Borehole Orientation Sensor - Hardware Realization

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Abstract — **Borehole measurement systems are used for measuring various parameters in gas, oil, water and other borehole exploration facilities. Measurement methods include the use of various sophisticated tools that are descended into boreholes. Nowadays there is a strong tendency of replacing analogue with digital well logging tools. In this article a hardware realization of one such digital device is presented.**

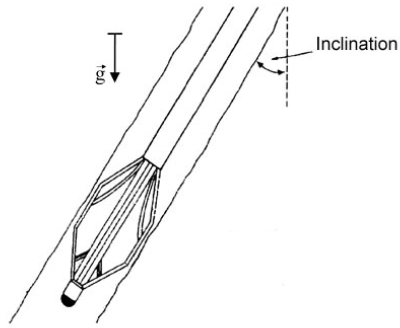
This device is designed to provide orientation information in borehole logging and directional drilling applications. To fully determine the orientation of a borehole two parameters have to be known: the angle between the borehole axis and true vertical (inclination) and the angle of its departure from magnetic North (azimuth). These values are vital for determining the trajectory and depth of a well, and are also very important as preliminary parameters in other geophysical measurements. The orientation module combines a 3-axis magnetometer and 2-axis MEMS accelerometer, analog and digital support circuits, microprocessor and algorithms required for orientation angles computation. The measured values are transmitted to the surface over a mono cable in real time. For this purpose a special digital communication protocol has been developed. In this article the general principles of operation are briefly explained and details related to the electronic design and realization are given.

Index Terms — **azimuth, borehole, inclination, orientation, sensor.**

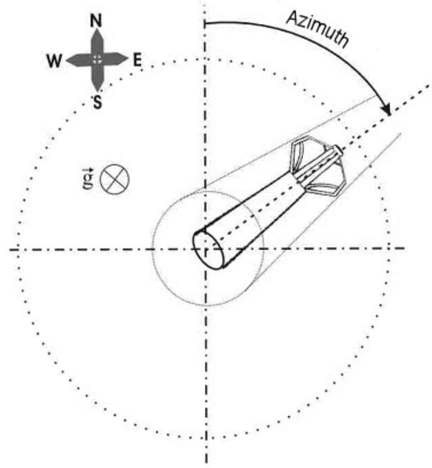
I. INTRODUCTION

Measuring the angle between the borehole axis and true vertical (inclination), and the angle of its departure from magnetic North (azimuth) is of great importance in the process of investigating the characteristics of a borehole (Fig.1). These values are vital for determining the trajectory and depth of a well, and are also very important as preliminary parameters in other geophysical measurements [1]. By industry standards, 0 degree inclination is vertical (downward pointing) and 90 degrees inclination is horizontal. The 0 degree azimuth coincides with North, 90 degree azimuth with East, 180 degree azimuth with South, and 270 degree azimuth with West [2].

In the past different methods of determining the inclination and azimuth have been developed. These methods include descending various sophisticated tools into boreholes and sending the gathered data to the surface. The older analogue logging tools were expensive and often unreliable. The time needed to perform a successful measurement was considerably long. With the development of digital technology it became possible to replace the analogue with digital logging systems. The digital logging tools are smaller, more reliable and more effective for processing and storing data, in comparison to analog logging tools. Using this advantage the overall time and costs of the logging process have been reduced.



(a)



(b)

Fig.1: Parameters to be measured: a) inclination b) azimuth

II. PROBLEM DESCRIPTION

Measuring the inclination of a well bore (its deviation from the vertical) is comparatively simple. As the vertical line is always parallel to the direction of earth's gravity all that is needed is to find the direction of the local gravity vector. An accelerometer uses the force of gravity as an input vector to determine the orientation of an object in space. Accelerometers, particularly the more advanced Micro-Electro-Mechanical Systems (MEMS) type, are becoming more popular and cost effective. A MEMS accelerometer consists of two micro-machined structures to form the plates of a capacitor, one of which is stationary. Under the influence of the gravitational force the free structure would displace to produce a change in capacitance. The device outputs a voltage proportional to the component of the gravity force along the sensitive axis [3].

