Angle-Meter NT

User Manual

Scleral search coil system for linear detection of three-dimensional angular movements

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1 Safety Information - read this first

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The coil frames of the Angle-Meter NT generate relatively **strong magnetic fields** which can lead to **injury to health**. **Capacitive and inductive coupling onto organisms and devices sensitive in this regard must be considered.**

The signals applied to the coil frames may have **hazardous voltage levels**. An inappropriate application (touching the conductors or the coil frames, capacitive and / or inductive couplings etc.) can come for **injuries to health**.

The inputs of the preamplifiers are not off-ground, i.e. the search coils are **not galvanic isolated from ground**. Depending on the measuring environment and application, this may be a possible risk for **injuries to health** and should be considered.

There are country-specific standards and regulations for applications on the human being. **The Angle-Meter NT has no approval for such applications and may never be used for applications on the human being.**

To prevent fire or shock hazard, do not expose the system to rain or moisture. Dangerously high voltages are present inside the device. **Do not open the cabinet**. Refer servicing to qualified personnel only.

Check the standards and regulations of your country and **the possible risks for injuries to health** before using the Angle-Meter NT. **Only qualified personnel may work with the system**, and only after becoming familiar with the concerning standards and regulations, possible risks and safety information of the Angle-Meter NT. **In no event shall Primelec, its employees or its suppliers be liable for any damages whatsoever.**

2 Measuring Principle

The magnetic field search coil technique introduced by Robinson [1] has become the most commonly used method for quantitative studies of eye and head movements in man and in experimental animals. The technique is based on phase-locked amplitude detection of the voltage induced in a search coil in the external ac magnetic field. The angular orientation or displacement of the search coil in three-dimensional (3D) space is detected by using two or three external magnetic fields, which are arranged in space quadrature. Demodulation of the induced signals with respect to the magnetic field directions is obtained on the basis of phase or frequency coding by driving the external magnetic fields in phase quadrature or at different frequencies [2]. In order to obtain reproducible results, the search coil measurements have to be restricted to the uniform part of the external magnetic fields.

The Angle-Meter NT uses an other approach to detect the angular orientation of a search coil. Three digitally synthesized sine wave signals of different frequencies are used to generate a magnetic field. This field induces a voltage in a search coil, where the spectral frequency components of the three field frequencies are proportional to the horizontal and vertical angular displacements of the search coil relative to the system's reference frame. The spectral frequency components are obtained by computing the Fast Fourier Transformation (FFT) of the digitized search coil signal. The use of a high performance digital signal processor (DSP) allows to compute the FFT and all required trigonometric calculations in real-time.

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[1] D. A. Robinson, "A method of measuring eye movement ..." IEEE Trans. Biomed. Eng., vol. BME-l0, pp. 137-145, 1963
[2] R. S. Remmel, "An inexpensive eye movement monitor ..." IEEE Trans. Biomed. Eng., vol. BME-31, pp. 388-390, 1984

The left part in the figure below schematically shows a search coil, placed at the center of the magnetic fields of the field coils X-X' (80 kHz) and Y-Y' (96 kHz). For simplicity, only two axes are shown.

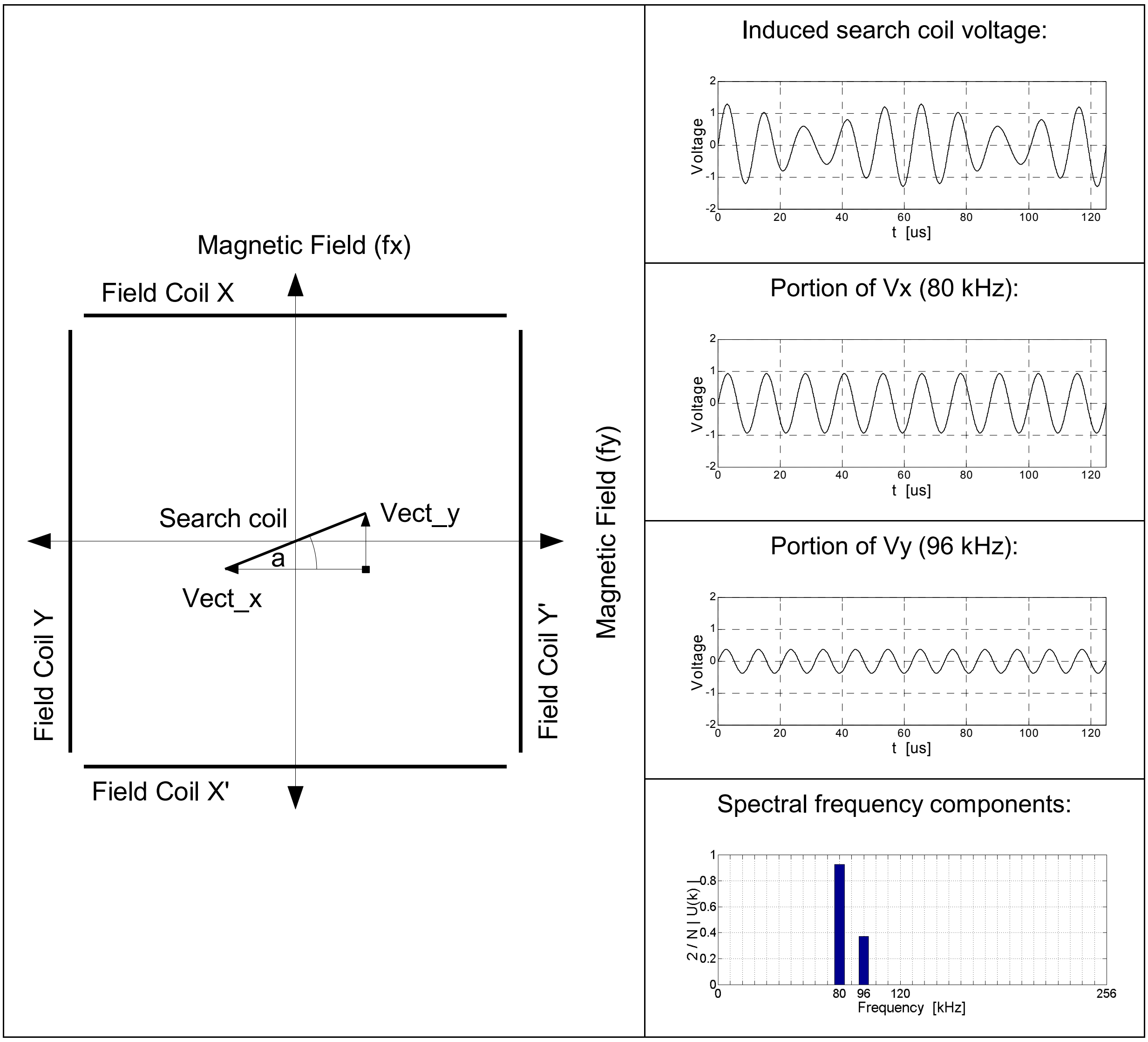


Figure 2-1: Measuring Principle

The correlation between the angular orientation of the search coil in the external magnetic field and the induced voltage is apparent if we look at the portions of Vx and Vy in the search coil signal. These portions correlate with the lengths of the vectors Vect_x and Vect_y, which are used to detect the angular orientation a of the search coil.

Conventional phase-locked amplitude detection systems use analog electronics to capture the portions of Vx and Vy in the search coil signal by demodulating the search coil signal with respect to the magnetic field directions. This may cause noise-, phase- and drift problems and requires relatively complex adjustments by the user. External A/D converters are required in order to obtain the angular orientation of the search coil, which increases the total system costs.

The Angle-Meter NT uses an other, more reliable measuring principle. The spectral frequency components of the search coil voltage are analyzed by computing the Fast Fourier Transformation (FFT) of the digitized search coil signal, which results directly the signed vector lengths of the vectors Vect_x and Vect_y. The use of a powerful digital signal processor (DSP) allows to compute the FFT and the trigonometric calculations in real-time. This approach offers various advantages compared to conventional systems and eliminates most of the weaknesses described above.

The figures below show again some examples to illustrate the correlation between the angular orientation of the search coil in the external magnetic field, the resulting induced search coil voltage and the computed signed vector lengths from the FFT, where

- α is the angular orientation of the search coil in the horizontal plane,
- β is the angular orientation of the search coil in the vertical plane,
- the magnetic field frequency f1 in the X-axis is 80 kHz,
- the magnetic field frequency f2 in the Y-axis is 96 kHz,
- the magnetic field frequency f3 in the Z-axis is 120 kHz and
- the signed vector lengths are scaled to ± 1 for better clarity

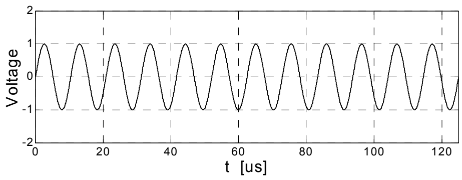
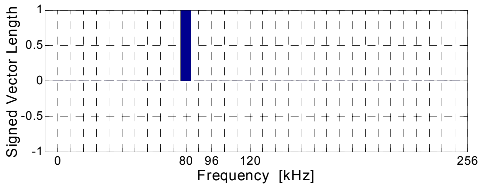
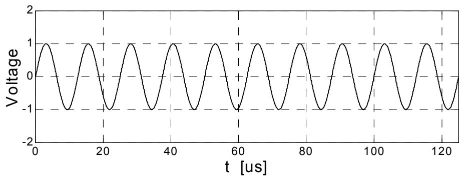
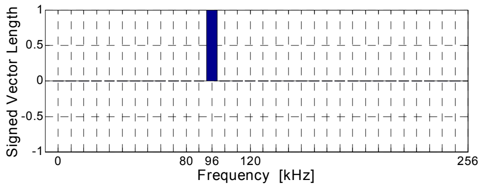
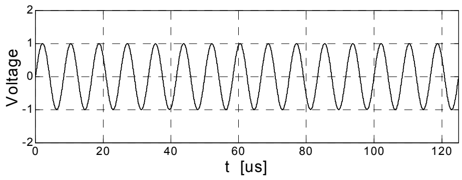
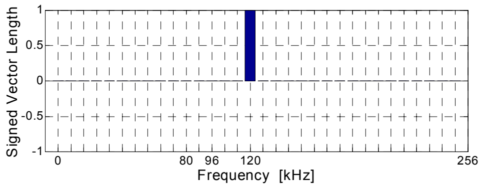
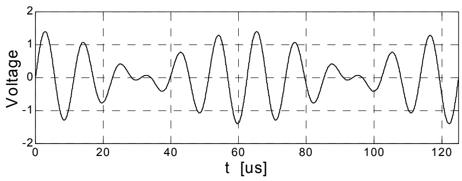
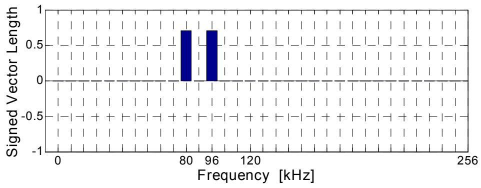
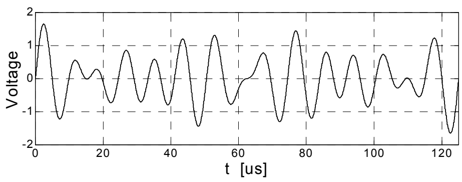
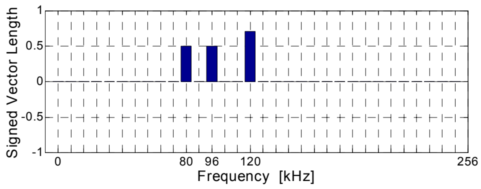
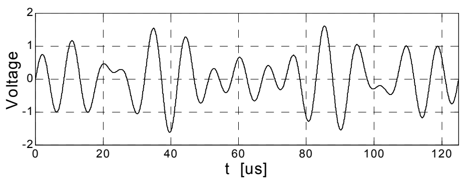
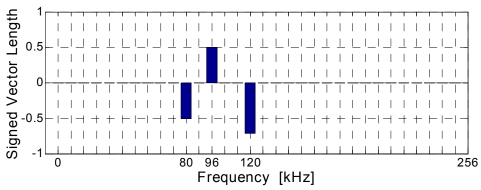
α	β	Induced search coil voltage	Signed vector lengths
0°	0°		
90°	0°		
0°	90°		
45°	0°		
45°	45°		
135°	-45°		

Table 2-1: Correlation Examples

3 Concept

The Angle-Meter NT mainly consists of four functional blocks:

- The base unit with the Generator Module and one or two Detector Module(s)
- The coil frame, arranged as a cube, which generates three magnetic fields
- The search coil(s), placed in the 3D-centre of the generated magnetic field
- The preamplifier(s) for the amplification of the search coil signal(s)

The Generator Module generates three sine wave signals of different frequencies. The signals are amplified by three power amplifiers within the Generator Module. The amplified voltages are applied via the Matching-Box to the coil frame. The resulting magnetic field induces a voltage in a search coil, which is pre-processed in the preamplifier. In the Detector Module, the signal is digitized, processed by a digital signal processor and outputted as analog and digital data.

4 Base Unit

The base unit of the Angle-Meter NT is designed in a modular form. It consists of the power supply, one Generator Module and one or two Detector Modules. The main switch at the base unit's back panel disconnects the device from the AC input voltage.

Figure 4-1: Base unit with the Generator Module and the Main Detector Module

Figure 4-2: Base unit plus Add-On Detector Module

5 Generator Module

The Generator Module generates three digitally synthesized sine wave signals of different frequencies, which are amplified by three power amplifiers with balanced outputs (field signals). These are used for the generation of the magnetic fields. The frequencies of the field signals are:

f1: 80 kHz (used for the generation of the magnetic field in the X-axis)
f2: 96 kHz (used for the generation of the magnetic field in the Y-axis)
f3: 120 kHz (used for the generation of the magnetic field in the Z-axis)

The amplitudes of the field signals are tuned at the factory to achieve the specified flux density and an optimal homogeneity of the magnetic field at the 3D-centre of the coil frame. The user may attenuate the tuned field signals in steps of 20 % down to zero. This allows to reduce the magnetic field strength, for example if extremely large search coils are used, or to turn off the magnetic field. See also the description of the Detector Module in this Manual.

The Generator Module also produces an internal synchronization signal, which is used by the Detector Modules to synchronize the start of the measurements.

The switch at the front panel is used to toggle the operation mode of the device between Power On and Standby, where the Standby mode means, that all internal electronics are not powered, except the small auxiliary power supply used by the front switch.

6 Coil Frame, Matching-Box

The field signals from the Generator Module are applied to the Matching-Box. Within the Matching-Box, the field signals are applied via three transformers to the capacitor networks, which build the capacitive part of three resonance circuits. Three pairs of one-turn field coils, arranged as a cube, are building the inductive part of the resonance circuits. The capacitor networks are tuned at the factory to adjust the resonance circuits to 80 kHz, 96 kHz and 120 kHz. The currents in the field coils generate three magnetic fields (80 kHz for the X-axis, 96 kHz for the Y-axis and 120 kHz for the Z-axis).

As mentioned, the amplitudes of the field signals are tuned at the factory to achieve the specified flux density and an optimal homogeneity of the magnetic field at the 3D-centre of the coil frame. This means, that the used search coils must be placed in the 3D-centre of the coil frame to achieve an optimal system linearity. The usable space with an acceptable field homogeneity around the 3D-centre of the coil frame is more or less proportional to the size of the coil frame. Therefore, larger coil frame are preferable in this regard.

Primelec offers both, standardized as well as user specified coil frames in various colors, arranged as a cube with an edge length in the range from 30 cm to 70 cm. Due to the monocoque construction, the restriction of the visual field is minimal. Our coil frame can be de- and remounted, which may be helpful during the building of user specified setups.

Caution: If the coil frame has “Removable Bars” (optional), do not remove or insert the “Removable Bars” while the system is operating! Turn off the power of the Angle-Meter NT before handling the bars.

If the coil frame is mounted on a turntable, seven slip ring contacts are required for wiring. See chapter 12 'System Installation' and 13 ‘Slip Ring Wiring’ for additional information.

An optimal quality of the magnetic field is fundamental for reliable measurements. Mismatched field intensities and extensive phase errors will lead to an inhomogeneous resulting field, which causes invalid results. Irradiation of external devices and metallic materials in or near to the field may be critical because of field distortion. To avoid problems, read chapter 14 'System Optimization' of this Manual.

See also chapter 15 ‘Tuning the system with a new coil frame’ for additional information if the user plans to fabricate a specific coil frame.

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Caution:
The coil frames of the Angle-Meter NT generate a relatively strong **magnetic field** in the frequency range from 80 kHz to 120 kHz. This can lead to **injury to health**. **Capacitive and inductive coupling onto organisms and devices sensitive in this regard must be considered.**

The signals applied to the coil frames may have **hazardous voltage levels**. An inappropriate application (touching the conductors or the coil frames, capacitive and / or inductive couplings etc.) can come for **injuries to health**.

Check the standards and regulations of your country and **the possible risk for injuries to health** before using the Angle-Meter NT. **Under no circumstances may the Angle-Meter NT be used for applications on the human being.**

7 Search Coils

A miniature search coil (for example 80 turns with a diameter of 2 mm), which is placed at the 3D-centre of the coil frame, picks up a signal. The spectral frequency components for f1, f2 and f3 of the induced signal are proportional to the angular displacements of the search coil relative to the system's reference frame (see chapter 2 'Measuring principle').

As mentioned, the search coils should be placed at the 3D-centre of the coil frame, since the homogeneity of the magnetic field is optimal in that position. If this is not practicable, the linearity of the output data may decrease. To avoid this in a certain range, the Angle-Meter NT allows an individual gain calibration for the X-, Y- and Z-signals of each measuring channel (see chapter 14.3 'Use of the gain correction').

The search coils may be manufactured by the user to achieve best results and highest flexibility for the specific application, but of course the Angle-Meter NT is also compatible with the search coils of third-party suppliers. The diameter and the number of turns determine the effective area of the search coil:

$$A_{eff} = n\ D^2\ pi / 4$$

The effective area of the search coil is one of the main parameter, which determine the quality of the measurement data: The larger the effective area the better the signal to noise ratio, the smaller the diameter the better the linearity. To achieve optimal results, the parameters of the used search coils must comply with the specification of the technical data.

8 Preamplifier

The preamplifier is capable to process four search coils signals (i.e. four measuring channels). To achieve best signal quality, the preamplifier is in a separate case which can be placed as close to the search coils as possible. To minimize stray pick-up, it should not be placed in the magnetic field. Please not that the aluminum enclosure of the preamp is grounded over the connection cable.

The preamplifier contains four amplifiers, a 4 to 1 multiplexer (MUX) and an output driver with balanced outputs. It can be operated in two gain modes: AGC (automatic gain control) and fixed gain. The AGC mode makes it possible to use various search coils under different conditions without the need for any system adjustments by the user and ensures always an optimal signal to noise ratio of the measuring data. The fixed gain mode allows an offset correction to minimize the influence of picked up stray signals. The system offers auto-tuning to automatically achieve optimal values for the gain- and offset-settings. See also chapter 14.5 'Choosing the best suited settings for your application'.

If the preamplifier is mounted on a turntable, nine slip ring contacts are required for wiring. See chapter 12 'System Installation' and 13 'Slip Ring Wiring' for additional information.

An optimal quality of the analog signal is fundamental to achieve best results. To avoid problems, read chapter 14 'System Optimization'.

⚠ **Caution:**
The inputs of the preamplifiers are not off-ground, i.e. **the search coils are not galvanic isolated from the system** (no input transformers are used). Depending on the measuring environment and application, this may be a possible risk for **injuries to health** and should be considered.

Check the standards and regulations of your country and **the possible risk for injuries to health** before using the Angle-Meter NT. **Under no circumstances may the Angle-Meter NT be used for applications on the human being.**

9 Detector Module

Each Detector Module controls one preamplifier, i.e. each is capable to process four measuring channels. Up to two Detector Modules can be plugged into the base unit, where the left Module is the Main Detector Module, which controls the level of the field signals generated by the Generator Module, and the right Module (optional) is the Add-On Detector Module.

The multiplexed input signal from the preamplifier is digitized by an analog to digital converter (ADC) and processed by a digital signal processor (DSP). Demultiplexing of the incoming data stream is achieved by the DSP, since it controls the MUX of the connected preamplifier. The spectral frequency components of the measuring signals are analyzed by computing the Fast Fourier Transformation (FFT) of the digitized input signal. The FFT provides directly the needed signed vector lengths to calculate the angular orientations of the search coils. The concerning trigonometric calculations are also executed in real-time by the DSP, where the synchronization signal from the Generator Module is monitored to obtain phase information.

The results from the calculations for each measuring channel are simultaneous available in real-time as analog output signals and - over the serial interface - as digital data. The format of the outputs is selectable: linear angular orientation data (search coil angles alpha, horizontal plane, and beta, vertical plane), signed vector lengths or signed vector angles from the FFT (f1 = X-axis, f2 = Y-axis and f3 = Z-axis).

The Detector Module has several parameters which determine the behavior of the Module:

- The format of the output signals
- The processing of the measuring channels
- The gain mode for the amplification of the search coil voltage
- The internal output filter
- The individual correction of offsets due to picked up stray signals
- The individual correction of gains due to nonlinearity
- The output voltage swing of the analog outputs

To change the settings of these parameters, use the menu or the "Remote Control Functions" over the serial interface. See chapters 9.3 'Menu' and 10.2.3 'Remote Control Functions' for a detailed description of the parameters and how to change their settings. See also chapter 14.5 'Choosing the best suited settings for your application'.

9.1 Display

During normal operation, the display (LCD) of the Detector Module shows the actual settings of some important parameters:

```
OM:D PR:4 GM:A
OF:- OC:- GC:-
```

OM: **O**utput **M**ode. The actual mode (format) of the output signals:

- D Angular Data, angular orientation of the search coil with the calculated angles alpha (horizontal plane) and beta (vertical plane)
- L Vector Length, signed vector length from the FFT-calculation for f1 (X-axis), f2 (Y-axis) and f3 (Z-axis)
- A Vector Angle, signed phase angle from the FFT-calculation for f1, f2 and f3

PR: **Pr**ocessing. The actual processing mode of the measuring channels:

1 Only one measuring channel (channel 1) is processed
2 Only two measuring channels (channel 1 and channel 2) are processed
4 All four measuring channels (channel 1 to channel 4) are processed

GM: **G**ain **M**ode. The actual gain mode for the amplification of the search coil signals:

A AGC, the automatic gain control of the preamplifier is enabled for all four measuring channels
F Fixed gain, the individual gain of the four measuring channels is set to a fixed value

OF: **O**utput **F**ilter. The actual setting of the digital output filter:

- The digital filter is disabled (not active)
+ The digital filter is enabled (active) and the output signals of all four measuring channels are feed trough the digital filter

OC: **O**ffset **C**orrection. The actual setting of the offset correction:

- The offset correction is disabled (not active)
+ The offset correction is enabled (active) and the output signals of all four measuring channels are calculated on the basis of the individual offset correction values

GC: **G**ain **C**orrection. The actual setting of the gain correction:

- The gain correction is disabled (not active)
+ The gain correction is enabled (active) and the output signals of all four measuring channels are calculated on the basis of the individual gain correction values

See chapters 9.3 'Menu', 10.2.3 'Remote Control Functions' and 14.5 'Choosing the best suited settings for your application' for details concerning the used parameters.

9.2 LEDs

To achieve an optimal system performance, the search coil signals of the used measuring channels have to be in a certain voltage range. If the preamplifier is operated in the AGC mode, this is automatically ensured as long as the parameters of the used search coils are within the technical specification and the field signals are not attenuated. If the preamplifier is operated in the fixed gain mode, the signal amplitudes depend on the effective area of the search coils, their angular orientation and position in the field, the attenuation of the field signals and the settings of the fixed gain values.

The four bicolor-LEDs at the front panel of the Detector Module are used as level indicators to monitor the signal amplitudes of each measuring channel:

LED Ch 'n' off: The signal amplitude from measuring channel 'n' is too small, therefore the signal to noise ratio of this channel’s output data may be decreased. Increase the fixed gain value for this channel and / or decrease the attenuation of the field signals in order to achieve an optimal s/n ratio.

LED Ch 'n' green: The signal amplitude from measuring channel n is within the desired voltage range. Reliable output data with an optimal signal to noise ratio is ensured.

LED Ch 'n' red: The signal amplitude from measuring channel 'n' is too high, the ADC may be overdriven and the output data may be corrupted! Decrease the fixed gain value for this channel and / or increase the attenuation of the field signals until the LED lights always green, independently of the angular orientation of the connected search coil.

The concerning LED of a used measuring channel should always light green to ensure reliable output data.

9.3 Menu

The settings of the parameters of each Detector Module is achieved by the menu or over the serial interface. This chapter describes the use of the menu.

The menu allows to change the settings of the following parameters:

- The intensity of the display illumination (LCD backlight)
- The strength of the magnetic field
- Enable / disable the correction of gains due to nonlinearity
- The gain mode for the amplification of the search coil voltage
- Enable / disable the correction of offsets due to picked up stray signals
- Enable / disable the digital filter for the output signals
- The mode (format) of the output signals
- The output voltage swing of the analog outputs
- The behavior of the Module at power on
- The processing of the measuring channels
- The saving and recalling of settings
- The output of some test signals

To enter the menu during normal operation, push the knob of the multifunctional rotary-/ push-button of the Detector Module for a time longer than one second. During the menu is active, turn the knob to select the desired parameter. To change the setting of the selected parameter, push the knob for a time shorter than one second and choose the new setting by turning the knob. To enter the new setting, push the knob for a time shorter than one second, to discard the new setting and restore the old setting of the actual parameter, push the knob longer than one second. To exit the menu, push the knob longer than one second instead of selecting a parameter.

9.3.1 How to use the Menu (Example)

To change the setting of the output voltage swing, follow these steps.

1. During normal operation, push the knob longer than one second in order to activate the menu:

OM:D PR:4 GM:A OF:- OC:- GC:-	↑ > 1 sec	█: Display Illum 3: Medium

2. Once the menu is activated, turn the knob until the parameter "H: Output Swing" is displayed. Note that the blinking cursor appears in the first line of the LCD, indicating that the menu is in the mode which scrolls trough the parameters (the actual setting of the parameter is displayed in the second line of the LCD).

