge length in the range from 250 mm to 700 mm. Within this range the exact dimensions can be specified by the customer.

The option "Removable Bars" makes it possible to open the coil frame by effortless removing of two bars. This unique feature may be essential to insert large objects into the coil frame, e.g. a primate chair. The removable bars are plugged into the coil frame such that both electrical connection and mechanical fixation is ensured and no tools are required to open and close the coil frame.



SEARCH COILS

Various search coils are applicable in terms of dimension, geometry, number of turns and material.



Torsional recordings require a dual search coil (frontal and sagittal plane), i.e. two recording channels are required. The CS681 provides eight recording channels, which is sufficient for practically any application. For example, simultaneous recording of horizontal, vertical and torsional binocular eye plus head movements requires six recording channels.

Primelec's partner CHRONOS VISION GmbH[1] manufactures and distributes scleral search coils which are perfectly suited for the CS681. CHRONOS VISION also offers customized scleral search coils, e.g. with embedded black markers for simultaneous recordings of 3D eye movements using videooculography.

CHRONOS VISION

[1] http://www.chronos-vision.de/downloads/CV_Product_SSC.pdf

MEASURING PRINCIPLE AND TECHNICAL DESCRIPTION

The magnetic field search coil technique introduced by Robinson[2] has become the most commonly used method for quantitative studies of eye and head movements in man and in experimental animals. A coil frame is used to generate an AC magnetic field. The coil frame consists of two or three field coils arranged in space quadrature, which are driven by field signals of different frequencies. The resulting magnetic field induces a voltage in a search coil which is placed in the coil frame. The spectral components of the field frequencies in the search coil signal are proportional to the sine of the horizontal and vertical angular displacements of the search coil relative to the coil frame.

Traditional search coil systems usually use analog electronics to demodulate the search coil signal with respect to the magnetic field directions. Additional analog to digital converters and a computer are used to capture the demodulated search coil signal and to calculate the angular orientation of the search coil. This approach requires fairly complex system adjustments by the user and may result in poor system performance with noise-, drift- and linearity issues.

The CS681 uses another approach to demodulate the search coil signal. The spectral components of the field frequencies are obtained by calculating the FFT (Fast Fourier Transformation) of the digitized search coil signal in real-time. This approach (introduced by Primelec in 1999) provides remarkable advantages compared to traditional search coil systems. Very high system performance is achieved and almost no system adjustments are required by the user.

Mainboard of the main unit

Three digitally synthesized sine wave signals of different frequencies are generated by the main unit. These field signals are applied to the coil frame to generate the AC magnetic field, which induces a voltage in the search coil(s). The CS681 comes with an external preamplifier to avoid routing the susceptible search coil signals over a long distance. The preamplifier mainly consists of eight amplifiers and two analog multiplexers. The amplifiers have ultra low noise input stages and digitally programmable gain. Their inputs are transformer-coupled for galvanic isolation between the search coils and the amplifiers. The outputs of the eight amplifiers are time-multiplexed by two 4:1 analog multiplexers. The output signals of the multiplexers are buffered and differentially transmitted to the main unit, which also controls the timing of the multiplexers.

The main unit contains two analog to digital converters which digitize the output signals of the multiplexers simultaneously and synchronized to the timing of the field signals. The use of a DSP (digital signal processor) and a FPGA (field programmable gate array) makes it possible to compute the FFT and the subsequent trigonometric calculations in real-time. The complete data processing for two search coils takes less than 125 us, resulting in a high-speed output data rate of up to 8000 readings per second. The computed output data is available over the USB interface and as analog signals over the integrated digital to analog converters.

