



## Features

- Precision closed loop inertial sensor with optical position feedback and fluid damping
- Single axis measurement range  $\pm 5^\circ$  to  $\pm 45^\circ$
- High resolution measurement  $< 0.0002^\circ$
- High accuracy over full measurement range ( $< 0.003^\circ$ )
- Low temperature drift ( $< 0.005^\circ$  over  $0-40^\circ\text{C}$ )
- ModBus over TCP/IP Ethernet, or RS485 interface.
- Supports assignable fixed IP, or DHCP
- Fully isolated power supplies, 19-30V dc input
- Rigid machined Anodised Aluminium housing (IP67)
- Two IP67 M8 connectors for network and power



## Description

The DCL inclinometer utilises a precision closed loop inertial inclinometer sensor to give extremely accurate and high resolution angle measurement in 1 axis of rotation. It has fully isolated power supplies, with ModBus communication protocol over (either) a TCP/IP Ethernet (10Mbit), or RS485 physical interface. The anodised Aluminium housing is sealed to IP67 making it suitable for use in the most demanding environments. A pair of industry standard IP67 sealed M8 connectors connect the network and power supply separately. They

are temperature compensated over the specified range to meet the needs of the specific application. The sensing element is the latest generation closed loop sensors with liquid damping and optical position feedback. This enables very high accuracy measurement with very low temperature drift, excellent long term stability, and excellent performance in applications with high vibration. These devices are manufactured and calibrated in our UK factory to guarantee performance to the stated specification.

## General Specifications

Parameter	Value	Unit	Notes
<b>Supply Voltage</b>	19-30	V dc	Supply is fully isolated internally, and protected against transients. Internal power modules are CE certified.
<b>Operating Current</b>	70	mA	Maximum value at 24V supply
<b>Operating Temperature</b>	-10 to 60	$^\circ\text{C}$	Maximum operating temperature range.
<b>Storage Temperature</b>	-20 to 70	$^\circ\text{C}$	Maximum storage temperature range.
<b>Weight</b>	845	g	
<b>Sealing</b>	IP67		Seal rating applies to housing and connectors.
<b>Frequency Response</b>	1	Hz	This is the frequency at which the output is 3dB less than the input value. This is adjustable between 0.125 and 7Hz via the ModBus control commands
<b>Physical Interface</b> Option 1	Ethernet 10baseT		Utilises 10Mbit Ethernet interface (compatible with 10/100/1000Mbit devices)
<b>Physical Interface</b> Option 2	RS485 2-Wire		Data format: 1 start bit, 8 data bits, 1 stop bit, no parity. Bit rate is adjustable between 115.2k, 57.6k, 38.4k, 19.2k, 9.6k, 4.8k and 2.4k via the digital interface
<b>Data Protocol</b>	ModBus over TCP/IP		For more details see section 'Control Command Set' and <a href="http://www.modbus.org">http://www.modbus.org</a>
<b>Default IP address</b>	192.168.16.130 :502	g	Shipping default static IP address. Can be changed with custom ModBus command. Port used for ModBus is port 502



## Performance Specifications

Parameter	DCL-05	DCL-20	DCL-45	Unit
Measuring range	±5	±20	±45	°
Zero Bias Error	±0.0025	±0.0025	±0.0025	°
Accuracy (@20°C)	±0.0025	±0.005	±0.01	°
<b>Temperature Errors</b>				
Zero Drift	±0.0002	±0.0002	±0.0002	°/°C
Sensitivity Drift	±0.002	±0.002	±0.002	%/°C
Accuracy 0 to 40°C	±0.006	±0.01	±0.02	°
Long Term Stability	±0.01	±0.01	±0.01	°
Resolution (@1Hz BW)	0.0002	0.0005	0.001	°

