COOPER Tools

# MFS-06

# Product Manual

Version 1.0

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metronix

| Revision History | | | |
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| **Manual name:** ***MFS-06*** | | **Product Manual** | |
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## Trademark

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## Group of persons this manual is aiming at

This manual is mainly aimed at persons who want to get an overview about the technical operation of the *MFS-06*.

It describes the hardware, the setup in field and gives instructions about trouble shooting, maintenance and repair.

## Other Manuals

The following manuals exist about the *GMS-06* measurement system:

- *MFS-06* magnetometer manual (this manual)
- *ADU-06* data logger
- *MFS-05* magnetometer manual
- *KIM 879* magnetometer manual
- Manual about network board
- Manual about the system CPU board
- Manual about system software *MAPROS*

## Packing list

Dear Customer, please check the completeness of the delivered goods against the delivered packing list.

If it happens that items are missing or damaged, please contact us straight away.

Many thanks!

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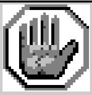
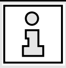
**The Meaning of the Symbols**

| | | |
|---|---|---|
|  | **Caution Symbol:** | **Note the Safety Instructions!**<br><br>**If the safety instructions are not noted personal injury and property damage can occur.** |

| | | |
|---|---|---|
|  | Information Symbol: | Important tips and tricks, which save time and make the work easier. |

# Table of Contents

# 1. Product Description

The broadband induction coil magnetometer *MFS-06* has been developed to measure variations of the Earth´s magnetic field, particulary for applications in Magnetotellurics (MT) and Controlled Source Audio Magnetotellurics (CSAMT). It covers a wide frequency range from 0.00025 Hz up to 10 kHz. In spite of its broad bandwidth, the *MFS-06* shows outstanding low-noise characteristics, extremely low temperature drift of input offset voltage and offset current and a very stable transfer function over temperature and time. The *MFS-06* is the result of many years of experience of metronix in the design, manufacture and application of induction coil magnetometers.

metronix magnetometers have been used by numerous customers througout the world - including geophysical exploration companies and research institutes.

A complete magnetic field measurement site consists of three single axis orthogonal sensors. Each sensor is enclosed in a shock resistant cylindrical plastic tube that acts as a protection against mechanical stress. These tubes are waterproof and also resistant to ultraviolet radiation. The magnetometer contains the electronics for preamplification of the sensor signal as well as for precise self calibration. The *MFS-06* magnetometer is connected to the metronix *ADU-06* data logger (or any other custom electronics) by a cable of up to 50 m length. Special care is taken to the fact that magnetometers are often used under rough environmental influences. All cables have ruggedized military standard connectors. The very high quality of the *MFS-06* data is achieved by a unique design for the ultra low noise and low frequency preamplifier.

## 1.1. Features

The *MFS-06* has several outstanding features which make it a first class instrument for the electromagnetic exploration:

- Wide frequency range from 1/4000 Hz to 10 kHz covered by only one sensor
- High linearity
- Ultra low noise
- High accuracy calibration with built-in precision calibration facility
- Wide operating temperature range from -25° C to +70° C
- high stability of the sensor´s transfer function due to magnetic field feedback
- built-in signal amplification and conditioning electronics
- easy field handling: one person can carry two magnetometers at one time

## 1.2. Technical Data

| | |
|---|---|
| Frequency range | 0.00025 Hz ..... 10 kHz |
| Frequency bands | 0.00025 Hz ..... 500 Hz (chopper on)<br>10 Hz ....10 kHz (chopper off) |
| Sensor noise | $1*10^{-2}$ nT/√Hz @0.01 Hz<br>$1*10^{-4}$ nT/√Hz @1 Hz<br>$5*10^{-7}$ nT/√Hz @ 1000 Hz (chopper off) |
| Output sensitivity | 0.2 V/(nT*Hz) f<< 4Hz<br>0.8 V/nT f>> 4Hz<br>for exact values refer to individual calibration file |
| Output voltage range | +/- 10V |
| Function | induction coil with magnetic field feed back |
| Connector | 8 pole PT02SE12-10S |
| Calibration coil sensitivity | 4 nT / V |
| Feedback cut-off frequency | 4 Hz |
| Supply voltage | +/- 12V to +/-15V stabilized and filtered |
| Supply current | +/- 25mA |
| Case | ruggedized, waterproof glas fibre reinforced case |
| Weight | appr. 8.5 kg |
| External dimensions | length 1250 mm, diameter 75mm |
| Operating temperature range | -25°C ..... + 70°C |

# 2. Sensor

The central part of the *MFS-06* magnetometer is the sensor coil. It consists of a high permeable ferrite core and several thousand copper turns. Due to it´s low skin depth the core material prevents the occurence of eddy currents in the measurement frequency range.
To achieve good mechanical stability the main structure of the sensor is based on the cylindrical tube which is made of fibre glass reinforced epoxy.