External preamplifier

[2] Robinson D.A. (1963), A method of measuring eye movements using a scleral search coil in a magnetic field, IEEE Transactions on Biomedical Engineering 10: 137-145

SPECIFICATIONS

Main Unit	
Recording Channels	8 channels
Recording Range	360° in the horizontal plane ±80° in the vertical plane
Output Data Rate	Depending on the number of processed channels, user selectable: - 8000 Hz (2 channels processed) - 4000 Hz (4 channels processed) - 2000 Hz (8 channels processed)
Resolution	< 0.0002° (digital output data)
Noise	Full bandwidth: < 0.0028° RMS, < 0.018° peak-peak (search coil at 180° hor, 0° vert) < 0.0035° RMS, < 0.024° peak-peak (search coil at 180° hor, 40° vert) 200 Hz Bandwidth (internal low pass filter, 200 Hz Bessel 4th order): < 0.0015° RMS, < 0.008° peak-peak (search coil at 180° hor, 0° vert) < 0.0018° RMS, < 0.010° peak-peak (search coil at 180° hor, 40° vert)
Drift	< 0.1° within 30 minutes after power-on (warm-up), negligible after warm-up
Linearity Error	Horizontal: ±0.3° max. within 360° range Vertical: ±0.3° max. within ±80° range
Low Pass Filter	Digital low pass filter with user selectable characteristics per channel: - Disabled - Bessel or Butterworth, IIR, 4th order, 500 Hz, 200 Hz or 50 Hz - Moving average (FIR) with 8, 16 or 32 taps
Front Panel	Field Signals: - Frequencies: 105.79 kHz, 113.93 kHz, 122.07 kHz (X, Y, Z-axis, note 1) - Nominal output voltage: Depends on the used coil frame (note 2) Preamplifier Interface: - Power supply and data interface to the external preamplifier Analog Outputs: - 24 analog outputs (14 bit resolution), user selectable data format - Voltage swing: ±2 V, ±2.5 V, ±4 V, ±4.5 V or ±5 V (user selectable) - Output impedance: 200 Ohm typical USB Interface: - USB 1.1 / 2.0 interface, bulk data transfer - System configuration - Output data (21 bit resolution) Mains Power Switch: - System power on / off Display with Touch Screen: - User adjustable contrast and backlight intensity - Menu system to control the system configuration
Rear Panel	Mains Power Input: - 230 VAC ±10 %, 50 Hz / 115 VAC ±10 %, 60 Hz (250 VA max.)
Outline Dimension	255 x 110 x 310 mm (w x h x d)
Weight	6.5 kg

Preamplifier	
Recording Channels	8 channels, user adjustable gain setting per channel
Input Impedance	600 Ohm typical (100 kHz)
Supply Voltage	±5 VDC, ±300 mA max. (power supply is provided by the main unit)
Outline Dimensions	76 x 35 x 154 mm (w x h x d)
Weight	420 g
Coil Frame	
In General	Three coils with two turns each, arranged as a cube Optional version “Removable Bars” available, which allows the straightforward opening of the coil frame, e.g. to insert a primate chair
Magnetic Flux Density	15 uT typical (note 3)
Coil Material	Anodized aluminum bars, cross section 8 mm
Coil Color	Various colors available, contact Primelec for further information
Dimension	Dimension L1 may be specified by the customer in the range from 250 to 700 mm, see drawing below
Weight	Depends on the coil dimensions, for example approx. 5 kg for L1 = 700 mm (including Matching-Box)
Search Coils	
Material	Preferably double insulated copper wire, Ø 20um
DC-Resistance	100 Ohm max. (note 4)
Effective Area	0.5 cm² ... 100 cm² (note 5)
Weight	Depends on material, dimensions and manufacturing process, for example approx. 2 mg for a double insulated copper coil with a diameter of 2 mm and 80 turns

Note 1: Other frequencies for the field signals on request, contact Primelec for further information.

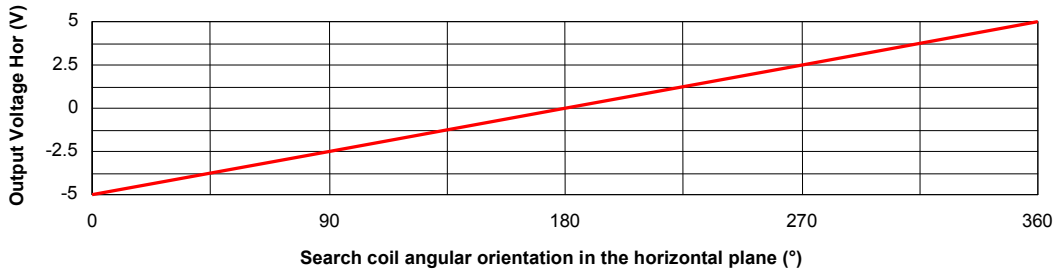
Note 2: The nominal output voltage of each field signal is tuned at the factory to achieve the specified magnetic flux density and an optimal field homogeneity at the 3D-centre of the coil frame. The tuned field signals may be attenuated by the operator in steps of 10 % down to zero.
The maximum output voltage of each field signal is 18.4 V_{RMS} differential measured.

