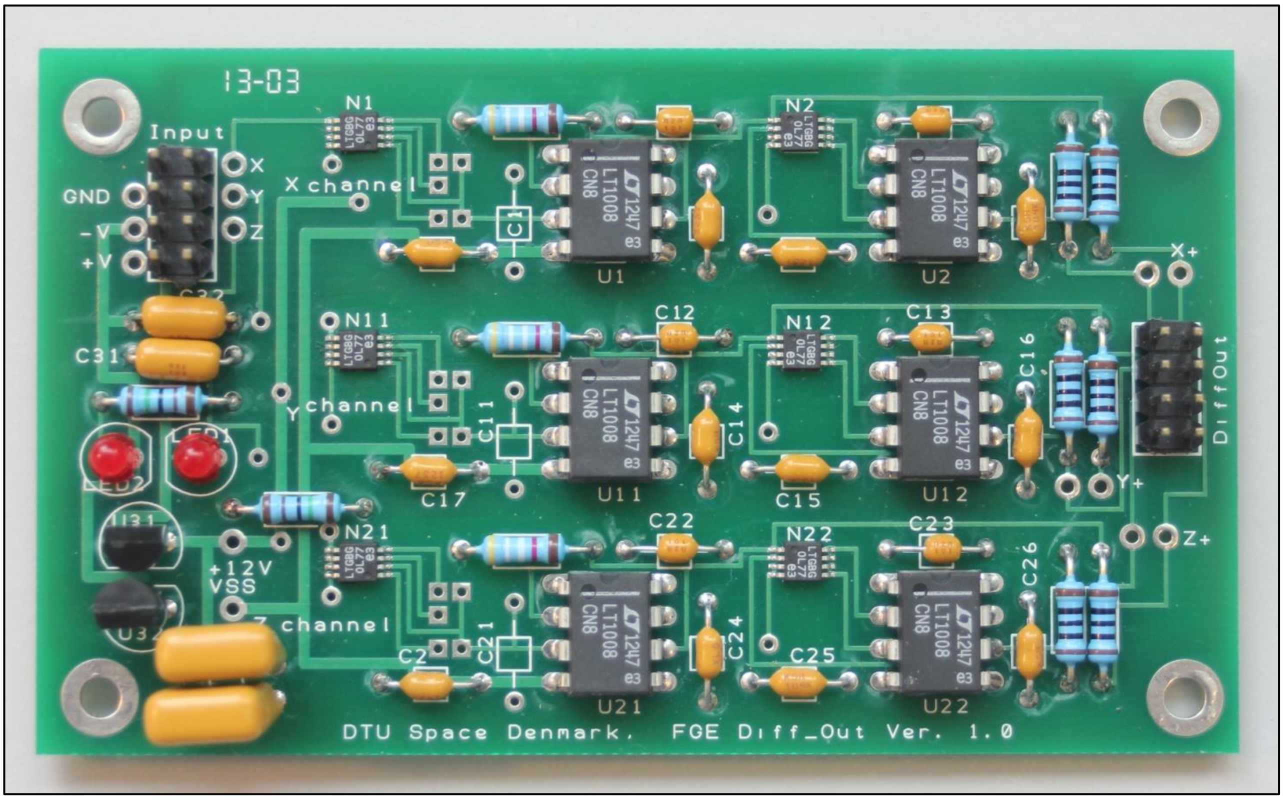
DTU Space

Differential output amplifier for the FGE magnetometer



FGE DiffOut board version 1.0

21 January 2014

Contents

Purpose

- DTU Space has developed a new circuit board (called DiffOut) for the FGE magnetometer that gives an additional differential analog output of the 3 fluxgate channels, x, y and z.

- The DiffOut board can easily be build into the FGE electronics box, and it will not affect the magnetometer and the normal single ended output to which it runs in parallel.

- The new output is developed as differential output, since this is supported by many modern dataloggers, which is designed for high resolution and high time accuracy (e. g. seismic dataloggers). But the DiffOut can also be used as single ended outputs.

- With the DiffOut board, the FGE magnetometers can fulfill INTERMAGNET's new 1. sec standard for time stamp and filters with use of a suitable fast datalogger. (But it can also be done with the normal single ended output)

- Sensor temperature T1 and electronics temperature T2 still need to be measured via the normal single ended output.

- The gain of the first amplifier in each channel can be set to either 1, ½ or ¼. This means that the differential output will be either 2, 1 or ½ times the normal output.

Description of DiffOut board

- The board measures 70*100 mm and can easily be built into the FGE magnetometer box.
- High precision op-amps are used together with matched resistor networks for high precision and stability.

Diagram:

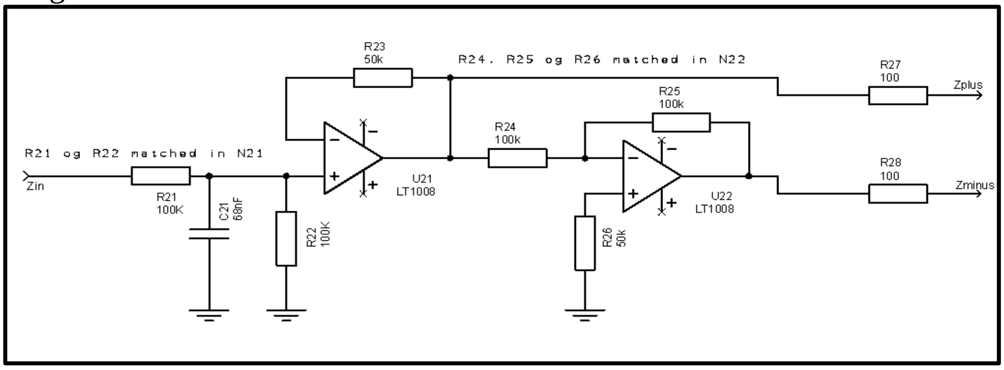


Fig. 1: Each of the 3 channels uses 2 opamps and 2 arrays of matched resistors.

