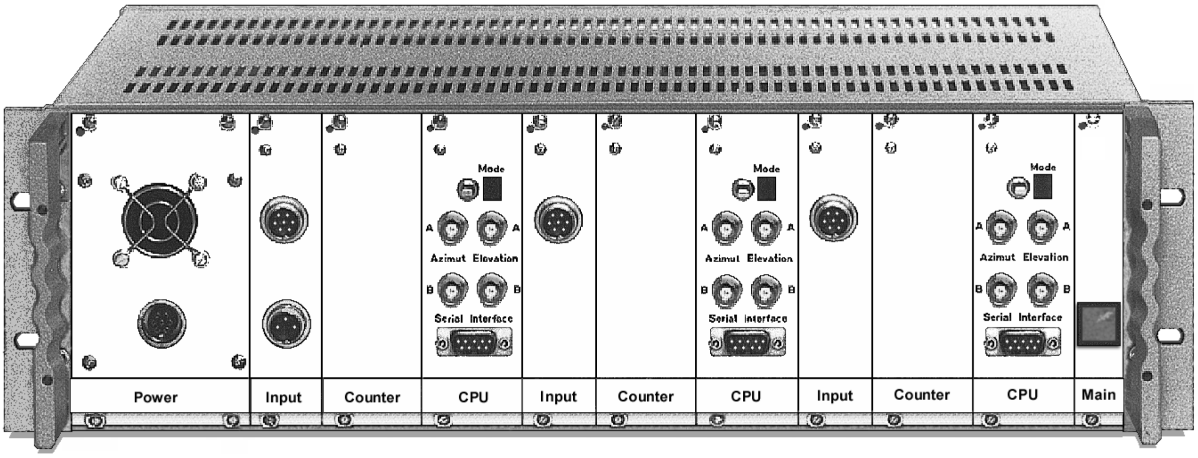
Angle-Meter

Technical description



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

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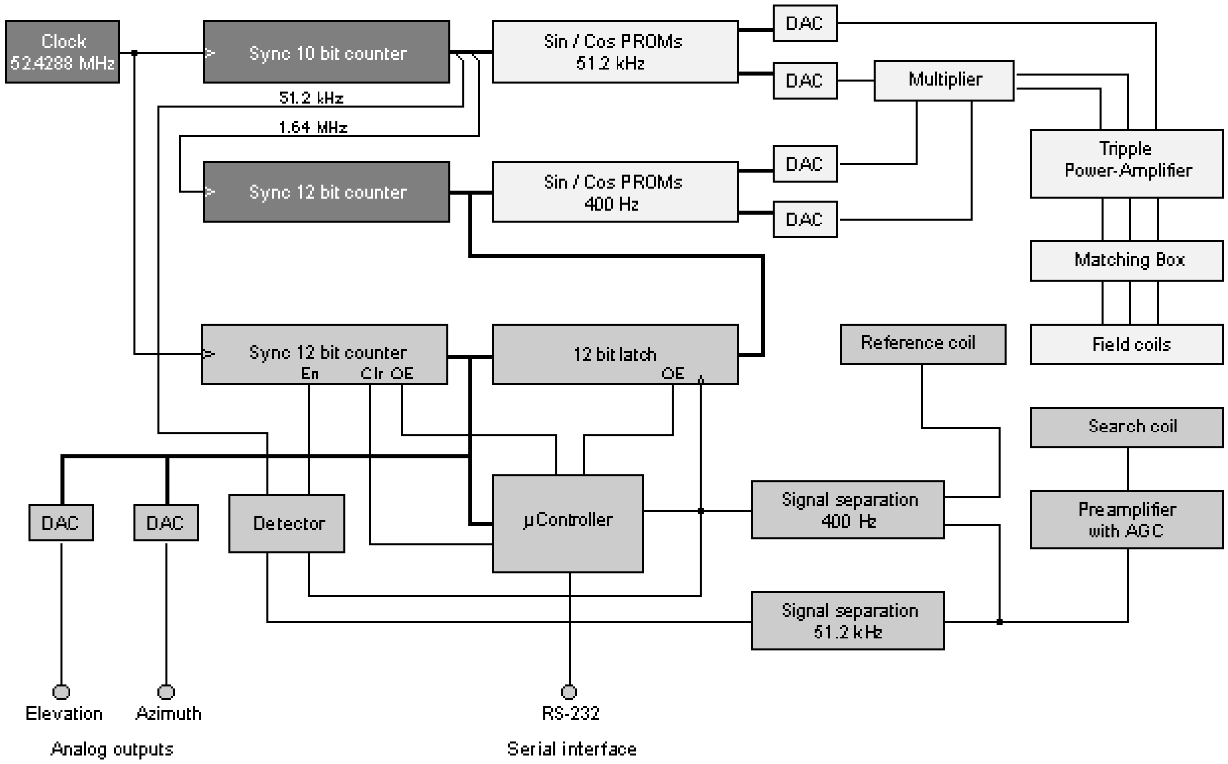
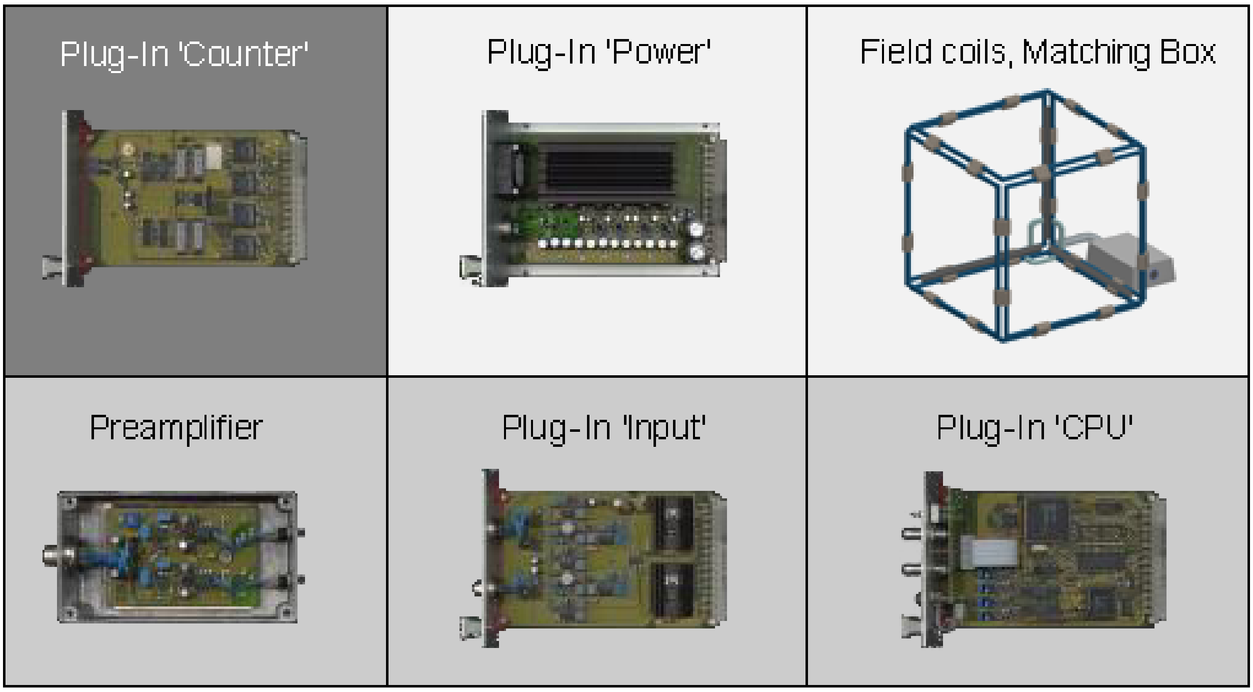
Block diagram



The layout of the system is given by the block diagram illustrated above (blocks needed for the signal demodulation are shown for one channel). The system basically consists of a magnetic field generation section and a signal demodulation section. The colors of the blocks in the diagram above and the type colors of the used hardware below indicate their usage:

Magnetic field generation	Signal demodulation	Both, magnetic field generation and signal demodulation



Magnetic field generation

The spatial revolution of the magnetic field vector consists of a fast rotation of 51.2 kHz about an axis $\underline{b}$ that changes its orientation in the horizontal plane by rotating at a much slower frequency of 400 Hz about an axis $\underline{a}$.

Signal generation
The 51.2 kHz and 400 Hz signals are digitally synthesized; the more complex digital part is implemented with high-speed, in-circuit programmable logic devices. The master clock (52.4288 MHz crystal oscillator) clocks a fast 10 bit synchronous counter, whose lower 9 bits cycles trough the address ranges of 9 by 8-bit bipolar PROMs. They hold the data for one sine and cosine cycle, respectively. The data outputs of the PROMs are fed into D/A converters in order to generate the 51.2 kHz analog sine and cosine wave signals. The generation of the 400 Hz analog sine and cosine wave signals is similar, except that the address counter of the concerning PROM's is clocked with 1.64 MHz and the DACs with the concerning PROM-data are modulated with the 51.2 kHz analog cosine signal.