Induction coil sensors do not measure the magnetic field itself but its time derivative. This is expressed in the law of induction:

$$V_{ind} = n \cdot \frac{d\Phi}{dt}$$

with

| | |
|---|---|
| $V_{ind}$ | induction voltage |
| $n$ | number of turns |
| $\Phi$ | magnetic flux |

The flux $\Phi$ which flows through one loop of the coil is calculated as

$$\Phi = B \cdot A = \mu_0 \cdot \mu_c \cdot H \cdot A$$

with

| | |
|---|---|
| $B$ | magnetic flux density parallel to the sensor axis |
| $\mu_0$ | permeablity constant |
| $\mu_c$ | permeability of the core |
| $A$ | cross section of the core |
| $\tilde{H}$ | magnetic field amplitude ($= \hat{H} \cdot e^{j\omega t}$) |
| $f$ | frequency |

For a sinusoidal magnetic field which can be written with a phasor as $\tilde{H} = \hat{H} \cdot e^{j\omega t}$ the induced voltage of the sensor output becomes

$$\tilde{V}_{ind} = \hat{V}_{ind} \cdot e^{j\omega \cdot t} = j \cdot \underbrace{2\pi \cdot n \cdot \mu_0 \mu_c \cdot A}_{S_0} \cdot f \cdot \hat{H} \cdot e^{j\omega \cdot t} = j \cdot f \cdot S_0 \cdot \tilde{H}$$

$S_0$ is defined as the sensor's sensitivity constant which gives the relation betwen the magnetic field's amplitude and the induction voltage. This equation is only a theoretically one. A non ideal sensor's equivalent circuit does not only contain the field proportional voltage source (which itself is not really proportional) but also some further elements:

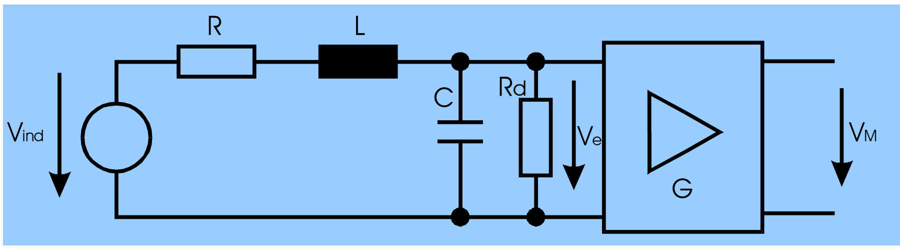



**Figure 2-1: Simplified equivalent circuit diagram for a sensor coil**

Referring to the source, the induced sensor voltage $V_{ind}$, the coil resistance $R$, the input resistance of the amplifier $R_d$, the coil inductivity $L$ and the capacity $C$ yield a damped serial resonance circuitry and the transfer function of the sensor will show a strong peak at its resonance frequency.
For the sensor itself, without the preamplifier, we get the transfer function

$$\frac{V_e}{V_{ind}} = \frac{R_d/(R_d+R)}{1-(f/f_0)^2 + j\cdot 2D\cdot (f/f_0)}$$

with the amplifier's input resistance $R_d$, Gain $G$, resonance frequency $f_0$ and attenuation $D$ defined as

$$f_0 = \frac{1}{2\pi\cdot\sqrt{A\cdot L\cdot C}} \qquad G = \frac{V_M}{V_e} \qquad 2D = \sqrt{\frac{R_d}{R_d+R}}\cdot\frac{\sqrt{L/C}}{R_d} + \frac{R}{\sqrt{L/C}}$$

Having this in mind the resulting transfer function between the magnetic field and the sensor output voltage becomes

$$F_{sensor} = \frac{V_e}{\tilde{H}} = \frac{j\cdot S_0\cdot R_d/(R_d+R)\cdot f}{1-(f/f_0)^2 + j\cdot 2D\cdot (f/f_0)}$$

The equivalent circuit diagram of the magnetometer leads to a frequency dependent sensitivity E(f) referred to the preamplifier output of:

$$E(f) = E_0\cdot\frac{V_e}{V_{ind}} \quad \text{with} \quad E_0 = G\cdot S_0$$

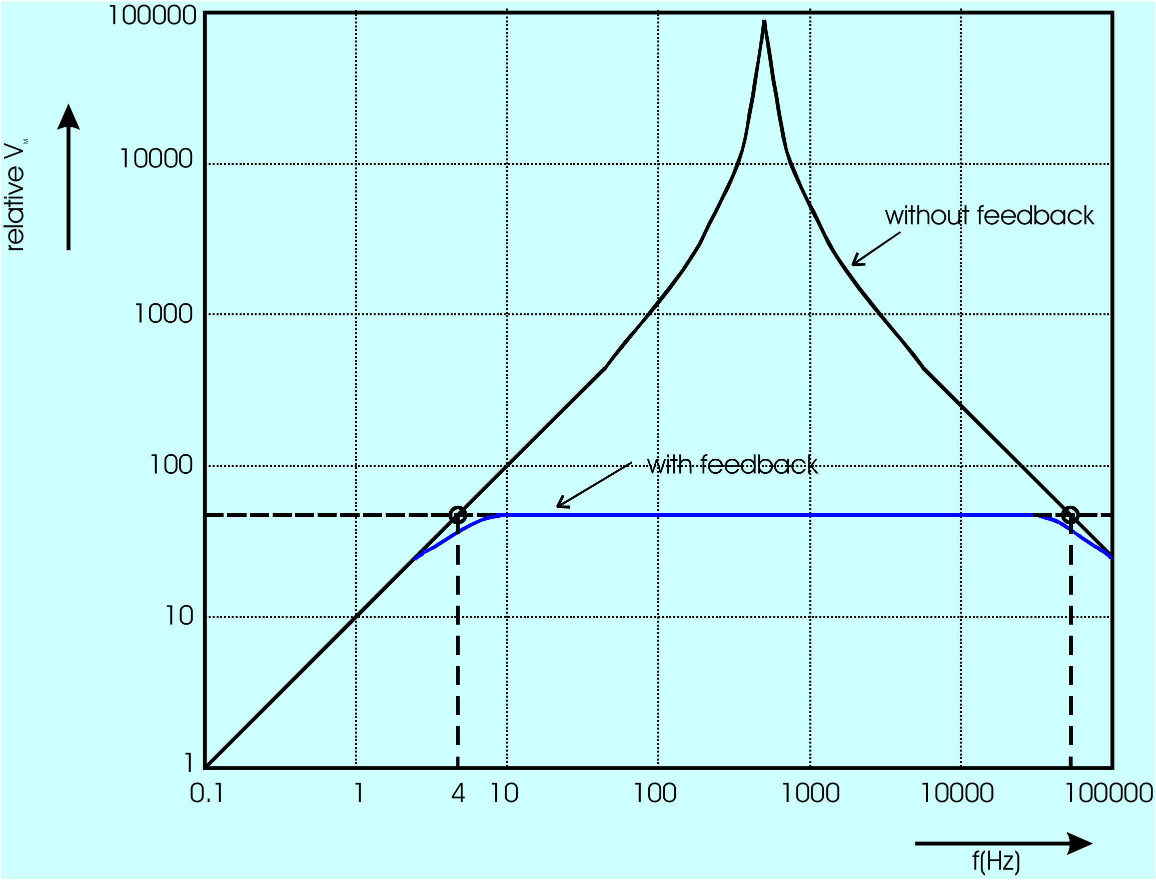



**Figure 2-2: relative frequency response of magnetometer *MFS-06* for H(f)=const.**

Figure 2-1 shows the principle frequency response of the output voltage $V_M$ of the *MFS-06*. Considering the feedback, the output voltage is given by:

$$V_M(f) = \frac{j \cdot f \cdot H(f) \cdot E(f)}{1 + j\dfrac{f}{f_c}}$$

The cut-off frequency of the magnetometer is set to $f_c = 4Hz$ .

Please consider that this figure shall only explain the feedback principle. Additional effects caused by the low-pass filtering of the sensor signal at 8192 Hz and other influences are not respected here.

# 3. Preamplifier

The integrated preamplifier performs the signal amplification of the sensor output voltage as well as the conditioning of the magnetic field feedback signal and the input of an externally applied calibration signal. Special care has been taken to avoid disturbance of the electronics by external electromagnetic noise.

To achieve DC characteristics close to the physical limits, the preamplification electronics is split into a lower frequency path (low-pass corner frequency 330 Hz) which is chopper stabilized in order to achieve excellent drift characteristics and a separate AC path with the same corner frequency. The output of these two amplification paths are used as an input for the magnetic feedback conditioning stage.
The following block diagram explains the design:

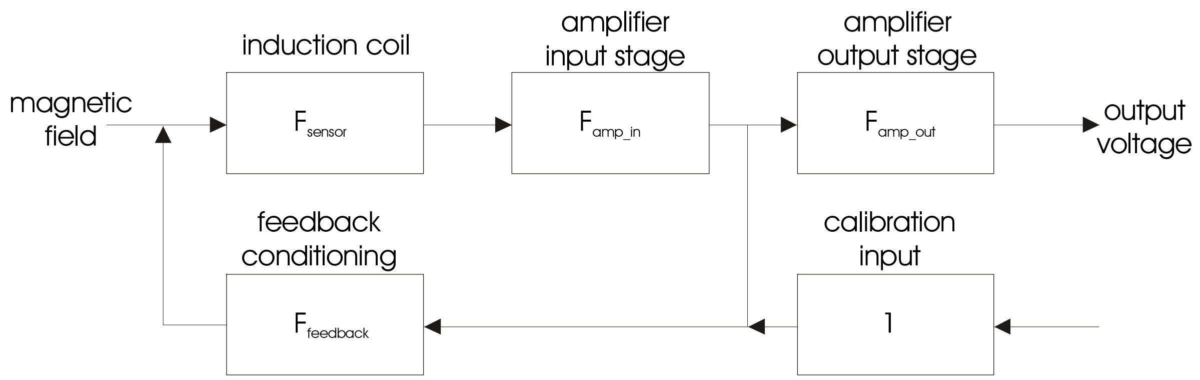



**Figure 3-1:** ***MFS-06*** **block diagram**

The resulting frequency characteristics of the *MFS-06* sensor system is dominated by the feedback loop. As it was demonstrated in chapter 2 of this manual, the characteristics of the sensor itself mostly depends on the resonance circuit formed by the main impedance and main capacity of the coil. This leads to a strong peek in the spectrum at the resonance frequency $f_0$.

In the above block diagram the summing function for the input node leads to the transfer function, assuming that Upre is the ouptut voltage of the amplifier input stage:

$$(H - U_{pre} \cdot F_{FB}) \cdot F_{sensor} \cdot F_{amp\_in} = U_{pre}$$

which is the same as

$$\frac{U_{pre}}{H} = \frac{1}{(F_{sensor} \cdot F_{amp\_in})^{-1} + F_{FB}}$$

Close to the resonance frequency the influence of the sensor transfer function disappears and the overall characteristics depends mainly on $F_{FB}$. This results in a flat frequency response of the sensor system over the whole frequency band of interest.

Additionally the preamplifier electronics contains an output line driver which provides an 8 kHz low-pass filter. The output buffer is able to drive cables up to 50 m length.