█: Display Illum 3: Medium	↻ / ↺	█: Output Swing 4: +/- 9 V

3. To change the setting of the output voltage swing, push the knob for a time shorter than one second. The cursor moves down to the second line of the LCD, indicating that the setting of the parameter now can be changed.

█: Output Swing 4: +/- 9 V	↑ < 1 sec	H: Output Swing █: +/- 9 V

4. To change the actual setting of the output voltage swing, turn the knob until the desired new setting is displayed in the second line of the LCD.

```
H: Output Swing        ↻ / ↺        H: Output Swing
▓: +/- 9 V                          ▓: +/- 4.5 V
```

5. To accept the new setting, push the knob for a time shorter than one second. To discard the new setting and restore the old setting, push the knob longer than one second. Note that the cursor moves back to the first line of the LCD, indicating that the menu is back in the mode which scrolls trough the parameters and the actual setting is displayed in the second line of the LCD.

To accept the new setting:

```
H: Output Swing          ↑          ▓: Output Swing
▓: +/- 4.5 V          < 1 sec       2: +/- 4.5 V
```

To discard the new setting:

```
H: Output Swing          ↑          ▓: Output Swing
▓: +/- 4.5 V          > 1 sec       4: +/- 9 V
```

6. To exit the menu and to go back to normal operation, push the knob longer than one second during the menu is in the mode which scrolls trough the parameters.

```
▓: Output Swing          ↑           OM:D PR:4 GM:A
2: +/- 4.5 V          > 1 sec        OF:- OC:- GC:-
```

Notes:

- Neither the analog outputs nor the serial interface are updated with the measuring data while the menu is activated. The analog outputs freeze at their last updated value and the serial interface is idle (i.e. no measuring data is transmitted) until the menu is no longer active and Detector Module is back to normal operation.
- To disable the activation of the menu of a Detector Module, push the knob during the power up sequence of the Angle-Meter NT until the message "Module Controls: Disabled" appears in the LCD. This prevents the change of any settings by the Menu or over the serial interface (Remote Control Functions) and ensures, that the concerning Detector Module is always in the normal operating mode until the system is set to standby or the power of the device is turned off.

9.3.2 Menu Settings

Parameter	Setting	Description
A: Display Illum	1: Off	The backlight of the LCD is turned off
	2: Dark	The backlight of the LCD is dark
	3: Medium	The backlight of the LCD is medium
	4: Bright	The backlight of the LCD is bright
B: Field Signals	0: Add-On Module	The intensity of the field signals can not be changed because of this is the Add-On Detector Module. Use the Main Detector Module if you want to change the setting of this parameter.
	1: Off	The field signals are turned off
	2: 20%	The field signals are attenuated to 20 % of their nominal values
	3: 40%	The field signals are attenuated to 40 % of their nominal values
	4: 60%	The field signals are attenuated to 60 % of their nominal values
	5: 80%	The field signals are attenuated to 80 % of their nominal values
	6: 100%	The field signals are at 100 % of their nominal values
C: Gain Corr	1: Disabled	The gain correction is disabled (not active)
	2: Enabled	The gain correction is enabled (active) and the output data of all four measuring channels is calculated on the basis of the individual gain correction values for each frequency of each channel. This means, that the signed vector lengths from the FFT-calculations are multiplied by the concerning gain correction values. If the search coil is placed outside the 3D-centre of the magnetic field, this allows the correction of the magnetic field inhomogeneity in a certain range. See also chapter 14.3 'Use of the gain correction'. Note that all gain correction values are set to 1.0 at the factory. To change the values, use the concerning "Remote Control Function" (see chapter 10.2.3 'Remote Control Functions').
D: Gain Mode	1: AGC	The gain mode of all four measuring channels is set to automatic gain control (AGC). This allows the use of different search coils without the need of any system recalibration, as long as the parameters of the used search coils are within the technical specifications. Due to the AGC, the gains change dynamically, depending on the field strength, the effective area of the used search coils and their angular orientation. This ensures an optimal signal to noise ratio of the system. Note that in this mode the offset correction is always disabled; it is not applicable due to the variable gain caused by the AGC (see also below, "E: Offset Corr).

Parameter	Setting	Description
	`2: Fixed`	The gain of all four measuring channels is set to an individual fixed value. This allows the use of an offset correction, which will minimize the influence of picked up stray signals (see also below, "E: Offset Corr"). If the fixed gain mode is selected, the values of the fixed gains must be individually adjusted for the used search coils. This can be done automatically by the use of the menu ("Do Auto-Tune", see below). To change the values manually, use the concerning "Remote Control Function" over the serial interface (see chapter 10.2.3 'Remote Control Functions'). The LEDs of the Detector Module indicate the voltage level of the concerning measuring channels; if the fixed gains are adjusted correctly, the concerning LEDs light green (see chapter 9.2 'LEDs'). Note that the peak value of the voltage changes depending on the angular orientation of the search coil (see chapter 2 'Measuring principle').
	`3: Do Auto-Tune`	First, the user has to prepare the tuning process by placing the used search coils into their positions in the field, where their angular orientations doesn't matter. Then the Auto-Tuning can be started. The system performs a routine, which evaluates the optimal gain for each channel regarding the currently connected search coils, where their actual angular orientation is considered by the routine. The execution time of the routine depends on the effective area of the used search coils (max 3 seconds). After the routine has performed, the evaluated gains are used (fixed gain values) and the Module is set to the fixed gain mode. See also above, "Fixed" gain mode.
`E: Offset Corr`	`0: Off (AGC)`	The offset correction is disabled (not active) and the setting can not be changed because of the gain mode is currently set to "AGC". If you want to use the offset correction, the gain mode of the Module must be set to "Fixed" (see above, "D: Gain Mode").
	`1: Disabled`	The offset correction is disabled (not active)
	`2: Enabled`	The offset correction is enabled (active) and the output data of all four measuring channels is calculated on the basis of the individual offset correction values for each frequency of each channel. This means, that the concerning offset correction values are subtracted from the signed vector lengths from the FFT-calculations. If the search coil signal is not clean, i.e. if there are picked up stray signals on the measuring signal, this allows to minimize the influence of the stray signals on the output signals. See also chapter 14.4 'Use of the offset correction'. Note that all offset correction values are set to zero at the factory. If the offset correction is enabled, the offset correction values must be individually adjusted for each frequency of each measuring channel. This can be done automatically by the use of the menu ("Do Auto-Tune", see below). To change the values manually, use the concerning "Remote Control Function" over the serial interface (see chapter 10.2.3 'Remote control functions').

Parameter	Setting	Description
	3: Do Auto-Tune	First, the user has to prepare the tuning process by placing the used search coils into their positions in the field and shielding them completely, so that they can not pick up a field signal. Therefore, under optimal conditions, there is now no signal from the search coil. If there is a remaining signal, this is the picked up stray signal which has to be eliminated to achieve optimal output data. Then the Auto-Tuning can be started. The system performs a routine, which detects the present input signal at each channel (which is, in fact, the picked up stray signal). Therefore, the signed vector lengths from the FFT-calculations during the routine are the offset correction values for the later use. The execution time of the routine is approximately 2 seconds. After the routine has performed, the offset correction of the Module is enabled and the detected offset correction values are used. See also above, "Enabled" offset correction.
F: Output Filter	1: Disabled	The digital filter is disabled (not active)
	2: Enabled	The digital filter is enabled (active) and the output signals of all four measuring channels are feed trough the digital filter. This means, that the signed vector lengths from the FFT-calculations are feed trough a digital IIR-Filter (6^{th} order Butterworth low pass filter, implemented on the DSP, with a cutoff frequency of one eighth of the output data rate of the analog outputs). If there are noisy measurement conditions, the use of the output filter may be helpful.
G: Output Mode	1: Angular Data	Based on the FFT-calculations, the DSP executes the trigonometric computations to determine the angles alpha (horizontal plane) and beta (vertical plane) between the angular orientation of the search coils and the coil frame. The results are available as analog outputs and as digital data over the serial interface. The voltage swing of the analog outputs is adjustable (see "H: Output Swing"), the progression is described in the technical data. See also the pinout of the connector with the analog outputs. The format of the digital data is described in chapter 10.1 'Transmitted Data'. For information concerning the processing speed and the resulting update rate of the outputs see "J: Processing" below.

Parameter	Setting	Description
	`2: Vector Length`	The signed vector lengths for f1 (X-axis), f2 (Y-axis) and f3 (Z-axis) from the FFT-calculations are available as analog outputs and as digital data over the serial interface. The voltage swing of the analog outputs is adjustable (see "H: Output Swing"). If the gain mode is set to "AGC", the output voltages are always scaled to fit the dominant vector in order to make full use of the available dynamic range. If the gain mode is set to "Fixed", the scaling of the output voltages is fixed. The scaling is based on a vector length of 40000. This may be useful to subtract offsets externally. For details, see chapter 14.5 ' Choosing the best suited settings for your application '. See also the pinout of the connector with the analog outputs. The format of the digital data is described in chapter 10.1 Transmitted Data'. For information concerning the processing speed and the resulting update rate of the outputs see "J: Processing" below.
	`3: Vector Angle`	The signed vector angles for f1 (X-axis), f2 (Y-axis) and f3 (Z-axis) from the FFT-calculations are available as analog outputs and as digital data over the serial interface. The voltage swing of the analog outputs is adjustable (see "H: Output Swing"). The output voltages are scaled to the range from -pi to pi. See also the pinout of the connector with the analog outputs. The format of the digital data is described in chapter 10.1 'Transmitted Data'. For information concerning the processing speed and the resulting update rate of the outputs see "J: Processing" below.
`H: Output Swing`	`+/- 2.5 V`	The range of the voltage swing of the analog outputs is set to ± 2.5 Volt
	`+/- 4.5 V`	The range of the voltage swing of the analog outputs is set to ± 4.5 Volt
	`+/- 5 V`	The range of the voltage swing of the analog outputs is set to ± 5 Volt
	`+/- 9 V`	The range of the voltage swing of the analog outputs is set to ± 9 Volt
	`+/- 10 V`	The range of the voltage swing of the analog outputs is set to ± 10 Volt

Parameter	Setting	Description
I: Power On Mode	1: Default	The parameters of the concerning Detector Module will be reset at each power up of the Angle-Meter NT to their default values, which are: • Display Illumination: Medium • Field Signals: 100% • Gain Correction: Disabled • Gain Mode: AGC • Offset Correction: Disabled • Output Filter: Disabled • Output Mode: Angular Data • Output Swing: ± 9 Volt • Processing: Ch1 → Ch4, 1 kHz
	2: Last State	The settings of the parameters of the concerning Detector Module will be recalled at each power up of the Angle-Meter NT to their state during the last power down of the Angle-Meter NT.
J: Processing	1: Ch1 → Ch1	The Detector Module processes only one measuring channel (Channel 1). The update rate of the analog outputs is 4 kHz for all output modes, where the update rate of the digital data over the serial interface is 2 kHz for the output mode "Angular Data" and 1 kHz for the output modes "Vector Length" and "Vector Angle".
	2: Ch1 → Ch2	The Detector Module processes only two measuring channels (Channel 1 and Channel 2). The update rate of the analog outputs is 2 kHz for all output modes, where the update rate of the digital data over the serial interface is 1 kHz for the output mode "Angular Data" and 500 Hz for the output modes "Vector Length" and "Vector Angle".
	3: Ch1 → Ch4	The Detector Module processes all four measuring channels (Channel 1 to Channel 4). The update rate of the analog outputs is 1 kHz for all output modes, where the update rate of the digital data over the serial interface is 500 Hz for the output mode "Angular Data" and 250 Hz for the output modes "Vector Length" and "Vector Angle".
K: Setups	1: Recall Mem 1	The settings of all parameters (including the values for fixed gain, gain correction and offset correction) are recalled from Memory 1 of the Detector Module.
	2: Save Mem 1	The actual settings of all parameters (including the values for fixed gain, gain correction and offset correction) are saved to Memory 1 of the Detector Module.
	3: Recall Mem 2	The settings of all parameters (including the values for fixed gain, gain correction and offset correction) are recalled from Memory 2 of the Detector Module.
	4: Save Mem 2	The actual settings of all parameters (including the values for fixed gain, gain correction and offset correction) are saved to Memory 2 of the Detector Module.

Parameter	Setting	Description
	`5: Recall Fact`	All parameters of the concerning Detector Module will be reset to their factory settings, which are: • Display Illumination: Medium • Field Signals: 100% • Gain Correction: Disabled • Gain Mode: AGC • Offset Correction: Disabled • Output Filter: Disabled • Output Mode: Angular Data • Output Swing: ± 9 Volt • Power On Mode: Default • Processing Mode: Ch1 → Ch4, 1 kHz • Gain Correction Values: 1.0 • Fixed Gain Values: 63 • Offset Correction Values: 0
`L: Test Signals`	`1: Off`	No test signals are active.
	`2: Min Output`	The Detector Module outputs the minimal possible value of the currently selected output swing at all analog outputs and 0 as digital data in the format "Angular Data" over the serial interface.
	`3: Mid Output`	The Detector Module outputs 0 Volt at all analog outputs and 2048 as digital data in the format "Angular Data" over the serial interface.
	`4: Max Output`	The Detector Module outputs the maximal possible value of the currently selected output swing at all analog outputs and 4095 as digital data in the format "Angular Data" over the serial interface.
	`5: Ramp Output`	The Detector Module outputs a ramp from the minimal to the maximal possible value of the currently selected output swing at all analog outputs and 0 ... 4095 (incremented by one) as digital data in the format "Angular Data" over the serial interface.

Table 9-1: Menu Settings

10 Serial Interface

The bidirectional serial interface (RS-232) of each Detector Module transmits the measuring data and is capable to change the settings of the parameters of the Detector Module by the use of Remote Control Functions. The delivered software for Windows 9x / 2000 / XP may be used in conjunction with the serial interface.

Interface settings: 115200 bps, 8 data bits, 1 stop bit, no parity

Handshake mode: Hardware (RTS / CTS)

Pinout: see chapter 18 'Pinouts'

10.1 Transmitted Data

During normal operation, the Detector Module continuously transmits the measuring data in the format of the currently selected output mode over the serial interface. Note that no data will be transmitted during the menu is activated or during the execution time of an eventually called Remote Control Function.

The format of the transmitted data depends on the currently selected output mode "Angular Data", "Vector Length" or "Vector Angle" (see chapter 14.5.5 'Output Mode' for additional information).

Continuous data flow (Output Mode = Angular Data, Processing = Ch1→Ch4):

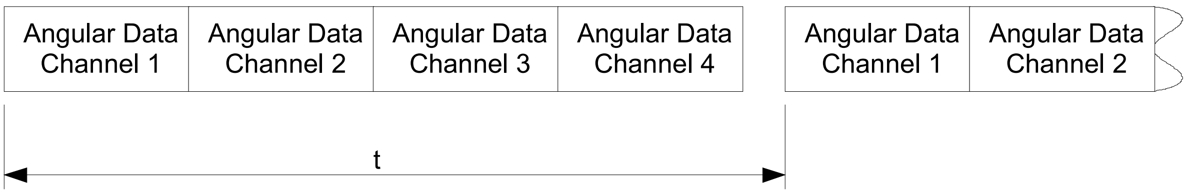


Figure 10-1: Continuous Dataflow over the Serial Interface

The time t depends on the selected output mode and the selected processing mode:

Output Mode	Processing Mode	Outputted measuring data	t	Data rate
Angular Data	Ch1→Ch1	Angles alpha and beta of Ch1 only	500 us	2 kHz
Angular Data	Ch1→Ch2	Angles alpha and beta of Ch1 and Ch2	1 ms	1 kHz
Angular Data	Ch1→Ch4	Angles alpha and beta of all channels	2 ms	500 Hz
Vector Length	Ch1→Ch1	Signed vector lengths of Ch1 only	1 ms	1 kHz
Vector Length	Ch1→Ch2	Signed vector lengths of Ch1 and Ch2	2 ms	500 Hz
Vector Length	Ch1→Ch4	Signed vector lengths of all channels	4 ms	250 Hz
Vector Angle	Ch1→Ch1	Signed vector angles of Ch1 only	1 ms	1 kHz
Vector Angle	Ch1→Ch2	Signed vector angles of Ch1 and Ch2	2 ms	500 Hz
Vector Angle	Ch1→Ch4	Signed vector angles of all channels	4 ms	250 Hz

Table 10-1: Update rate of the measuring data over the Serial Interface

Note that the table above indicates only the update rate of the serial data. The update rate of the analog outputs is independently of the selected output mode and depends only on the selected processing mode (see also chapter 14.5.7 'Processing Mode').

The dataflow consists of data packets which are sequentially transmitted. Each transmitted data packet starts with a *PacketInfoByte*, immediately followed by one or several *DataBytes*, where the number of *DataBytes* within a packet depends on the type of the transmitted data packet.

Each *PacketInfoByte* indicates the beginning and the type of the transmitted packet, i.e. it determines the meaning of the immediately following *DataBytes.*

10.1.1 Structure of Transmitted Bytes

The most significant bit (B7) of each transmitted byte in the dataflow determines the meaning of the remaining bits (B6...B0) of the concerning byte.

B7	B6 to B0	Usage	Note
0	XXXXXXX	DataByte	XXXXXX contains data according to the type of the data packet
1	XXYYZZZ	PacketInfoByte	XX denotes the format of the packet, YY denotes the measuring channel number, ZZZ is reserved for feature use

Table 10-2: Structure of transmitted bytes

10.1.1.1 PacketInfoByte

B7	B6	B5	B4	B3	B2	B1	B0
BID	**FOP**	**FOP**	**CHN**	**CHN**	**RES**	**RES**	**RES**

BID (Byte Identifier)

1 B7 = 1 indicates a *PacketInfoByte*
The byte contains information in the remaining bits B6...B0 concerning the immediately following *DataBytes*. Note that each *PacketInfoByte* indicates the start of a data packet

FOP (Format of Packet)

00 **Angular Data**
The following *DataBytes* will transmit measuring data in the format 'Angular Data' of the measuring channel number indicated by CHN

01 **Vector Length**
The following *DataBytes* will transmit measuring data in the format 'Vector Length' of the measuring channel number indicated by CHN

10 **Vector Angle**
The following *DataBytes* will transmit measuring data in the format 'Vector Angle' of the measuring channel number indicated by CHN

11 **Parameter Data**
The following *DataByte(s)* will transmit the actual setting(s) of the requested parameter(s). Please note that CHN has no meaning if FOP = 11

CHN (Channel Number)

00 **Channel 1**
The following *DataBytes* will transmit measuring data of channel 1 in the format indicated by FOP

01 **Channel 2**
The following *DataBytes* will transmit measuring data of channel 2 in the format indicated by FOP

10 **Channel 3**
The following *DataBytes* will transmit measuring data of channel 3 in the format indicated by FOP

11 **Channel 4**
The following *DataBytes* will transmit measuring data of channel 4 in the format indicated by FOP

RES (Reserved)

- These bits are reserved for future use

10.1.1.2 DataByte

B7	B6	B5	B4	B3	B2	B1	B0
BID	**X**	**X**	**X**	**X**	**X**	**X**	**X**

BID (Byte Identifier)

0 B7 = 0 indicates a *DataByte*
The byte contains data in the remaining bits B6...B0 according to the lastly transmitted *PacketInfoByte*

X (Data)

B6…B0 contain measuring data or parameter data according to the lastly transmitted *PacketInfoByte*, i.e. depending on the type of the data packet.
Note that the Bit 6 of certain DataBytes is a sign bit, where sign = 0 indicates positive and sign = 1 indicates negative values.

10.1.2 Structure of Transmitted Data Packets

The dataflow consists of sequentially transmitted data packets. Each transmitted data packet begins with a *PacketInfoByte*, immediately followed by one or several *DataBytes*, where the number of *DataBytes* within a packet depends on the type of the transmitted data packet.

10.1.2.1 Angular Data

Based on the FFT-calculations, the DSP executes the trigonometric computations to determine the angular displacement alpha (horizontal plane) and beta (vertical plane) of the search coil relative to the system's reference frame (coil frame). The angular data is scaled from 0 to 4095 for the angle alpha (representing the range from 0° to 359.91°) and from 1024 to 3072 for the angle beta (representing the range from -90° to +90°). The angular data is transmitted in data packets consisting of one *PacketInfoByte* plus four *DataBytes* per channel.

PacketInfoByte	UpperAlpha	LowerAlpha	UpperBeta	LowerBeta

PacketInfoByte: See description above

DataBytes UpperAlpha, UpperBeta

B7	B6	B5	B4	B3	B2	B1	B0
0	**0**	**0**	**D11**	**D10**	**D9**	**D8**	**D7**

DataBytes LowerAlpha, LowerBeta

B7	B6	B5	B4	B3	B2	B1	B0
0	**D6**	**D5**	**D4**	**D3**	**D2**	**D1**	**D0**

10.1.2.2 Vector Length

The signed vector lengths sVectLenX (f1, X-axis), sVectLenY (f2, Y-axis) and sVectLenZ (f3, Z-axis) from the FFT-calculations are transmitted in data packets consisting of one *PacketInfoByte* plus nine *Databytes* per channel.

PacketInfoByte	UpperX	MidX	LowerX	UpperY	MidY	LowerY	UpperZ	MidZ	LowerZ

PacketInfoByte: See description above

DataBytes UpperX, UpperY, UpperZ

B7	B6	B5	B4	B3	B2	B1	B0
0	**Sign**	**D19**	**D18**	**D17**	**D16**	**D15**	**D14**

Databytes MidX, MidY, MidZ

B7	B6	B5	B4	B3	B2	B1	B0
0	**D13**	**D12**	**D11**	**D10**	**D9**	**D8**	**D7**

DataBytes LowerX, LowerY, LowerZ

B7	B6	B5	B4	B3	B2	B1	B0
0	**D6**	**D5**	**D4**	**D3**	**D2**	**D1**	**D0**

10.1.2.3 Vector Angle

The values for the signed vector angles sVectAngX (X-axis), sVectAngY (Y-axis) and sVectAngZ (Z-axis) from the FFT-calculations are in the range from -pi to pi. For transmission, they are multiplied by 2600 and transmitted in data packets consisting of one *PacketInfoByte* plus six *DataBytes* per channel.

PacketInfoByte	UpperX	LowerX	UpperY	LowerY	UpperZ	LowerZ

PacketInfoByte: See description above

DataBytes UpperX, UpperY, UpperZ

B7	B6	B5	B4	B3	B2	B1	B0
0	**Sign**	**D12**	**D11**	**D10**	**D9**	**D8**	**D7**

Databytes LowerX, LowerY, LowerZ

B7	B6	B5	B4	B3	B2	B1	B0
0	**D6**	**D5**	**D4**	**D3**	**D2**	**D1**	**D0**

10.1.2.4 Parameter Data

The actual settings of all parameters of the Detector Module can be requested over the serial interface by the use of the Remote Control Functions (‘Read Parameter’, see chapter 10.2.3 'Remote Control Functions'). The actual setting of the requested parameter is transmitted on request once in a data packet consisting of one *PacketInfoByte* plus one or several *DataBytes*. The number of *DataBytes* and the format of the *DataBytes* (7 Bit Parameter, 14 Bit Parameter or 21 Bit Parameter) depends on the requested parameter.

7 Bit Parameter:	PacketInfoByte	Data	[Data]		
14 Bit Parameter:	PacketInfoByte	UpperData	LowerData	[14 Bit Data]	
21 Bit Parameter:	PacketInfoByte	UpperData	MidData	LowerData	[21 Bit Data]

PacketInfoByte: See description above

DataByte 7 Bit Parameter:

B7	B6	B5	B4	B3	B2	B1	B0
0	**D6**	**D5**	**D4**	**D3**	**D2**	**D1**	**D0**

DataByte Upper 14 Bit Parameter:

B7	B6	B5	B4	B3	B2	B1	B0
0	**D13**	**D12**	**D11**	**D10**	**D9**	**D8**	**D7**

DataByte Lower 14 Bit Parameter:

B7	B6	B5	B4	B3	B2	B1	B0
0	**D6**	**D5**	**D4**	**D3**	**D2**	**D1**	**D0**

DataByte Upper 21 Bit Parameter:

B7	B6	B5	B4	B3	B2	B1	B0
0	**Sign**	**D19**	**D18**	**D17**	**D16**	**D15**	**D14**

DataByte Mid 21 Bit Parameter:

B7	B6	B5	B4	B3	B2	B1	B0
0	**D13**	**D12**	**D11**	**D10**	**D9**	**D8**	**D7**

DataByte Lower 21 Bit Parameter:

B7	B6	B5	B4	B3	B2	B1	B0
0	**D6**	**D5**	**D4**	**D3**	**D2**	**D1**	**D0**

10.2 Received Data

The setting of all parameters of the Detector Module may be achieved over the serial interface by the use of “Remote Control Functions”. The Detector Module executes a certain Function after receiving a valid data packet from an external computer.

Each data packet consists of one *FunctionByte*, one or several *DataBytes*, one *ControlByte* and one *TerminatorByte*, where the number of *DataBytes* within a packet depends on the type of the Function.

Notes:

- Neither the analog outputs nor the serial interface are updated with measurement data during the execution time of Remote Control Functions. The analog outputs freeze at their last updated value and the serial interface is idle (i.e. no measuring data is transmitted) until the concerning Remote Control Function is executed.
- To disable the execution of any Remote Control Function, push the Menu button of the Detector-Module(s) during the power up sequence of the Angle-Meter NT until the message "Module Controls: Disabled" appears in the Display. This prevents the execution of any Remote Control Function and ensures, that the concerning Detector Module always updates the measurement data until the power of the device is switched off.