The azimuth (angle of departure from magnetic north) is rather more difficult to measure. In order to do this, earth's magnetic field has to be detected. A compass needle would settle pointing along the local magnetic field vector, that otherwise is known as the local magnetic north. With the advent of magnetic sensors that operate within the earth's magnetic field such as Anisotropic Magneto-resistive (AMR) sensors, an electronic version of the magnetic compass became a possibility. Such a device has definite advantage over the mechanical version due to its electrical output and high accuracy. The AMR sensors are realized as Wheatstone bridges to measure magnetic fields [4]. With power supply applied to the bridges, the sensors convert any incident magnetic field in the sensitive axis directions to a differential voltage outputs proportional to the magnetic field strength.

III. PRINCIPLES OF OPERATION

To completely determine the orientation of the borehole a three-axis magnetic sensor (electronic compass) and a two-axis accelerometer (tilt sensor) are used. Knowing the tilt of the compass, the horizontal components of the earth's magnetic field can be calculated from the 3-axis magnetic reading. The mathematical approach behind is to measure the magnetic field components in the coordinate frame of the compass device, and also to measure the pitch(φ) and roll(θ), where φ and θ are the rotational angles of the compass. With the pitch and roll information the magnetic components are transformed to the local level plane coordinate system. Then the heading is calculated using the transformed X and Y quantities as defined in Fig.2.

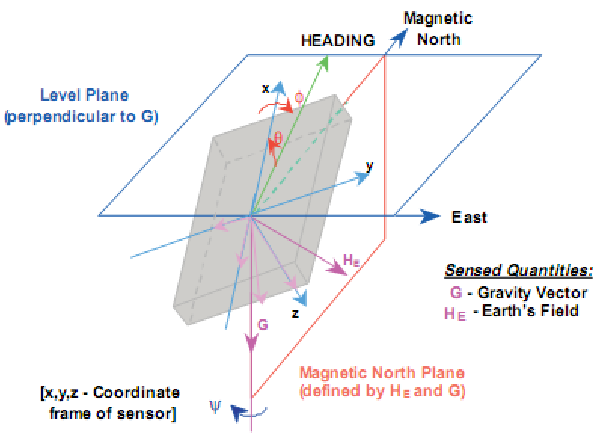


Fig.2: Illustration of gravity and magnetic vectors in the compass coordinate system

The horizontal magnetic components (X_H, Y_H) are used to determine the heading direction. These values can be found for any roll and pitch orientation by using the following formulas:

$$Xh = X\bullet\cos(\varphi) + Z\bullet\cos(\theta)\bullet\sin(\varphi)$$
$$Yh = Y\bullet\cos(\theta) + Z\bullet\cos(\varphi)\bullet\sin(\theta)$$

Because the magnetic and geographic poles do not coincide, the magnetic north and geographic north are not aligned in general. This local variation (declination angle) is described by the angular difference between the magnetic and geographic north, and should be considered in the mathematical calculations.

Fig.3. shows a functional block diagram of an electronically gimbaled compass providing a numerical output of the heading direction (azimuth) and the local gravity direction in terms of roll and pitch (inclination).

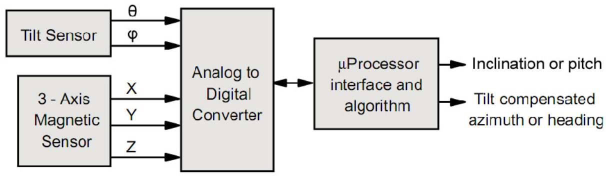


Fig.3: Functional block diagram of a strap-down electronic compass

IV. DESIGN DESCRIPTION

The orientation probe contains both a 3-axis AMR magnetometer, HMC1043 and 2-axis MEMS accelerometer, ADXL203. The combination of these two sensor systems enables the inclination and azimuth angles to be fully determined. The sensors are positioned in a plain which is normal to the probe so that their X and Y axis are overlapped. The accelerometer is most sensitive to tilt when its sensitive axis are perpendicular to the force of gravity, that is, parallel to the earth's surface. At this orientation, its sensitivity to changes in tilt is highest [5].