Gain

Fig. 1 shows the circuit of one of the 3 channels. The first op-amp U21 has a non-inverted gain G1=R21/(R22+R21), while the second op-amp U22 has an inverting gain G2=-R24/R26 =-1.

Output is: Uout= Uin * G1 – Uin * G2

=> **Uout = 2 * G1 * Uin**

R21 and R22 are matched resistors in N21 (LT5400 from Linear Technology with 4 resistors) These 4 resistors can be combined with small short circuits of soldering on the board (Fig. 2A) to chose different gain of G1 (1, ½ or ¼).

Fig. 3 shows how the 3 possible gains are soldered.

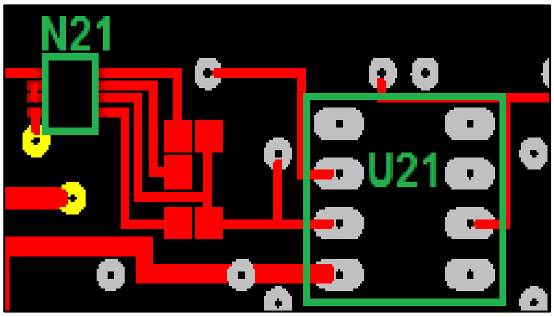


Fig. 2: Gain G1 can be set by soldering between pads.

Output span

Since the span of the input voltage x, y and z from the FGE board are +-12 Volt, the span of the DiffOut output will also be +-12 Volt for Gain G1=1.

For G1=½ output span will be +-6 Volt, while a gain G1=1/4 will decimate the output span to be

+-3 Volt.

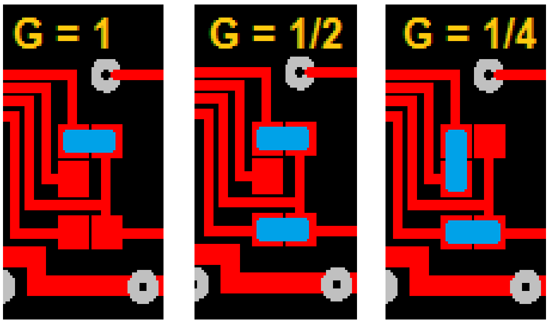


Fig. 3: Soldering pads for different gain

So check if the used datalogger or AD converter can use +-12V, +-6V or only +-3V!

1. order lowpass filter

It is possible to mount a capacitor in each channel, if a 1.st order lowpass filter is wanted (like the 1 Hz lowpass filter in the FGE normal single ended output). In Fig. 1 it is shown as C21.

The first order cutoff frequency f0 is affected by R21 and R22 in parallel (Rp) and can be calculated as:

f0 = 1/(2*pi * C21 * R), where Rp=R21//R22

G=1:	R21=100k, R22=nc	Rp=100k
G=½:	R21=100k, R22=100k	Rp=50k
G=1/4:	R21=100k, R22=300k	Rp=75k

The capacitor can be calculated from this formular: C21 = 1/(2*pi * Rp * f0)

Capacitor	Gain and Rp		
f0 [Hz]	1 100k	0.5 50k	0.25 75k
0.1	**16 uF**	**32 uF**	**21 uF**
0.3	**5.3 uF**	**11 uF**	**7.1 uF**
1	**1.6 uF**	**3.2 uF**	**2.1 uF**
3	**530 nF**	**1.1 uF**	**707 nF**
10	**160 nF**	**320 nF**	**210 nF**
30	**53 nF**	**106 nF**	**71 nF**

Table 1: Capacitors for lowpass filter

The cutoff frequency f0 has been measured with filters on x and y channel. Fig. 4 shows this. Remark the z channel without lowpass filter, which shows the ObsDaq ADC's own filter at 30 Hz.

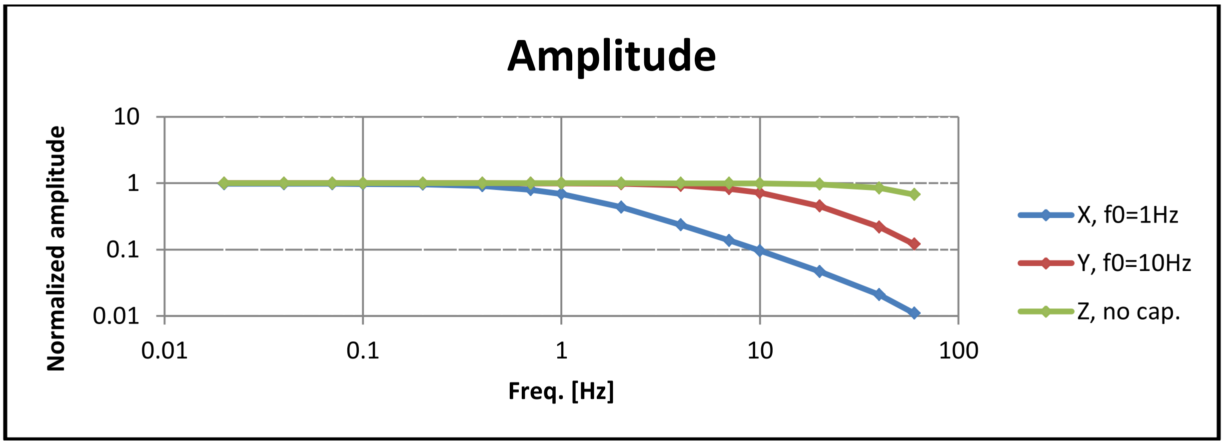


Fig. 4: Transfer function for x, Y and Z with lowpass filter on X (1 Hz) and Y (10 Hz).