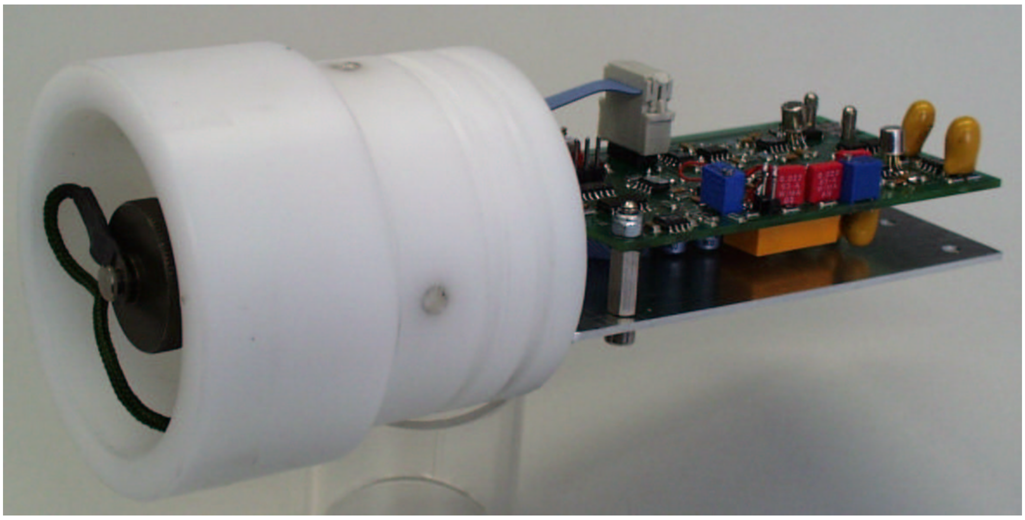


**Figure 3-2: Preamplifier of *MFS-06***

# 4. Transfer Function of MFS-06

The transfer function of the *MFS-06* magnetometer is determined by the transfer function of the preamplifier, the feedback electronics and the sensor transfer function.

The theoretical overall transfer function is defined by the following equation:

$$F_{Sensor} = \frac{V_{output}}{H} = 0.8 \frac{V}{nT} \cdot \frac{P_1}{1+P_1} \cdot \frac{1}{1+P_2}$$

with $P_1 = j \cdot \frac{f}{4Hz}$ and $P_2 = j \cdot \frac{f}{8192Hz}$

This theoretical transfer function is **only an approximation** of the real transfer function (approx. up to 500 Hz with Chopper On) which is delivered by the calibration of the sensor. Each sensor is delivered with a calibration file which has a 3 column ASCII format. The left column represents the frequency, the middle one represents the sensor sensitivity in $\frac{V}{nT \cdot Hz}$ and the right one the phase in degree.

# 5. Integrated Calibration Facility

The integrated calibration facility makes it easy for the user to perform an online calibration or test of the magnetometer transfer function. A differential test signal can simply be injected into the CAL inputs and is internally added to $U_{pre}$ without further amplification as shown in Figure 3-1. A voltage on the CAL input results in a magnetic field according to

$$H = 4\frac{nT}{V} \cdot U_{cal}$$

This makes it easy to calculate the resulting transfer function of the magnetometer using the formula

$$F_{MFS-06} = \frac{U_{out}}{U_{cal}} \cdot \frac{1}{4\frac{nT}{V} \cdot f}$$

External magnetic field variations do not disturb the measurement if a correlation analyser (e.g. Solartron 1250) is used. The input signal must be in the range of ±10V peak to peak.
If the metronix *ADU-06* is used as data logger the magnetometer characteristics will be tested regularly as a part of the normal system self test.

# 6. Calibration by Manufacturer

metronix takes special care of the initial calibration of all *MFS-06* magnetometers as part of the ISO9001 certified production process. Tests have demonstrated an excellent long time stability of the transfer function.
The calibration is performed in the „Magnetsrode“ magnetometer laboratory which is operated by the Institute for Geophysics of the Technical University of Braunschweig, mostly to calibrate space flight magnetometers. It offers special environmental circumstances and has an extremely low distortion level.
A large cylindrical coil (l = 3.6 m; d = 30 cm) has been calibrated by a reference sensor with an accuracy of better than ±0.2%. It is used to generate a homogenious magnetic field of known strength as input signal. The input signal for the solenoid coil comes from a Solartron 1250 spectral response analyser which is able to perform calculation of transfer functions with a given statistical accuracy.

Each magnetometer is calibrated to

$$E = 0.2 \frac{V}{nT \cdot Hz}$$

at a frequency of 0.1 Hz.

A calibration file is generated in a frequency range between 0.1 Hz and 10 kHz. Lower frequency calibration is not required because the sensor obeys the mathematical rules (theoretical transfer function with a very high precision.

Table 6-1 gives an example of a calibration file delivered along with the sensor. Note that not all calibration results are given here due to limited space, gaps are marked by dots here.

Each magnetometer is shipped with the original calibration data set which contains the measured values of amplitude and phase of the transfer function over the specified frequency band.

The calibration file is split into 2 sections first section with the chopper switched on, 2$^{nd}$ section with the chopper switched off.

Figure 6-1 and Figure 6-2 show the plots of the calibration function of MFS-06 Ser. #002.