10.2.1 Structure of Received Bytes

The upper three Bits (MSBs) of each received byte of a Remote Control Function indicate the usage of the Byte, the lower five Bits contain the specific data:

B7	B6	B5	B4 to B0	Usage	Note
0	0	X	XXXXX	FunctionByte	XXXXXX denotes the Function
0	1	0	XXXXX	DataByte1	XXXXX contains Data (used by each function)
0	1	1	XXXXX	DataByte2	XXXXX contains Data (used only by certain functions)
1	0	0	XXXXX	DataByte3	XXXXX contains Data (used only by certain functions)
1	0	1	XXXXX	DataByte4	XXXXX contains Data (used only by certain functions)
1	1	0	XXXXX	ControlByte	XXXXX contains (((B5...B1) / 2) XOR 11111) of the FunctionByte
1	1	1	XYYYY	TerminatorByte	X contains (B0 XOR 1) of the FunctionByte, YYYY contains ((B3...B0) XOR 1111) of DataByte1

Table 10-3: Structure of received bytes

10.2.2 Structure of Received Data Packets

FunctionByte	DataByte1	DataByte2	DataByte3	DataByte4	ControlByte	TerminatorByte

Note that DataByte2 … DataByte4 are used only by certain functions. Unused DataBytes are not transmitted within the concerning data packet.

Example:
To set the "Power Up Mode" of the Detector Module to "Last State", transmit this data packet:

FunctionByte	DataByte1	ControlByte	TerminatorByte
00001000	**010**00001	**110**11011	**111**11110

10.2.3 Remote Control Functions - Overview

Description	Function	Data1	Data2	Data3	Data4	Control	Terminator
Set Display Illum	0	0...3	not used	not used	not used	31	28...31
Set Field Signals	1	0...5	not used	not used	not used	31	10...15
Set Gain Corr	2	0...1	not used	not used	not used	30	30...31
Set Gain Mode	3	0...2	not used	not used	not used	30	13...15
Set Offset Corr	4	0...2	not used	not used	not used	29	29...31
Set Output Filter	5	0...1	not used	not used	not used	29	14...15
Set Output Mode	6	0...1	not used	not used	not used	28	30...31
Set Output Swing	7	0...4	not used	not used	not used	28	11...15
Set Power On Mode	8	0...1	not used	not used	not used	27	30...31
Set Processing	9	0...2	not used	not used	not used	27	13...15
Set Setups	10	0...4	not used	not used	not used	26	27...31
Set Test Signals	11	0...4	not used	not used	not used	26	11...15
Read Parameter	15	0...16	not used	not used	not used	24	0...15
Set Gain Corr Ch1 X	16	0...30	0...31	0...31	0...31	23	16...31
Set Gain Corr Ch2 X	17	0...30	0...31	0...31	0...31	23	0...15
Set Gain Corr Ch3 X	18	0...30	0...31	0...31	0...31	22	16...31
Set Gain Corr Ch4 X	19	0...30	0...31	0...31	0...31	22	0...15
Set Gain Corr Ch1 Y	20	0...30	0...31	0...31	0...31	21	16...31
Set Gain Corr Ch2 Y	21	0...30	0...31	0...31	0...31	21	0...15
Set Gain Corr Ch3 Y	22	0...30	0...31	0...31	0...31	20	16...31
Set Gain Corr Ch4 Y	23	0...30	0...31	0...31	0...31	20	0...15
Set Gain Corr Ch1 Z	24	0...30	0...31	0...31	0...31	19	16...31
Set Gain Corr Ch2 Z	25	0...30	0...31	0...31	0...31	19	0...15
Set Gain Corr Ch3 Z	26	0...30	0...31	0...31	0...31	18	16...31
Set Gain Corr Ch4 Z	27	0...30	0...31	0...31	0...31	18	0...15
Set Gain Fix Ch1	28	0...7	0...31	not used	not used	17	24...31
Set Gain Fix Ch2	29	0...7	0...31	not used	not used	17	8...15
Set Gain Fix Ch3	30	0...7	0...31	not used	not used	16	24...31
Set Gain Fix Ch4	31	0...7	0...31	not used	not used	16	8...15
Set Offs Corr Ch1 X	32	0...31	0...31	0...31	0...31	15	16...31
Set Offs Corr Ch2 X	33	0...31	0...31	0...31	0...31	15	0...15
Set Offs Corr Ch3 X	34	0...31	0...31	0...31	0...31	14	16...31
Set Offs Corr Ch4 X	35	0...31	0...31	0...31	0...31	14	0...15
Set Offs Corr Ch1 Y	36	0...31	0...31	0...31	0...31	13	16...31
Set Offs Corr Ch2 Y	37	0...31	0...31	0...31	0...31	13	0...15
Set Offs Corr Ch3 Y	38	0...31	0...31	0...31	0...31	12	16...31
Set Offs Corr Ch4 Y	39	0...31	0...31	0...31	0...31	12	0...15
Set Offs Corr Ch1 Z	40	0...31	0...31	0...31	0...31	11	16...31

Description	Function	Data1	Data2	Data3	Data4	Control	Terminator
Set Offs Corr Ch2 Z	41	0...31	0...31	0...31	0...31	11	0...15
Set Offs Corr Ch3 Z	42	0...31	0...31	0...31	0...31	10	16...31
Set Offs Corr Ch4 Z	43	0...31	0...31	0...31	0...31	10	0...15

Table 10-4: Remote Control Functions - Overview

Notes:

- Functions not explicitly listed (12...14, 44...63) are reserved for factory used functions or future use respectively.
- Function 1 ("Set Field Signals") is only applicable at the Main Detector Module, i.e. the field signals will not change if function 1 is sent to the Add-On Detector Module.
- Function 15 ("Read Parameter") causes the Detector Module to transmit the actual setting of a certain parameter, indicated by the content of DataByte1 (see table below).

10.2.4 Remote Control Functions - Meaning of the DataByte(s)

Description	F#	Data	Description
Set Display Illum	0	Data1 = 0	The backlight of the LCD is turned off
	0	Data1 = 1	The backlight of the LCD is dark
	0	Data1 = 2	The backlight of the LCD is medium
	0	Data1 = 3	The backlight of the LCD is bright
Set Field Signals Please note: This function is only applicable at the Main Detector Module	1	Data1 = 0	The field signals are turned off
	1	Data1 = 1	The field signals are attenuated to 20 % of their nominal value
	1	Data1 = 2	The field signals are attenuated to 40 % of their nominal value
	1	Data1 = 3	The field signals are attenuated to 60 % of their nominal value
	1	Data1 = 4	The field signals are attenuated to 80 % of their nominal value
	1	Data1 = 5	The field signals are at 100 % of their nominal value
Set Gain Corr	2	Data1 = 0	The gain correction is disabled (not active)
	2	Data1 = 1	The gain correction is enabled (active) and the output data of all four measuring channels is calculated on the basis of the individual gain correction values for each frequency of each channel. This means, that the signed vector lengths from the FFT-calculations are multiplied by the concerning gain correction values. If the search coil is placed outside of the 3D-centre of the magnetic field, this allows the correction of the magnetic field inhomogeneity in a certain range. See also chapter 14.3 'Use of the gain correction'. Note that all gain correction values are set to 1.0 at the factory. If the gain correction is enabled, the gain correction values must be individually adjusted for each frequency of each measuring channel. To change the values, use the concerning Remote Control Function (see below, "Set Gain Corr ChN fM").

Description	F#	Data	Description
Set Gain Mode	3	Data1 = 0	The gain mode of all four measuring channels is set to automatic gain control (AGC). This allows the use of different search coils without the need of any system recalibration, as long as the parameters of the used search coils are within the technical specifications. Due to the AGC, the gains change dynamically, depending on the field strength, the effective area of the used search coils and their angular orientation. This ensures an optimal signal to noise ratio of the measuring data. Note that in this mode the offset correction is always disabled; it is not applicable due to the variable gain caused by the AGC (see also below, "Set Offset Corr").
	3	Data1 = 1	The gain of all four measuring channels is set to an individual fixed value. This allows the use of an offset correction, which will minimize the influence of picked up stray signals (see also below, "Set Offset Corr"). Please note, that the fixed gain values are relative values in the range from 0 to 255. If the fixed gain mode is selected, the values of the fixed gains must be individually adjusted for the used search coils. This can be done automatically by the use of the Remote Control Function "Do Auto-Tune concerning Gain Mode", see below. To change the values manually, use the concerning "Remote Control Function" over the serial interface (see below, "Set Gain Fix ChN"). The LEDs of the Detector Module indicate the voltage level of the concerning measuring channels; if the fixed gains are adjusted correctly, the concerning LEDs light green (see chapter 9.2 'LEDs'). Note that the peak value of the voltage changes depending on the angular orientation of the search coil (see chapter 2 'Measuring principle').
	3	Data1 = 2	Do Auto-Tune concerning Gain Mode First, the user has to prepare the tuning process by placing the used search coils into their positions in the field, where their angular orientations doesn’t matter. Then the Auto-Tuning can be started. The system performs a routine, which evaluates the optimal gain for each channel regarding the currently connected search coils, where their actual angular orientation is considered by the routine. The execution time of the routine depends on the effective area of the used search coils (max. 3 seconds). After the routine was performed, the evaluated gains are applied (fixed gain values) and the Module is set to the fixed gain mode. See also above, "Fixed" gain mode.
Set Offset Corr	4	Data1 = 0	The offset correction is disabled (not active)

Description	F#	Data	Description
	4	Data1 = 1	The offset correction is enabled (active) and the output data of all four measuring channels is calculated on the basis of the individual offset correction values for each frequency of each channel. This means, that the concerning offset correction values are subtracted from the signed vector lengths from the FFT-calculations. If the search coil signal is not clean, i.e. if there are picked up stray signals on the measuring signal, this allows to minimize the influence of the stray signals on the output signals. See also chapter 14.4 'Use of the offset correction'. Note that all offset correction values are set to zero at the factory. If the offset correction is enabled, the offset correction values must be individually adjusted for each frequency of each measuring channel. This can be done automatically by the use of the Remote Control Function "Do Auto-Tune concerning Offset Correction", see below. To change the values manually, use the concerning "Remote Control Function (see below, "Set Offs Corr ChX fN).
	4	Data1 = 2	Do Auto-Tune concerning Offset Correction First, the user has to prepare the tuning process by placing the used search coils into their positions in the field and shielding them completely, so that they can not pick up a field signal. Therefore, under optimal conditions, there is now no signal from the search coil. If there is a remaining signal, this is the picked up stray signal which has to be eliminated to achieve optimal output data. Then the Auto-Tuning can be started. The Detector Module performs a routine, which detects the present input signal at each channel (which is, in fact, the picked up stray signal only). Therefore, the signed vector lengths from the FFT-calculations during the routine are the offset correction values for the later use. The execution time of the routine is approximately 2 seconds. After the routine has performed, the offset correction of the Module is enabled and the detected offset correction values are used. See also above, "Enabled" offset correction.
Set Output Filter	5	Data1 = 0	The digital filter is disabled (not active)
	5	Data1 = 1	The digital filter is enabled (active) and the output signals of all four measuring channels are feed trough the digital filter. This means, that the signed vector lengths from the FFT-calculations are feed trough a digital IIR-Filter (6^{th} order Butterworth low pass filter, implemented on the DSP, with a cutoff frequency of one eighth of the output data rate of the analog outputs). If there are noisy measurement conditions, the use of the output filter may be helpful.

Description	F#	Data	Description
Set Output Mode	6	Data1 = 0	Angular Data Based on the FFT-calculations, the DSP executes the trigonometric computations to determine the angles alpha (horizontal plane) and beta (vertical plane) between the angular orientation of the search coils and the coil frame. The results are available as analog outputs and as digital data over the serial interface. The voltage swing of the analog outputs is adjustable (see "Set Output Swing"), the progression is described in the technical data. See also the pinout of the connector with the analog outputs. The format of the digital data is described in chapter 10.1 'Transmitted Data'. For information concerning the processing speed and the resulting update rate of the outputs see "Set Processing" below.
	6	Data1 = 1	Vector Length The signed vector lengths for f1 (X-axis), f2 (Y-axis) and f3 (Z-axis) from the FFT-calculations are available as analog outputs and as digital data over the serial interface. The voltage swing of the analog outputs is adjustable (see "H: Output Swing"). If the gain mode is set to "AGC", the output voltages are always scaled to fit the dominant vector in order to make full use of the available dynamic range. If the gain mode is set to "Fixed", the scaling of the output voltages is fixed. The scaling is based on a vector length of 40000. This may be useful to subtract offsets externally. For details, see chapter 14.5 ' Choosing the best suited settings for your application '. See also the pinout of the connector with the analog outputs. The format of the digital data is described in chapter 10.1 'Transmitted Data'. For information concerning the processing speed and the resulting update rate of the outputs see "Set Processing" below.
	6	Data1 = 2	Vector Angle The signed vector angles for f1 (X-axis), f2 (Y-axis) and f3 (Z-axis) from the FFT-calculations are available as analog outputs and as digital data over the serial interface. The voltage swing of the analog outputs is adjustable (see "Set Output Swing"). The output voltages are scaled to the range from -pi to pi. See also the pinout of the connector with the analog outputs. The format of the digital data is described in chapter 10.1 'Transmitted Data'. For information concerning the processing speed and the resulting update rate of the outputs see "Set Processing" below.
Set Output Swing	7	Data1 = 0	The range of the voltage swing of the analog outputs is set to ± 2.5 Volt
	7	Data1 = 1	The range of the voltage swing of the analog outputs is set to ± 4.5 Volt

Description	F#	Data	Description
	7	Data1 = 2	The range of the voltage swing of the analog outputs is set to ± 5 Volt
	7	Data1 = 3	The range of the voltage swing of the analog outputs is set to ± 9 Volt
	7	Data1 = 4	The range of the voltage swing of the analog outputs is set to ± 10 Volt
Set Power On Mode	8	Data1 = 0	The parameters of the concerning Detector Module will be reset at each power up of the Angle-Meter NT to their default values, which are: • Display Illumination: Medium • Field Signals: 100% • Gain Correction: Disabled • Gain Mode: AGC • Offset Correction: Disabled • Output Filter: Disabled • Output Mode: Angular Data • Output Swing: ± 9 Volt • Processing: Ch1 → Ch4, 1 kHz
	8	Data1 = 1	The settings of the parameters of the concerning Detector Module will be recalled at each power up of the Angle-Meter NT to their state during the last power down of the Angle-Meter NT.
Set Processing	9	Data1 = 0	The Detector Module processes only one measuring channel (Channel 1). The update rate of the analog outputs is 4 kHz for all output modes, where the update rate of the digital data over the serial interface is 2 kHz for the output mode "Angular Data" and 1 kHz for the output modes "Vector Length" and "Vector Angle".
	9	Data1 = 1	The Detector Module processes only two measuring channels (Channel 1 and Channel 2). The update rate of the analog outputs is 2 kHz for all output modes, where the update rate of the digital data over the serial interface is 1 kHz for the output mode "Angular Data" and 500 Hz for the output modes "Vector Length" and "Vector Angle".
	9	Data1 = 2	The Detector Module processes all four measuring channels (Channel 1 to Channel 4). The update rate of the analog outputs is 1 kHz for all output modes, where the update rate of the digital data over the serial interface is 500 Hz for the output mode "Angular Data" and 250 Hz for the output modes "Vector Length" and "Vector Angle".
Set Setups	10	Data1 = 0	The settings of all parameters (including the values for fixed gain, gain correction and offset correction) are recalled from Memory 1 of the Detector Module.
	10	Data1 = 1	The actual settings of all parameters (including the values for fixed gain, gain correction and offset correction) are saved to Memory 1 of the Detector Module.
	10	Data1 = 2	The settings of all parameters (including the values for fixed gain, gain correction and offset correction) are recalled from Memory 2 of the Detector Module.

Description	F#	Data	Description
	10	Data1 = 3	The actual settings of all parameters (including the values for fixed gain, gain correction and offset correction) are saved to Memory 2 of the Detector Module.
	10	Data1 = 4	All parameters of the concerning Detector Module will be reset to their factory settings, which are: • Display Illumination: Medium • Field Signals: 100% • Gain Correction: Disabled • Gain Mode: AGC • Offset Correction: Disabled • Output Filter: Disabled • Output Mode: Angular Data • Output Swing: ± 9 Volt • Power On Mode: Default • Processing Mode: Ch1 → Ch4, 1 kHz • Gain Correction Values: 1.0 • Fixed Gain Values: 63 • Offset Correction Values: 0
Set Test Signals	11	Data1 = 0	No test signals are active.
	11	Data1 = 1	The Detector Module outputs the minimal possible value of the currently selected output swing at all analog outputs and 0 as digital data in the format "Angular Data" over the serial interface.
	11	Data1 = 2	The Detector Module outputs 0 Volt at all analog outputs and 2048 as digital data in the format "Angular Data" over the serial interface.
	11	Data1 = 3	The Detector Module outputs the maximal possible value of the currently selected output swing at all analog outputs and 4095 as digital data in the format "Angular Data" over the serial interface.
	11	Data1 = 4	The Detector Module outputs a ramp from the minimal to the maximal possible value of the currently selected output swing at all analog outputs and 0 ... 4095 (incremented by one) as digital data in the format "Angular Data" over the serial interface.

<table>
<tr><th>Description</th><th>F#</th><th>Data</th><th>Description</th></tr>
<tr><td>Read Parameter</td><td>15</td><td>Data1 = 1</td><td>Causes the Detector Module to transmit the actual settings of the general parameters (packet with thirteen 7 Bit Parameters), which are:
Display Illum (7 Bit Parameter)
Field Signals (7 Bit Parameter)
Gain Corr (7 Bit Parameter)
Gain Mode (7 Bit Parameter)
Offset Corr (7 Bit Parameter)
Output Filter (7 Bit Parameter)
Output Mode (7 Bit Parameter)
Output Swing (7 Bit Parameter)
Power On Mode (7 Bit Parameter)
Processing Mode (7 Bit Parameter)
Setups Mode (7 Bit Parameter)
Test Signal Mode (7 Bit Parameter)
Module Mode (7 Bit Parameter)
For a detailed description of the format of the Parameter Data, see chapter 10.1 ‘Transmitted Data’.</td></tr>
<tr><td></td><td>15</td><td>Data1 = 4</td><td>Causes the Detector Module to transmit the actual settings of the gain correction values for f1 (X-axis) of all four channels (packet with four 21 Bit Parameter). Note that the gain correction values are multiplied by 200000 for the transfer.
For a detailed description of the format of the Parameter Data, see chapter 10.1.
For a detailed description of the usage of the gain correction values, see "Set Gain Corr" above.</td></tr>
<tr><td></td><td>15</td><td>Data1 = 5</td><td>Causes the Detector Module to transmit the actual settings of the gain correction values for f2 (Y-axis) of all four channels (packet with four 21 Bit Parameter). Note that the gain correction values are multiplied by 200000 for the transfer.
For a detailed description of the format of the Parameter Data, see chapter 10.1.
For a detailed description of the usage of the gain correction values, see "Set Gain Corr" above.</td></tr>
<tr><td></td><td>15</td><td>Data1 = 6</td><td>Causes the Detector Module to transmit the actual settings of the gain correction values for f3 (Z-axis) of all four channels (packet with four 21 Bit Parameter). Note that the gain correction values are multiplied by 200000 for the transfer.
For a detailed description of the format of the Parameter Data, see chapter 10.1.
For a detailed description of the usage of the gain correction values, see "Set Gain Corr" above.</td></tr>
<tr><td></td><td>15</td><td>Data1 = 8</td><td>Causes the Detector Module to transmit the actual settings of the fixed gain values of all four channels (packet with four 14 Bit Parameter).
For a detailed description of the format of the Parameter Data, see chapter 10.1.
For a detailed description of the usage of the fixed gain values, see "Set Gain Mode" above.</td></tr>
</table>

Description	F#	Data	Description
	15	Data1 = 12	Causes the Detector Module to transmit the actual settings of the offset correction values for f1 (X-axis) of all four channels (packet with four 21 Bit Parameter). For a detailed description of the format of the Parameter Data, see chapter 10.1. For a detailed description of the usage of the offset correction values, see "Set Offset Corr" above.
	15	Data1 = 13	Causes the Detector Module to transmit the actual settings of the offset correction values for f2 (Y-axis) of all four channels (packet with four 21 Bit Parameter). For a detailed description of the format of the Parameter Data, see chapter 10.1. For a detailed description of the usage of the offset correction values, see "Set Offset Corr" above.
	15	Data1 = 14	Causes the Detector Module to transmit the actual settings of the offset correction values for f3 (Z-axis) of all four channels (packet with four 21 Bit Parameter). For a detailed description of the format of the Parameter Data, see chapter 10.1. For a detailed description of the usage of the offset correction values, see "Set Offset Corr" above.
	15	Data1 = 16	Causes the Detector Module to transmit the actual settings of the relative values for the field voltages U f1, U f2 and U f3 (packet with three 14 Bit Parameter). The field voltages are adjusted at the factory for an optimal field homogeneity at the 3D-centre of the coil frame. Therefore, they should remain unchanged and are read-only values for the user. However, if you plan to change these values for some reasons, please contact Primelec for the suitable software tool.
Set Gain Corr ChN fM	16 … 27	Data1 = MostUpper Data2 = Upper Data3 = Lower Data4 = MostLower	Sets the gain correction value for channel N, frequency M. The allowed range of the gain correction values is between 0.0 and 5.0. Note that the gain correction values are multiplied by 200000 for the transmission. For a detailed description of the usage of the gain correction values, see "Set Gain Corr" above.
Set Gain Fix ChN	28 … 31	Data1 = Upper Data2 = Lower	Sets the fixed gain value for channel N. The allowed range of the fixed gain values is between 0 and 255. For a detailed description of the usage of the fixed gain values, see "Set Gain Mode" above.
Set Offs Corr ChN fM	32 … 43	Data1 = MostUpper Data2 = Upper Data3 = Lower Data4 = MostLower	Sets the offset correction value for channel N, frequency M. The allowed range of the offset correction values is between -100000 and +100000. Note that the MSB of Data 1 acts as a sign bit, where sign = 0 indicates positive and sign = 1 indicates negative values. For a detailed description of the usage of the offset correction values, see "Set Offset Corr" above.

Table 10-5: Remote Control Function - Meaning of the DataByte(s)

Note: The range of data not explicitly listed in the table above is reserved for factory used settings or future use respectively.

11 Analog Outputs

The analog outputs of each Detector Module are implemented by twelve 12-Bit digital to analog converters (DACs). Depending on the currently selected output mode and processing mode, the DACs are continuously updated with the results of the DSP's computations.

Note that the analog outputs are not updated during the menu is activated or during the execution time of an eventually called Remote Control Function.

Output Mode	Processing Mode	Updated analog outputs	Update rate
Angular Data	Ch1→Ch1	Angles alpha and beta of Ch1 only	4 kHz
Angular Data	Ch1→Ch2	Angles alpha and beta of Ch1 and Ch2	2 kHz
Angular Data	Ch1→Ch4	Angles alpha and beta of all channels	1 kHz
Vector Length	Ch1→Ch1	Signed vector lengths f1, f2 and f3 of Ch1 only	4 kHz
Vector Length	Ch1→Ch2	Signed vector lengths f1, f2 and f3 of Ch1 and Ch2	2 kHz
Vector Length	Ch1→Ch4	Signed vector lengths f1, f2 and f3 of all channels	1 kHz
Vector Angle	Ch1→Ch1	Signed vector angles f1, f2 and f3 of Ch1 only	4 kHz
Vector Angle	Ch1→Ch2	Signed vector angles f1, f2 and f3 of Ch1 and Ch2	2 kHz
Vector Angle	Ch1→Ch4	Signed vector angles f1, f2 and f3 of all channels	1 kHz

Table 11-1: Update rate of the analog outputs

The output voltage swing of the analog outputs depends on the actual setting of the parameter "Output Swing" (see chapter 14.5.6 'Output Swing' for details). The progression of the output voltages in the "Angular Data" output mode is described in the technical data. To make full use of the DAC's dynamic range in the "AGC" mode, the output voltages in the "Vector Length" output mode are always scaled to fit the dominant vector. In the "Vector Angle" output mode, the output voltages are scaled to the range from -pi to pi.

12 System Installation

The figure below shows the required cabling for a system with two Detector Modules (i.e. eighth measuring channels). If your system consist only of one Detector Module (i.e. four measuring channels), the cabling of the right Detector Module is omitted. *Turn off the main switch at the rear panel of the Angle-Meter NT before wiring the system! Check the indicated value for the line voltage on the label at the rear of the base unit (115 VAC* ***or*** *230 VAC). The Angle-Meter NT may be installed and used by qualified research personnel only.*

If the coil frame is installed on a turntable, it is strongly recommended to place the preamplifier(s) also on it to minimize the lengths of the connection wires between the search coil(s) and the Preamplifier. See chapter 13 'Slip Ring Wiring' for additional information if required.

Note: Use only the delivered original cables. Should you need extension cables, please contact Primelec.