Parameter	Notes
Measuring range	Defines the calibrated measurement range.
Zero Bias Error	This is the <b>maximum</b> angle from the device when it is placed on a perfectly level surface. The zero bias error can be removed from measurement errors either by mechanical adjustment, or as a fixed offset value after installation.
Accuracy (@20°C)	This is the <b>maximum</b> error between the measured and displayed value at any point in the measurement range when the device is at room temperature (20°C).
<b>Temperature Errors</b>	Temperature change can cause a drift of the zero position and the sensitivity of the inclinometer. These parameters are defined below:
Zero Drift	If the device is mounted to a level surface in the zero position, this value is the <b>maximum</b> drift of the output angle per °C change in temperature.
Sensitivity Drift	When the temperature changes there is a change in sensitivity of the sensor's output. The error this causes in the measurement is calculated from the formula: <b><math>E_{sd} = SD \times \Delta T \times \theta</math></b> Where: <b><math>E_{sd}</math></b> is the change in output (in degrees) due to sensitivity temperature change <b><math>SD</math></b> is the sensitivity drift specification from the above table <b><math>\Delta T</math></b> is the change in temperature in °C <b><math>\theta</math></b> is the current angle of the inclinometer axis in question in degrees.
Accuracy 0 to 40°C (with compensation)	This is the <b>maximum</b> error between the measured and displayed value at any point in the measurement range at any temperature over the calibrated temperature range (devices are individually characterised and compensated for optimum temperature performance).
Long Term Stability	Stability depends on environment (temperature, shock, vibration and power supply). This figure is based on being powered continuously in an ideal environment.
Resolution (@1Hz bandwidth)	Resolution is the smallest measurable change in output.



### Connector and Connection Details

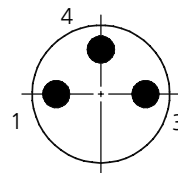
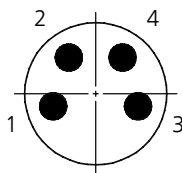
There are two M8 connection sockets on the inclinometer sensor. The power cable is 3 pin, the Ethernet network connector is 4 pin. The mating connector details are shown below. All mating connectors, cables and accessories are available from us on request.

#### Ethernet Connections

M8 Pin No.	Wire Colours	Function	Ethernet RJ45 Pin
1	Brown	Tx D1+	1
2	White	Tx D1-	2
3	Blue	Rx D2+	3
4	Black	Rx D2-	6

#### Power Connections

M8 Pin No.	Wire Colours	Function
1	Brown	+ve Supply (24Vdc)
3	Blue	0V Supply
4	Black	Not Connected



#### Binder M8 Straight Connector



3 pin : EL-CON-99-3402-00-03  
4 pin : EL-CON-99-3376-00-04

#### Binder M8x3pin Moulded PUR Cable



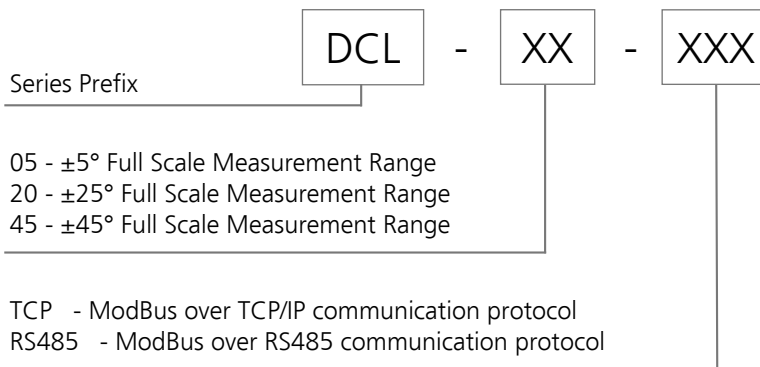
2m : EL-CAB-79-3406-52-03  
5m : EL-CAB-79-3406-55-03