Signal amplification
The three synthesized analog signals (51.2 kHz sin, 400 Hz sin x 51.2 kHz cos, 400 Hz cos x 51.2 kHz cos) control the power stage that generates the driving voltages for the field coils. The power stage is composed of a tripple power-amplifier with symmetrical outputs, where each field coil pair is driven by one amplifier. The main advantage of this arrangement is the symmetrical voltage drive of the field coils, which limits undesirable capacitive couplings within the laboratory environment. To reduce harmonic distortions and to avoid phase errors, the power-amplifiers are bandwidth limited with a cut-off frequency of 200 kHz . The typical output voltage of each amplifier is 15 V RMS.

Field coils
Three pairs of one-turn field coils, arranged as a monocoque cube, are building the inductive part of three parallel resonance circuits. An external Matching Box contains the capacitor networks needed to tune the resonance circuits to 51.2 kHz. The three driving voltages from the power-amplifiers are applied over toroidal transformers with a transfer ratio of 1:1.5 to these resonance circuits. The resulting currents in the field coils generate three magnetic fields of equal magnitude with a rotating magnetic flux density vector, where the applied voltages (approx. 22 V RMS) are kept in non hazardous regions. To damp the resonance currents, each field coil contains a terminated current transformer. The terminated output signal of the current transformer on the field coil with the non-modulated signal (51.2 kHz sin) is used for the signal demodulation ('Reference coil').
Our field coils are available 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. The field coils can be de- and remounted, which may be helpful during the building of user specified setups.
An optimal magnetic field is the base for reliable measurements. Phase errors and asymmetric field intensity can cause invalid results. Irradiation of external devices and metallic materials in or near to the field may be critical because of field deformation.

To avoid problems, follow these hints:

- If you are manufacturing your own field coils 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!
- If you own several Angle-Meters and field coils, please keep in mind that each device is adjusted with the related field coils. Watch the serial numbers of the devices and the field coils to avoid confusion. Do not swap plug-ins between the devices.
- Avoid third-party devices with electrical radiation (transmitters, computers, CRTs, electric motors etc.) near to the field coils. This may cause an irregular deformation of the magnetic field, which will lead to noisy output data.
- Avoid large metallic parts (iron, aluminum, copper, reinforced concrete etc.) near to the field coils. Those may cause an asymmetrical damping of the magnetic fields, which will lead to nonlinear output data.
- Do not disconnect the field coils from the Matching Box during the field signals are turned on. This will lead to a capacitive load, which may overheat the power amplifiers.

Demodulation of angular position parameters

Search coil

A miniature search coil (for example 80 turns with a diameter of 2 mm), which is placed in the magnetic field of the field coils, picks up an amplitude-modulated signal with a typical amplitude of 3 mVpp. The search coil signal consists essentially of a slowly modulating sinusoid (400 Hz) superimposed on a fast varying sinusoid (51.2 kHz).

Preamplifier

The search coil is connected to the symmetrical inputs of the preamplifier, which is a high-speed amplifier with automatic gain control. Due to its wide bandwith, the amplifier produces practically no phase errors in the relevant frequency range. As long as the effective area of the search coil is within the specified area (2.5 cm^2 ... 20 cm^2), the AGC of the preamplifier regulates the symmetrical output to a voltage of 450 mVpp. If the effective area of the search coil falls below the specified area, the output voltage of the preamplifier drops and the system noise may increase. The effective area A of the search coil can be calculated as follows:

$$A = n\, d^2\, \pi / 4$$

where n is the number of turns of the search coil and d is the diameter of the search coil.

The preamplifier has two channels, i.e. the signals of two search coils can be processed. To achieve best results, the preamplifier is in a separate case which can be placed as close to the search coils as possible. An optimal quality of the analog signal is very important for a high system performance. Follow these hints to achieve best results:

- The effective area of the used search coils should be as large as allowed by the application 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 to minimize offsets on the output signals due to irradiation on the search coil signal.
- Place the search coils as precisely as possible in the 3D-centre of the field coils to achieve optimal output data in terms of system linearity.
- Place the preamplifier at least 1 m from the field coils to minimize irradiation on the measuring signal. If not possible, an additional shielding of the preamplifier may be helpful (aluminum, copper or permalloy).

