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SENSITIVITY OF VEMA-04.1 MAGNETOMETER

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Vema-04.1, a four channel magnetometer, which is currently being developed at Department of Aviation Technical Studies, has an innovative design of sensor's electronic circuits, based on complex programmable logic device (CPLD). By change in CPLD program, we are able to set different magnetometer operating modes, directly influencing its sensitivity. As the sensors (detecting elements and electronic circuits) are in principle digital, it is possible to influent sensitivity directly by the system clock management. For determining sensitivity of each magnetometer channel we have used a pair of Helmholtz coils (HC). The article deals with sensitivity determination for all four channels of the developed magnetometer.

Keywords: magnetometer, measurement, sensitivity, static conversion characteristic

1 INTRODUCTION

Sensitivity of a magnetometer can be generally increased by various techniques: change in detecting element parameters, change in electronic circuit parameters or combination of both. In our case, detecting elements haven't changed compared to the older types of magnetometers and are composed of relax type ferrosonds based on amorphous ribbon core [1]. The basic function principle is shown in Figure 1. The probe is excited into positive saturation and relaxed within the time *t*+ to the value of external measured magnetic field B_{ex}. Then the probe is excited into negative saturation and again relaxed within the time *t*-. These two time intervals are measured by binary counters, the difference between them carries information of the measured magnetic field B_{ex}. Therefore, we are trying to reach the highest clock frequency for counters, since the sensitivity depends directly on the precision of time measurement. This type of probes is successfully used in industry and laboratories for over 15 years.

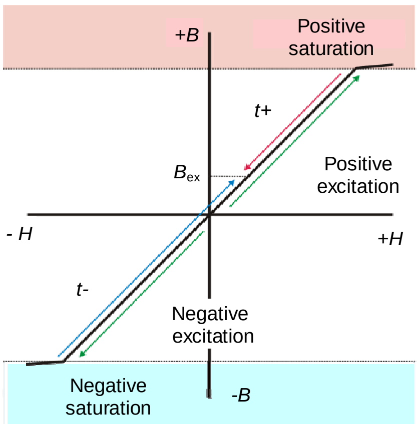

Fig. 1. Basic function principle

The electronics of the new magnetometer is based on a CPLD CoolRunner II. There is one significant difference from the conception presented in [2] – currently we are using two clock oscillators, one for driving the excitation of probes and one for driving the counters, in order to obtain statistically independent signals. By this we will be able to use also autooscillating and microwire based magnetic sensors. By change in CPLD program, we are able to set different magnetometer operating modes, directly influencing its sensitivity. As the sensors (detecting elements and electronic circuits) are in principle digital, it is possible to influent sensitivity directly by the system clock management. The CPLD in the developed magnetometer can operate in a proper mode, when the counters are triggered by both system clock edges, or in a special mode, when the clock signal is used as the least significant bit and counters are triggered only by falling edge of the system clock.

2 MEASUREMENT WORKSTATION

Helmholtz coils (HC) are used for calibration of magnetic probes and field sensors. Constants values of HC, that we have used, see (1), are: $K_1 = 1.913\times10^{-3}$T/A for HC1 and $K_2 = 10^{-3}$ T/A for HC2

$$\frac{B}{\frac{\mu_0 NI}{2R}} = \left[1+\left(\frac{x-a/2}{R}\right)^2\right]^{-3/2} + \left[1+\left(\frac{x+a/2}{R}\right)^2\right]^{-3/2} \quad (1)$$

Our measurement workstation consisted of two pairs of Helmholtz coils. The larger one, labelled HC1, was used to create homogenous magnetic field during measurement of static conversion characteristics of each magnetometer probe. The smaller one, labelled HC2, was used to create sinusoidal magnetic field, which we used to analyse noise parameters of measurements from the magnetometer. HC1 was powered from Agilent E3645 DC Power Supply. The value of DC current through HC1 was measured by Agilent 34401A Multimeter. The sine wave through HC2 was generated by Agilent 33220A Function Generator. Block scheme of the workstation is shown in Figure 2. The red-coloured connectors (marked by *) are the input terminals of coils windings.