#### Binder M8x4pin to Ethernet



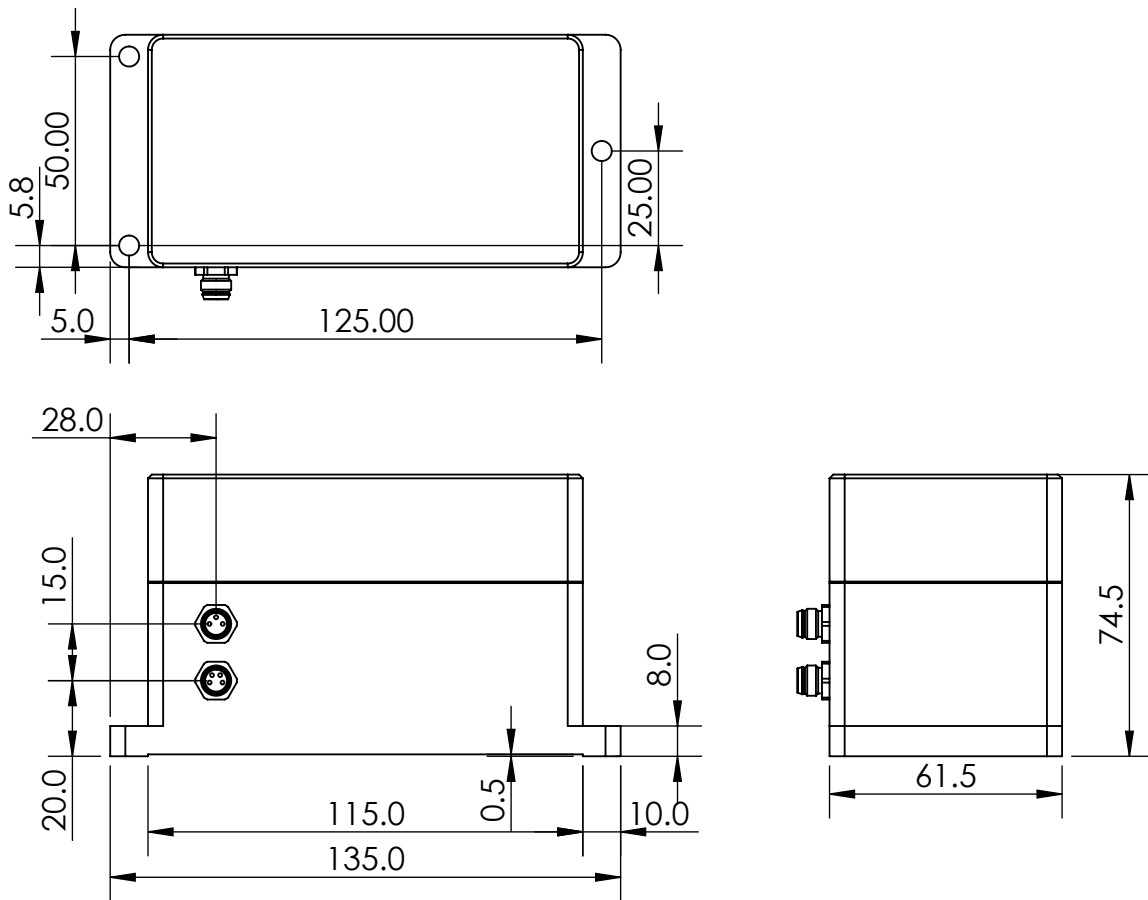
2m : EL-CAB-M8x4FS-RJ45M-2  
5m : EL-CAB-M8x4FS-RJ45M-5  
10m : EL-CAB-M8x4FS-RJ45M-10

### Part Numbering



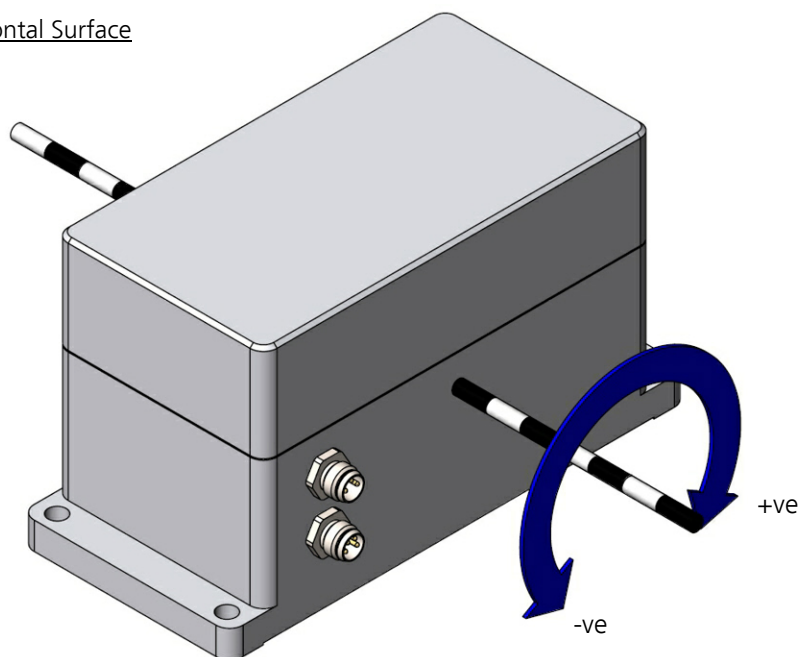


### Housing Drawing



### Axis Direction and Mounting Orientation

Mounted on Horizontal Surface



**Control Command Set - ModBus over TCP/IP Interface**

Data is transmitted and received over a 10baseT Ethernet interface using the ModBus TCP/IP protocol. The following section provides some basic information about the communication between the host PC or PLC and the DCL. The full ModBus on TCP/IP specification can be obtained from:

[http://www.modbus.org/docs/Modbus\\_Messaging\\_Implementation\\_Guide\\_V1\\_0b.pdf](http://www.modbus.org/docs/Modbus_Messaging_Implementation_Guide_V1_0b.pdf)

The device (the inclinometer) acts as a server. The PC or PLC acts as the client. The client needs to open a valid TCP/IP socket with the device before communication can take place. The default IP address of the devices at the time of shipping is 192.168.16.130. This can be changed using the software application provided. It can also be changed to DHCP mode where the device will negotiate a dynamic IP address with the DHCP server. To switch to DHCP mode the IP address is changed to 0.0.0.0.

The byte order for all 16-bit values is Big Endian (most significant byte first).

Read and write access to the device is done using ModBus Function Code 3 (read holding registers) and ModBus Function Code 6 (write single register) commands. These two function codes provide the basic functionality needed by most users.

Below is a list of the register locations for reading and writing:

Parameter	Address	ModBus Register Address	Description	Read/Write
Sensor Angle	0x00	40,001	Address 0x00 returns the upper 16 bits of the closed loop sensor X axis angle. This combines with address 0x01 to form a 32 bit signed integer value equal to the measured angle x 10,000.	Read Only
	0x01	40,002		
Sensor Temperature	0x06	40,007	Returns a 16 bit signed integer value equal to the temperature of the sensor in degrees C x 100	Read Only
Filter Index	0x09	40,010	Returns a 16 bit integer value between 0 and 8 which relates to a table of filter responses from 0.125 to 7Hz	Read / Write
Angle Offset	0x12	40,019	Address 0x12 returns the upper 16 bits of the X axis angle offset. This combines with address 0x13 to form a 32 bit signed integer value equal to the offset angle x 10,000. The offset is used for zeroing the output after installation.	Read Only
	0x13	40,020		



## Frequency Response Filter Indexes

The frequency response of the inclinometer output can be changed to any of the response times shown in the table by setting the filter index value in the relevant ModBus parameter (0x09).

The closed loop sensors has a built in mechanical and electronic filter with a 15Hz cutoff frequency. The outputs are then passed through an analogue second order 5Hz Butterworth anti-aliasing filter. Finally there is a digital 2nd order Butterworth low pass filter implemented in a FIR algorithm. It is this digital filter which is controlled by this parameter. For structural monitoring applications it is normal to use the slowest filter response (0.125Hz) as it is not likely there will be sudden changes in output, and the slow response will give the best measurement resolution.

Filter Index	Frequency Response (Hz)	Damping Time (ms)
0	0.125	8000
1	0.25	4000
2	0.5	2000
3	1	1000
4	2	500
5	3	333
6	4	250
7	5	200
8	7	143

## Reading a Holding Register

The data from the device is stored in holding registers as detailed on page 4. Function code 0x03 is used to read these registers. Below is the command and response message format, including the error response in the even there is an error.

	Byte Data	No Of Bytes	Description
Command	0x03	1	Function code for read register
	0x0000	2	Starting register (0x0000 is X axis angle)
	0x0002	2	Number of registers to read
Response	0x03	1	Function code for read register
	0x04	1	Byte count (2 x number of registers)
	0x0000	2	First and second register data : 0x0000705D = 28765 (decimal) = 2.8765°
	0x705D	2	

## Writing to a Holding Register

Data can be written to some registers, such as the registers that store the filter indexes for each axis frequency response. Function code 0x06 is used to write these registers as detailed below.