The amplified search coil signal is electronically demodulated in terms of the angular position parameters $\alpha(t)$ and $\beta(t)$, which will be called Azimuth and Elevation, respectively.

Demodulation of the angle $\alpha(t)$

The demodulation of the angle $\alpha(t)$ is performed as follows (see also the block diagram above): The output signal from the preamplifier is multiplied with the high-frequency carrier (51.2 kHz sin) from the reference coil in a four-quadrant multiplier. The multiplied output is low-pass filtered in a second-order Butterworth filter. The low-pass filtered signal is fed into a phase-locked loop device, which is used as a narrow-band filter to track the slow field frequency component of 400 Hz. The TTL output of the PLL, corresponding to the tracked field frequency, latches the state of the 1.64 MHz field generation counter. The latched value is directly proportional to the angular parameter $\alpha(t)$, i.e. Azimuth.

Demodulation of the angle $\beta(t)$

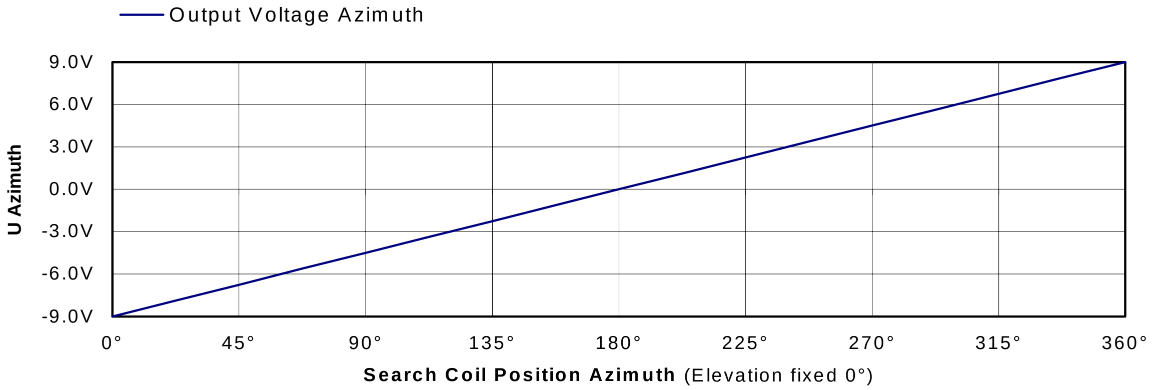
The demodulation of the angle $\beta(t)$ can be obtained in essentially the same way. The amplified search coil signal is first fed into a phase-locked loop device in order to track the fast field frequency component of 51.2 kHz. The phase of the TTL output of the PLL is compared within the detector with the 51.2 kHz reference clock from the fast synchronous 10 bit counter. The resulting pulse-width modulated signal carries information on both phase angles $\alpha(t)$ and $\beta(t)$. The phase $\beta(t)$ is detected by sampling this signal at the time instants $t_\alpha = \alpha / 2\, \pi\, f$. For this purpose, a window discriminator generates a time window of 19 µs by processing the 400 Hz position signal and the 51.2 kHz reference clock. The window generator and the pulse width modulated output signals fed into a sequential logic within the detector. The resulting output of the detector enables a synchronous 12 bit counter, which is clocked by the master clock (52.4288 MHz). The µController clears this counter periodically, according to the 400 Hz position signal.

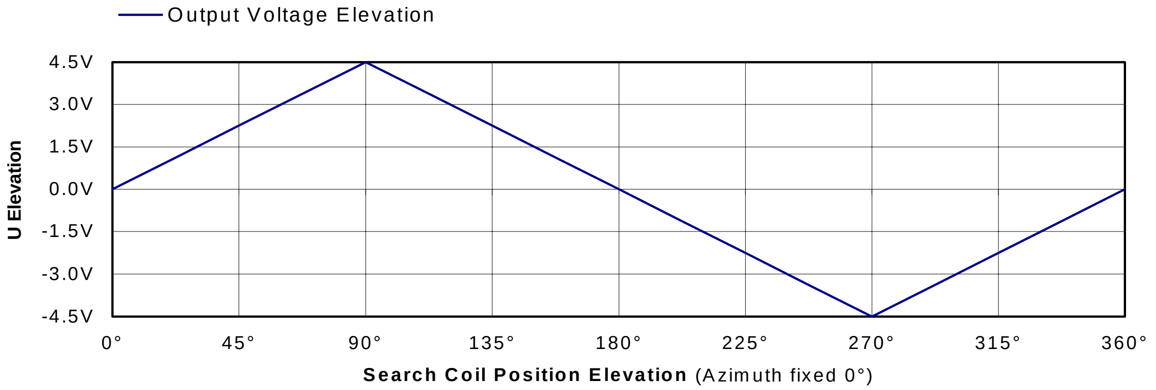
Therefore, the content of the synchronous 12 bit counter is proportional to the angular parameter $\beta(t)$, i.e. Elevation.