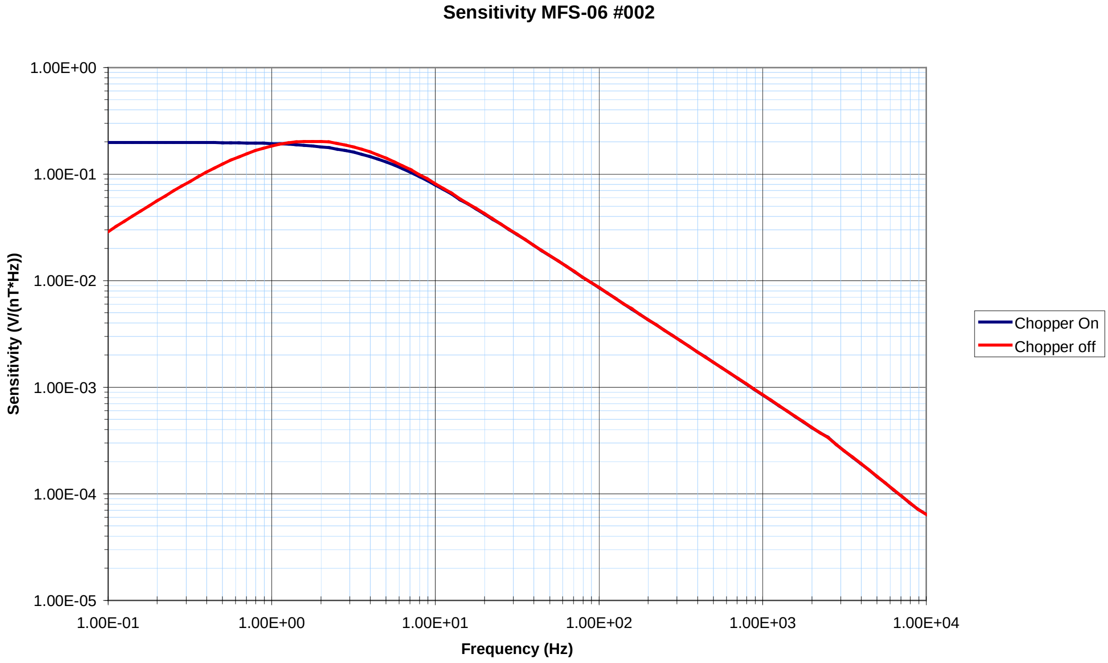



**Figure 6-1: Typical sensitivity calibration curve of MFS-06 (here Ser.#002)**

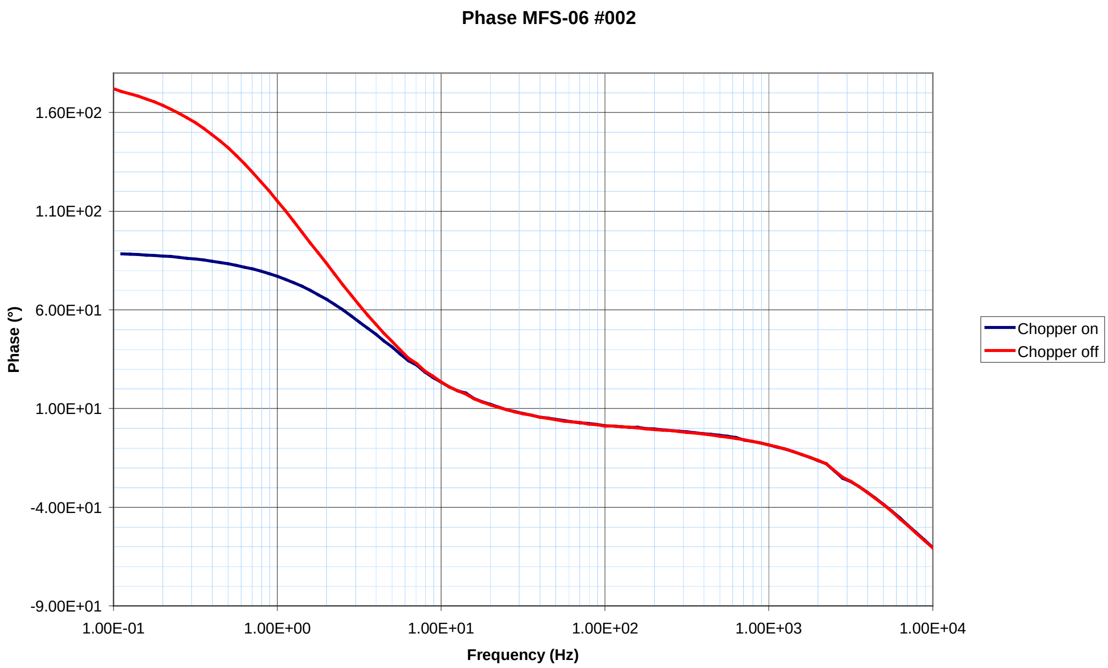



**Figure 6-2: Typical phase calibration curve of MFS-06 (here Ser.#002)**

```
Calibration    measurement    with Solartron
Metronix GmbH  Kocherstr. 3    38120 Braunschweig

Magnetometer   #002    Date: 12/19/00    Time: 13:28:20


Chopper On
FREQUENCY      MAGNITUDE      PHASE
Hz             deg
1.00E-01       1.99E-01       8.87E+01
1.12E-01       1.99E-01       8.85E+01
1.26E-01       1.98E-01       8.83E+01
1.41E-01       1.99E-01       8.81E+01
1.58E-01       1.99E-01       8.79E+01
1.78E-01       1.98E-01       8.76E+01
2.00E-01       1.98E-01       8.73E+01
2.24E-01       1.98E-01       8.70E+01
2.51E-01       1.99E-01       8.66E+01
2.82E-01       1.98E-01       8.62E+01
3.16E-01       1.98E-01       8.58E+01
  .
  .
  .
  .
3.55E+03       2.19E-04       -2.95E+01
3.98E+03       1.92E-04       -3.22E+01
4.47E+03       1.67E-04       -3.53E+01
5.01E+03       1.45E-04       -3.86E+01
5.62E+03       1.26E-04       -4.20E+01
6.31E+03       1.09E-04       -4.54E+01
7.08E+03       9.43E-05       -4.92E+01
7.94E+03       8.18E-05       -5.29E+01
8.91E+03       7.15E-05       -5.66E+01
1.00E+04       6.38E-05       -6.04E+01

Chopper off
FREQUENCY      MAGNITUDE      PHASE
Hz             deg
1.00E-01       2.88E-02       1.72E+02
1.12E-01       3.22E-02       1.71E+02
1.26E-01       3.61E-02       1.69E+02
1.41E-01       4.04E-02       1.68E+02
1.58E-01       4.51E-02       1.67E+02
1.78E-01       5.04E-02       1.65E+02
2.00E-01       5.62E-02       1.64E+02
2.24E-01       6.26E-02       1.62E+02
2.51E-01       6.96E-02       1.60E+02
2.82E-01       7.73E-02       1.57E+02
3.16E-01       8.55E-02       1.55E+02
3.55E-01       9.45E-02       1.52E+02
3.98E-01       1.04E-01       1.49E+02
  .
  .
  .
  .
3.16E+03       2.52E-04       -2.69E+01
3.55E+03       2.21E-04       -2.95E+01
3.98E+03       1.92E-04       -3.23E+01
4.47E+03       1.68E-04       -3.54E+01
5.01E+03       1.45E-04       -3.87E+01
5.62E+03       1.26E-04       -4.21E+01
6.31E+03       1.10E-04       -4.57E+01
7.08E+03       9.44E-05       -4.94E+01
7.94E+03       8.20E-05       -5.31E+01
8.91E+03       7.18E-05       -5.68E+01
1.00E+04       6.40E-05       -6.07E+01
```