Channels were measured in ascending order, all of them are using vector-type probes. Changes in ambient magnetic field were monitored by the VEMA-030 magnetometer (Fig. 3) with a sensitivity of 5 nT.

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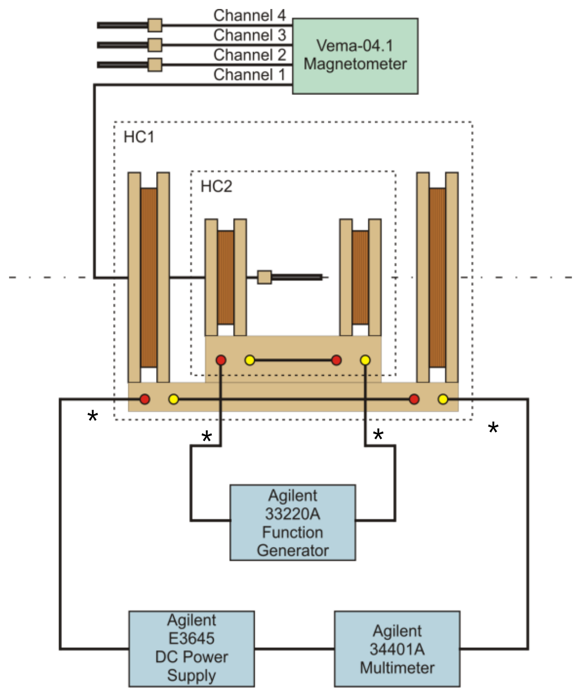

Fig. 2. Block scheme of the measurement workstation

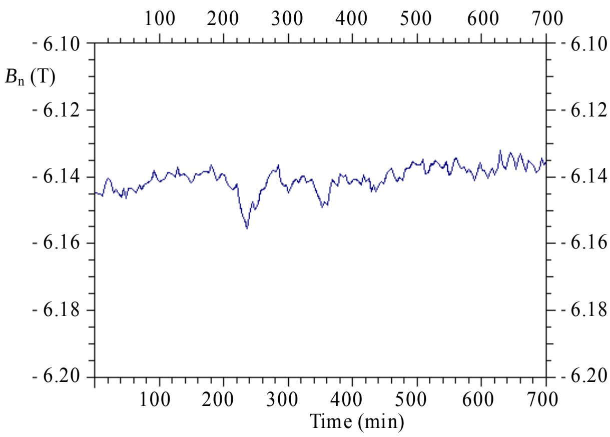

Fig. 3. Magnetic field recorded by VEMA-030

3 MEASUREMENT RESULTS

During our measurement we obtained static characteristics of the probes as they are shown in Figure 4. From these characteristic we could specify the range of the magnetic field induction, in which we can safely use these probes. This range was determined in values from -100 μT to +100 μT. Current clock oscillator, that drives the counters of the magnetometer, has the frequency of 100 MHz. The counters are in dual-edge triggered mode which means that 1 count equals 5 ns. The 100 MHz frequency is used for these reasons:

- It is below the maximal reachable frequency value in order to avoid possible signal glitches that may occur when working with the highest possible value.
- It gives us sufficient precision and sensitivity for optimization of the program in CPLD and analogue electronics.
- It is standardized value of clock oscillator frequency.

As can be seen, characteristic of each channel slightly differs. An analysis was performed in order to specify steepness, offset and non-linearity of the characteristics and it was done with the use of open-source program QtiPlot. Values of mentioned parameters are shown in Tab. 1.

Table 1. Channels parameters

Channel	Steepness	Offset	Full scale non-
1	0.76	7675	1.77
2	0.76	7427	1.16
3	0.75	7802	1.53
4	0.69	6872	0.95

The difference in sign of magnetic field between record from VEMA-030 and the offsets from Tab. 1 is caused by orientation of the probes – they were oriented against each other.