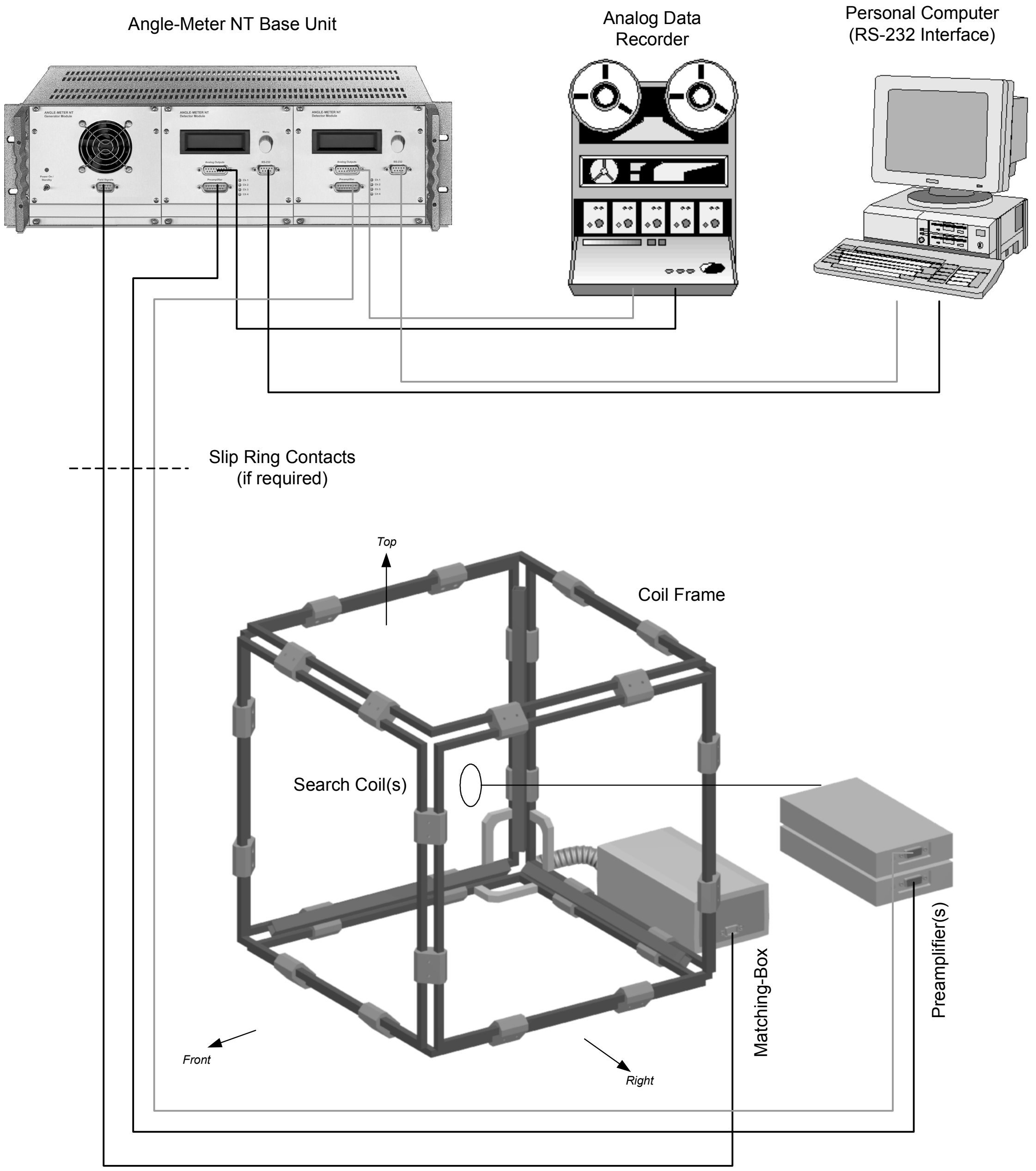


Figure 12-1: System Installation

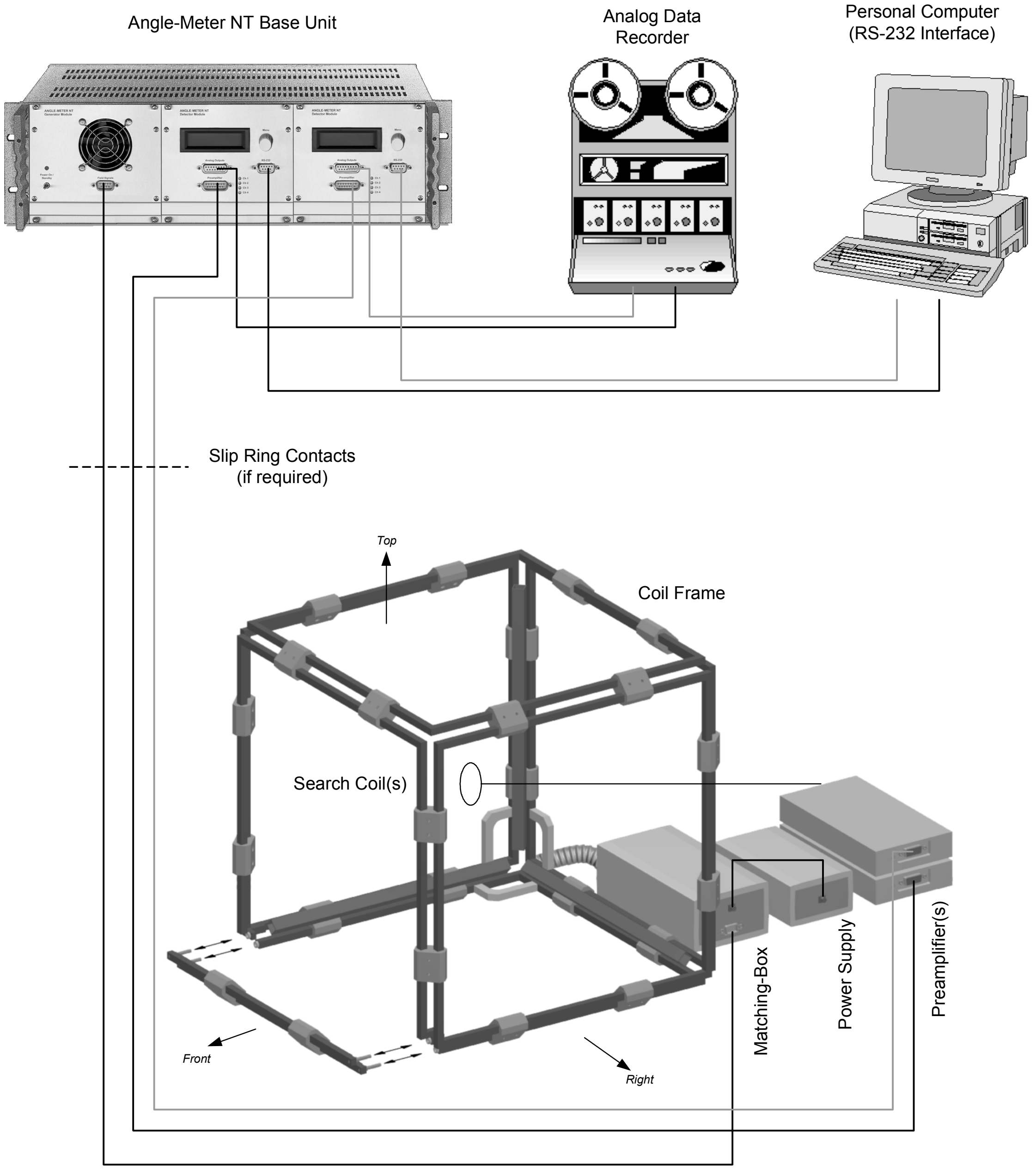


Figure 12-2: System Installation, Coil Frame with option "Removable Bars"

Once the system is wired, the Angle-Meter NT can be turned on. The main switch at the rear panel of the Angle-Meter NT may remain switched on (except during system wiring) and the switch at the front panel of the Generator Module is used to toggle the operation mode of the device between Power On and Standby, where the Standby mode means, that all internal electronics are not powered, except the small auxiliary power supply for the front switch.

Caution: Do not remove or insert the "Removable Bars" while the system is operating! Turn off the power of the Angle-Meter NT before handling the bars.

13 Slip Ring Wiring

If slip rings are required, e.g. if a Turn Table is used, use the following table to avoid problems.

Signal #	Signal Name	Angle-Meter NT Connector	Wiring AMNT - Slip Rings	Slip Ring Contact	Wiring Slip Rings - Ext. Device	Ext. Device on Turntable
1	V f1 +	"Field Signals", Pin 4	AWG 22, Shielded TP	1 (500 mA)	AWG 22, Shielded TP	Matching-Box, Pin 4
2	V f1 -	"Field Signals", Pin 5	AWG 22, Shielded TP	2 (500 mA)	AWG 22, Shielded TP	Matching-Box, Pin 5
3	GND	"Field Signals", Pin 6	Shield	3 (250 mA)	Shield	Matching-Box, Pin 6
4	V f2 +	"Field Signals", Pin 2	AWG 22, Shielded TP	4 (500 mA)	AWG 22, Shielded TP	Matching-Box, Pin 2
5	V f2 -	"Field Signals", Pin 1	AWG 22, Shielded TP	5 (500 mA)	AWG 22, Shielded TP	Matching-Box, Pin 1
6	GND	"Field Signals", Pin 3	Shield	6 (250 mA)	Shield	Matching-Box, Pin 3
7	V f3 +	"Field Signals", Pin 7	AWG 22, Shielded TP	7 (500 mA)	AWG 22, Shielded TP	Matching-Box, Pin 7
8	V f3 -	"Field Signals", Pin 8	AWG 22, Shielded TP	8 (500 mA)	AWG 22, Shielded TP	Matching-Box, Pin 8
9	GND	"Field Signals", Pin 9	Shield	9 (250 mA)	Shield	Matching-Box, Pin 9
10	MUX A0	"Preamplifier", Pin 6	AWG 24, Shielded TP	13 (250 mA)	AWG 24, Shielded TP	Preamplifier, Pin 6
11	MUX A1	"Preamplifier", Pin 5	AWG 24, Shielded TP	14 (250 mA)	AWG 24, Shielded TP	Preamplifier, Pin 5
12	Signal +	"Preamplifier", Pin 8	AWG 24, Shielded TP	15 (250 mA)	AWG 24, Shielded TP	Preamplifier, Pin 8
13	Signal -	"Preamplifier", Pin 15	AWG 24, Shielded TP	16 (250 mA)	AWG 24, Shielded TP	Preamplifier, Pin 15
14	Calc/Meas	"Preamplifier", Pin 12	AWG 24, Shielded TP	17 (250 mA)	AWG 24, Shielded TP	Preamplifier, Pin 12
15	Fix/AGC	"Preamplifier", Pin 13	AWG 24, Shielded TP	18 (250 mA)	AWG 24, Shielded TP	Preamplifier, Pin 13
16	+5V	"Preamplifier", Pin 1	AWG 24, Shielded TP	10 (250 mA)	AWG 24, Shielded TP	Preamplifier, Pin 1
17	-5V	"Preamplifier", Pin 3	AWG 24, Shielded TP	12 (250 mA)	AWG 24, Shielded TP	Preamplifier, Pin 3
18	GND	"Preamplifier", Pin 4	Shield	11 (250 mA)	Shield	Preamplifier, Pin 4

Notes:

A Recommended Cable for Signals # 1 to 9: 3 twisted pairs AWG 22, pair shields, e.g. Belden 8777 (http://www.belden.com/)
B Recommended Cable for Signals # 10 to 18: 4 twisted pairs AWG 24, common shield, e.g. Belden 9504 (http://www.belden.com/)
C Signals # 3, 6, 9 and 18 (GND) may use the same slip ring contact. Separate slip ring contacts are recomended for minimal signal crosstalk.
D Crosstalk from Signals # 1&2, 4&5, 7&8 and 12&13 to other signals must be minimized. Use appropriate layout of the slip ring contacts.
E Signals # 10 to 18 are used for 4 measuring channels (1 Preamplifier). For 8 measuring channels (2 Preamplifiers), signals # 10 to 18 are used twice.

Table 13-1: Slip Ring Wiring

14 System Optimization

The performance of the Angle-Meter NT mainly depends on the following parameters :

- Homogeneity and strength of the magnetic field at the position of the search coil(s)
- Effective area and geometry of the search coil(s)
- Offset failures due to irradiation on the search coil signal(s)

The system ground of the Angle-Meter NT is internally connected to earth potential. This should be considered if third-party devices are connected to the Angle-Meter NT, since ground loops may occur under certain circumstances.

14.1 Optimizing the Magnetic Field Homogeneity

Due to the magnetic field search coil technique used by the Angle-Meter NT, an optimal quality of the magnetic field is the basic condition for reliable measurements. Asymmetric field intensities, crosstalk and phase errors lead to an inhomogeneous resulting field and therefore may cause inaccurate output data. Irradiation of external devices and metallic materials in or near to the field may be critical because of field distortion. To avoid problems, follow these hints:

- If you are manufacturing your own coil frames and Matching-Boxes, do it carefully - it will pay. Only use first quality components, twist all connection wires carefully and minimize contact resistances. Adjust the resonance circuits and magnetic field strengths exactly! See chapter 15 'Tuning the system with a new coil frame' for an overview of how to do this.
- If you own several Angle-Meter NTs and coil frames delivered by Primelec, please keep in mind that each device is adjusted with the related coil frame. Watch the serial numbers of the base units and the coil frames to avoid confusion. Do not swap Modules between the base units.
- If you are using extension cables to connect the Matching-Box, only use very high quality cables, i.e. shielded twisted pairs for each balanced field signal. Keep the cables as short as any possible. Improper cabling and inappropriate slip rings may lead to crosstalk between the field signals, resulting in nonlinear output data.
- Avoid third-party devices with electrical radiation (transmitters, computers, CRTs, electric motors etc.) near to the coil frame. If these radiated frequencies are in the spectrum of the magnetic field frequencies of the Angle-Meter NT, this may cause an irregular distortion of the magnetic field, which will lead to noisy output data.
- Avoid large metallic parts (iron, aluminum, copper, reinforced concrete etc.) near to the coil frame. Those may cause an asymmetrical damping of the magnetic fields, which will lead to nonlinear output data.
- Do not disconnect the coil frame from the Matching-Box during the field signals are turned on. This will lead to a heavy capacitive load, which may overheat and destroy the power amplifiers of the Generator Module.

14.2 Optimizing the Measuring Signal Quality

A good quality of the input signal is very important. Follow these hints to achieve best results:

- The effective area of the used search coils should be as large as allowed by the application in order to achieve an optimal signal to noise ratio. Make sure that the parameters of the used search coils are within the values specified in the technical data.
- Twist the two connection wires of the search coils extremely careful and hold their length as short as possible in order to minimize offsets on the output signals due to stray pick-up on the search coil signal.

- Place the search coils as precisely as possible in the 3D-centre of the coil frame in order to achieve optimal output data in terms of system linearity.
- Place the preamplifier least 1 m from the coil frame to minimize irradiation on the measuring signal. If not possible, an additional shielding of the preamplifier may be helpful (aluminum, copper or permalloy).

14.3 Use of the Gain Correction

If a search coil is placed in the inhomogeneous area of the magnetic field, the outputs of the measuring channel are no longer directly proportional to the angular displacements of the search coil relative to the system's reference frame. This is the case, if the search coils are outside the 3D-centre of the coil frame or if the magnetic fields are damped asymmetrically. The gain correction of the Angle-Meter NT allows the correction of such linearity errors in a certain range.

If the gain correction is enabled (active), the outputs of the measuring channels are calculated on the basis of the individual gain correction values for each frequency of each channel. This means, that the signed vector lengths from the FFT-calculations are multiplied by the concerning gain correction values. If the actual gain mode is set to "AGC", the influence of the gain correction is limited. To achieve the full influence of the gain correction, use the fixed gain mode.

The table below shows the measuring signal and the resulting signed vector lengths from the FFT-calculations without gain correction:

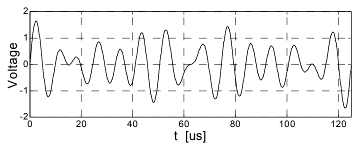
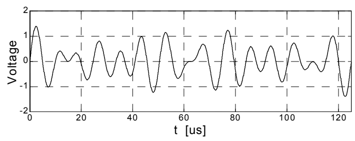
Conditions	Measuring signal	Signed vector lengths from the FFT-calculations, scaled to ± 1
The search coil is placed **within** the homogeneous area of the magnetic field with angular orientations alpha = 45° and beta = 45°		sVectLenX = 0.5 sVectLenY = 0.5 sVectLenZ = 0.7071
The search coil is placed **outside** the homogeneous area of the magnetic field with angular orientations alpha = 45° and beta = 45°		sVectLenX = 0.475 sVectLenY = 0.36 sVectLenZ = 0.6081

Table 14-1: Gain Correction Example

To determine the gain correction values, place the search coil into their position in the field with an angular orientation alpha = 45° and beta = 45°. The output mode "Vector Length" provides the signed vector lengths from the FFT-calculations, where the gain correction should be disabled at this time in order to avoid false results due to eventually existing, invalid gain correction values. After scaling the captured signed vector lengths to ± 1, the gain correction values can be calculated:

gainCorrX = 0.5 / sVectLenX

gainCorrY = 0.5 / sVectLenY

gainCorrZ = 0.7071 / sVectLenZ

All gain correction values are set to 1.0 at the factory. To change the values, use the concerning "Remote Control Function" over the serial interface.

After the valid gain correction values have been set and the gain correction was enabled, the system linearity is improved. Note that all gain correction values are permanently stored (non-volatile) in the Detector Module.

14.4 Use of the Offset Correction

Picked up stray signals on the measuring signal may lead to offsets and / or noise on the output signals. Stray signals may be picked up by inaccurately twisted connection wires of the search coils, by connectors in the signal path, by the preamplifier and so on (see chapter 14.2 'Optimizing the measuring signal quality').

If the source of the stray signal is the magnetic field generated by the Angle-Meter NT, the stray signal may lead to offsets on the output signal. Stray signals caused by a radiated field of a third-party device may lead to noisy output signals, if the radiated frequencies are in the spectrum of the magnetic field frequencies of the Angle-Meter NT.

The offset correction of the Angle-Meter NT allows to minimize offsets on the output signals. If the offset correction is enabled (active), the outputs of the measuring channels are calculated on the basis of the individual offset correction values for each frequency of each channel. This means, that the concerning offset correction values are subtracted from the signed vector lengths from the FFT-calculations. Note that the offset correction is not applicable if the gain mode is set to "AGC" (the variable signal gain caused by the AGC would lead to invalid corrections).

The table below shows the measuring signal and the resulting signed vector lengths from the FFT-calculations without offset correction:

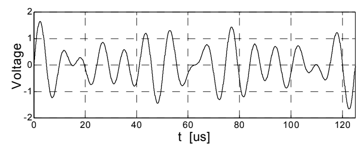
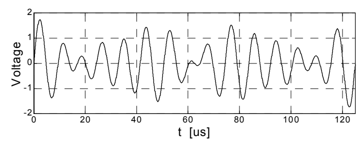
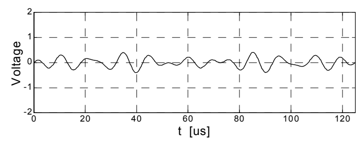
Conditions	Measuring signal	Signed vector lengths from the FFT-calculations
Optimal conditions. The search coil signal is "clean", i.e. no stray signals are picked up.		sVectLenX = 18330 sVectLenY = 18382 sVectLenZ = 25959
The **search coil signal is influenced by a picked up stray signal** caused by inaccurately twisted connection wires.		sVectLenX = 15030 sVectLenY = 20220 sVectLenZ = 29854
The **search coil is completely shielded**, the remaining measuring signal consists only of the picked up stray signal.		sVectLenX = -3300 sVectLenY = 1838 sVectLenZ = 3895

Table 14-2: Offset Correction Example

To determine the offset correction values, place the search coils into their position in the field and shield them completely, such that they can not pick up a field signal. Therefore, under optimal conditions, there is now no signal from the search coil. If there is a remaining signal, this is the picked up stray signal which has to be subtracted in order to eliminate offsets on the output signals. The output mode "Vector Length" delivers the signed vector lengths from the FFT-calculations, where the offset correction should be disabled at this time to avoid false results due to eventually existing, invalid offset correction values. The offset correction values for future use are now represented by the actual signed vector lengths.

Note that the Angle-Meter NT offers an Auto-Tuning function, which captures the remaining measuring signals of the completely shielded search coils and therefore determines the offset correction values for each measuring channel automatically. See chapters 9.3 'Menu' or 10.2.3 'Remote Control Functions' for additional info.

All offset correction values are set to zero at the factory. To change the values, use the concerning "Remote Control Function" over the serial interface.

After the valid offset correction values have been set and the offset correction was enabled, the offset on the output signals is minimized. Note that all offset correction values are permanently stored (non-volatile) in the Detector Module.

14.5 Choosing the best suited settings for your application

14.5.1 Field Signals

The field signals may be attenuated, for example, if very large search coils are used. The field signals may be turned off completely, for example, if it is meanwhile required to execute other measurements without the influence caused by the magnetic field. Under normal conditions, the field signals should remain to 100 % of their nominal values.

14.5.2 Gain Mode

Both gain modes of the Angle-Meter NT ("AGC" or "Fixed") have their pros and limitations:

AGC	Fixed
+ **Easy system handling** The AGC allows the use of different search coils without the need of any system recalibration by the user.	+ **Full system functionality** Both, the gain correction and the offset correction are fully applicable. Under difficult measuring conditions, the use of these correction functions can improve the precision of the output signals significantly.
+ **Optimal signal to noise ratio** The AGC automatically ensures an optimal signal to noise ratio of the measuring signal under all conditions, which minimizes the noise on the output signals.	- **Gain readjusting may be required** Due to the fixed gain of the measuring signal, the setting of new fixed gain values may be required after the search coils have been changed. The use of the Auto-Tuning function is recommended in order to achieve optimal gain values.
- **Partly limited system functionality** Due to the dynamic change of the signal amplification caused by the AGC, the offset correction is not applicable and the functionality of the gain correction is limited.	

Table 14-3: Gain Mode pros and limitations

Suggestion: Use the AGC mode whenever possible. Under difficult measuring conditions, the fixed gain mode may be preferred due to the applicability of the gain- and offset correction.

14.5.3 Gain Correction, Offset Correction

If there are difficult measuring conditions, the use of the gain- and offset correction can improve the precision of the output signals dramatically. But - as mentioned elsewhere in this manual - with an optimal homogeneity of the magnetic field and an optimized measuring signal, the use of the corrections may no longer be necessary.

Both correction functions have to be parameterized correctly in order to ensure reliable results. Otherwise, the output signals may be invalid and misleading. Therefore, it is only suggested to enable the correction functions if their usage is really adequate.

14.5.4 Output Filter

The use of the output filter can be helpful under noisy measuring conditions. The lowpass function of the filter may reduce the noise on the output signals significantly, where the upper bandwith of the acquired measuring signal is lowered (the specifications of the output filter can be seen in the technical data).
It is suggested to enable the output filter, if an improvement of the noise on the output signals can be achieved and if the limitation of the upper bandwith is acceptable by the application.

14.5.5 Output Mode

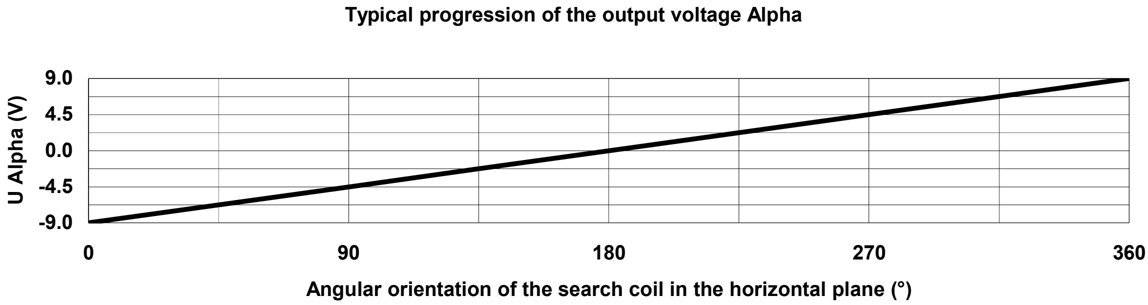
The choice of the used output mode ("Angular Data", "Vector Length" or "Vector Angle") depends on your demands on the format of the output signals:

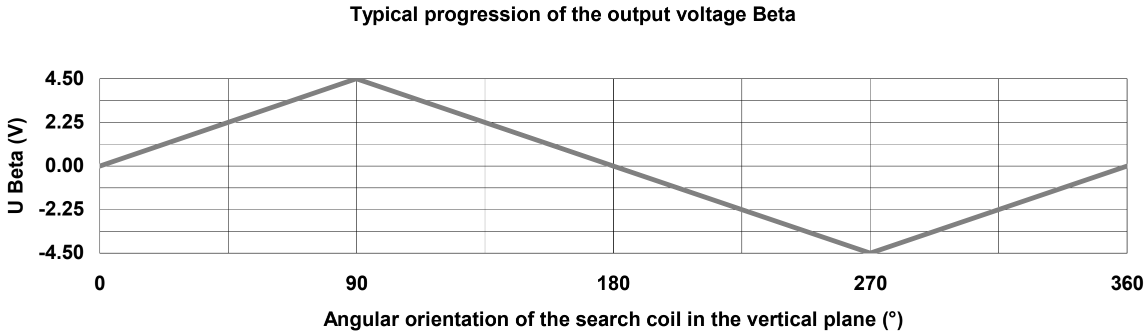
- Angular Data:

  The output signals alpha and beta represent in real-time the angular displacements `a` (horizontal plane) and `b` (vertical plane) of the search coil relative to the system's reference frame (coil frame). Internally, alpha and beta are calculated on the basis of the signed vector lengths from the FFT-calculation by trigonometric functions. Due to the AC-coupled characteristic of this measuring principle, drift on the output signals is practically eliminated.

  The use of this output mode is strongly suggested, if the goal of your application is to capture the two angles `a` and `b` respectively.

  The output signals are available simultaneously in two forms: as analog output voltages and as digital data over the serial interface. The resolution of the output signals is 0.0879°, where their update rate depends on the actual processing mode (see below, "Processing Mode"). The digital data is scaled from 0 to 4095 for the angle alpha (representing the range from 0° to 359.91°) and from 1024 to 3072 for the angle beta (representing the range from -90° to +90°). The voltage swing of the analog outputs is adjustable (see below, "Output Swing"). The figures below show the typical progression of the analog outputs, where the output swing was set to ± 9 V.





- Vector Length:

  The output signals sVectLenX, sVectLenY and sVectLenZ represent the spectral components of the three field frequencies f1 (80 kHz, X-axis), f2 (96 kHz, Y-axis) and f3 (120 kHz, Z-axis) of the induced voltage in the search coil. Since the spectral frequency components are proportional to the horizontal and vertical angular displacements of the search coil relative to the system's reference frame (coil frame), they can be used to calculate the angular orientation alpha and beta of the search coil.

  The output signals of this output mode are comparable to the outputs delivered by a conventional (analog) phase-locked amplitude detection system, where the advantages of the digital signal processing used by the Angle-Meter NT still are available.

  This output mode is used to obtain the needed information to determine the correction values used by the gain- and offset correction functions. Furthermore, this output mode may be used if your application includes the recording of torsional eye movements.

  The output signals (representing the signed vector lengths from the FFT), are simultaneously available in two forms: as analog output voltages and as digital data over the serial interface, where their update rate depends on the actual processing mode (see below, "Processing Mode").

  In this output mode, the scaling of the analog output voltages depends on the actually used gain mode. If the gain mode is set to "AGC", the output voltages are always scaled to fit the dominant vector in order to make full use of the available dynamic range. If the gain mode is set to "Fixed", the scaling of the output voltages is fixed. The scaling is based on a vector length of 40000. Vector lengths larger than 40000 will saturate the DACs without any notice, which will lead to saturated output voltages. The user has to avoid this by using appropriate settings for the fixed gain values. Please note that inappropriate settings of the offset correction values and the gain correction values may also saturate the DACs.