The measured values have to pass through a complex processing procedure in order to be transformed into final orientation parameters. Before digitalisation, the sensor outputs are conditioned and amplified by additional analogue circuitry. The differential outputs of the magnetic sensor bridges are fed into high precision instrumentation amplifiers to perform the difference measurement and amplification. It is important to have all three magnetic sensor gains equal. As the probe is supposed to work in high temperature environment it was essential to use precision, temperature stable resistors to avoid the amplifier gain drift with temperature. All the measured data is sampled by an 12-bit A/D converter and transferred to a microcontroller. The microcontroller corrects the sensor outputs for voltage offsets and performs all the mathematical calculations before transmitting the data on a serial data link. It is capable of transmitting either the raw magnetometer and accelerometer outputs or the system orientation angles. The high sampling resolution provides angular accuracy of ±0.1° for azimuth and inclination in the tilt range of ±70°. For the same accuracy in the full range of ±90° a 3-axis accelerometer should be used.

The gathered values are transmitted to the surface over a mono cable in real time. For this purpose a special digital communication protocol has been developed. Data is sent in blocks of 8-bit words and there are 6 words in each package. An 8-bit word that lasts 4.8 ms consists of a start bit, 8 data bits, one parity bit and two stop bits (Fig.4).

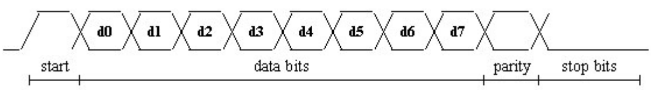


Fig.4: Data word format

Each bit lasts 400µs, and is presented by a stream of negative voltage pulses which are superposed to the supply voltage on the line. Each bit has a SYNC pulse that lasts 50µs (1/8 of the whole bit) at the beginning of the bit. If DATA BIT=1 (logical HIGH) there is also the same type of negative pulse in the middle of the bit. START BIT is presented the same as DATA BIT=1. If DATA BIT=0 (logical LOW) there is no negative pulse in the middle of the bit. This is presented in the following figures.

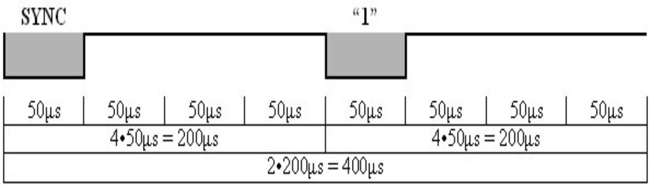


Fig.5: Data bit = 1

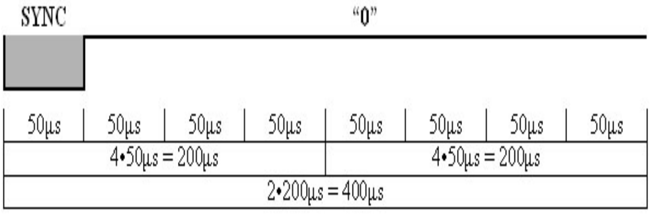


Fig.6: Data bit = 0

2 STOP BITS are presented as pause that lasts 2*400µs and during that time there are no pulses on LINE. The first data bit after START BIT is a LSB, the eight bit is a MSB [6].

The system is powered from the surface using DC regulated voltage. In order to provide stable voltage levels needed for the circuitry, and at the same time keep the power dissipation as low as possible, a combined switching-linear power supply is being used. It consists of a switching (step-down) voltage converter and two linear regulators. The switching power regulator is more efficient but it may produce interference to all the other circuits in the system. Therefore the linear regulators have been added to provide additional stabilization and filtering. This way a lower voltage drop over the linear regulators is achieved, so the power dissipation is significantly lowered.