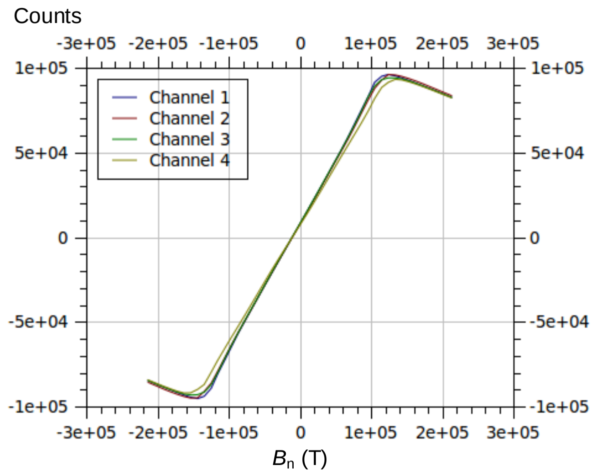

Fig. 4. Static characteristics of the probes

Since we are using digital data processing, we can enhance the precision of the measurement by approximating the conversion characteristics with polynomial fitting curve of third order (Fig. 5). Increase in polynomial order would surely result into better precision, but we are not increasing it, as the required computing performance rises much faster than the value of obtained precision.

In our magnetometer, the CPLD is communicating with MBED microcontroller based on the NXP LPC1768, which is providing interface to USB port of the measurement server. MBED also computes the differences between relaxation time intervals that are carrying the information about value of the measured magnetic field and so lowers the computing load of the measurement server. Information sent by MBED is number of counts, so we need to specify the equations for conversion to the value of magnetic field, while counts is an independent variable.

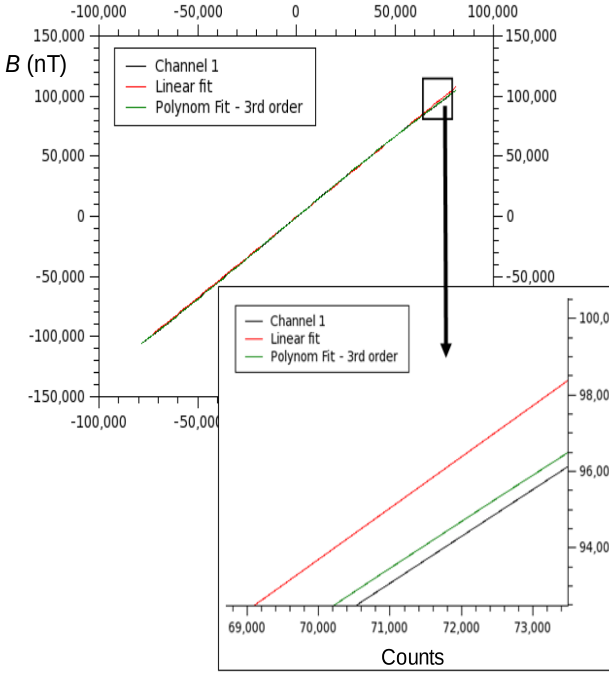

Fig. 5. Difference in approximations

Current values of sensitivities and transfer constants for each channel of the developed magnetometer, with clock frequency of 100 MHz and dual-edge triggered counters, are shown in Table 2.