	Byte Data	No Of Bytes	Description
Command	0x06	1	Function code for write register
	0x0009	2	Register to write (0x0009 is filter coefficient)
	0x0001	2	Data to write (16 bit). 0x0001 = 0.125Hz
Response (same as command)	0x06	1	Function code for write register
	0x0009	2	Register to write (0x0009 is X1 axis filter)
	0x0001	2	Data to write (16 bit). 0x0003 = 1Hz



## Examples of Reading Angle

### Example 1: Read the angle

#### Command

```
function code
| starting reg. to read (0x0000)
| | number of reg. to read (0x0002)
| | |
03 00 00 00 02
```

#### Response (positive angle)

```
function code
| byte count
| | angle (0x0000705d = 28765 decimal (2.8765 degrees))
| | |
03 04 00 00 70 5d
```

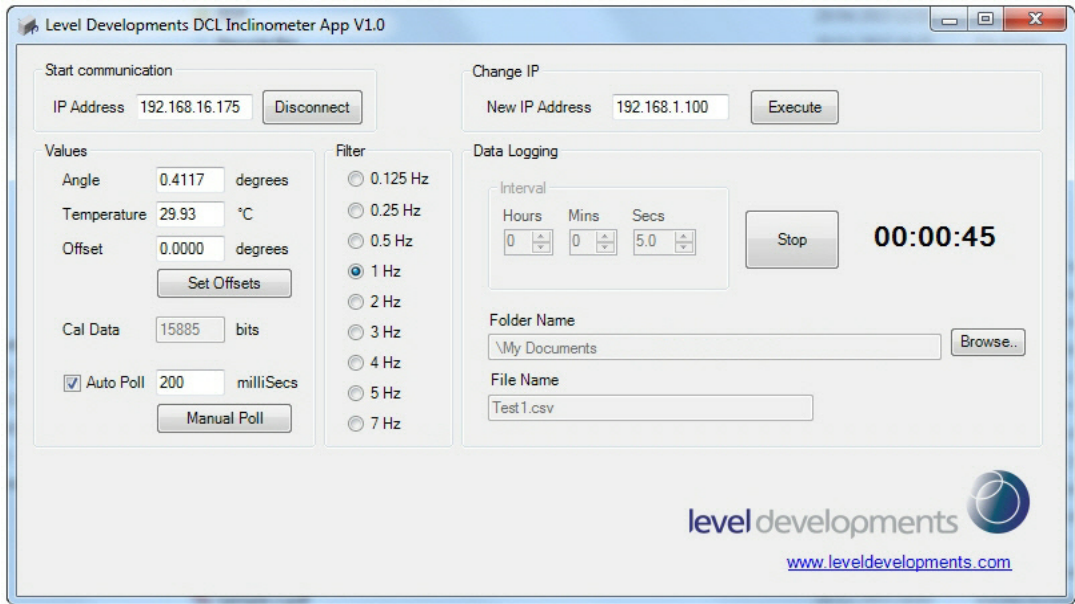
#### Response (negative angle)

```
function code
| byte count
| | angle (0xffffa54d = -23219 decimal (-2.3219 degrees))
| | |
03 04 ff ff a5 4d
```



## Configuration Application

The device ships with a small Windows based application for displaying and logging the inclinometer data, and for network configuration. Using this application it is possible to read data from the device, log it to a csv file, change the static IP address, switch to DHCP mode, and change the filter coefficients and the zero offset values.



The device is shipped by default with the static IP address of 192.168.16.130. It should only be connected to a network where this address is free or reserved. After connection to the network and powering up the device, click the 'Connect' button to open the TCP/IP socket to the device. The angle and temperature values can then be retrieved by clicking the 'Poll' button. Checking the 'Auto Poll' check box will poll the device at regular intervals as specified in the relevant text box.

To change the IP address, type the new IP address into the 'Change IP' text box and click 'Execute'. This will close the current connection, change the device's IP address. The device can then be re-connected using the new IP address.



Please take care to record any change in the IP address. If the modified IP address is not recorded then it will not be possible to communicate with the device and it will need to be returned to the factory for resetting.

To change to DHCP mode, change the IP address to 0.0.0.0. Internally the device will switch to DHCP mode, and attempt to connect to a DHCP server. If it is successful the DHCP server will assign an IP address to the device. In order to connect to it at this stage check the DHCP server to see which IP address it has assigned, and then connect as before using this IP address.

The current filter setting is read from the device when the connection is made, and shown in the corresponding radio button. Clicking a different value will update the setting in the device accordingly. This setting is saved after power down.