Since our purpose in this test is not to affect the signal, we normally do not use these capacitors.

Connections

The board uses two 8-pin connectors for input and output, but it is also possible to solder wires directly in pads on the board.

Input:
Power: +15Vdc and -15Vdc.
X, Y and Z: wires are soldered on the FGE board, at the same point where the normal single-ended output amplifier are connected.

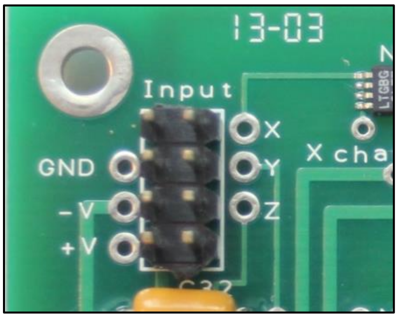


Fig. 5: Input connector

GND	Xin
GND	Yin
-15V	Zin
+15V	nc.

Tabel 2: Input

Output:
The differential output can also be used as single ended output, if GND is used instead of 'minus'. But then the output signals are only half the size.

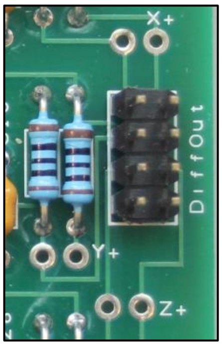


Fig. 6: Output connector

Xminus	Xplus
Yminus	Yplus
Zminus	Zplus
GND	GND

Tabel 3: Output connections

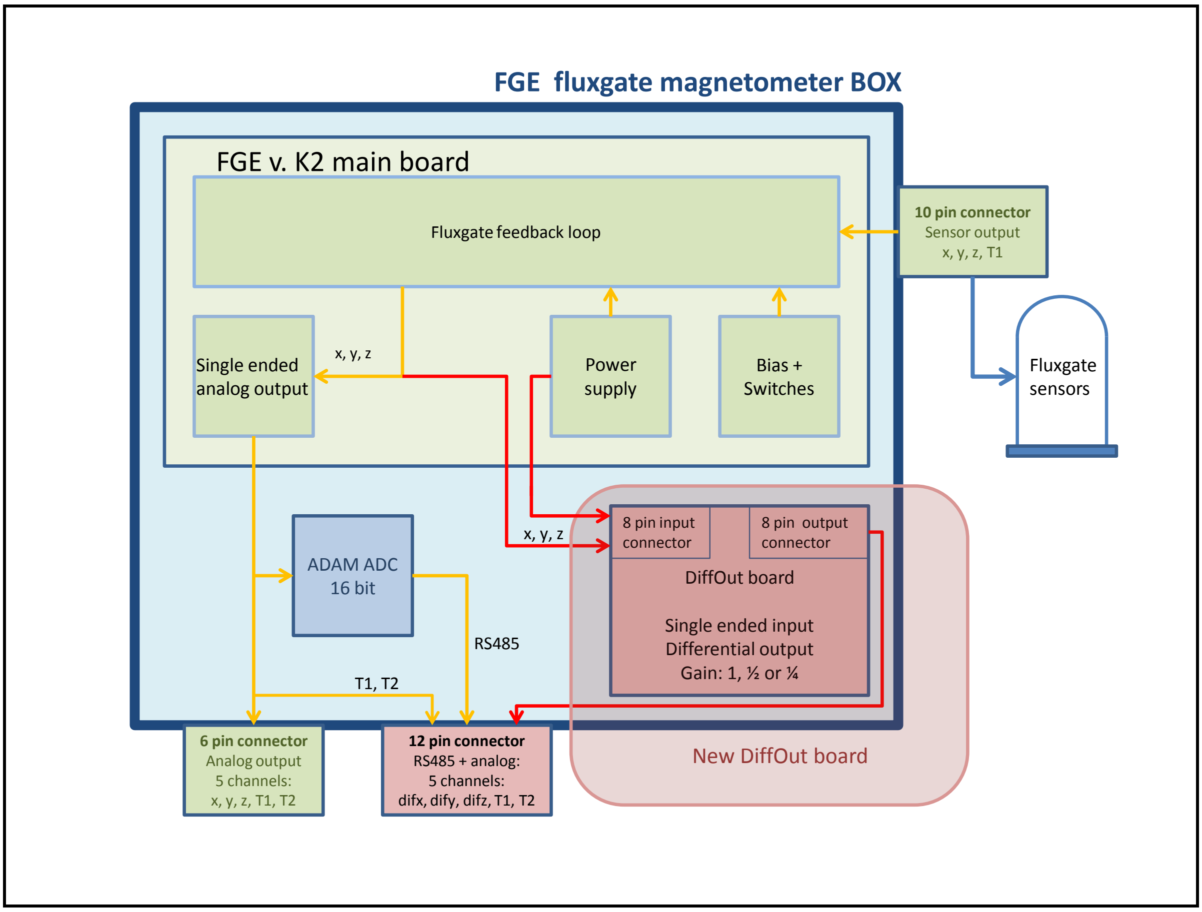


Fig. 7: Block diagram of FGE with new DiffOut board in box.