Table 2. Sensitivities and transfer constants

Channel	Sensitivity (count/nT)	Transfer constant (nT/count)
1	0.76	1.31
2	0.76	1.32
3	0.75	1.33
4	0.69	1.44

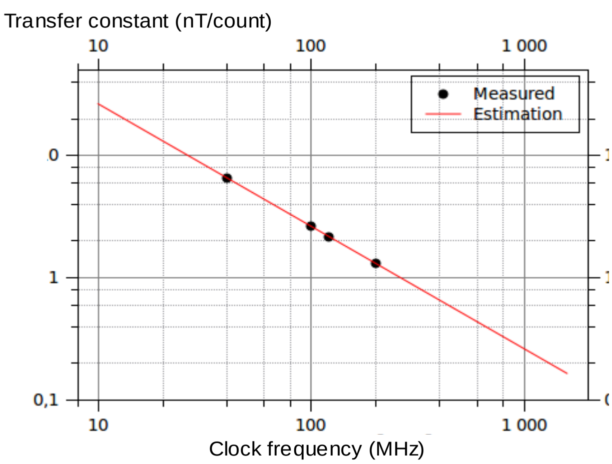

Fig. 6. Estimated sensitivity

In the nearest future, we are going to increase the clocking frequency of counters in the magnetometer. As the CoolRunner II CPLD has top clock frequency limit of 256 MHz for single-edge triggered counters [3], in order to achieve better sensitivity we have to overcome one fundamental problem.

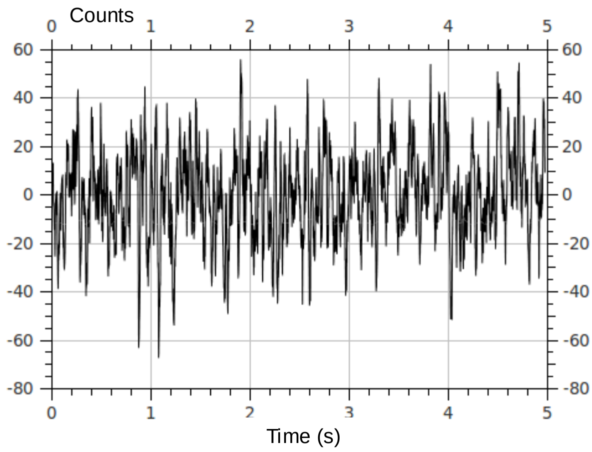

Fig. 7. Example of measured signal waveform after MWA20

When implementing dual-edge triggered counters, the frequency limit decreases to 128 MHz. This is the reason why we are going to use the clock signal as the least significant bit (LSB) and single-edge triggered counters.

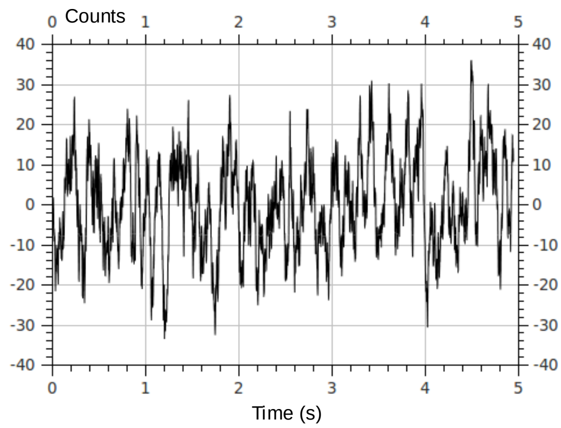

Fig. 8. Example of measured signal waveform after MWA50

With good design structure of program within CPLD we estimate to obtain clocking frequency of 200 MHz, single-edge triggered counters, the clock signal as LSB and therefore reach the transfer constant below 10^{-9} T/count. Figure 6 shows the trend line of measurements we have done so far. The graph shows, that the transfer constant just below 10^{-9} T/count should be reachable around frequency of about 300 MHz, if the counters are in single-edge triggered mode. This estimation is based on the physical principle of the developed magnetometer and on the measurements we have done so far, because the transfer constant and therefore the sensitivity is proportional to the clock frequency that drives binary counters in the magnetometer.