Example 1

α is the angular orientation of the search coil in the horizontal plane, β is the angular orientation of the search coil in the vertical plane.

The setting for the Output Swing is +/- 5 V. **The setting for the fixed gain value is correct**.

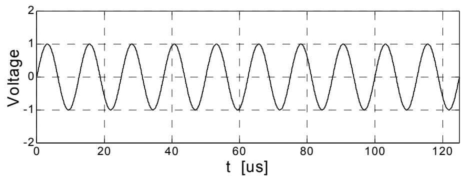
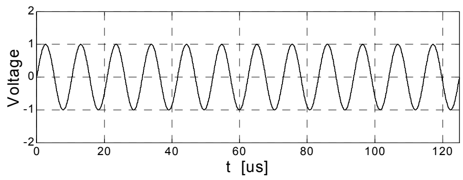
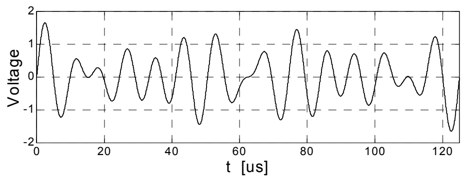
α	β	Induced search coil voltage	Vector Lengths	Output Voltage
0°	0°		f1: 36045 f2: 32 f3: 34	Vf1: 4.506 V Vf2: 0.004 V Vf3: 0.004 V
90°	0°		f1: 36 f2: 36051 f3: 33	Vf1: 0.005 V Vf2: 4.506 V Vf3: 0.004 V
45°	45°		f1: 18023 f2: 18025 f3: 25491	Vf1: 2.253 V Vf2: 2.253 V Vf3: 3.186 V

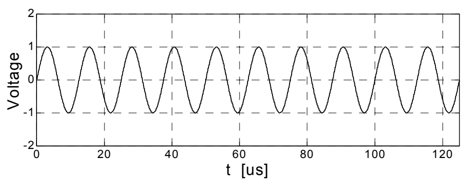
Table 14-4: Output Mode Example 1

The setting for the fixed gain value is optimal in this example. The output voltages do not reach the full range of the output swing, by which some dynamic range of the DACs remains reserved. This is recommended in order to handle position offsets of the search coil in a certain range and to prevent saturation caused by electrical drift effects.

Example 2

α is the angular orientation of the search coil in the horizontal plane, β is the angular orientation of the search coil in the vertical plane.

The setting for the Output Swing is +/- 5 V. **The setting for the fixed gain value is too high**.

α	β	Induced search coil voltage	Vector Lengths	Output Voltage
0°	0°		f1: 41025 f2: 36 f3: 39	Vf1: 5.000 V (*) Vf2: 0.005 V Vf3: 0.005 V

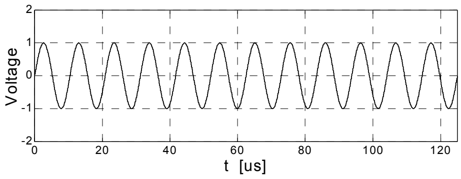
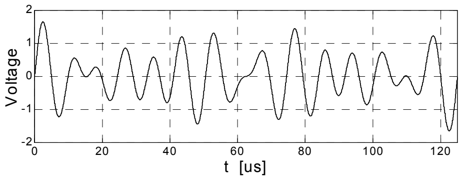
90°	0°		f1: 41 f2: 41032 f3: 38	Vf1: 0.005 V Vf2: 5.000 V (*) Vf3: 0.004 V
45°	45°		f1: 20513 f2: 20515 f3: 29013	Vf1: 2.564 V Vf2: 2.564 V Vf3: 3.627 V

Table 14-5: Output Mode Example 2

As one can see are the analog output voltages incorrect (*) at certain angular orientations of the search coil. The DACs are saturated due to the incorrect setting of the fixed gain value, which is too high in this example.

It is recommended to execute the function 'Do Auto-Tune' in the Gain Mode Menu in order to achieve optimal settings for the fixed gain values. This function determines the optimal settings for the fixed gain values of all four measuring channels in the Detector Module. However, if a search coil is placed outside of the 3D-centre of the field coils, this function may determine incorrect fixed gain values under certain circumstances (depending on the angular orientation of the search coils during the execution of the function). The user should check the determined settings by turning the search coil(s) over the relevant range and check the analog output signals for saturation effects. More precisely, the digitally outputted vector lengths may be checked - they must be below 40000, independently of the angular orientation of the search coil(s).

- Vector Angle:

  The output signals sVectAngX, sVectAngY and sVectAngZ represent the phase angles phi of the three frequencies f1 (80 kHz, X-axis), f2 (96 kHz, Y-axis) and f3 (120 kHz, Z-axis) of the induced voltage in the search coil, where phi lies in the range from -pi to pi. Internal, phi is used in order to determine the sign of the signed vector lengths.

  Under normal circumstances, this output mode will not be used. However, it may be helpful during trouble shooting, for example if you are manufacturing your own coil frame. An exactly tuned system normally outputs values for phi = -pi/2 or phi = pi/2, depending in the actual polarity (+/-) of the search coil.

  The output signals are simultaneously available in two forms: as analog output voltages and as digital data over the serial interface, where their update rate depends on the actual processing mode (see below, "Processing Mode"). The analog output voltages are scaled to the range from -pi to pi, the digital data is multiplied by 2600 for transmission.

14.5.6 Output Swing

The range of the output swing of the analog outputs is selectable to match the output voltages to the input voltage range of the connected external device, for example a data recorder. To achieve an optimal signal to noise ratio, it is suggested to make full use of the available input voltage range of the connected device by choosing the appropriate output swing.

14.5.7 Processing Mode

In order to increase the update rate of the output signals, the number of the processed measuring channels can be limited:

Processing Ch1→Ch1	Processing Ch1→Ch2	Processing Ch1→Ch4
The Detector Module processes only one measuring channel (channel 1). The update rate of the analog outputs is 4 kHz for all output modes. The update rate of the digital data over the serial interface is 2 kHz for the output mode "Angular Data" and 1 kHz for the output modes "Vector Length" and "Vector Angle".	The Detector Module processes only two measuring channels (channel 1 and channel 2). The update rate of the analog outputs is 2 kHz for all output modes. The update rate of the digital data over the serial interface is 1 kHz for the output mode "Angular Data" and 500 Hz for the output modes "Vector Length" and "Vector Angle".	The Detector Module processes all four measuring channels (channel 1 to channel 4). The update rate of the analog outputs is 1 kHz for all output modes The update rate of the digital data over the serial interface is 500 Hz for the output mode "Angular Data" and 250 Hz for the output modes "Vector Length" and "Vector Angle".

Table 14-6: Processing Mode Description

The table below indicates the suggested processing mode to achieve the highest available update rates, depending on the number of the used search coils.

Search Coils	Angle-Meter NT is equiped with one Detector Module	Angle-Meter NT is equipped with two Detector Modules	
		Main Detector Module	Add-On Detector Module
1	Ch1 → Ch1	Ch1 → Ch1	Not used
2	Ch1 → Ch2	Ch1 → Ch1	Ch1 → Ch1
3	Ch1 → Ch4	Ch1 → Ch2	Ch1 → Ch1
4	Ch1 → Ch4	Ch1 → Ch2	Ch1 → Ch2
5	-	Ch1 → Ch4	Ch1 → Ch1
6	-	Ch1 → Ch4	Ch1 → Ch2
7	-	Ch1 → Ch4	Ch1 → Ch4
8	-	Ch1 → Ch4	Ch1 → Ch4

Table 14-7: Processing Mode Suggestions

15 Tuning the System with a new Coil Frame

This chapter describes the required steps to setup a suitable Matching-Box and to tune the field voltages if the user plans to fabricate a specific coil frame.

⚠

Caution:
The coil frames of the Angle-Meter NT generate a relatively strong **magnetic field** in the frequency range from 80 kHz to 120 kHz. This can lead to **injury to health**. **Capacitive and inductive coupling onto organisms and devices sensitive in this regard must be considered.**

The signals applied to the coil frames may have **hazardous voltage levels**. An inappropriate application (touching the conductors or the coil frames, capacitive and / or inductive couplings etc.) can come for **injuries to health**.

Check the standards and regulations of your country and **the possible risk for injuries to health** before using the Angle-Meter NT. **Under no circumstances may the Angle-Meter NT be used for applications on the human being.**

Only qualified personnel may work on the system, and only after becoming familiar with the concerning standards and regulations, safety notices and the functional principle of the Angle-Meter NT. **In no event shall Primelec, its employees or its suppliers be liable for any damages whatsoever.**

15.1 Coil Frame

The coil frame should consist of three field coils (X-, Y- and Z-coil), each with two windings. Depending on the size of the coil frame the required field coil current (i.e. the resonance current) is up to 20 A. This must be considered for the evaluation of the material used for the coil frames and the wiring. Aluminium bars (cross section 8 x 8 mm) may be used for the coil frames. Two copper wires with 1.5 mm^2 in parallel are suggested for the wiring. The connection wires must be twisted carefully in order to prevent stray fields and unwanted additional inductance.

15.2 Matching-Box

15.2.1 Transformers

The Matching-Box contains application specific transformers. The turn ratio depends on the size of the used coil frame. Coil frames below 50 cm have 1 : 1 transformers, coil frames between 50 cm and 70 cm have 1 : 1.5 transformers in order to achieve higher field voltages. The use of coil frames larger than 70 cm is not recommended.

The transformers are based on ferrite toroids with a rather large diameter to ease the winding process (e.g. EPCOS series N30, B64290L0674X830). The primary winding has 30 turns, the number of turns of the secondary winding depends on the size of the coil frame: 30 turns (coil frame up to 50 cm) or 45 turns (coil frame 50 … 70 cm). Use insulated copper wire, diameter 0.5 mm, for both windings.

15.2.2 Resonance Circuit Tuning

Three sets of capacitors in the Matching-Box are connected in parallel with the appropriate field coils (LC resonance circuits). The required total capacitance per resonance circuit depends on the frequency of the field signal and the total inductance of the coil. The total inductance of the coil varies depending on the size of the coil frame and the wiring of the coil.

Due to the influencing of the wiring on the resulting total inductance, the tuning of the resonance circuits assumes completely wired coil frames, i.e. the connection wires must have final lengths and exact twisting.

Adjust the total capacitance of each set of capacitors to achieve resonance at the specified frequencies. Get started by quantifying the total inductance of the coil frames. The measured inductance (L) is used to estimate the required total capacitance (C) for each resonance circuit:

$C = ((1 / 2 \text{ pi } f_R)^2) / L$

X-Axis: f_R = 80.0 kHz, Y-Axis: f_R = 96.0 kHz, Z-Axis: f_R = 120.0 kHz

Use metallized polypropylene film capacitors (e.g. EPCOS, series B3265x) for the resonance circuits. Tune the resonance circuits one by one. Start in each case with a capacitance value which is slightly lower than estimated and tune the resonance circuits by adding capacitors in parallel until the circuits are exactly in resonance at the specified frequencies (i.e. zero degree phase lag between the output voltage and the output current of the power amplifier).

Notes:

- An exactly tuned resonance circuit behaves as an ohm resistive load for the power amplifier. During the tuning process the power amplifier may have to drive a capacitive or inductive load. Therefore use low field voltages (approx. 1 V RMS, setting see below) during the tuning process to prevent overloading the power amplifier. Inappropriate handling may destroy the power amplifier.
- Mismatched resonance circuits will cause phase errors and drift on the system's measuring data outputs or even damage the power amplifiers.
- See the figure at the end of this chapter for an example of a Matching-Box.
- See the figure at the end of this chapter for an appropriate adapter to measure the phase lag of the power amplifier's output voltage and output current with an oscilloscope (Mode X-Y).

15.3 Field Voltage Tuning

Once the resonance circuits are tuned exactly, the tuning of the three nominal field voltages X, Y and Z is required to calibrate the generated magnetic field. Note that the field voltages can achieve hazardous levels, precautions in this regard must be considered. The correct settings for the field voltages depend on the size of the coil frame, the used transformers, the quality of the resonance circuits and the frequency of the field signals. The setting of the nominal field voltages is accomplished with the program "Angle-Meter NT – Enhanced Remote Control" over the serial interface RS-232 of the Angle-Meter NT (see the figures at the end of this chapter). Once the field voltages are exactly calibrated, the system can be used with various search coils without the need for recalibration of the field voltages.

15.3.1 Coarse Tuning

Adjust the three nominal field voltages to achieve the typical magnetic flux densities at the 3D-center of the coil frame, which are 15 uT (80 kHz, X-axis), 12.5 uT (96 kHz, Y-axis) and 10 uT (120 kHz, Z-axis). Tune the nominal field voltages one by one until the typical flux density is achieved in each axis. Do not overload the power amplifiers (max. 350 mA output current per channel with ohm resistive load, i.e. exactly tuned resonance circuits assumed).

15.3.2 Fine Tuning

A fine tuning of the nominal field voltages is required to calibrate the magnetic field at the 3D-center of the coil frame. Adjust the nominal field voltages in small steps until the induced voltage in a given search coil, which is placed at the 3D-centre of the coil frame, is equal in all three axes. See table on next page for details.

Step	Instruction
1.	**Connect a computer to the serial interface RS-232 of the Angle-Meter NT.** The program “Angle-Meter NT - Enhanced Remote Control” must be installed on the computer.
2.	Use the **following settings** for the Angle-Meter NT: • Field Signals: 100% • Gain Correction: Disabled • Gain Mode: Fixed • Offset Correction: Disabled • Output Filter: Disabled • Output Mode: Vector Length • Output Swing: +/-10 V (if this overshoots the maximal input voltage range of the used external data acquisition system, use the maximal admissible output swing instead) • Processing: Ch1 → Ch4 • Test Signals: Off
3.	Place a search coil at the **3D-center** of the coil frame and **connect it to Channel 1** of the Preamplifier. Any search coil with specifications as described in the technical data of the Angle-Meter NT may be used. Do not move the position of the search coil within the coil frame during the following steps, i.e. vary only the angular orientation of the search coil if prompted.
4.	Use the program “Angle-Meter NT - Enhanced Remote Control” to set an **adequate fixed gain value for Channel 1** (you may use the function ‘Do Auto-Tune’ of the ‘Gain Mode’ to evaluate an adequate value). The level indicator LED of Channel 1 must be green.
5.	**Turn the search coil accurately until all of the following conditions are true:** • Vector length for **Ch1 f1** (sVectLenX) has the **maximal achievable value** • Vector length for **Ch1 f2** (sVectLenY) has a **value as close to zero as achievable** • Vector length for **Ch1 f3** (sVectLenZ) has a **value as close to zero as achievable** **Do not move the position, but vary only the angular orientation of the search coil.** Fix the search coil once it has an angular orientation such that these conditions are true. The search coil should now have an orthogonal orientation relative to the coil frame axis X, and a parallel orientation relative to the coil frame axes Y and Z. **Note the value of the vector length for Ch1 f1** (**sVectLenX_MAX**) for later use in steps 6 and 7.
6.	**Turn the search coil accurately until all of the following conditions are true:** • Vector length for **Ch1 f1** (sVectLenX) has a **value as close to zero as achievable** • Vector length for **Ch1 f2** (sVectLenY) has the **maximal achievable value** • Vector length for **Ch1 f3** (sVectLenZ) has a **value as close to zero as achievable** **Do not move the position, but vary only the angular orientation of the search coil.** Fix the search coil once it has an angular orientation such that these conditions are true. The search coil should now have an orthogonal orientation relative to the coil frame axis Y, and a parallel orientation relative to the coil frame axes X and Z. Use the program “Angle-Meter NT - Enhanced Remote Control” to increase or decrease the relative value of the nominal field voltage **U f2 (96 kHz, Y-axis)** until the **value for Ch1 f2 is equal to sVectLenX_MAX** (see step 5).
7.	**Turn the search coil accurately until all of the following conditions are true:** • Vector length for **Ch1 f1** (sVectLenX) has a **value as close to zero as achievable** • Vector length for **Ch1 f2** (sVectLenY) has a **value as close to zero as achievable** • Vector length for **Ch1 f3** (sVectLenZ) has the **maximal achievable value** **Do not move the position, but vary only the angular orientation of the search coil.** Fix the search coil once it has an angular orientation such that these conditions are true. The search coil should now have an orthogonal orientation relative to the coil frame axis Z, and a parallel orientation relative to the coil frame axes X and Y. Use the program “Angle-Meter NT - Enhanced Remote Control” to increase or decrease the relative value of the nominal field voltage **U f3 (120 kHz, Z-axis)** until the **value for Ch1 f3 is equal to sVectLenX_MAX** (see step 5).

Table 15-1: Field Voltage Fine Tuning - Step by Step

15.4 Figures

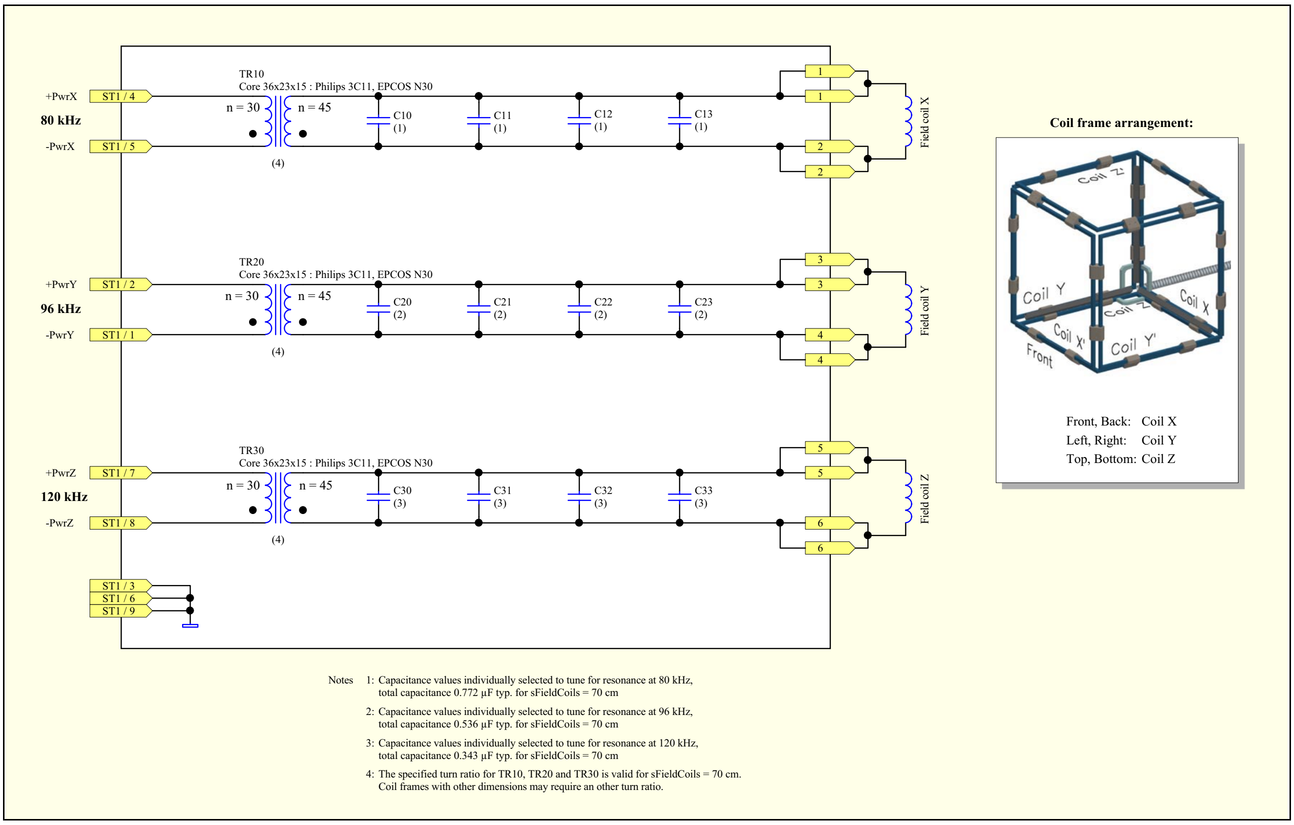


Figure 15-1: Example of a Matching-Box

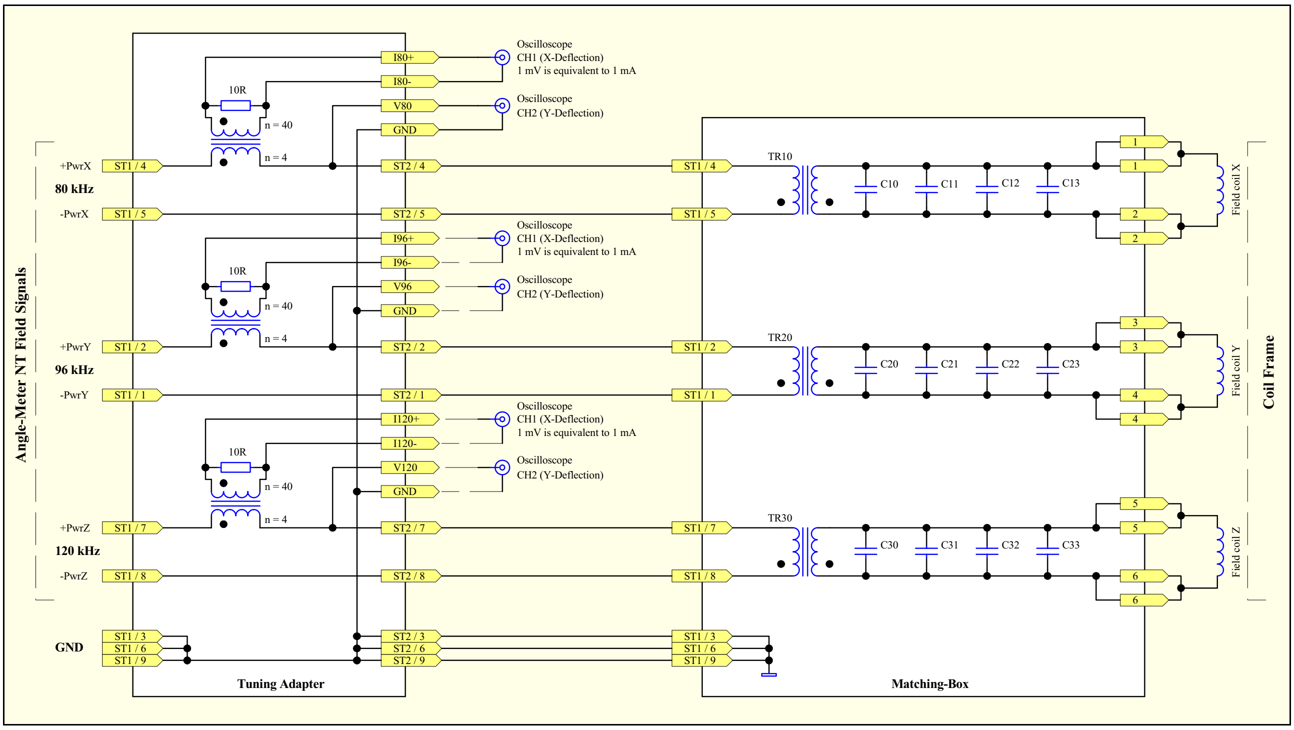


Figure 15-2: Resonance Tuning Adapter

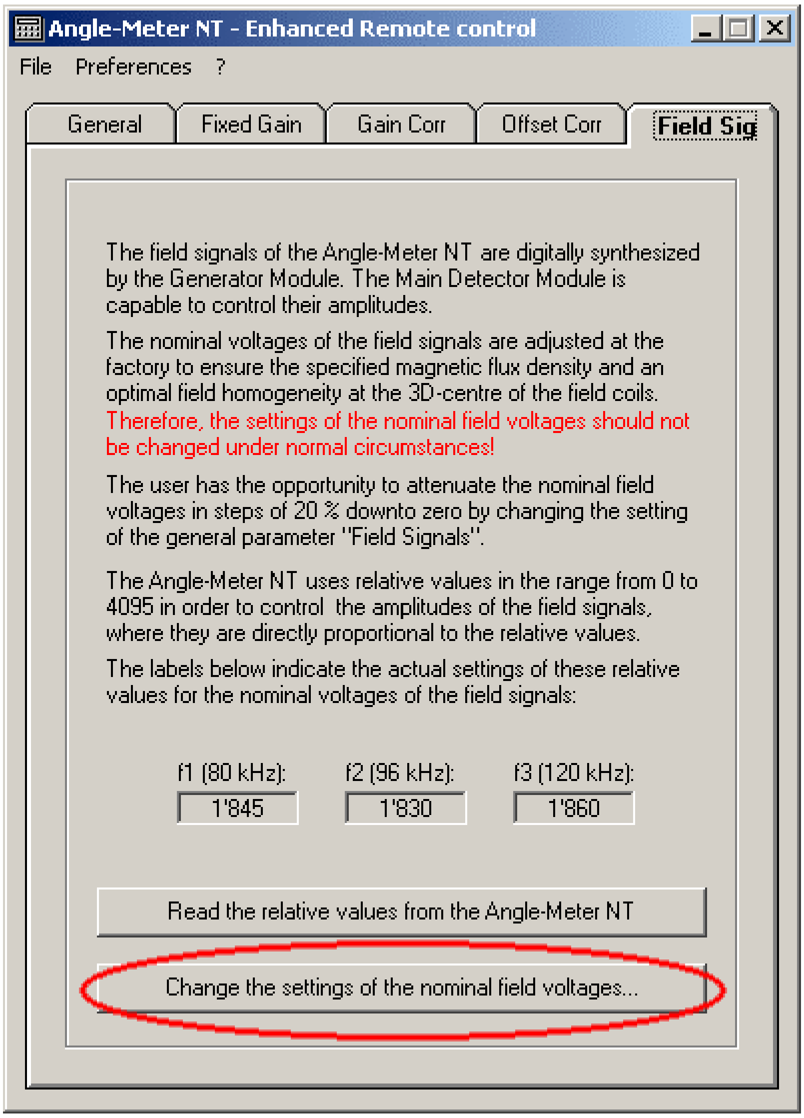


Figure 15-3: Software "Angle-Meter NT - Enhanced Remote Control"