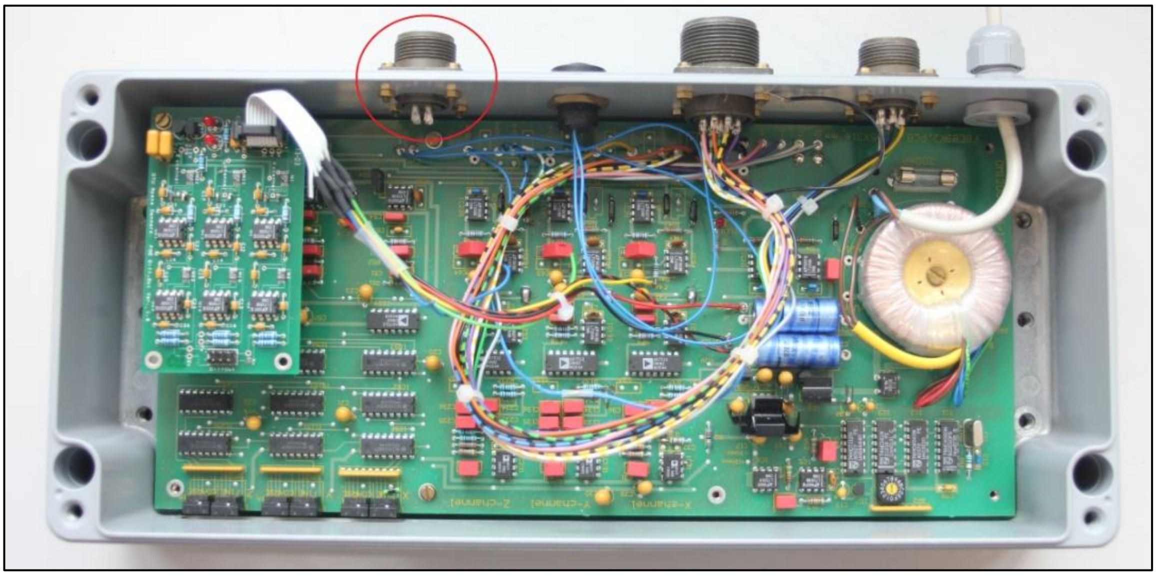


Fig. 8: FGE electronics box with new DiffOut board to the left.

Fig. 8 shows how the small DiffOut board can be placed in the FGE electronics box. The red ring shows the connector that can be replaced with a new 12 pin connector, where both the differential outputs, temperature T1 and T2 and RS485 (digital out) from ADAM ADC will be connected. This is shown in the block diagram in Fig. 7.

Pin		
A	X-	differential X-
B	X+	differential X+
C	Y-	differential Y-
D	Y+	differential Y+
E	Z-	differential Z-
F	Z+	differential Z+
G	T1	single ended sensor temperature
H	T2	single ended electronic temp.
J	GND	Signal ground
K	nc	
L	DATA+	rs485 data+
M	DATA-	rs485 data-

Table 4: 12 pin connector with differential output

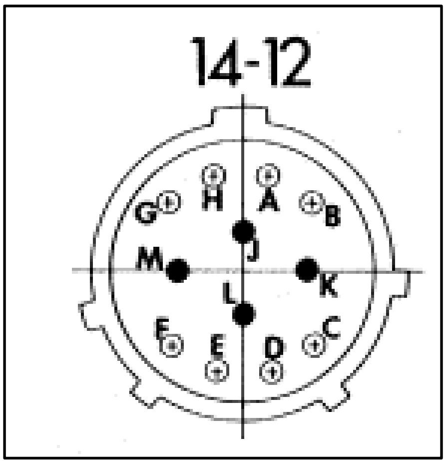


Fig. 9: 12 pol Amphenol

Measurements on DiffOut

The transfer function of the DiffOut was measured at DTU Space's laboratories. For frequency tests we have used a high precision waveform generator controlled by a computer to generate stable sine curves between 0.0083 Hz (120 s) and 60 Hz (16.7 ms).
Data was collected by MinGeo's new data acquisition system ObsDaq vers. 5.5 with 3 channels 24 bit ADC (called x, y and z) at a sample rate of 128 Hz.

A number of periods are recorded for each frequency and the data is analyzed by non-linear fitting using a Marquardt-leveling algorithm.

Frequency respons

The x- and y-input of the DiffOut board were connected to the waveform generator, and the x- and y-output were connected to x- and y-channel of the ADC. The generator was connected directly to z-channel of the ADC as a reference. For each frequency, the amplitude was measured on all 3 channels, and the delay was measured between x and z (reference), and between y and z.

It is seen in Fig. 10, that the delay in the DiffOut is near 1 us for frequencies above 1 Hz. The scatter in delay below 1 Hz is attributed to artefects from the measurement procedure.