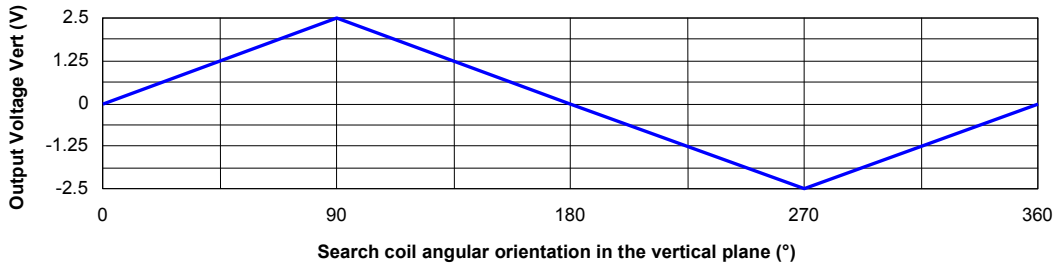
Note 3: The specified magnetic flux density refers to the nominal output voltage of the field signals. The magnetic flux density may be reduced by the operator in steps of 10 % down to zero.

Note 4: The DC resistance should not be higher than specified to achieve the specified noise of the system’s output data. Higher DC resistance may increase the noise of the system’s output data.

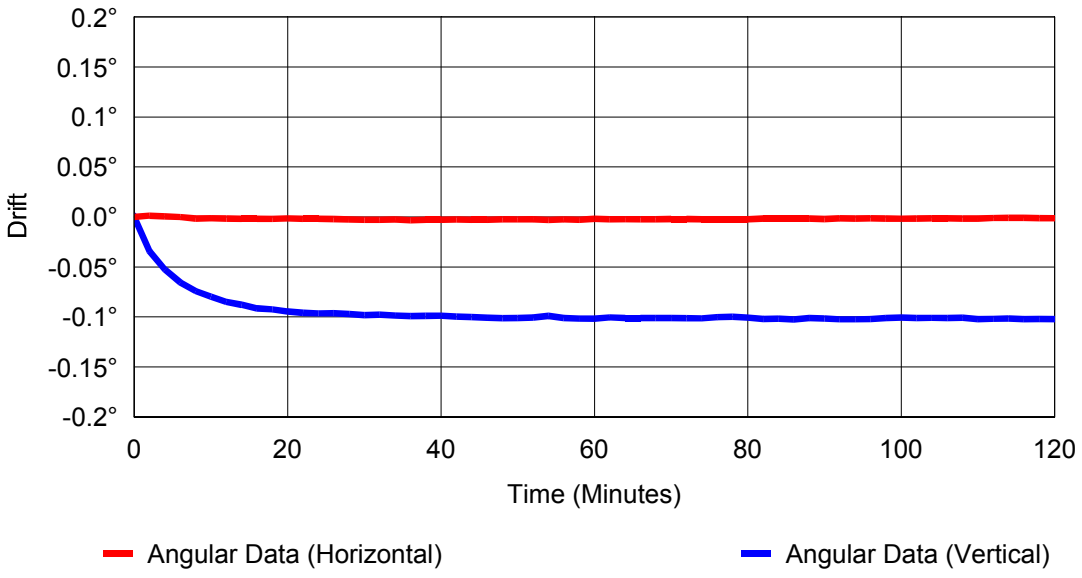
Note 5: Effective Area = n D² pi / 4 (where n is the number of turns and D is the diameter)
Smaller effective area may be used, possibly resulting in increased noise on the system’s output data. Larger effective area (up to 1000 cm²) may be used by reducing the magnetic flux density.