**Table 6-1: Example for a calibration file (the dots indicate that not all lines are shown here)**

# 7. Sensor Noise

In an electromagnetic measurement system special care has to be taken to noise. The various sources of noise in the system can be referenced back to an equivalent input noise voltage at the preamplifier input for comparism purpose which is expressed in the equation

$$\sqrt{\frac{\overline{u^2}}{\Delta f}} \approx \sqrt{\frac{\overline{u_{amp}^2}}{\Delta f} + \frac{\overline{u_R^2}}{\Delta f} + \frac{\overline{i_{amp}^2}}{\Delta f} \cdot (\omega^2 L^2)}$$

with

| | |
|---|---|
| $\sqrt{\overline{u_{amp}^2} / \Delta f}$ | preamplifier noise voltage density (typ. $1.6\,nV/\sqrt{Hz}$ ) |
| $\sqrt{\overline{u_R^2} / \Delta f}$ | thermal noise of sensor resistance (typ. $2.7 nV/\sqrt{Hz}$ ) |
| $\sqrt{\overline{i_{amp}^2} / \Delta f}$ | preamplifier noise current density (typ. $10\,fA/\sqrt{Hz}$ ) @chopper off |

To rereference this noise voltage back to the magnetic field the formula

$$\sqrt{\frac{\overline{H^2}}{\Delta f}} = \frac{\sqrt{\frac{\overline{u^2}}{\Delta f}}}{E_o \cdot f} = \frac{1nT}{28.8\mu V/\sqrt{Hz} \cdot f} \cdot \sqrt{\frac{\overline{u^2}}{\Delta f}}$$

is used. These two equations show that the current noise is spectrally flat whereas the voltage noise of the amplifier and the coil resistance increase proportional with 1/f to low frequencies. For higher frequencies it is possible to eliminate a part of the preamplifier noise if the chopper path is switched off. This can be done with a pulse on the HCHOP line.

Magnetometer noise is measured at metronix with an HP spectrum analyser. To keep environmental noise away from the sensor the measurements are done with the magnetometer in a multiple shielded mumetal chamber.

Additionally, the noise of the magnetometer is measured by a parallel sensor test. The correlation between two parallelly located sensors is determined and by this means, in connection with the measured amplitude spectra, the noise of the sensor can be computed.

Figure 7-1 shows the typical noise characteristics of the *MFS-06*.