Special constraints were set by the size of the printed circuit board (PCB) which needed to be compact enough to fit in the casing 3.5cm wide (Fig.7). The casing has to be made of a non-magnetic metallic material. The operation of the probe is limited in the presence of magnetic materials which affect the magnetometer. It could be influenced by metalwork used inside well bores, as well as the metalwork used in drilling equipment. Under such conditions, only borehole inclination can be logged (without directional information).

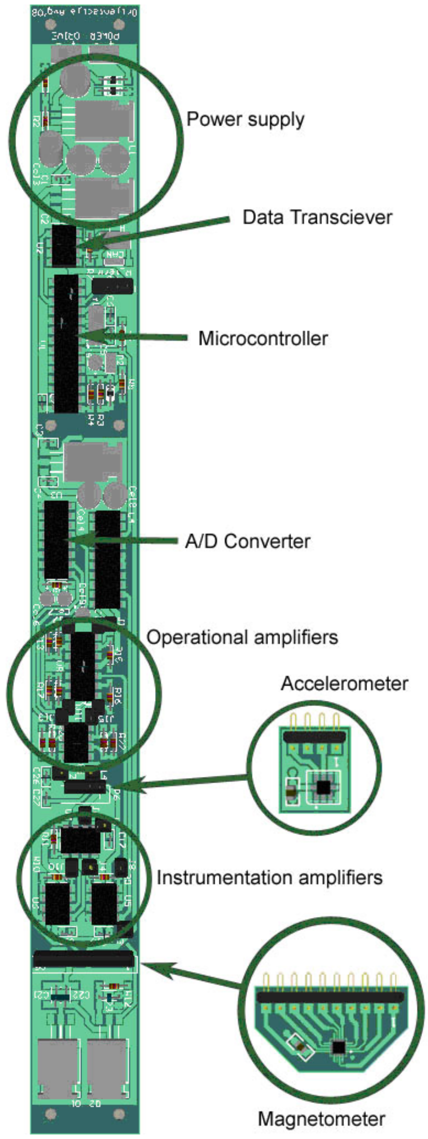


Fig. 7: PCB layout

V. CONCLUSION

The aim of this article was to present a hardware realization of a tool designed to provide orientation information in borehole logging and directional drilling applications. The MEMS and AMR sensors of a new generation have been used for measuring the borehole inclination and azimuth. As the tool is supposed to work in high temperature environment the main issue related to electronics design was the need for components with wide temperature ranges and low temperature dependence of their parameters. The power dissipation had to be kept at the lowest possible level to avoid additional raise of temperature by self heating. Within the mentioned limitations in design, it was a challenging task to provide a reliable logging device with improved resolution and accuracy.

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REFERENCES

[1] G. Mančić, S. Martinović, M. Živanov, “Geofizički karotaž – osnovni principi”, (in Serbian) DIT NIS-Naftagas, Novi Sad, 2002.
[2] Makinhole.com's Glossary, "Directional Drilling Terms Defined", www.makinhole.com/glossary.htm
[3] Caruso, M., Withanawasam, L., "Vehicle Detection and Compass Applications using AMR Magnetic Sensors", Honeywell SSEC, www.ssec.honeywell.com
[4] Honeywell International Inc. "3-Axis Magnetic Sensor HMC1043" , 2007. www.honeywell.com/magneticsensors
[5] Analog Devices, "Precision ±1.7g Single-/Dual-Axis iMEMS Accelerometer", 2006. www.analog.com
[6] M. Slankamenac, K. Knapp, M. Živanov: “The Industrial Communication Protocol in the Digital Borehole Measurement System”, PSU-UNS International Conference on Engeneering and Evironment, Novi Sad, 2005.