The complete digital logic as well as all counters used for the demodulation of angular position parameters are implemented with high-speed, in-circuit programmable logic devices.

Analog outputs

The µController serves continuously the concerning D/A converters with the data of the angular position parameters (azimuth, angle α, and elevation, angle β) of two search coils, connected to channel A and B, respectively:





Please note: The output voltage swings shown in the diagrams (± 9 V for azimuth resp. ± 4.5 V for elevation) are calibrated for 50 mV / degree. Other progressions on request.

Serial interface

The µController serves continuously the serial interface (RS-232) with the data of the angular position parameters (azimuth and elevation) of two search coils, connected to channel A and B, respectively.

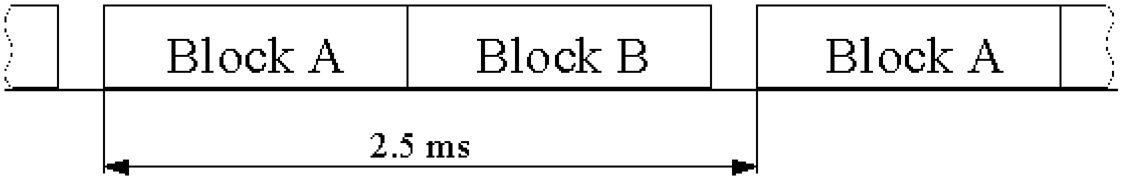
Parameters: 38'400 bps, No parity, 8 Databits, 1 Stopbit

Pinout: 2 = RxD, 3 = TxD, 5 = GND, 7 = RTS, 8 = CTS

Cable to PC: D-Sub 9 pole female connectors on both sides,
pins 3-2, 2-3, 5-5, 7-8, 8-7 are connected

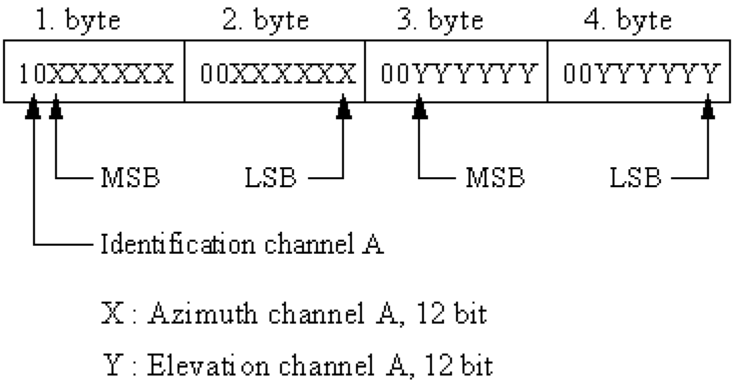
Continuous dataflow

Block A contains the data of the angular position parameters of channel A (4 bytes), Block B contains the data of the angular position parameters of channel B (4 bytes). A hardware handshake (RTS / CTS) can be enabled or disabled by software (see 'Remote control functions').



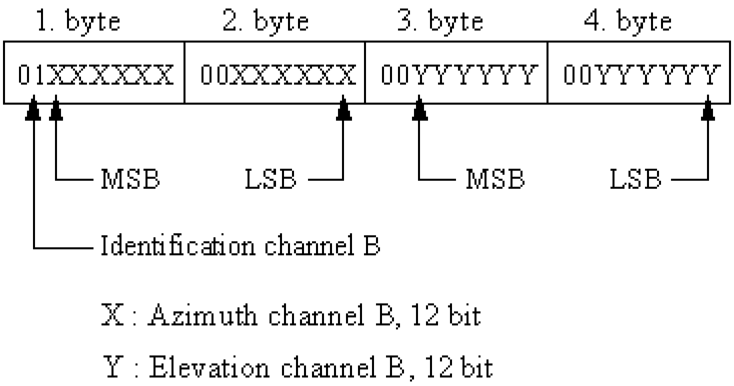
Dataformat Block A

As described above, Block A contains the angular position data of the search coil connected to channel A:



Dataformat Block B

As described above, Block B contains the angular position data of the search coil connected to channel B:



Remote control functions

The Angle - Meter can be remote controlled using the serial interface and a PC. For a step by step explanation, see the examples at the end of this chapter.