Typical progression of the analog output signals (note 6)

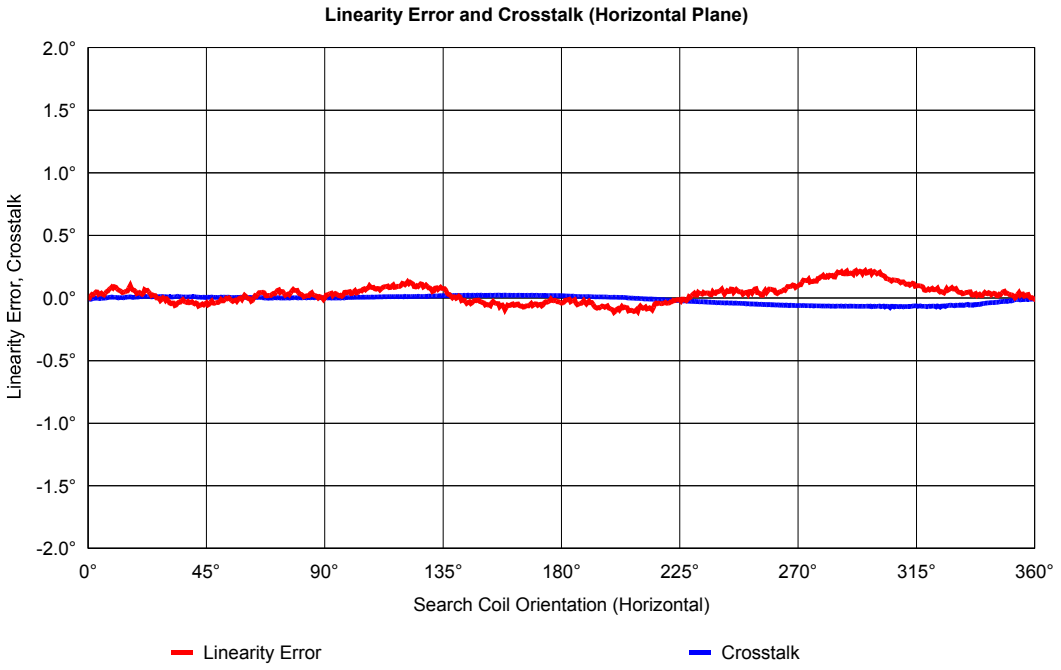


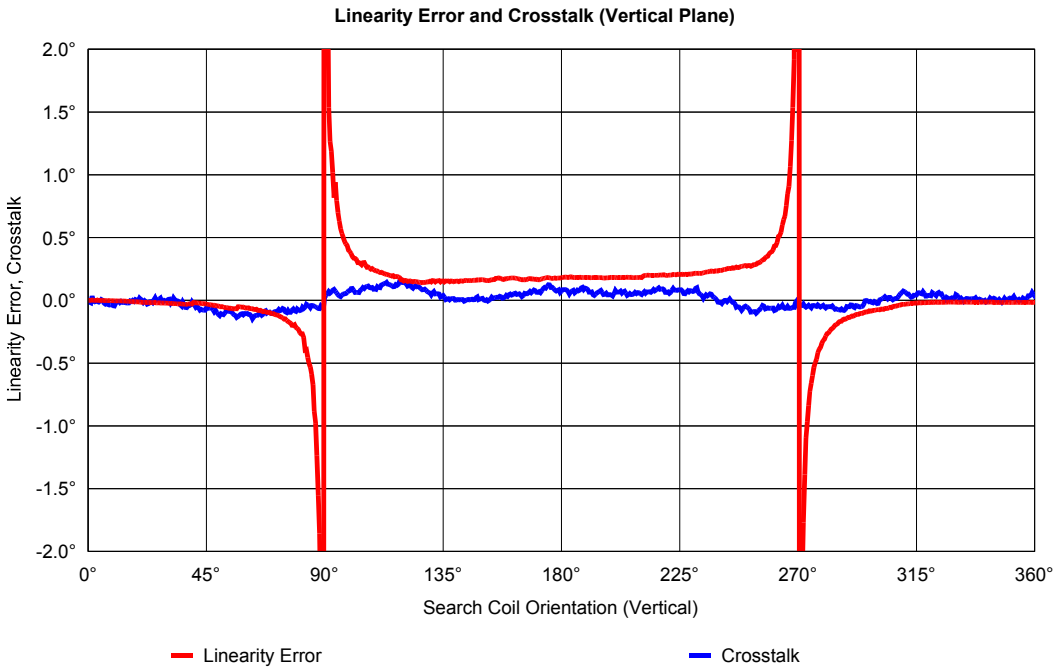


Warm-Up Drift (note 7)



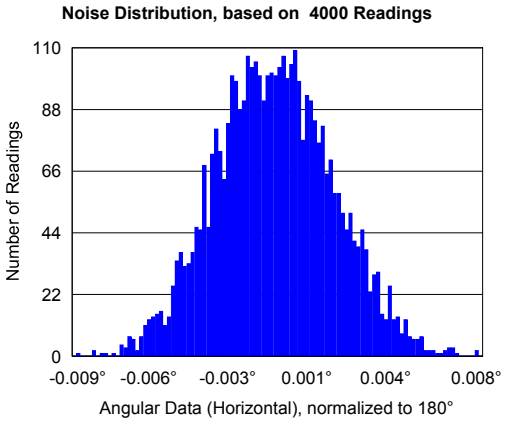
Linearity Error and Crosstalk (note 7)