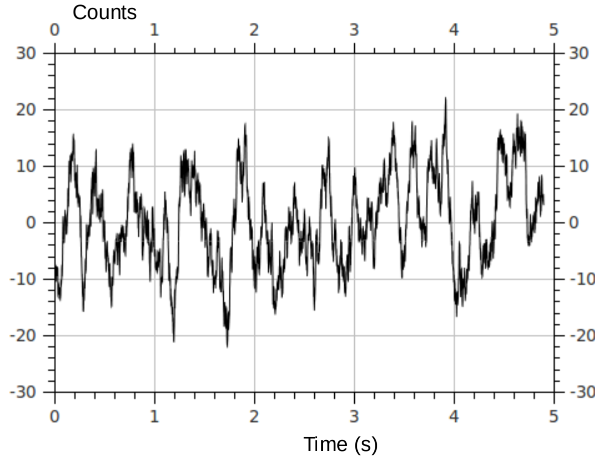

Fig. 9. Example of measured signal waveform after MWA100

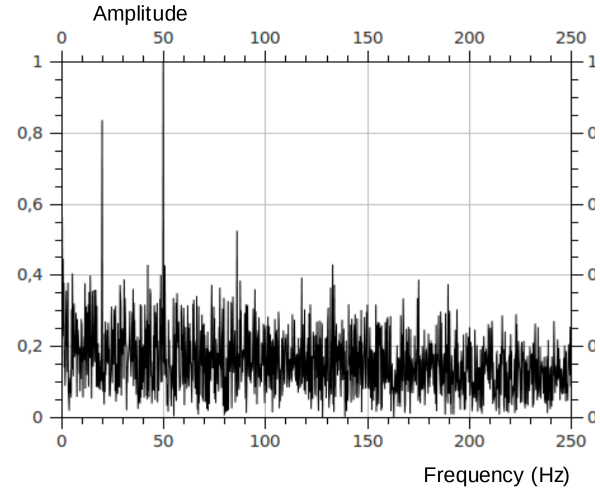

Fig. 10. Frequency spectrum after offset removal

Table 3. SNR and standard deviations after MWA

SNR = 1.5	MWA over 20 samples	MWA over 50 samples	MWA over 100 samples
Standard deviation (counts)	18.24	11.60	8.01

4 BASIC NOISE PARAMETERS

All of the analogue parts of sensors are using exactly the same component types, so they have almost identical noise parameters. Measurement was done in our laboratory, where the industrial 50 Hz field was present.

We also powered HC2 with sine waveform, to determine signal-to-noise ratio (SNR) and observe frequency spectrum of measured magnetic field.

Examples of measured signal waveforms, after application of moving window averaging (MWA) over 20, 50 and 100 samples, are shown in Figures 7, 8, 9. Table 3 shows standard deviations after moving window averages.

Averaging over 100 samples was done in order to remove from the signal the two known frequencies, 20 Hz and 50 Hz, and therefore obtain the noise value, which can be specified as the standard deviation of the signal after removing known, meaningful (information carrying) frequencies.

In Figure 10 is shown an example of normalized frequency spectrum of measured signal after offset removal. This spectrum was obtained with fast Fourier transform in QTI Plot. Clearly visible are 20 Hz and 50 Hz frequencies.

5 CONCLUSION

Measurements, that we have done till this time, prove that the magnetometer transfer constant below 10^{-9} T/count is reachable with this type of magnetometer and probes. Currently we are experiencing some complications, so the 200 MHz magnetometer prototype is not finished yet, we are still waiting for a few components to complete the design, and so we can continue the measurements.

In the nearest future measurements of deep analysis of noise parameters of the magnetometer are also planned. We have to specify values of noises that come from analog electronics part, from the probe itself and from the digital part of the magnetometer. And then, based on the results possibly optimize these parts.

The discussed magnetometer is developed mainly for these purposes:

a) precise long-term measurements of magnetic field
b) research of magnetic field mapping and imaging
c) research in security systems based on magnetic sensors
d) upgrading parameters of industrial magnetometers, for example HFT system – project APVV-0454-07

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