Functionbyte	**Function**; see note 4
00000000b	*Reset*. The Angle - Meter will be reseted.
00000001b	*Test mode a* : Fullscale sawtooth on all outputs.
00000010b	*Test mode b* : Fullscale rectangle on all outputs.
00000011b	*Test mode f* : constant values (Databyte 1, 2) on all outputs; see note 1
00000100b	*Measurement mode*
05h...07h	Reserved
00001000b	*Setting an offset* (Databyte 1, 2) *on Channel A, Azimuth;* see note 2
00001001b	*Setting an offset* (Databyte 1, 2) *on Channel B, Azimuth;* see note 2
00001010b	*Setting an offset* (Databyte 1, 2) *on Channel A, Elevation;* see note 2
00001011b	*Setting an offset* (Databyte 1, 2) *on Channel B, Elevation;* see note 2
0Ch...0Fh	Reserved
00010000b	*Show the firmware release* on the seven segment LED
11h...12h	Reserved
00010011b	*Field generator On / Off*, depending on value of Databyte 1; see note 3
00010100b	*Enable hardware handshake* (default). The Angle-Meter monitors the signal CTS and transmits measuring data only if CTS = High.
00010101b	*Disable hardware handshake*. The Angle-Meter continuously transmits measuring data.
16h...3Fh	Reserved

Databytes	Property
01nnnnnnb	*Databyte 1*; see notes 1-3
10nnnnnnb	*Databyte 2*; see notes 1-3

Terminatorbyte	Property
11000000b	After receiving the *Terminatorbyte*, the Angle-Meter executes a function according to the previously received *Functionbyte*.

Note 1, constant values: HHHHHHLLLLLLb (range 0..4095)
Databyte 2 : **10**HHHHHHb (upper 6 Bits of 12 Bit value)
Databyte 1 : **01**LLLLLLb (lower 6 Bits of 12 Bit value)

Note 2, offset value: SHHHHHLLLLLLb (range ± HHHHHLLLLLLb * 2, i.e. ± 0..4094)
Databyte 2 : **10**SHHHHHb, where
S : Sign, 0 = positive (add offset), 1 = negative (subtract offset)
HHHHHb : upper 5 Bits of 11 Bit value
Databyte 1 : **01**LLLLLLb (lower 6 Bits of 11 Bit value)

Note 3, field On / Off: *Databyte 1* : **01**111111b = field generator On
Databyte 1 : **01**000000b = field generator Off

Note 4, check CTS: Before sending any data to the Angle-Meter, CTS must be checked:
CTS = 0 : Angle-Meter is busy, i.e. not ready to receive data
CTS = 1 : Angle-Meter is ready to receive data

Examples:

1.) To show the firmware release on the seven segment LED, follow these steps:

1. Loop until Signal CTS = 1 (i.e. the Angle-Meter is ready to receive data)
2. Send the *Functionbyte*, character (`10h`), to the Angle-Meter
3. Loop until Signal CTS = 1 (i.e. the Angle-Meter is ready to receive data)
4. Send the *Terminatorbyte*, character (`C0h`), to the Angle-Meter

2.) To set an offset of -120° on the Elevation of channel A, follow these steps:

1. Determine the offset value : 2048 / 180 x 120 / 2 = 683 (`1010101011b`)
2. Add `100000000000b` (indicating Sign = 1, negativ) to the offset value:
   offset value = `101010101011b`
3. Determine *Databyte 1* : **`01`**`LLLLLLb`, = **`01`**`101011b` (`6Bh`)
4. Determine *Databyte 2* : **`10`**`SHHHHHb`, = **`10`**`101010b` (`AAh`)
5. Loop until Signal CTS = 1 (i.e. the Angle-Meter is ready to receive data)
6. Send the *Functionbyte*, character (`0Ah`), to the Angle-Meter
7. Loop until Signal CTS = 1 (i.e. the Angle-Meter is ready to receive data)
8. Send *Databyte 1*, character (`6Bh`), to the Angle-Meter
9. Loop until Signal CTS = 1 (i.e. the Angle-Meter is ready to receive data)
10. Send *Databyte 2*, character (`AAh`), to the Angle-Meter
11. Loop until Signal CTS = 1 (i.e. the Angle-Meter is ready to receive data)
12. Send the *Terminatorbyte*, character (`C0h`), to the Angle-Meter