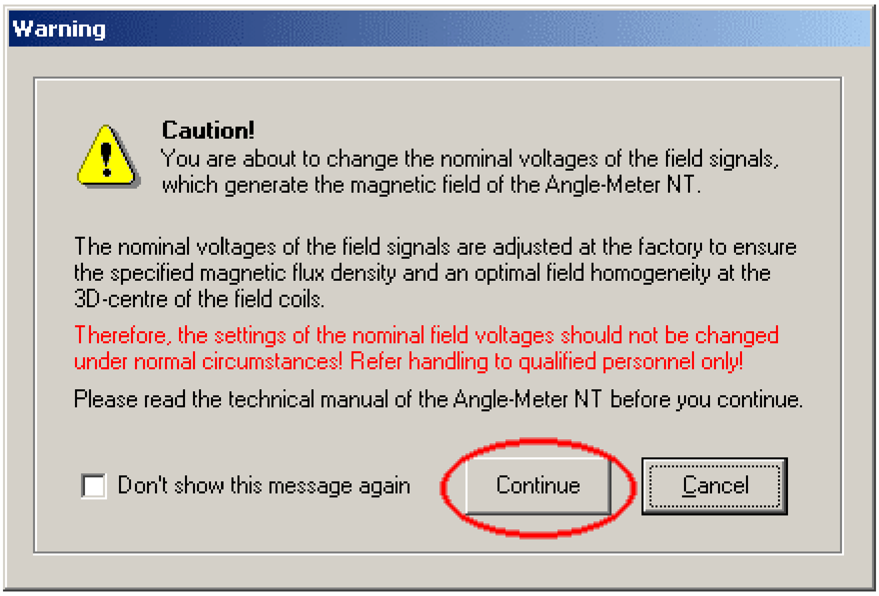


Figure 15-4: Enhanced Remote Control - Warning Hint

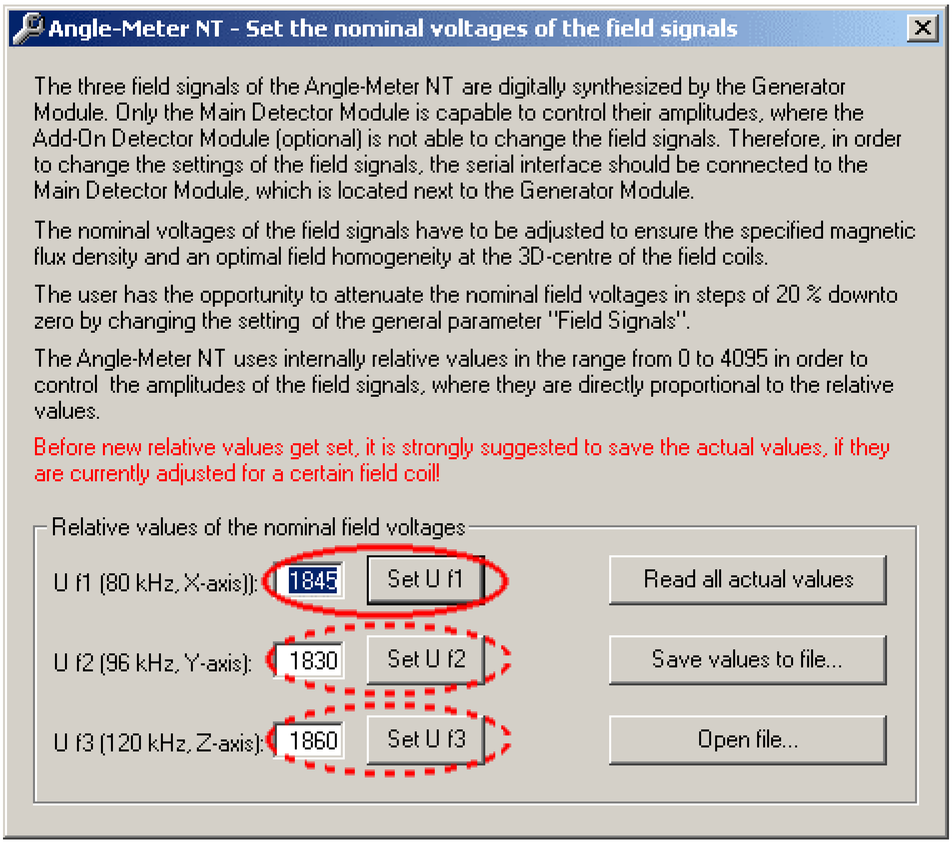


Figure 15-5: Enhanced Remote Control - Set the nominal voltages of the field signals

16 Block Diagrams

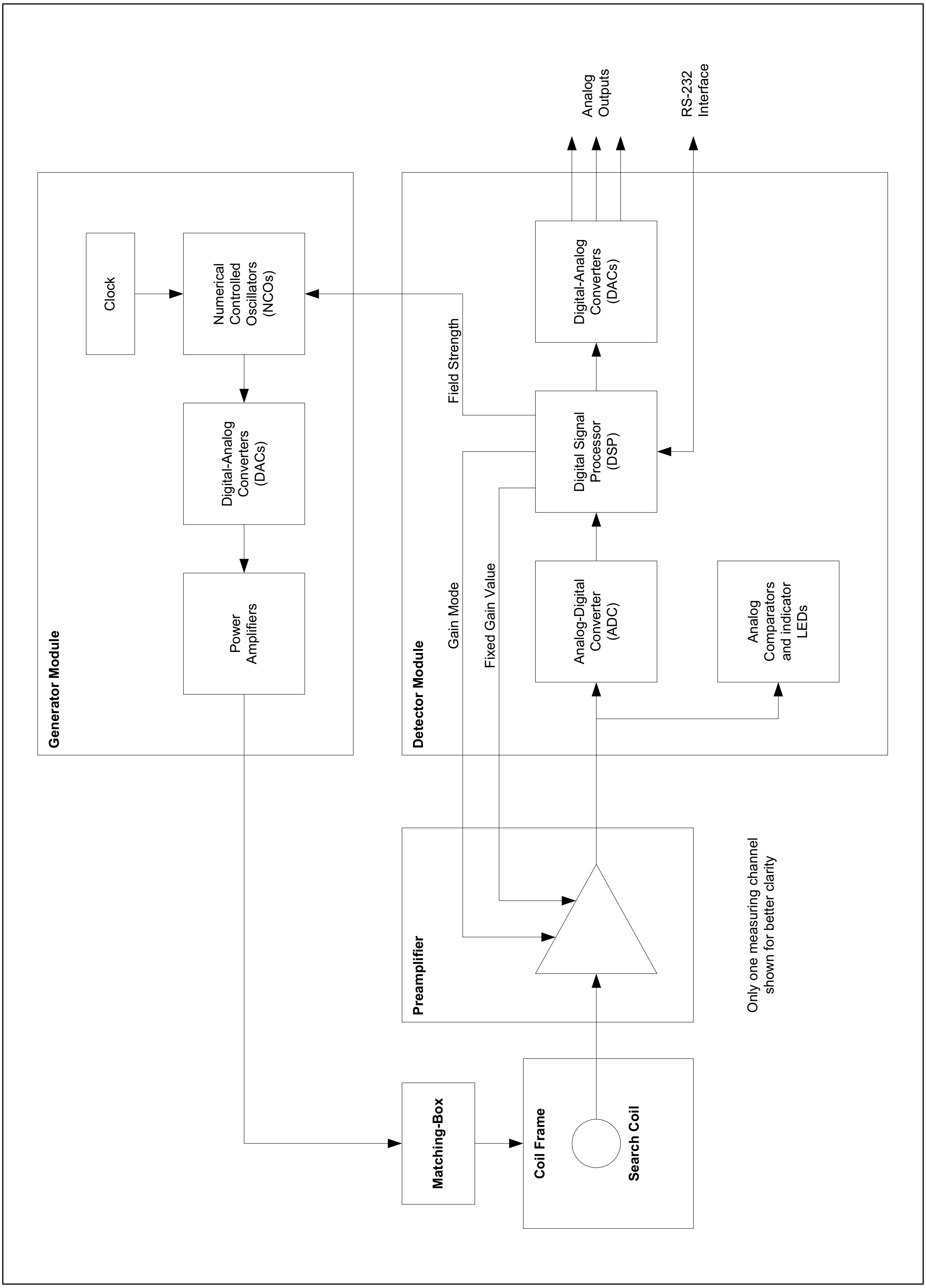


Figure 16-1: Block Diagram - System Overview

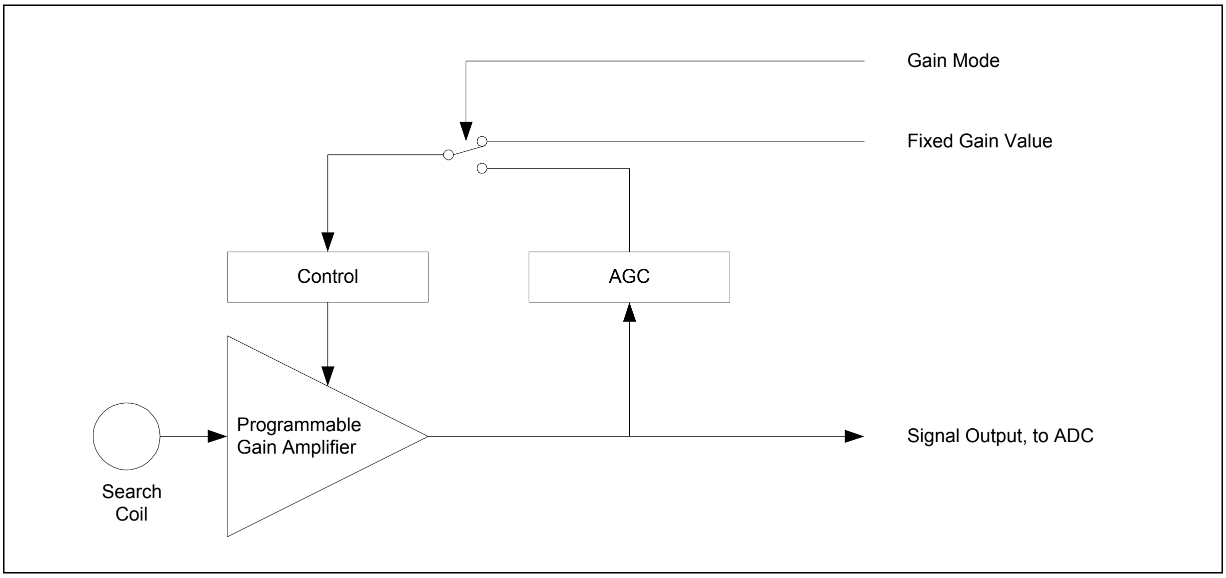


Figure 16-2: Block Diagram - Preamplifier Overview

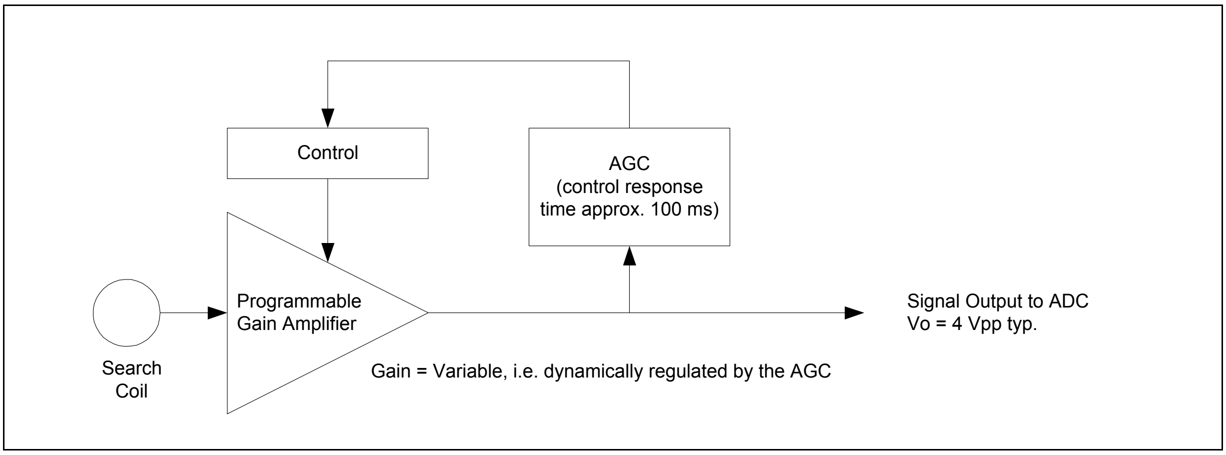


Figure 16-3: Block Diagram - Preamplifier, Gain Mode = AGC

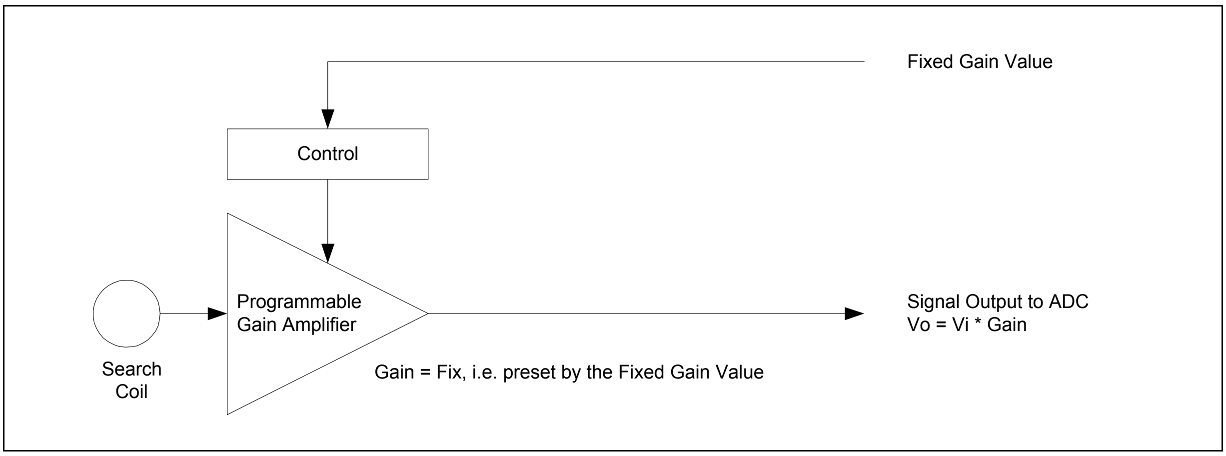


Figure 16-4: Block Diagram - Preamplifier, Gain Mode = Fixed

17 Flowchart

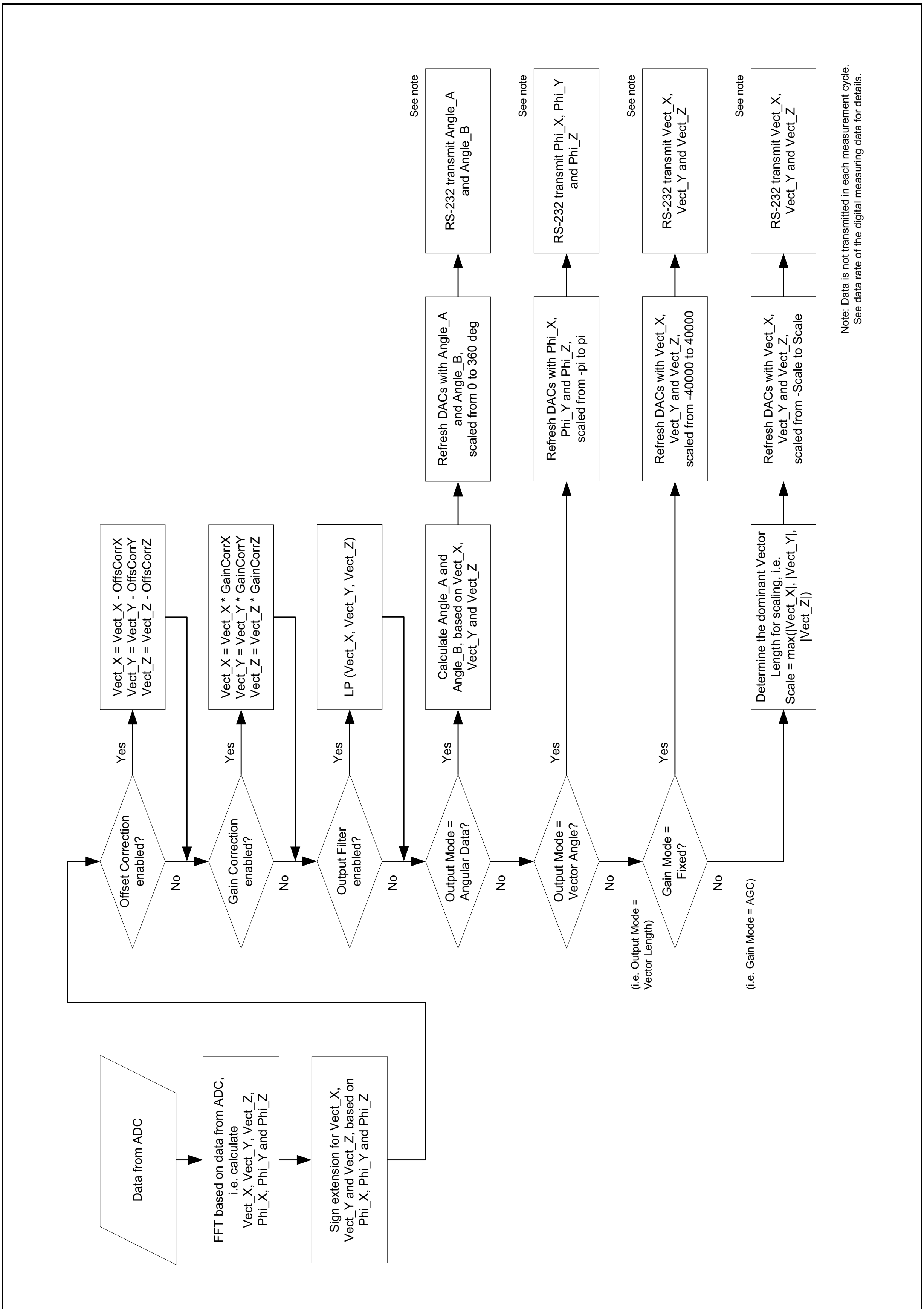


Figure 17-1: Flowchart - DSP Main Task (Measuring Cycle)

18 Pinouts

18.1 Preamplifier Inputs (3 contacts socket connectors):

Pin 1	Pin 2	Pin 3
Search coil -	N.C.	Search coil +

Suitable pin connectors for the search coils: Binder, series 719, part number 09-9747-00-03

18.2 Preamplifier Outputs / Control Signals (15 contacts D-SUB pin connector):

Pin 1	Pin 2	Pin 3	Pin 4	Pin 5	Pin 6	Pin 7	Pin 8
+ 5V	GND	- 5V	GND	MUX A1	MUX A0	GND	Signal +
Pin 9	**Pin 10**	**Pin 11**	**Pin 12**	**Pin 13**	**Pin 14**	**Pin 15**	
+ 5V	GND	- 5 V	Calc/Meas	Fix/AGC	N.C.	Signal -	

18.3 Field Signals (9 contacts D-SUB pin connector):

Pin 1	Pin 2	Pin 3	Pin 4	Pin 5	Pin 6	Pin 7	Pin 8	Pin 9
V f2 -	V f2 +	GND	V f1 +	V f1 -	GND	V f3 +	V f3 -	GND

18.4 Analog Outputs (15 contacts D-SUB socket connector):

The meaning of the outputted voltages differs depending on the actual output mode:

Angular Data: Signals alpha (angular orientation in the horizontal plane) and beta (angular orientation in the vertical plane) of the processed channels are outputted at the indicated pins

Vector Length: Signals sVectLenX (f1, X-axis), sVectLenY (f2, Y-axis) and sVectLenZ (f3, Z-axis) of the processed channels are outputted at the indicated pins

Vector Angle: Signals sVectAngX (f1, X-axis), sVectAngY (f2, Y-axis) and sVectAngZ (f3, Z-axis) of the processed channels are outputted at the indicated pins

Pin 1	Pin 2	Pin 3	Pin 4	Pin 5	Pin 6	Pin 7	Pin 8
Ch1 alpha or Ch1 f1	Ch1 beta or Ch1 f2	Ch2 alpha or Ch1 f3	Ch2 beta or Ch2 f1	Ch3 alpha or Ch2 f2	Ch3 beta or Ch2 f3	Ch4 alpha or Ch3 f1	Ch4 beta or Ch3 f2
Pin 9	**Pin 10**	**Pin 11**	**Pin 12**	**Pin 13**	**Pin 14**	**Pin 15**	
GND	GND	GND	Ch4 f3	Ch4 f2	Ch4 f1	Ch3 f3	

18.5 Serial Interface RS-232 (9 contacts D-SUB socket connector):

An external computer (COM port) may be connected with a straight male / female interface cable.

Pin 1	Pin 2	Pin 3	Pin 4	Pin 5	Pin 6	Pin 7	Pin 8	Pin 9
N.C.	TxD	RxD	N.C.	GND	N.C.	CTS	RTS	N.C.

19 Technical Data

In General

Number of measuring channels:	Four channels in the Basic-System, expandable by the use of an Add-On Detector Module to eight channels. Applications using more than eight measuring channels are also practicable, please contact Primelec for details.
AC input voltage:	230 VAC ± 10 %, 50 Hz (115 VAC ± 10 %, 60 Hz on request)
Power consumption:	250 VA max. during normal operation, 5 VA max during Standby
LC-Display:	2 x 16 characters, backlight intensity selectable by the user
Control elements:	Main switch at the rear panel, Power On / StandBy switch, multifunctional rotary-/ push-button for the menu of each Detector Module (operation may be locked by the user)
Dimensions:	19" / 3 HU rack mountable or desktop case, approx. 483 x 140 x 380 mm (w x h x d)
Mass:	Basic-System approx. 10 kg, Add-On Detector Module approx. 1 kg

Field signal generation

In general:	Three sine wave field signals (crystal-controlled digitally synthesized), amplified by three physically separated power amplifiers with balanced outputs
Frequencies:	80 kHz, 96 kHz and 120 kHz
Maximum output voltage:	14 Vpp → GND (balanced 28 Vpp)
Nominal output voltages:	Depend on the size of the used coil frame, where the nominal output voltages are tuned at the factory to achieve the specified flux density (see "Nominal magnetic flux density" below) and an optimal field homogeneity at the 3D-centre of the coil frame. The factory-tuned nominal output voltages may be attenuated by the user in steps of 20 % down to zero
Output impedance:	< 0.2 Ω in the relevant frequency spectrum
Power bandwidth:	> 5 MHz

Coil frame

In general:	Three coils with two turns each, arranged as a monocoque cube, therefore minimal restriction of the visual field
Frame material:	Anodized Aluminum, cross section 8 mm
Frame dimensions:	Various sizes available (s_{max} = 70 cm)
Frame colors:	Various colors available
Mass:	Depends on the frame dimensions, for example approx. 5 kg for s = 70 cm (including the required Matching Box)
Nominal magnetic flux density:	Approx. 15 uT (80 kHz, X-axis), 12.5 uT (96 kHz, Y-axis) and 10 uT (120 kHz, Z-axis) at the nominal output voltage of the field signals. The magnetic flux density may be reduced by the user in steps of 20 % down to zero (see "Nominal output voltages" above)

Search coils

Material:	Preferably double insulated copper wire, Ø 20µm
Mass:	Depends on material, dimensions and manufacturing process, for example approx. 2 mg for a double insulated copper coil with d = 2 mm and n = 80
DC-Resistance:	Max. 300 ohm (3 ohm ... 100 ohm typical)
Diameter:	2 mm ... 40 mm typical (see also "Effective area")
Number of turns:	1... 1000 typical (see also "Effective area")
Effective area:	1 cm² ... 32 cm² (A_{eff} = n D² pi / 4) The range of the effective area specified above refers to the nominal magnetic flux density. If the flux density is reduced by attenuating the field signals to 20 % of their nominal values, the allowed effective area may be up to 160 cm².