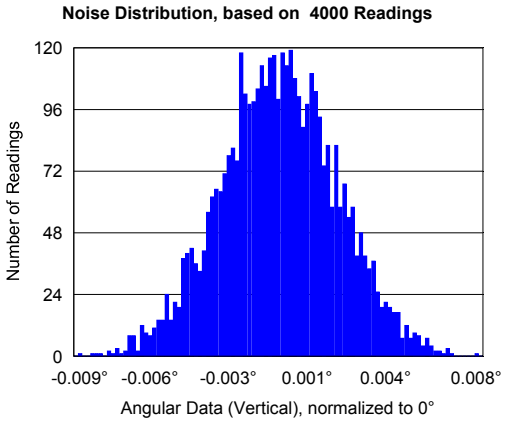




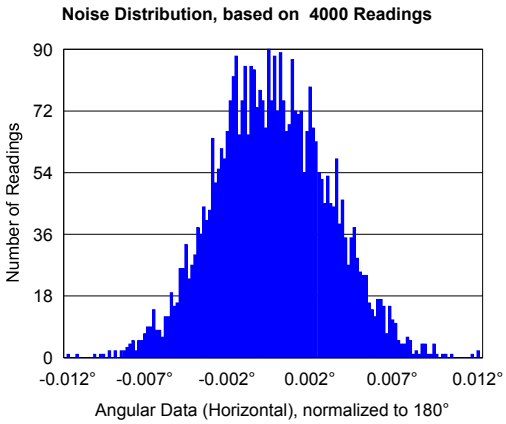
Distribution of Angular Noise (note 7)

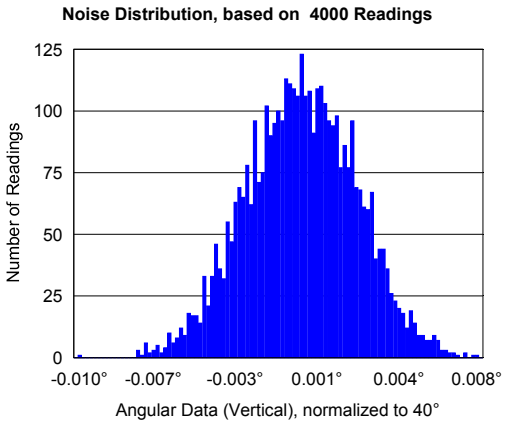
Search Coil Orientation: Horizontal 180°, Vertical 0°