The X and Y offset values are also read from the device when the connection is made (default value is 0.0). To change the offset values type the desired offset values into the relevant boxes and click the 'Set Offsets' button. These offsets can be used to zero out any initial zero point errors after installation. The values are stored after power down.





## Control Command Set - ModBus over RS485 interface

Data is transmitted and received over RS485 in half duplex (2-wire) mode using the ModBus RTU protocol. The following section provides some basic information about the serial communication between the host PC or PLC and the Inclinometer. The full ModBus specification can be obtained from <http://www.modbus.org>. ModBus is a command/response protocol over a serial bus.

The default ModBus serial parameters are: 38400 baud, 1 start bit, 8 data bits, no parity and 1 stop bit. The 8 data bits are sent LSB first. The baud rate can be changed to 115200, 57600, 38400, 19200, 9600, 4800 or 2400 by sending the appropriate command.

The byte order for all 16-bit values is Big Endian (most significant byte first).

Read and write access to the Inclinometer is done using ModBus Function Code 3 (read holding registers) and ModBus Function Code 6 (write single register) commands. These two function codes provide the basic functionality needed by most users of the Inclinometer. A user defined ModBus function code 110 is provided for less commonly used, off-line functions such as setting serial port parameters and changing the device address.

ModBus device address must be in the range 1 to 247. All devices are shipped with a default address of 100 (decimal). Address 0 is the ModBus broadcast address. With this address all devices will perform the action of the function code. The maximum number of these devices that can be connected on a single network is 128.

All ModBus commands and responses have a 16-bit CRC for error detection. ModBus RTU data is in binary format rather than ASCII, so it cannot be viewed properly on a text terminal.

Below is a list of the register locations for reading and writing:

## ModBus Registers

Parameter	Address	ModBus Register Address	Description	Read/Write
Sensor Angle	0x00	40,001	Address 0x00 returns the upper 16 bits of the closed loop sensor X axis angle. This combines with address 0x01 to form a 32 bit signed integer value equal to the measured angle x 10,000.	Read Only
	0x01	40,002		
Sensor Temperature	0x06	40,007	Returns a 16 bit signed integer value equal to the temperature of the sensor in degrees C x 100	Read Only
Filter Index	0x09	40,010	Returns a 16 bit integer value between 0 and 8 which relates to a table of filter responses from 0.125 to 7Hz	Read / Write
Angle Offset	0x12	40,019	Address 0x12 returns the upper 16 bits of the X axis angle offset. This combines with address 0x13 to form a 32 bit signed integer value equal to the offset angle x 10,000. The offset is used for zeroing the output after installation.	Read / Write
	0x13	40,020		



## Frequency Response Filter Indexes

The frequency response of the inclinometer output can be changed to any of the response times shown in the table by setting the filter index value in the relevant ModBus parameter (0x09).

The closed loop sensors has a built in mechanical and electronic filter with a 15Hz cutoff frequency. The outputs are then passed through an analogue second order 5Hz Butterworth anti-aliasing filter. Finally there is a digital 2nd order Butterworth low pass filter implemented in a IIR algorithm. It is this digital filter which is controlled by this parameter. For structural monitoring applications it is normal to use the slowest filter response (0.125Hz) as it is not likely there will be sudden changes in output, and the slow response will give the best measurement resolution.

Filter Index	Frequency Response (Hz)	Damping Time (ms)
0	0.125	8000
1	0.25	4000
2	0.5	2000
3	1	1000
4	2	500
5	3	333
6	4	250
7	5	200
8	7	143

## Reading a Holding Register

The data from the device is stored in holding registers as detailed on page 4. Function code 0x03 is used to read these registers. Below is the command and response message format, including the error response in the even there is an error.

	Byte Data	No Of Bytes	Description
Command	0x64	1	Slave address 100
	0x03	1	Function code for read register
	0x0000	2	Starting register (0x0000 is X axis angle)
	0x0002	2	Number of registers to read
	0xCDFE	2	CRC-16 of all bytes

Response	0x64	1	Slave address 100
	0x03	1	Function code for read register
	0x04	1	Byte count (2 x number of registers)
	0x0000	2	First and second register data : 0x0000A69C = 42652 (decimal)
	0xA69C	2	
	0xB4FC	2	CRC-16 of all bytes

Error Response	0x64	1	Slave address 100
	0x83	1	ModBus error function code
	0x01	1	Exception Code (0x01 invalid function code, 0x02 invalid register address)
	0x90EF	2	CRC-16 of all bytes

**Writing to a Holding Register**

Data can be written to some registers, such as the registers that store the filter indexes for each axis frequency response. Function code 0x06 is used to write these registers as detailed below.