Preamplifier

In general:	The preamplifier is placed in a separate box and processes four search coils. It can be set to AGC or fixed gain by the user.
Pinout:	See chapter 18 'Pinouts'
Dimensions:	Approx. 100 x 40 x 200 mm (w x h x d)
Mass:	Approx. 330 g

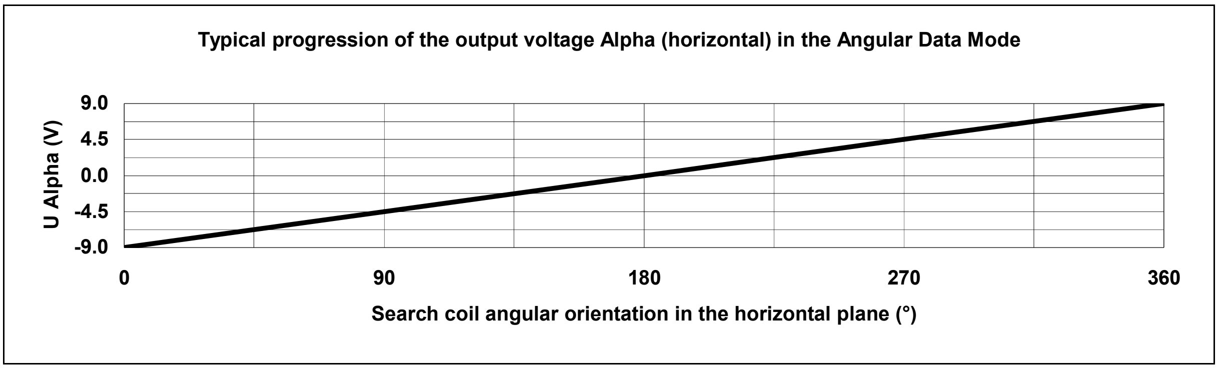
Measuring data

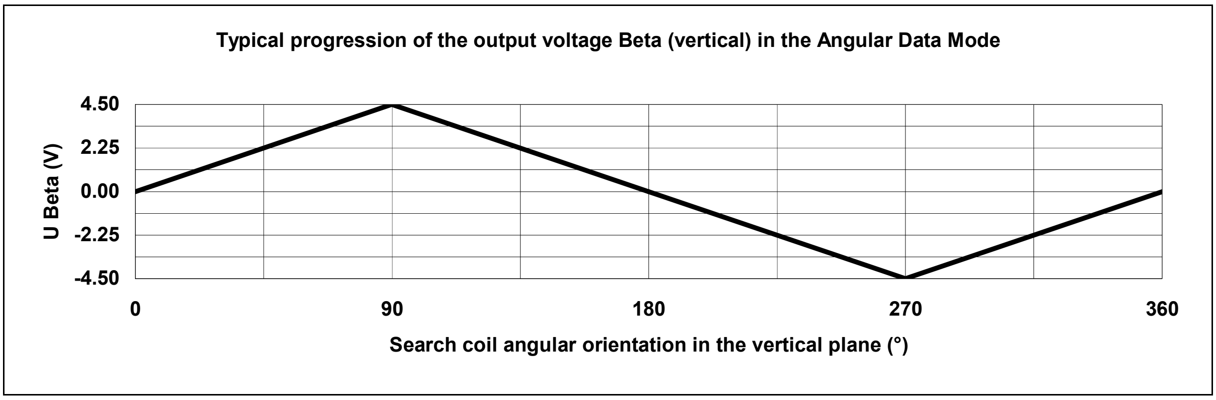
In general:	The output format of the measuring data can be selected by the user (linear angular data for the horizontal and the vertical plane, signed vector lengths or signed vector angles for X, Y and Z)
Detection range:	360° in the horizontal plane > ± 80° in the vertical plane
Resolution of the angular data:	< 0.05°
Output filter:	6^{th} order digital Butterworth low pass filter with a cutoff frequency of one eighth of the output data rate of the analog outputs. The filter may be enabled or disabled by the user.
Drift:	< 0.1° during warm-up (see also diagram below)
Linearity error horizontal:	< 0.5° over 360° (see also diagram below)
Linearity error vertical:	< 0.3° over ± 80° (see also diagram below)
Crosstalk horizontal / vertical:	< 0.2° in the specified range (see also diagrams below)
Noise:	< 0.09°pp (see also diagrams below)

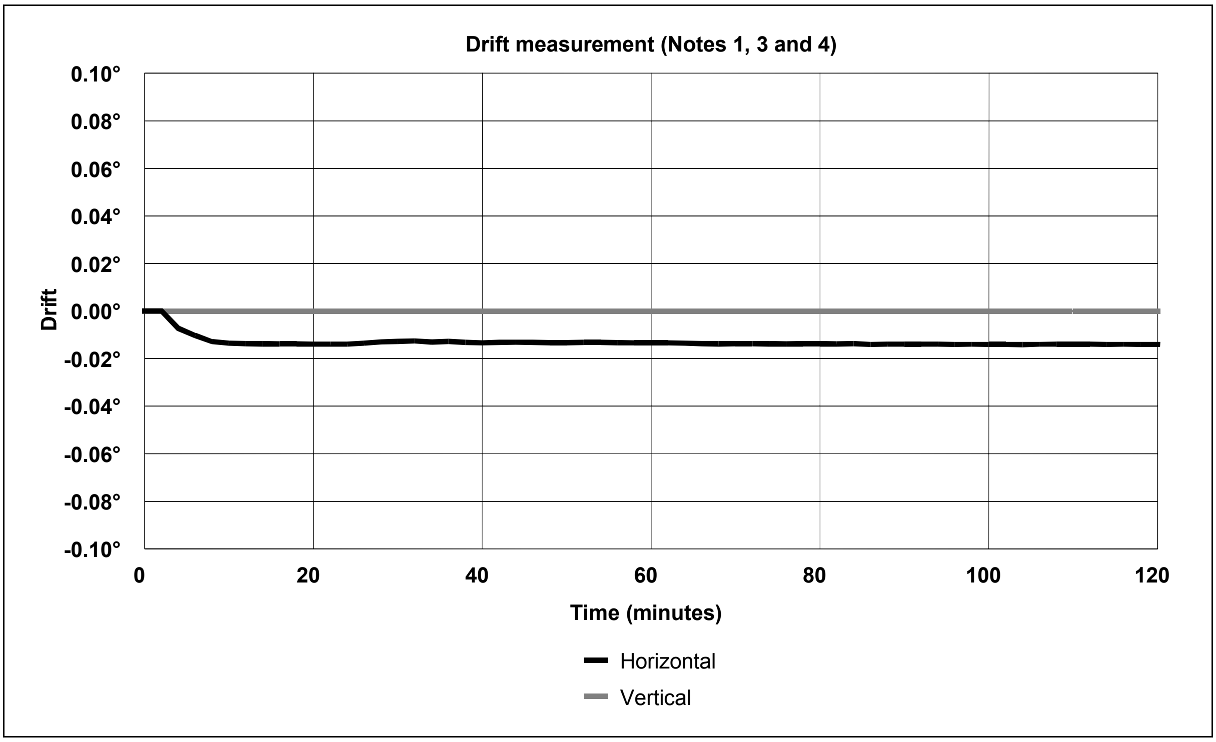
Analog outputs

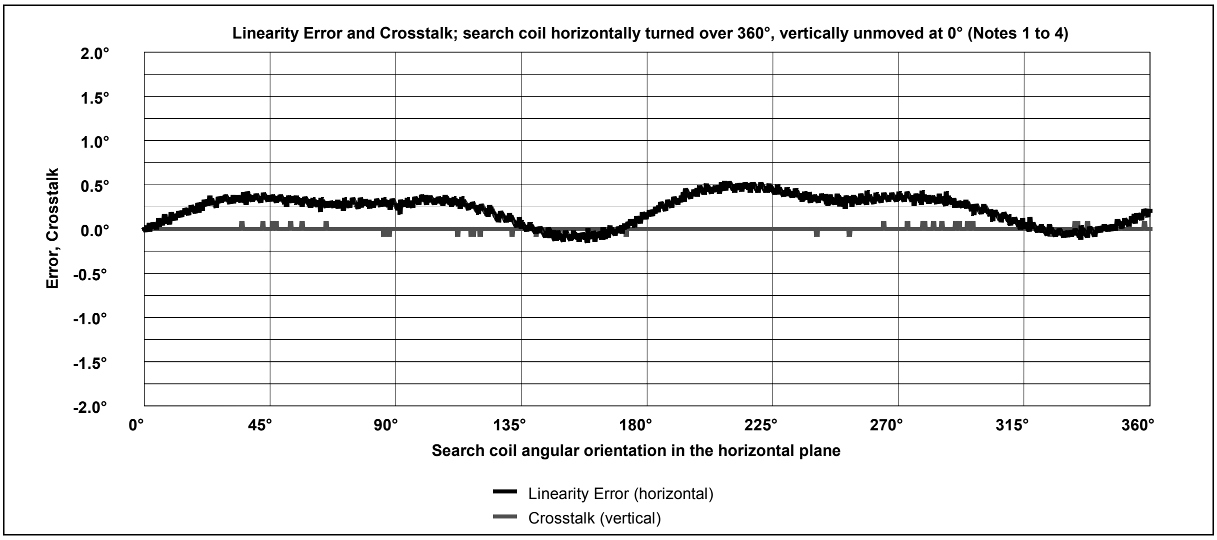
Update rate:	4 kHz, 2 kHz or 1 kHz (depending on the number of processed measuring channels), selectable by the user
Output voltage swing:	± 2.5 V, ± 4.5 V, ± 5 V, ± 9 V, ± 10 V; selectable by the user
Output impedance:	51 ohm typical
Pinout:	See chapter 18 'Pinouts'

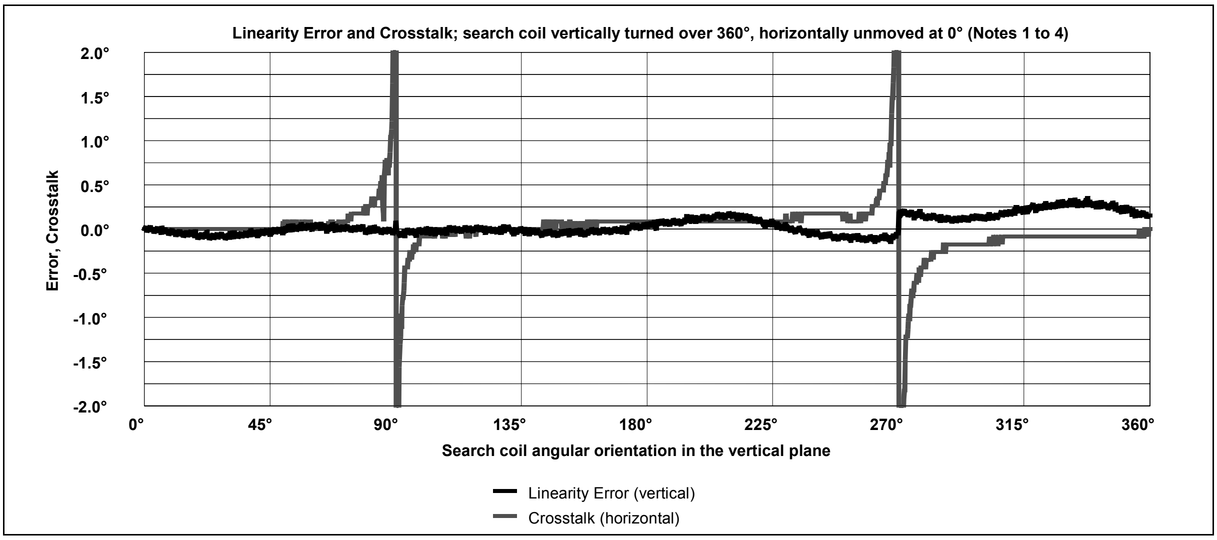
Diagrams

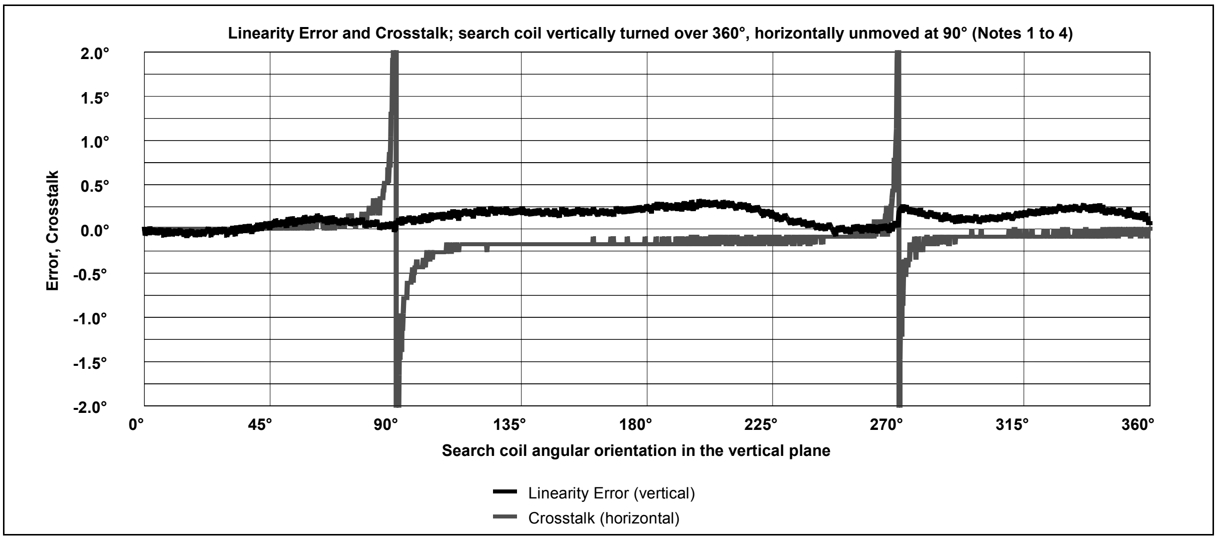

Typical progression of the output voltage Alpha (horizontal) in the Angular Data Mode
U Alpha (V)
9.0
4.5
0.0
-4.5
-9.0
0
90
180
270
360
Search coil angular orientation in the horizontal plane (°)

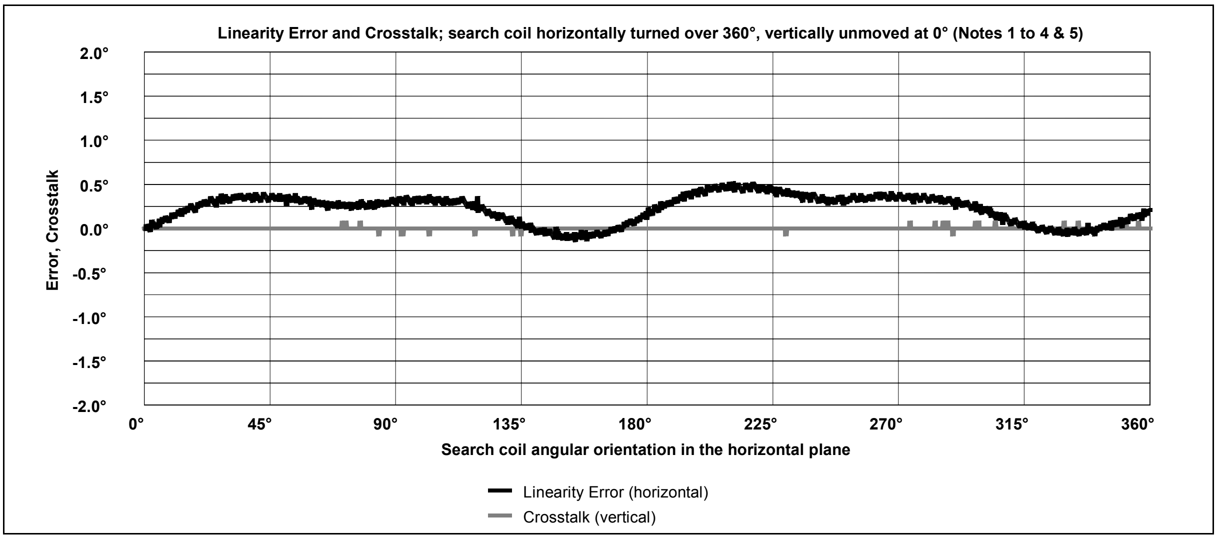

Typical progression of the output voltage Beta (vertical) in the Angular Data Mode
U Beta (V)
4.50
2.25
0.00
-2.25
-4.50
0
90
180
270
360
Search coil angular orientation in the vertical plane (°)

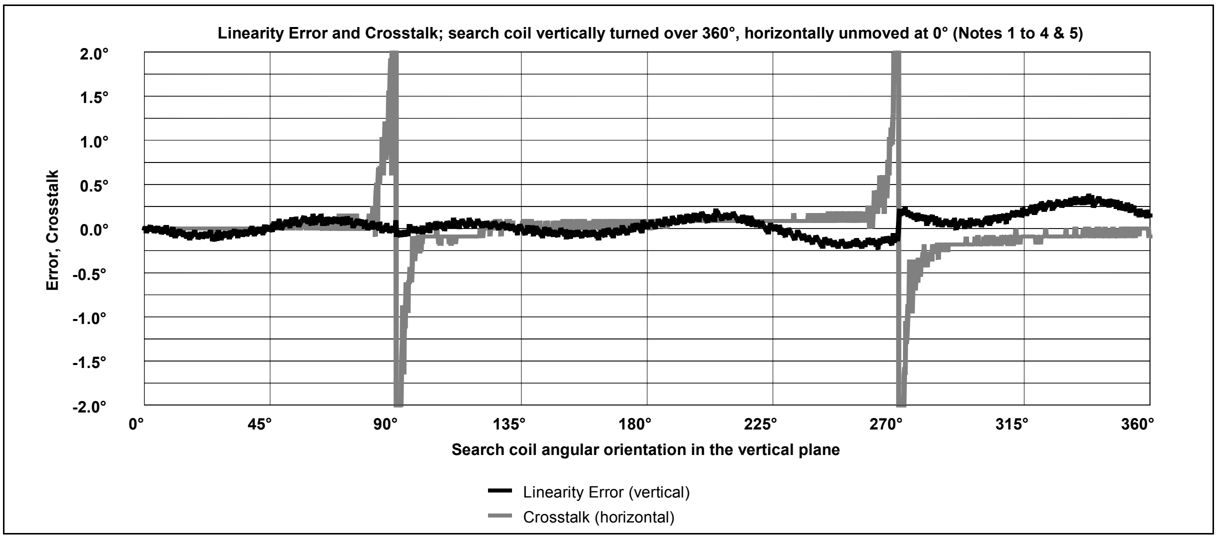

Drift measurement (Notes 1, 3 and 4)
Drift
0.10°
0.08°
0.06°
0.04°
0.02°
0.00°
-0.02°
-0.04°
-0.06°
-0.08°
-0.10°
0
20
40
60
80
100
120
Time (minutes)
Horizontal
Vertical

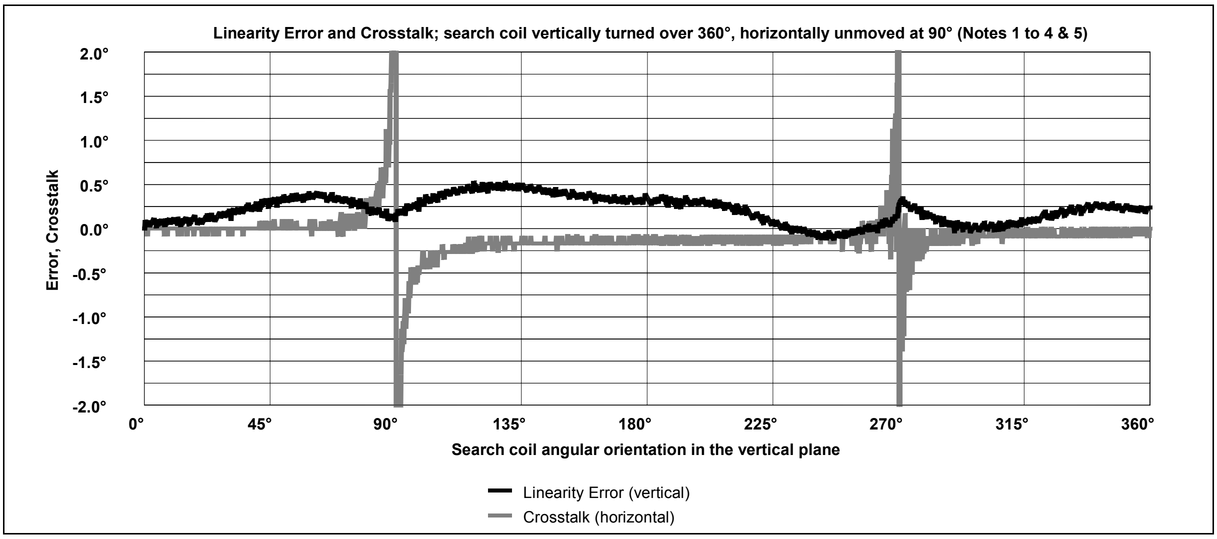

Linearity Error and Crosstalk; search coil horizontally turned over 360°, vertically unmoved at 0° (Notes 1 to 4)
2.0°
1.5°
1.0°
0.5°
0.0°
-0.5°
-1.0°
-1.5°
-2.0°
Error, Crosstalk
0°
45°
90°
135°
180°
225°
270°
315°
360°
Search coil angular orientation in the horizontal plane
Linearity Error (horizontal)
Crosstalk (vertical)


Linearity Error and Crosstalk; search coil vertically turned over 360°, horizontally unmoved at 0° (Notes 1 to 4)
2.0°
1.5°
1.0°
0.5°
0.0°
-0.5°
-1.0°
-1.5°
-2.0°
Error, Crosstalk
0°
45°
90°
135°
180°
225°
270°
315°
360°
Search coil angular orientation in the vertical plane
Linearity Error (vertical)
Crosstalk (horizontal)

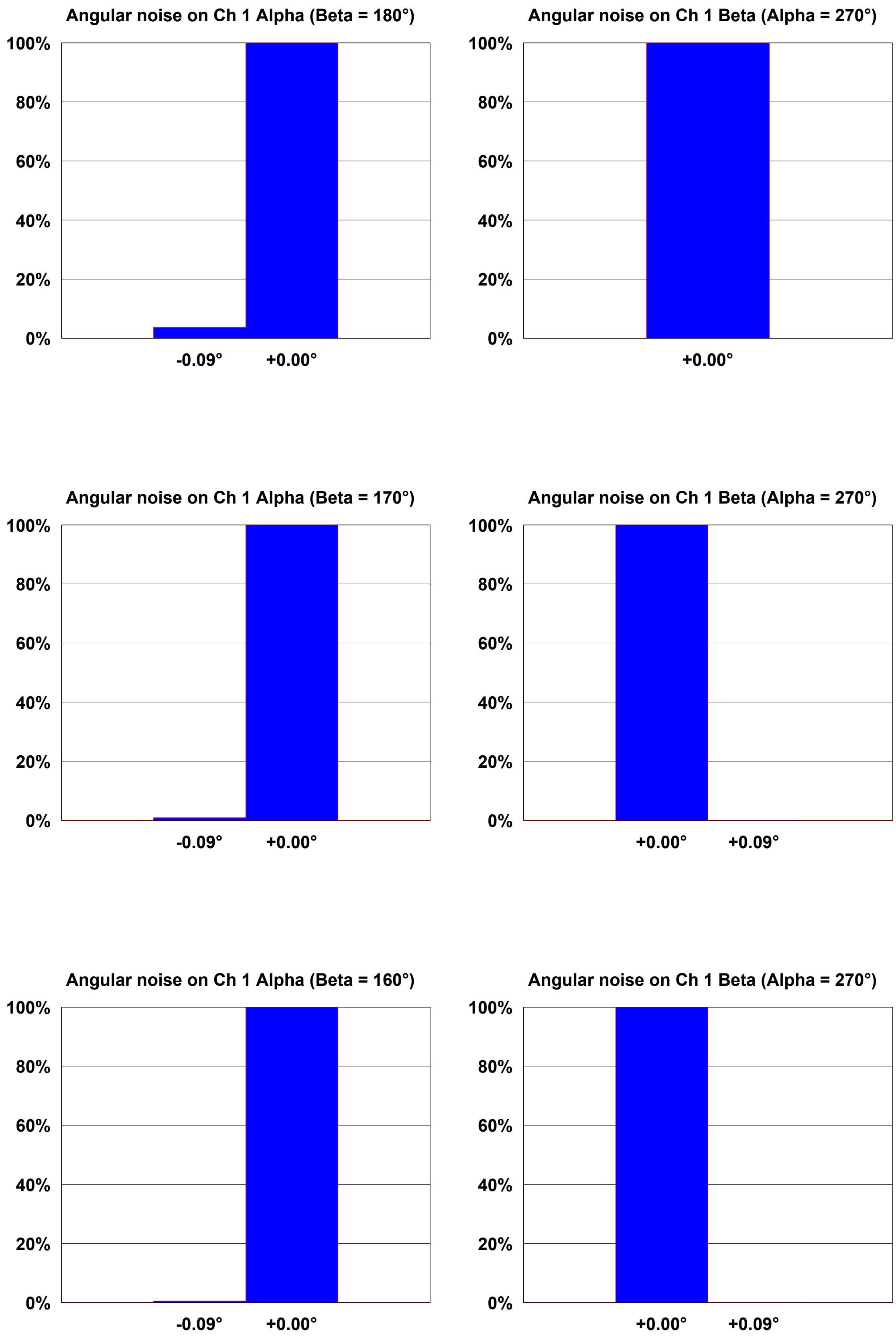

Linearity Error and Crosstalk; search coil vertically turned over 360°, horizontally unmoved at 90° (Notes 1 to 4)
2.0°
1.5°
1.0°
0.5°
0.0°
-0.5°
-1.0°
-1.5°
-2.0°
Error, Crosstalk
0°
45°
90°
135°
180°
225°
270°
315°
360°
Search coil angular orientation in the vertical plane
Linearity Error (vertical)
Crosstalk (horizontal)


Linearity Error and Crosstalk; search coil horizontally turned over 360°, vertically unmoved at 0° (Notes 1 to 4 & 5)
Error, Crosstalk
2.0°
1.5°
1.0°
0.5°
0.0°
-0.5°
-1.0°
-1.5°
-2.0°
0°
45°
90°
135°
180°
225°
270°
315°
360°
Search coil angular orientation in the horizontal plane
Linearity Error (horizontal)
Crosstalk (vertical)

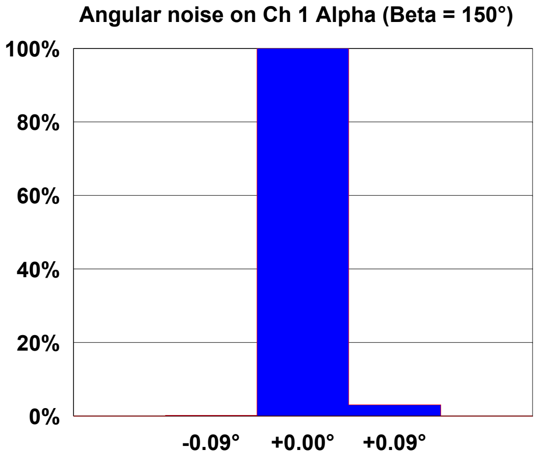

Linearity Error and Crosstalk; search coil vertically turned over 360°, horizontally unmoved at 0° (Notes 1 to 4 & 5)
Error, Crosstalk
2.0°
1.5°
1.0°
0.5°
0.0°
-0.5°
-1.0°
-1.5°
-2.0°
0°
45°
90°
135°
180°
225°
270°
315°
360°
Search coil angular orientation in the vertical plane
Linearity Error (vertical)
Crosstalk (horizontal)