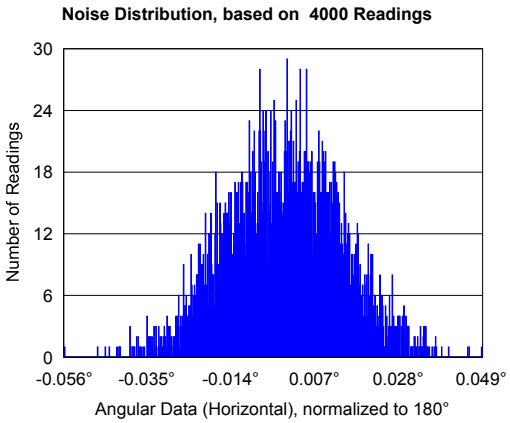


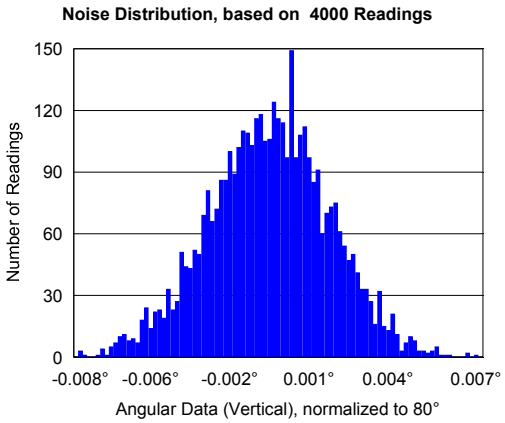
Search Coil Orientation: Horizontal 180°, Vertical 40°





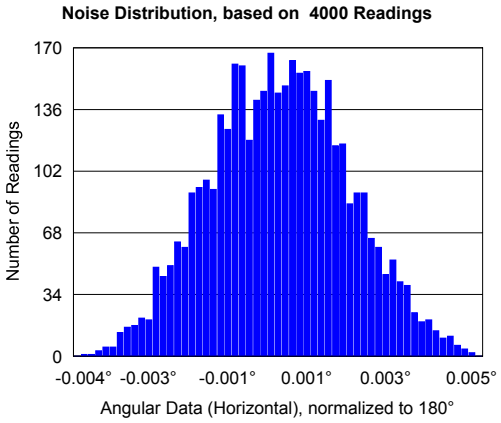
Search Coil Orientation: Horizontal 180°, Vertical 80°

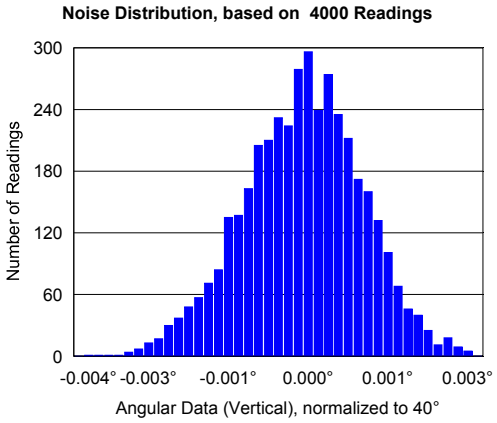




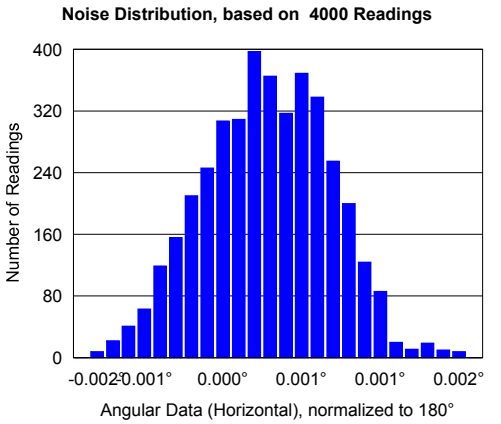
Distribution of Angular Noise (note 8, note 9)