	Byte Data	No Of Bytes	Description
Command	0x64	1	Slave address 100
	0x06	1	Function code for write register
	0x0009	2	Register to write (0x0009 is axis filter)
	0x0003	2	Data to write (16 bit). 0x0003 = 0.5Hz
	0x103C	2	CRC-16 of all bytes

Response (same as command)	0x64	1	Slave address 100
	0x06	1	Function code for write register
	0x0009	2	Register to write (0x0009 is axis filter)
	0x0003	2	Data to write (16 bit). 0x0003 = 0.5Hz
	0x103C	2	CRC-16 of all bytes

Error Response	0x64	1	Slave address 100
	0x83	1	ModBus error function code
	0x01	1	Exception Code (0x01 invalid function code, 0x02 invalid register address, 0x03 parameter out of range)
	0x90EF	2	CRC-16 of all bytes

**Changing the BAUD Rate**

The BAUD rate of the device can be changed using the special function code 0x6E and special command code 0x8F.

	Byte Data	No Of Bytes	Description
Command	0x64	1	Slave address 100
	0x6E	1	Function code - 0x6E
	0x8F	1	LD command - 0x8F = set baud
	0x03	1	1 = 2400
			2 = 4800
			3 = 9600
			4 = 19200
			5 = 38400
			6 = 57600
7 = 115200			
0x5AF8	2	CRC-16 of all bytes	



### Changing the Device Address

The Address of the device can be changed using the special function code 0x6E and special command code 0x91. The device will reply with the original address in the response, and will change internally after the response has been sent.

	Byte Data	No Of Bytes	Description
Command	0x64	1	Slave address 100
	0x6E	1	Function code - 0x6e
	0x91	1	LD command - 0x91 = change address
	0x01	1	New Address = 1
	0xD299	2	CRC-16 of all bytes
Response	0x64	1	Slave address 100
	0x6E	1	Function code - 0x6e
	0x91	1	LD command - 0x91 = change address
	0x00	1	0 = success 1 = failed
	0x1359	2	CRC-16 of all bytes

### Examples of Reading Angle

#### Example 1: Read the angle from the sensor with address 100 (0x64):

##### Command

```

address (0x64 = 100 decimal)
| function code
| | starting reg. to read (0x0000)
| | | number of reg. to read (0x0002)
| | | |
| | | | CRC-16
| | | |
64 03 00 00 00 02 cd fe

```

##### Response (positive angle)

```

address (0x64 = 100 decimal)
| function code
| | byte count
| | | angle (0x0000a69c = 42652 decimal (42.652 degrees))
| | | |
| | | | CRC-16
| | | |
64 03 04 00 00 a6 9c b4 fc

```

##### Response (negative angle)

```

address (0x64 = 100 decimal)
| function code
| | byte count
| | | angle (0xffffda7d7 = -153641 decimal (-153.641 degrees))
| | | |
| | | | CRC-16
| | | |
64 03 04 ff fd a7 d7 54 bf

```



**Example 2: Change the frequency response to 0.5Hz:**

**Command**

```
address (0x64 = 100 decimal)
| function code
| | register to write to (0x0009)
| | | data to write (0x0003 = 0.5Hz)
| | | |
| | | | CRC-16
| | | | |
64 06 00 09 00 03 10 3c
```

**Response**

```
address (0x64 = 100 decimal)
| function code
| | register written to (0x0009)
| | | data written (0x0003 = 0.5Hz)
| | | |
| | | | CRC-16
| | | | |
64 06 00 09 00 03 10 3c
```

**Example 3: Change the device address from 100 to 1:**

**Command**

```
address (0x64 = 100 decimal)
| special function code
| | LD command for change address
| | | new address (0x01)
| | | |
| | | | CRC-16
| | | | |
64 6e 91 01 d2 99
```

**Response**

```
address (0x64 = 100 decimal)
| special function code
| | LD command for change address
| | | Success/Fail (0x00 = success)
| | | |
| | | | CRC-16
| | | | |
64 6e 91 00 13 59
```