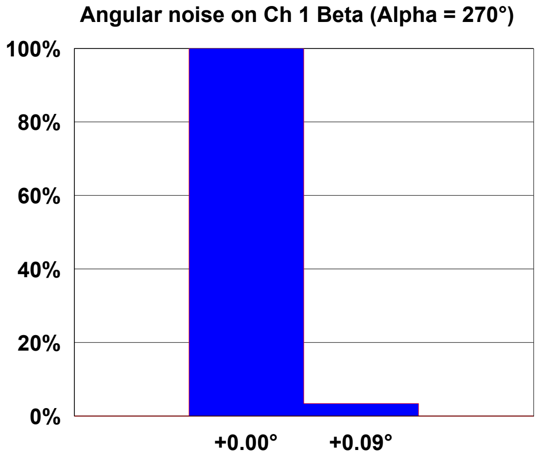

Linearity Error and Crosstalk; search coil vertically turned over 360°, horizontally unmoved at 90° (Notes 1 to 4 & 5)
Error, Crosstalk
2.0°
1.5°
1.0°
0.5°
0.0°
-0.5°
-1.0°
-1.5°
-2.0°
0°
45°
90°
135°
180°
225°
270°
315°
360°
Search coil angular orientation in the vertical plane
Linearity Error (vertical)
Crosstalk (horizontal)

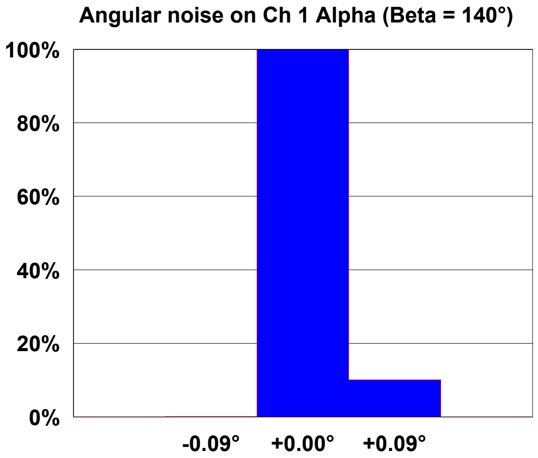
Distribution of angular noise (Notes 1 to 4 & 8)

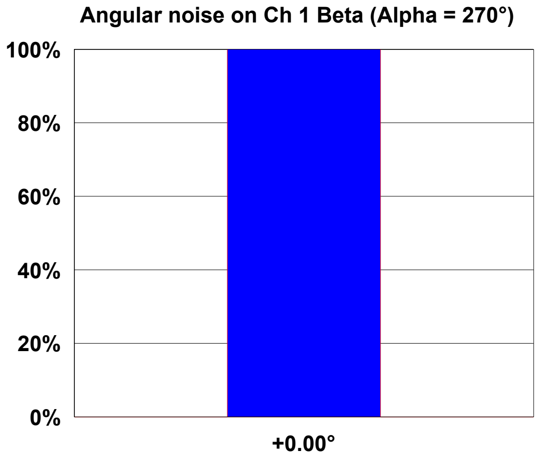


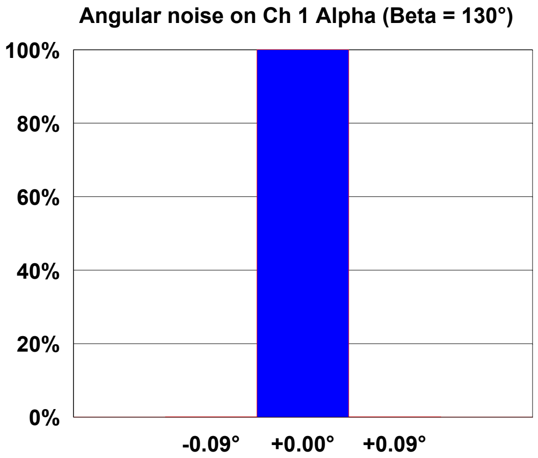
Distribution of angular noise, cont. (Notes 1 to 4 & 8)

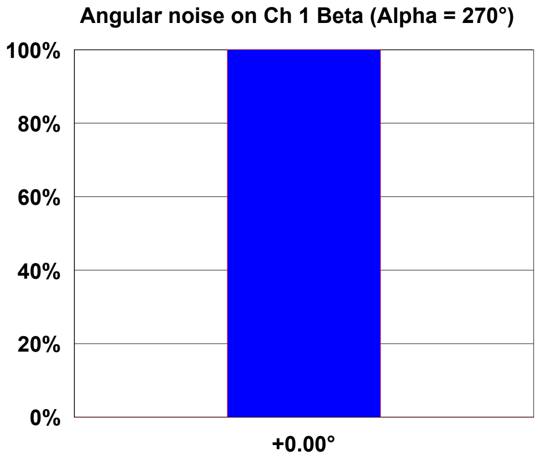




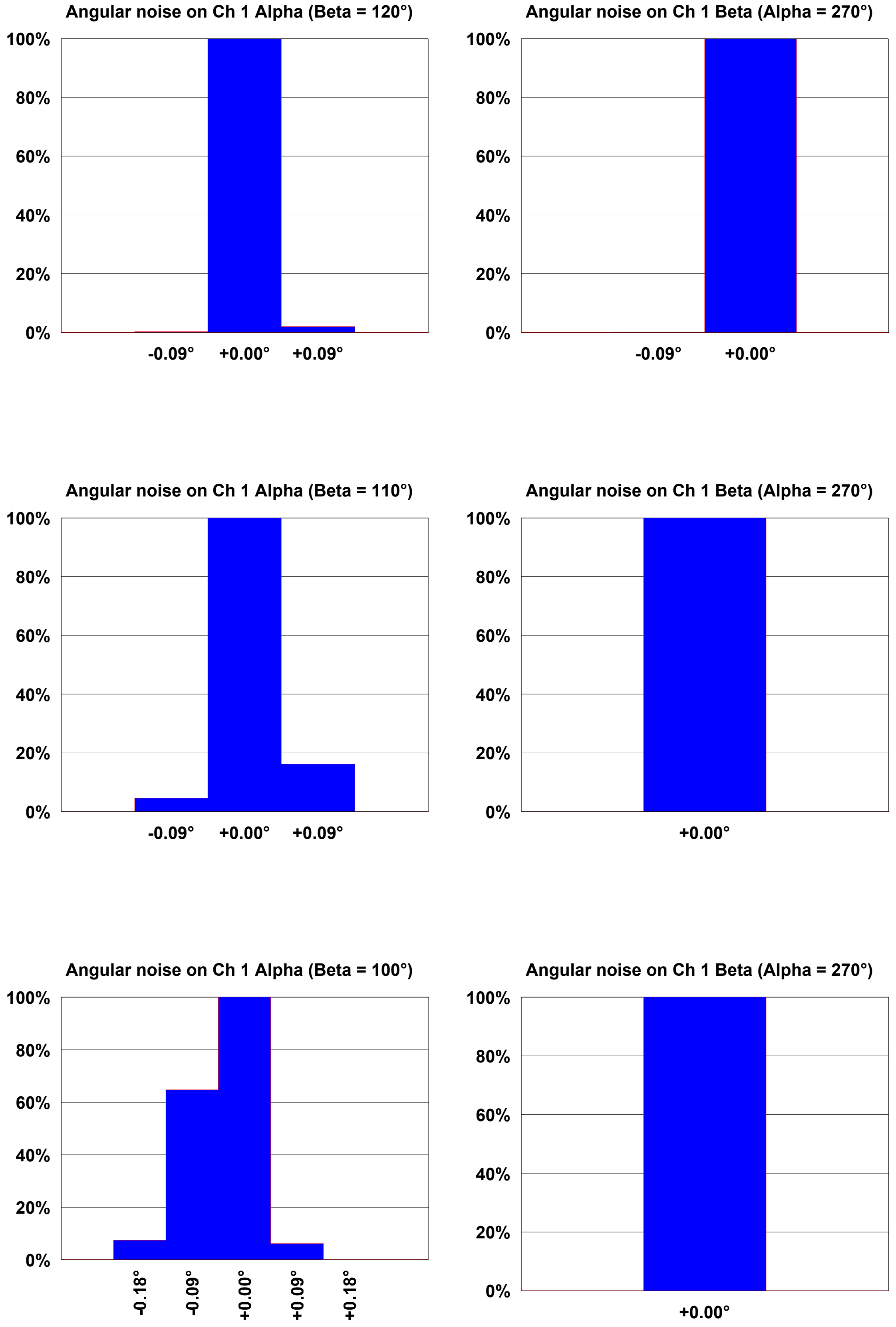




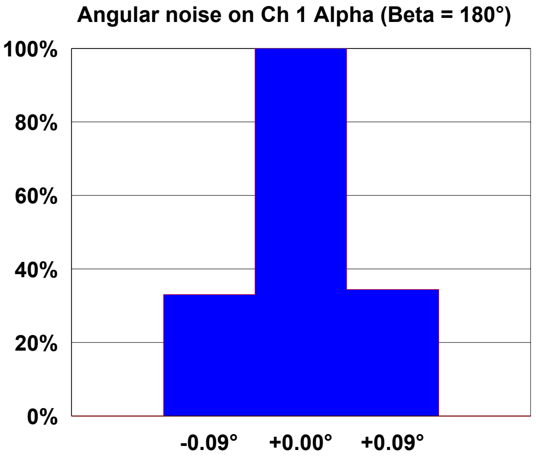


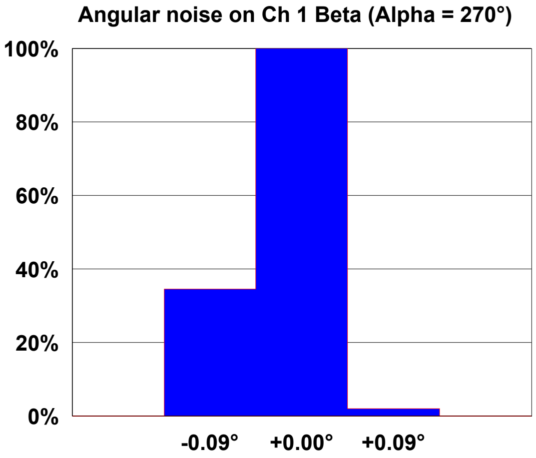


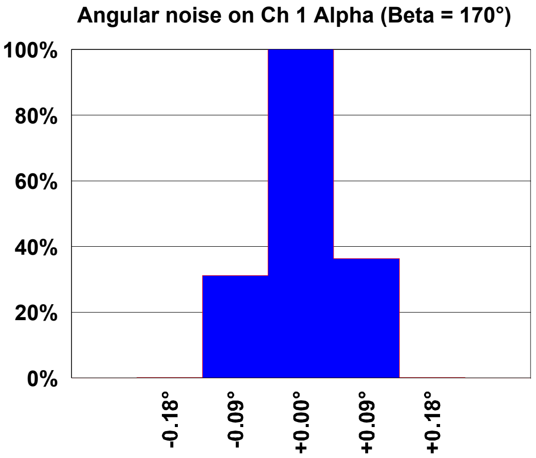
Distribution of angular noise, cont. (Notes 1 to 4 & 8)

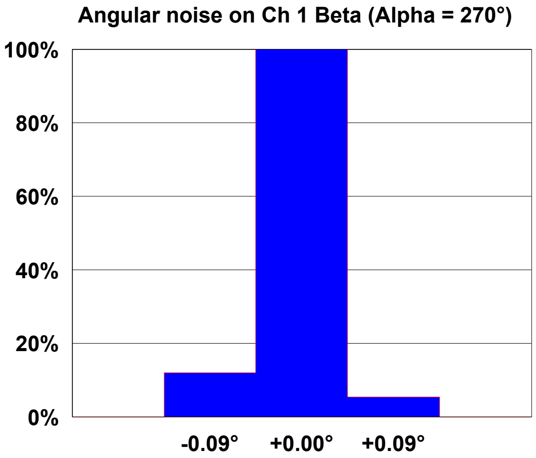


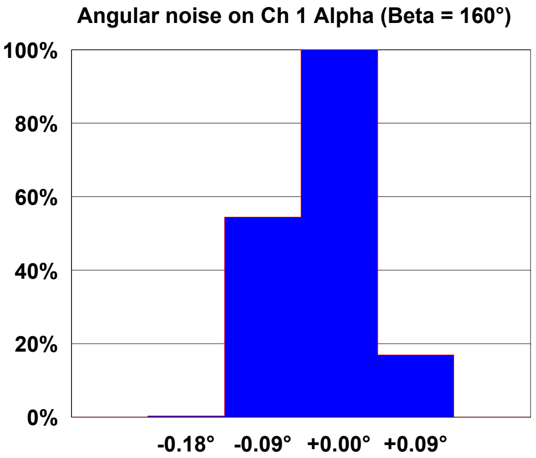
Distribution of angular noise (Notes 1 to 4 & 6 & 8)

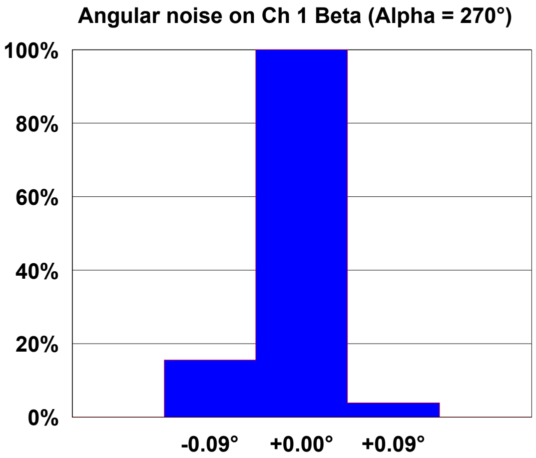




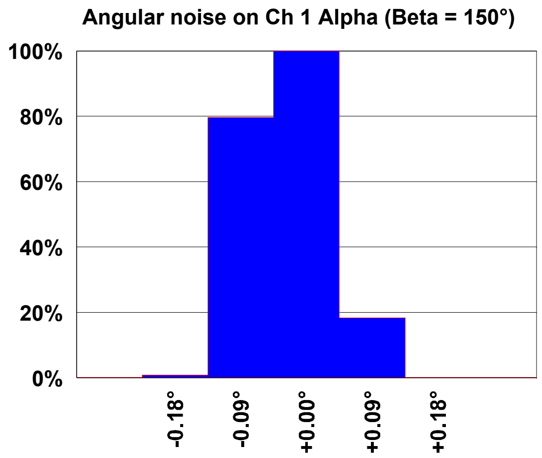


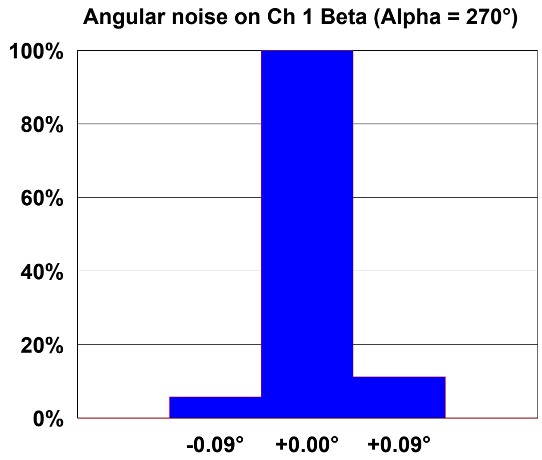


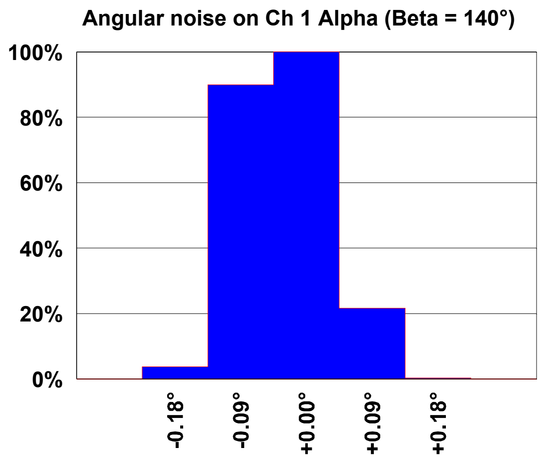


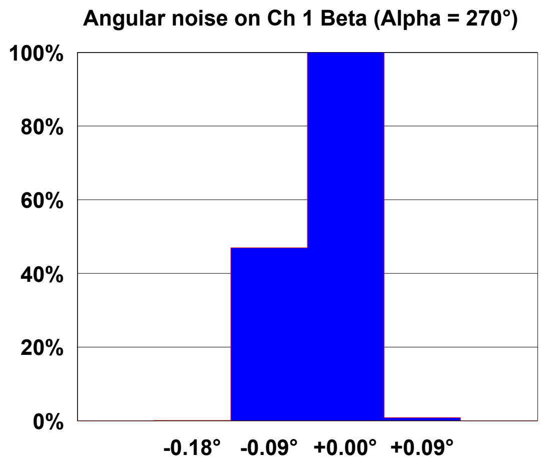


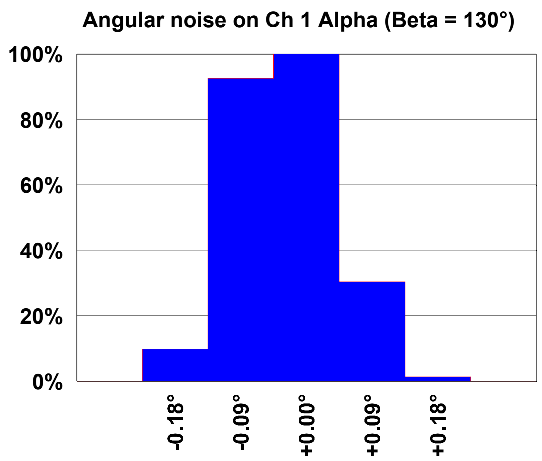
Distribution of angular noise, cont. (Notes 1 to 4 & 6 & 8)

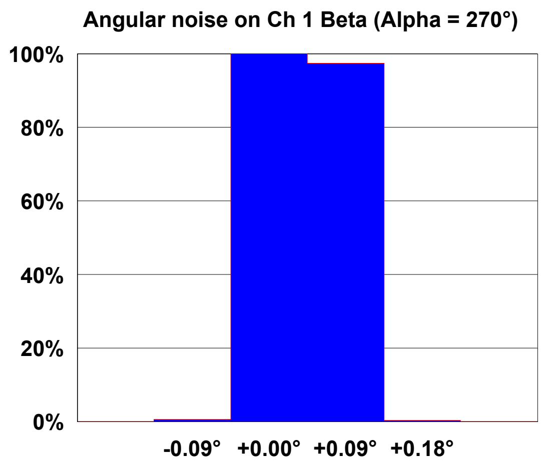




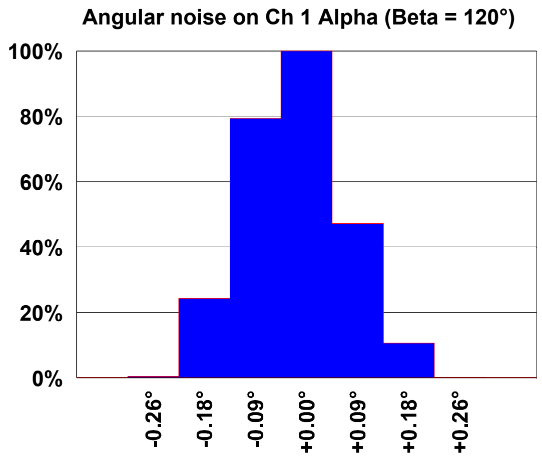


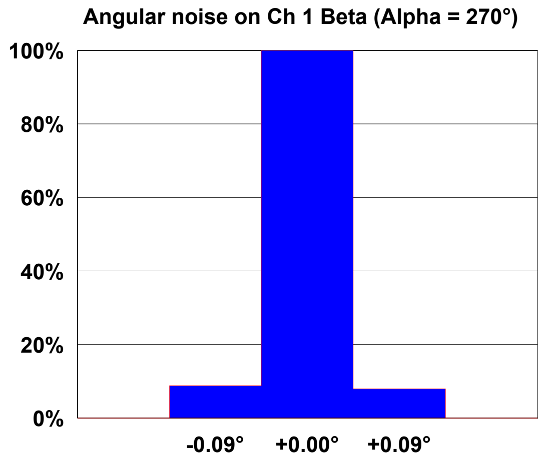


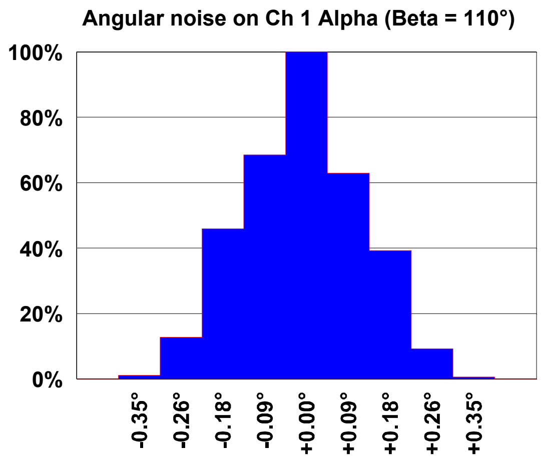


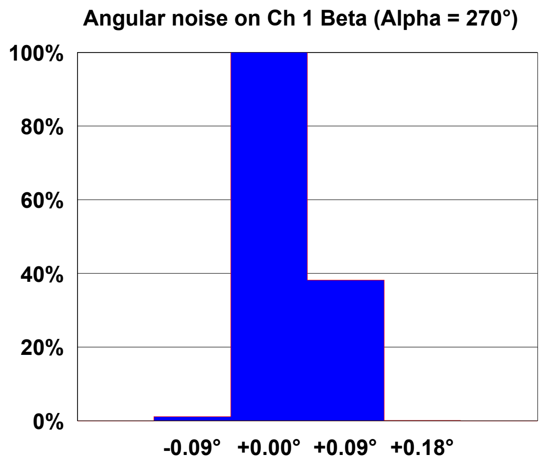


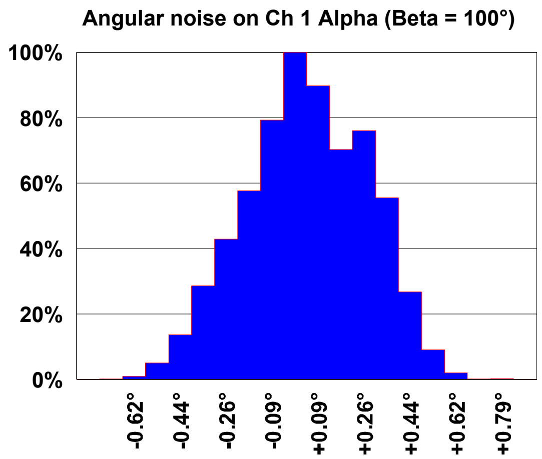
Distribution of angular noise, cont. (Notes 1 to 4 & 6 & 8)

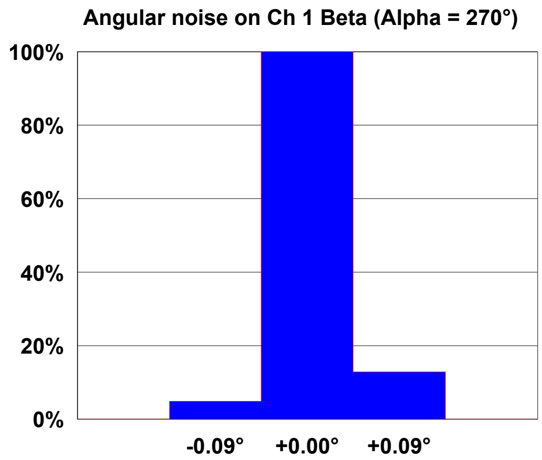




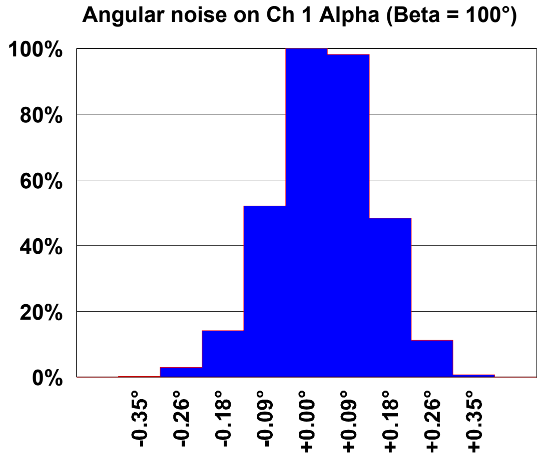


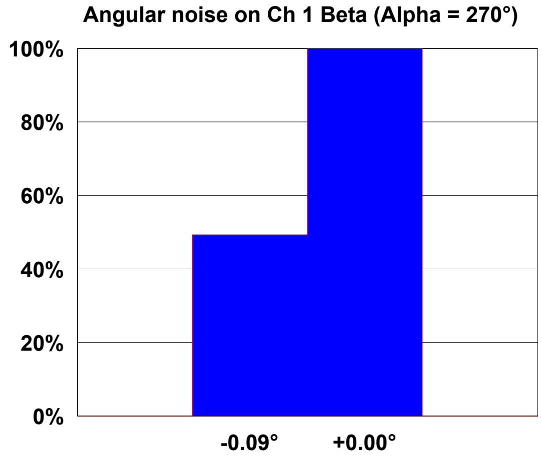






Distribution of angular noise (Notes 1 to 4 & 6 to 8)





Note 1: Measurement executed with 8 channels working (i.e. max. internal power dissipation). The data was acquired over the serial interface. Measuring channel 1 was used, where the performance of all measuring channels is identical. Settings:

- Field signals at 100 % of their nominal value (unless otherwise noted)
- Gain Correction disabled
- Gain Mode AGC
- Offset Correction disabled
- Output Mode Angular Data
- Output Filter disabled (unless otherwise noted)
- Output Swing ± 9 V
- Processing Mode Ch1 → Ch4

Note 2: Measurement executed with a stepper-motor driven search coil under software control

Note 3: Used coil frame formed as a monocoque cube, s = 700 mm

Note 4: Used search coil with an effective area = 10.8 cm^2 (Ø 37mm, 1 turn), DC-Resistance = 7 ohm, placed at the 3D-center of the coil frame

Note 5: Field signals attenuated to 40 % of their nominal value (i.e. reduced magnetic flux density)

Note 6: Field signals attenuated to 20 % of their nominal value (i.e. reduced magnetic flux density)

Note 7: Output filter enabled during the measurement

Note 8: Distribution of angular noise based on 5000 continuously acquired samples

20 Personal Notes