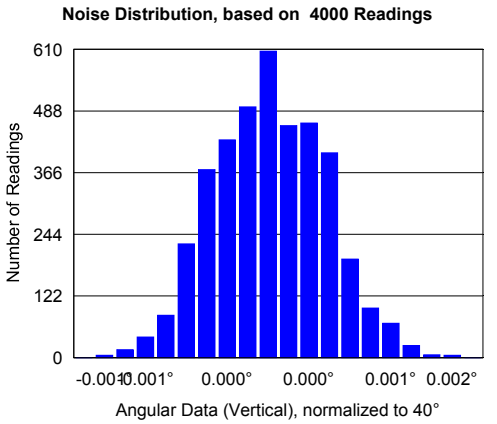
Search Coil Orientation: Horizontal 180°, Vertical 40° (note 8)





Search Coil Orientation: Horizontal 180°, Vertical 40° (note 9)





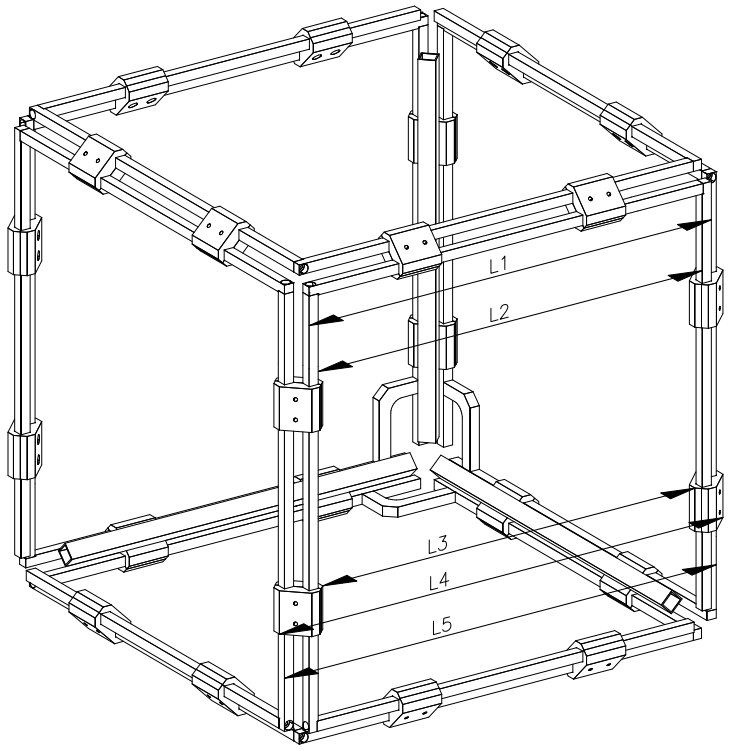
Note 6: Output Mode: Angular Data, Output Swing: ±5 Volt

Note 7: Used setup for the performance measurements:
- Coil frame L1 = 700 mm
- Search coil effective area = 10.8 cm^2, R_{DC} = 4.8 Ohm
- Angular data acquired over the USB interface
- 8 channels processed
- Gain correction disabled
- Offset correction disabled
- Field signals magnitude 100 %
- Preamplifier gain setting = 17
- Low pass filter disabled (unless otherwise noted)

Note 8: Used setup as described in note 7, except for:
- Low pass filter enabled, characteristics: Bessel, 200 Hz, 4^{th} order, IIR

Note 9: Used setup as described in note 7, except for:
- Low pass filter enabled, characteristics: Bessel, 50 Hz, 4^{th} order, IIR

Coil Frame Mechanical Dimensions



L1	250 … 700 mm
L2	L1 – 16 mm
L3	L1 – 27 mm
L4	L1 + 36 mm
L5	L1 + 26 mm

Notes:

- Dimension L1 may be specified by the customer in the range from 250 mm to 700 mm, the other dimensions (L2 to L5) are resultant
- The field coils consist of anodized aluminium bars (cross section 8 mm), the color may be specified by the customer
- The drawing above is not full-scale and schematically depicts a coil frame with L1 = 350 mm

Examples (frequently used dimensions):

L1	L2	L3	L4	L5
350 mm	334 mm	323 mm	386 mm	376 mm
500 mm	484 mm	473 mm	536 mm	526 mm
700 mm	684 mm	673 mm	736 mm	726 mm