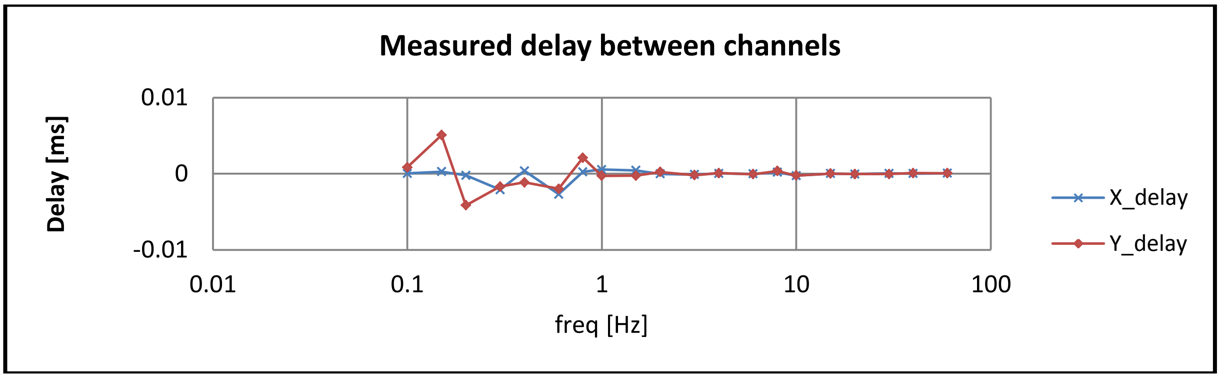


Fig. 10: Delay of channel x and y relative to reference. Delay is below 1 us above 1 Hz.

The phase between DiffOut x, y and the reference is shown in Fig. 11. The phase is constant and almost zero up to at least 60 Hz.

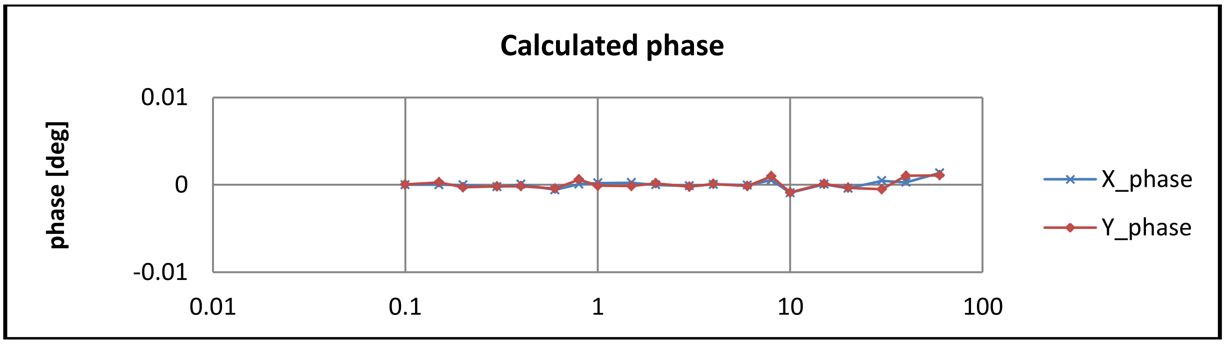


Fig. 11: Phase between channel x, y and the reference.

The amplitude at all frequencies was measured. It is seen back in Fig 4 in z channel, that the ObsDaq ADC is cutting off the amplitude above 30 Hz, due to internal filtering.

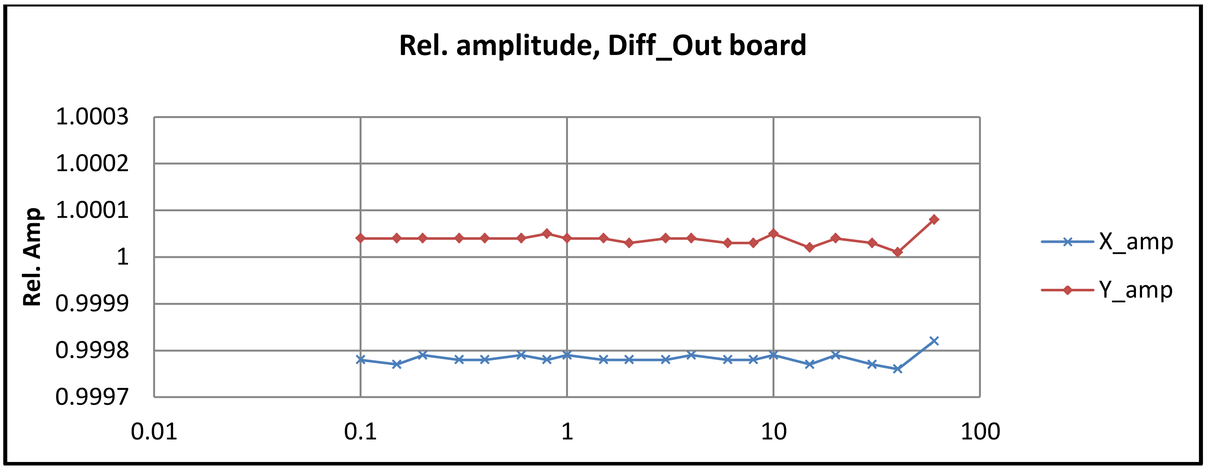


Fig. 12: Amplitude of x and y relative to z. Difference is about 0.1 o/oo.

When the relative amplitude is calculated, data shows (Fig. 12) that the DiffOut is linear up to at least 40 Hz, measured with the ObsDaq AD converter.