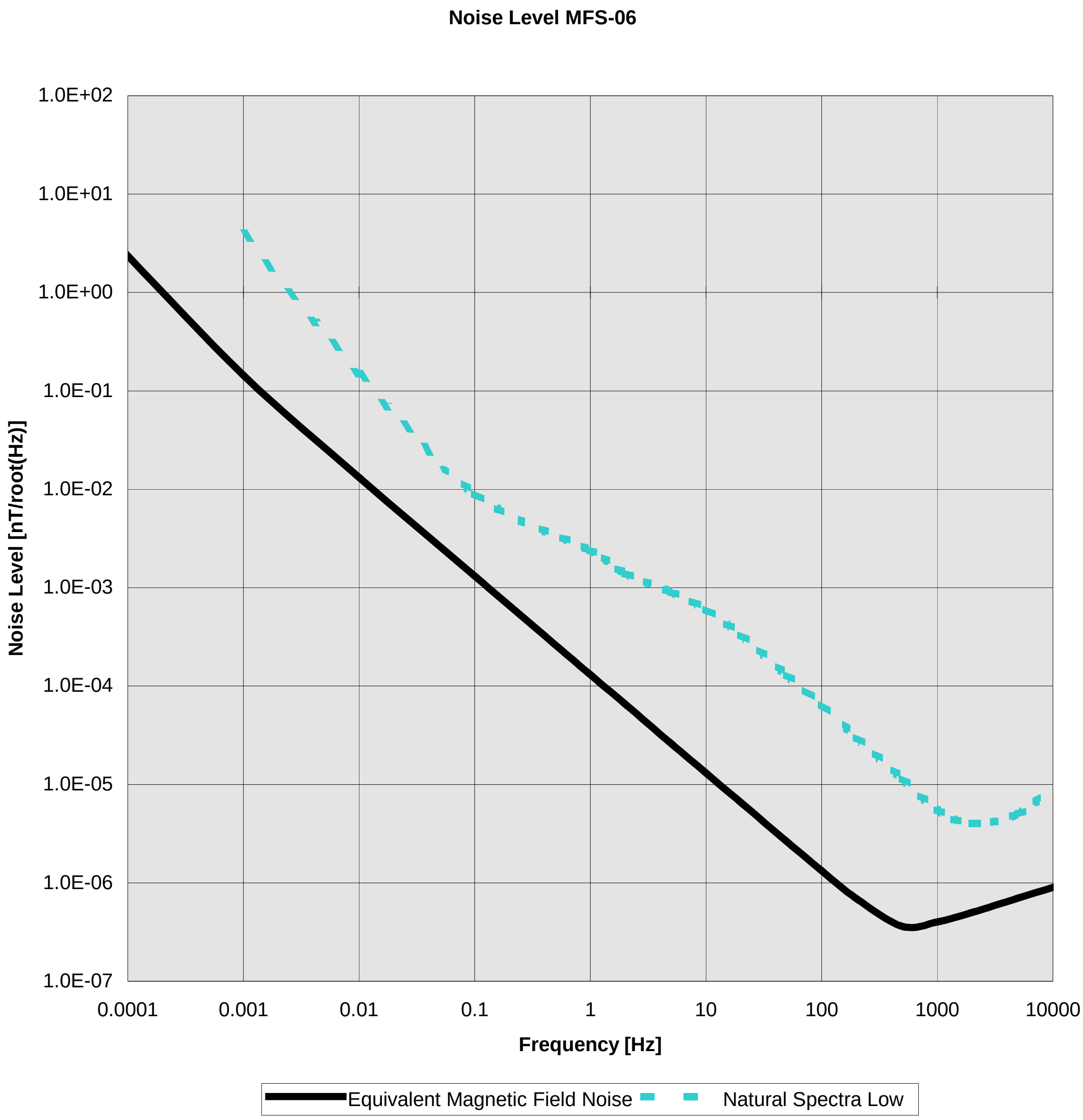



**Figure 7-1: Typical Noise Chart of the *MFS-06* in comparison with the natural magnetic field varitions on a quiet day**

# 8. Installation of Magnetometers

To avoid low frequency distortion due to mechanical vibrations of the sensor it should be dug into the soil. If this is not done, significant noise may be created caused by wind which can make a measurement unusable. The z component magnetometer should be dug into the soil at least to the amount of half of its size. In order to obtain optimum results the free end of the sensor should be covered by a protection cap like a plastic bucket.

Special care must be taken to the exact alignment of the magnetometer tube. It’s bottom side (that one without the cable connector) must point exactly to the corresponding (positive sensor) direction:

- **X magnetometer to the North**
- **Y magnetometer to the East**
- **Z magnetometer to the ground**

A positive flux change in the positive sensor direction will cause a positive change in the output voltage.

## 8.1. Electrical Connection

All magnetometer cables from metronix are shielded twisted pair cables which perform optimum protection against external distortion. Connectors with military specification have best outdoor characteristics including water proofness. Nevertheless care should be taken to avoid intrusion of particles. Each connector has a protection cap which can be removed by turning it counterclockwise. Please ensure that the expensive connectors are always protected by the caps during assembling or disassembling of the MT system.
To connect a cable to a magnetometer rotate it to the coded position, put connector into the input plug and lock it with the bayonette by turning it clockwise.

The *MFS-06* can be directly connected to the *ADU-06* data logger. Due to the easy setup procedure of a metronix *GMS-06* system the magnetometer cables simply have to be put into the corresponding *ADU-06* ports.

In case that other custom electronics are used connection should be simple according to the above pin assignment.

Special care must be taken with custom electronics to avoid a wrong use of the power supply inputs! The magnetometer electronics may be damaged immediately if the power is connected the wrong way!

> The Chopper On/Off Signal is a standard TTL input. Low level (<0.5V) will switch the chopper amplifier off. High level (>3.5V) will switch the chopper on. If you use the sensor with custom electronics, make sure to switch the signal on and off with a delay of about 100ms or more in order to properly initialize the sensor.

## 8.2. Installation with ADU-06

This chapter describes the setup of the *MFS-06* in the field in connection with the *ADU-06*.

### 8.2.1. Standard 5-channel MT Setup

Figure 8-1 illustrates the field setup of a five channel MT station. Only a few components are required:

- *ADU-06* (5-channel version)
- GPS-antenna (optional)
- 3 magnetometers like *MFS-05*, *MFS-06* or *KIM 879*
- 3 magnetometer cables
- 4 electric field probes
- 4 electric field cables
- 1 grounding rod + cable
- Network cable
- Field computer (may be any ruggedized laptop) with *MAPROS* software (only required to program *ADU-06* or during online-processing)

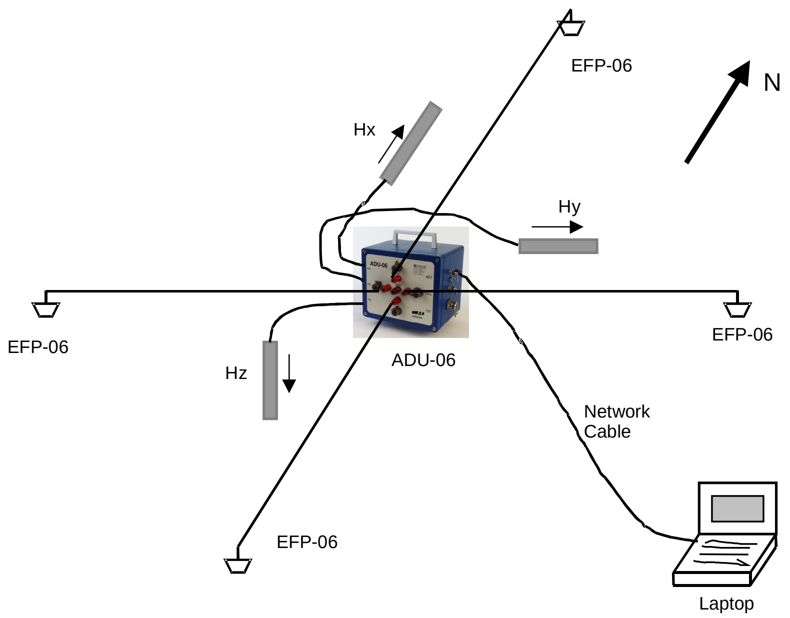



**Figure 8-1: Typical 5-channel MT field setup**

### 8.2.2. Connection of the Sensors to the ADU-06

Now you can install the sensors:

| | |
|---|---|
| **1.** | Dig the four *EFP 06* into the soil and connect them with the input of the E-Field cable drum. |
| **2.** | Connect the other end of the 50m E-cable with the appropriate input terminals of the *ADU-06*. The North-probe will be connected with the terminal labeled "N" of the *ADU-06*. In the same way the "S", "E", "W" input terminals of the ADB are connected with the corresponding probes. Make sure that the E-Field cables are unreeled completely and the cable is not moving in the wind. |
| **3.** | Stick-in the delivered grounding rod close to the *ADU-06* and connect it with the black GND-input clamp of the *ADU-06*. |
| **4.** | Connect one end of the magnetometer cables with the HX, HY resp. HZ magnetometer. For this purpose first remove the magnetometer's protection cap. Now push the end of the cable through the rubber flap in the middle of the protection cap. After having it connected with the socket properly, the magnetometer's protection cap is pushed over the magnetometer's head again. Please note that the reel of the magnetometer cable (if there is one) always should be placed near the *ADU-06*. The exact positioning and installation procedure of the magnetometer is described below. It is very important to notice the hints given there in order to obtain best results. |
| **5.** | Connect the plugs on the other end of the magnetometer cables with the corresponding input sockets on the *ADU-06* i.e. the cable of the HX sensor with the socket labeled "HX", the cable of the HY sensor with the "HY" socket and the cable of the HZ sensor with the "HZ" socket of the *ADU-06*. |

The correct direction of the sensors can be fixed by using a compass and two sticks:

A field helper rams the first stick into the soil according to the command of the other helper with the compass. The second stick is rammed behind the first stick. The correct alignment is found when the needle of the compass points to North for HX resp. East for HY and the sticks as well as the ring and bead sights of the compass are in line.

The horizontal direction is balanced using a level. The exact vertical position of the HZ-magnetometer can also be fixed by a level.

The magnetometers must be installed in a way, that any movement of the sensors due to micro-vibrations is avoided. Such motion of an induction coil magnetometer in the stationary earth magnetic field would cause significant artificial noise. For this reason the horizontal magnetometers must be dug and covered by soil completely. The vertical HZ-component should be dug-in to at least half of its length or better to 4/5 of its length. An additional coverage of the HZ sensor by a kind of bucket helps to reduce wind influences.

**The cables close to the magnetometers must be fixed in a way that they cannot move in the wind!!**

# 9. Pinout of External Connector

The following tables show the wireing of the connectors of the *MFS-06*.

| **Target**<br><br>**PT07E12-10S (magnetometer socket)** | **Origin**<br>**RM 2.54mm 3Mpost 10pole socket** | **Specification** | **Colour** | **Cat.** |
|---|---|---|---|---|
| A | 2 | +15V \ twisted | green | 1 |
| B | 1 | -15V / | white | 1 |
| C | 8 | +CAL \ twisted | red | 4 |
| D | 7 | -CAL / | white | 4 |
| E | | n.c. | white | 3 |
| F | 3 | GND \ twisted | white | 3 |
| G | 5 | HCHOP / | orange | 2 |
| H | | n.c. | | |
| J | 6 | Signal \ twisted | yellow | 4 |
| K | 4 | Signal /<br>Return | white | 4 |

**Table 9-1: Pinout of sockets for the H-Field Sensors (internal cables)**

| **Target**<br><br>**PT06E12-10P** | **Origin**<br><br>**PT06E12-10P** | **Specification** | **Colour** | **Cat.** |
|---|---|---|---|---|
| A | A | +15V \ twisted | brown | 1 |
| B | B | -15V / | white | 1 |
| C | C | +CAL \ twisted | green | 4 |
| D | D | -CAL / | brown | 4 |
| E | E | not connected | | 3 |
| F | F | GND \ twisted | white | 3 |
| G | G | HCHOP / | green | 2 |
| H | H | not connected | | |
| J | J | Signal \ twisted | yellow | 4 |
| K | K | Signal /<br>Return | white | 4 |

**Table 9-2: Pinout of magnetometer cable**

# 10. Trouble Shooting

This chapter describes our experience to localize possible errors of the system and methods how to fix them or get around it.

## 10.1. Parallel Sensor Test

In order to check the functionality of the sensors it is a good idea to perform a so called parallel sensor test. For this purpose 2 or more magnetometers are positioned horizontally and parallel with a distance of about 2 m from each other. The electric field lines are layed out parallel and perpendicular to the magnetic sensors. Use a single probe for each line (all together four of them). Now you record time series. If everything works fine you must see well correlated time series of the electric and the magnetic channels. A noisy sensor can be found out by this method easily.

## 10.2. Check of Magnetometer Cable

The pinout of the magnetometer cable is given in chapter 9. Check the cable by using an Ohm-meter pin by pin according to the table. Also check for damages of the cable´s isolation.

**Never pull the sensor out of the soil on its cable because either the cable connector or the sensor socket will be damaged by this procedure.**