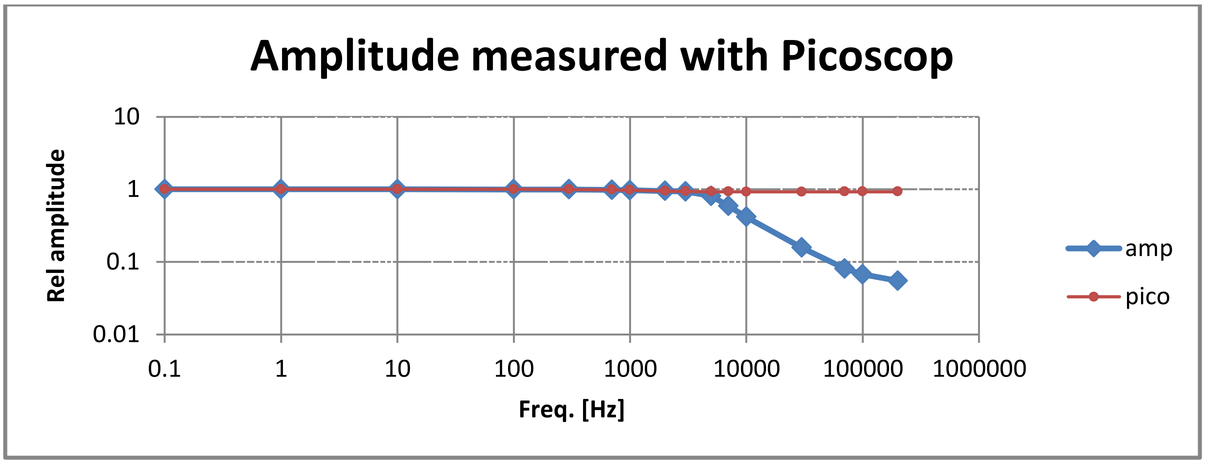


Fig. 13: Relative amplitude (gain) of DiffOut.

Fig. 13 show the transfer function for DiffOut measured with a scope. It is seen that gain of DiffOut is linear up to about 4 kHz.

Linearity

The linearity was calculated by measuring output versus input and then using linear regression. Fig. 14 shows the plot and the linear trend line with coefficients.

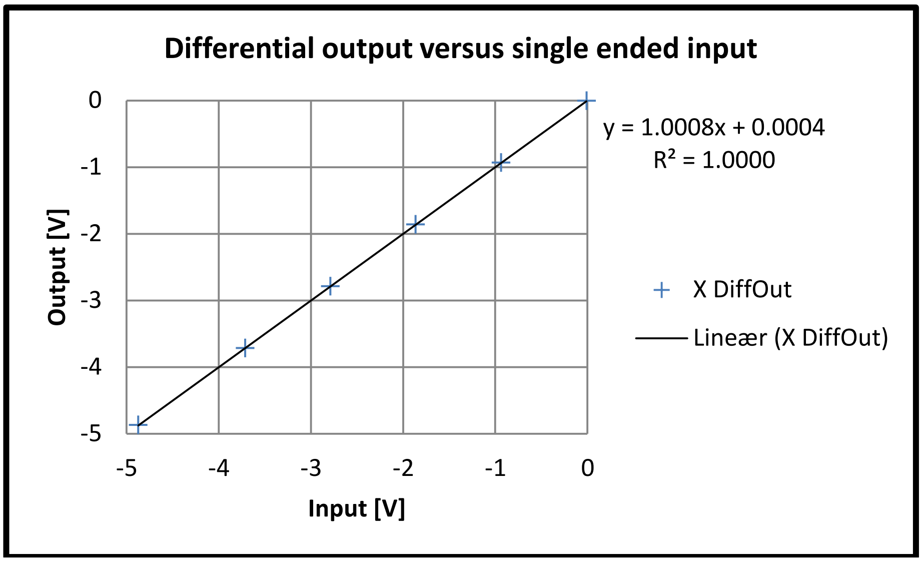


Fig. 14: Differential output versus input.

Temperature stability

The DiffOut board was mounted in a FGE box together with the normal FGE electronics. 3 fluxgate sensors were placed in a zero field cylinder at constant temperature to give stable output. The temperature of the box was changed every 4 hour.
Output (x, y, z and T2 electronics temperature) was then measured for both normal single ended output and the differential output.
Finally we have compared the FGE output with the DiffOut output for different temperatures.

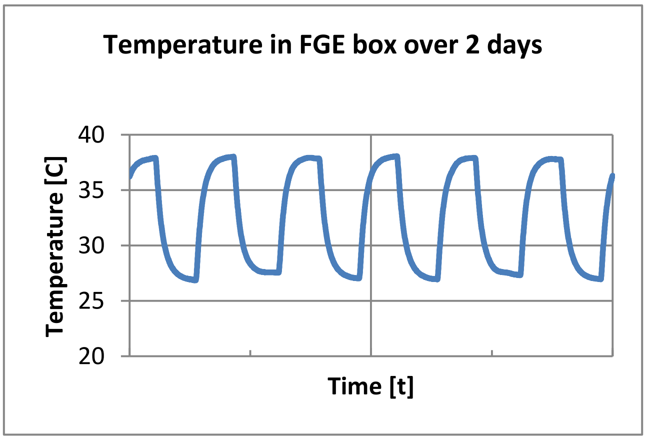


Fig. 15: Temperature of FGE box during 2 days.

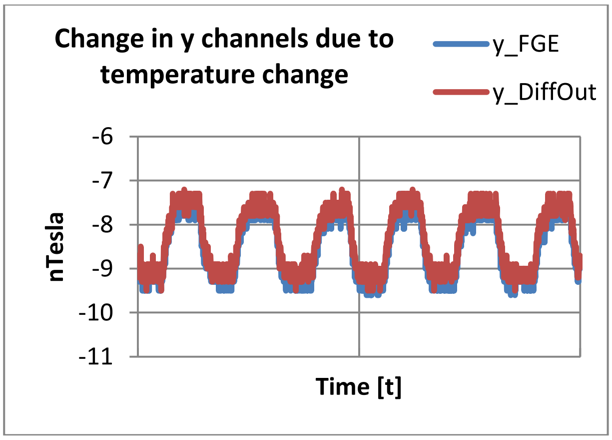


Fig. 16: Output of channel y for both normal FGE and DiffOut.

Fig. 15 shows the temperature measured in the FGE electronic box, where it varies between 27 and 38 degrees Celcius in a 4 hour period. Fig. 16 shows that the output of channel y varies in the same pattern for both normal single ended output andDiffOut. Channel y is shown, since this channel has the highest temperature coefficient, so it is easier to see.

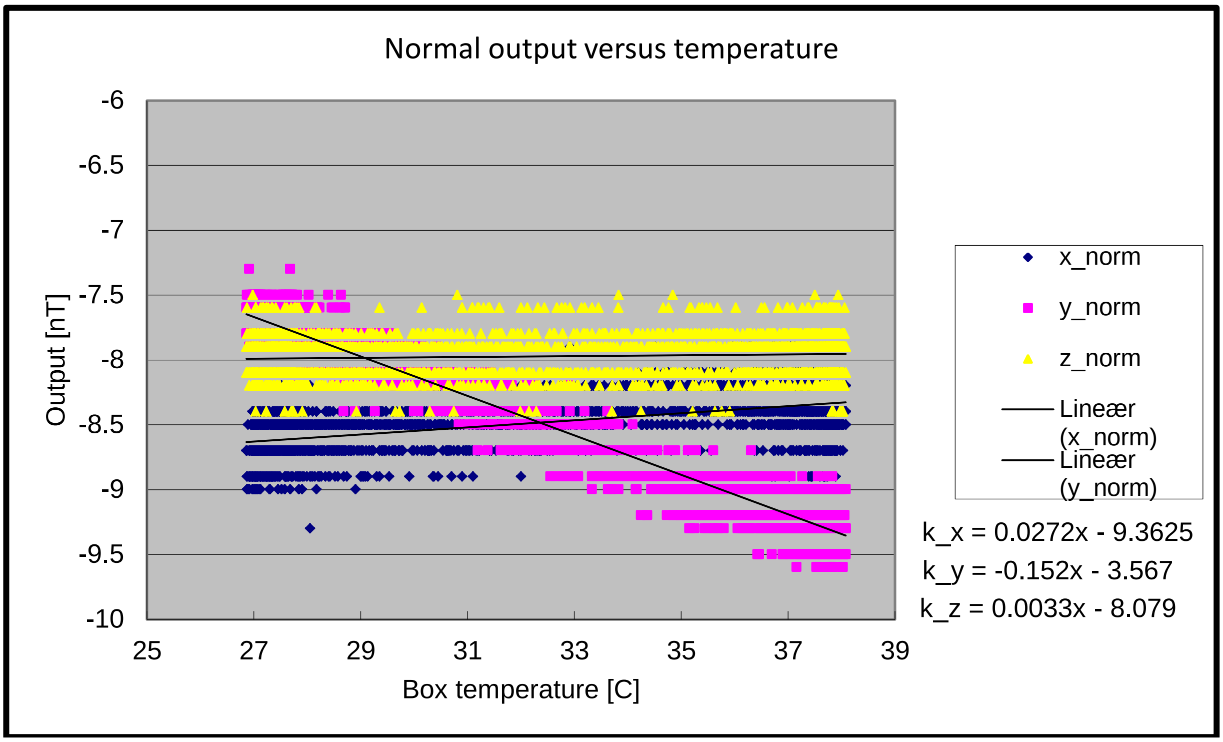


Fig. 17: Normal FGE output versus box temperature.

Fig. 17 shows the temperature coefficients k of the normal FGE fluxgate feedback loop and single ended output amplifiers. The y channel (on this FGE) has a rather big temperature coefficient (k_y= -0.15 nT/degree Celcius).

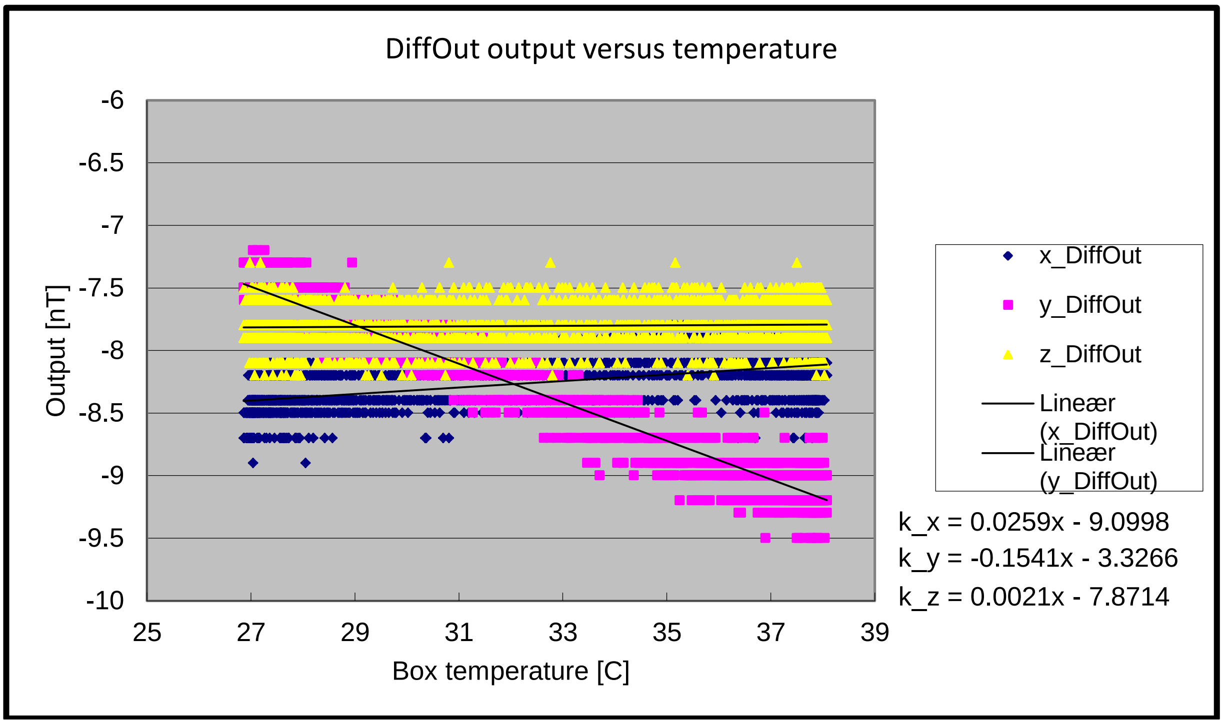


Fig. 18: DiffOut output versus box temperature.

Fig. 18 shows the same data, but with DiffOut output instead of the normal single ended output. Temperature coefficients are almost the same.

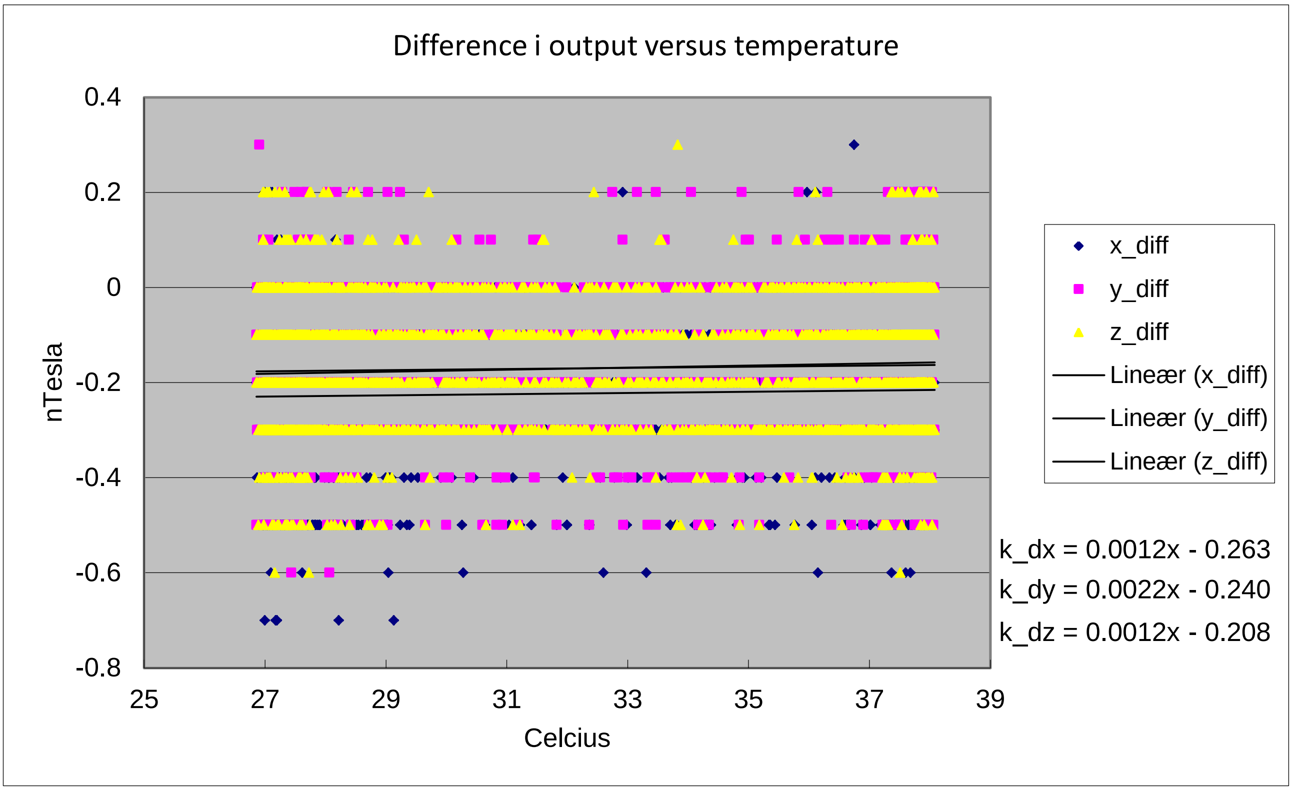


Fig. 19: The differences in output between normal output and DiffOut.

Fig. 19 shows the calculated differences between the normal outputs and the differential outputs, which is the difference between the two output amplifiers. The differences in temperature coefficients are around 0.002 nT/degree, which is only a few % of the normal FGE's temperature coefficients.

Conclusion

The new differential output board DiffOut has:

- linear amplitude between 0.01 and 4 kHz
- No delay or phase shift
- Very good linearity
- Very small temperature coefficient

From this we conclude, that the DiffOut board will not affect the fluxgate signal in any way.