BROADBAND TRI-AXIS MAGNETIC FIELD MEASUREMENT SYSTEM

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Abstract- The interaction effects between electromagnetic fields and biological tissues depend on the frequency range of the exposure fields. The measurement of low-frequency magnetic fields with regard to human exposure typically requires two field meters, one working in the frequency bandwidth from 20 Hz to 2 kHz and the other working from 2 kHz to a few hundred kHz. This is why the authors propose a tri-axis measurement system which covers alone the wide frequency range from 40 Hz to 150 kHz. It can be used for both spot measurements and long term monitoring of the magnetic field especially inside the residential buildings.

I. Background

The magnetic field measurements inside residential buildings are generally taken in the middle of the room at about one meter from the ground or in locations where people spend a significant amount of time, for example, the bed. A gaussmeter is, typically, a hand-held device that provides a simple way of performing such measurements. However, these measurements should also be performed several times over the course of a day or, if there are concerns related to the prolonged high level exposure, a long-term survey is required. The computer-based system that we here propose is able to perform long-term measurements over a wide frequency bandwidth.

II. Description of the Tri-Axis Measurement System

The simplified block diagram of the measurement system, containing the active sensor module and the data acquisition device, is shown in Figure 1. The time derivative of magnetic flux density, induction, is obtained by separately measuring the three components of the magnetic field with an external probe that contains three orthogonal identical coils of known characteristics.

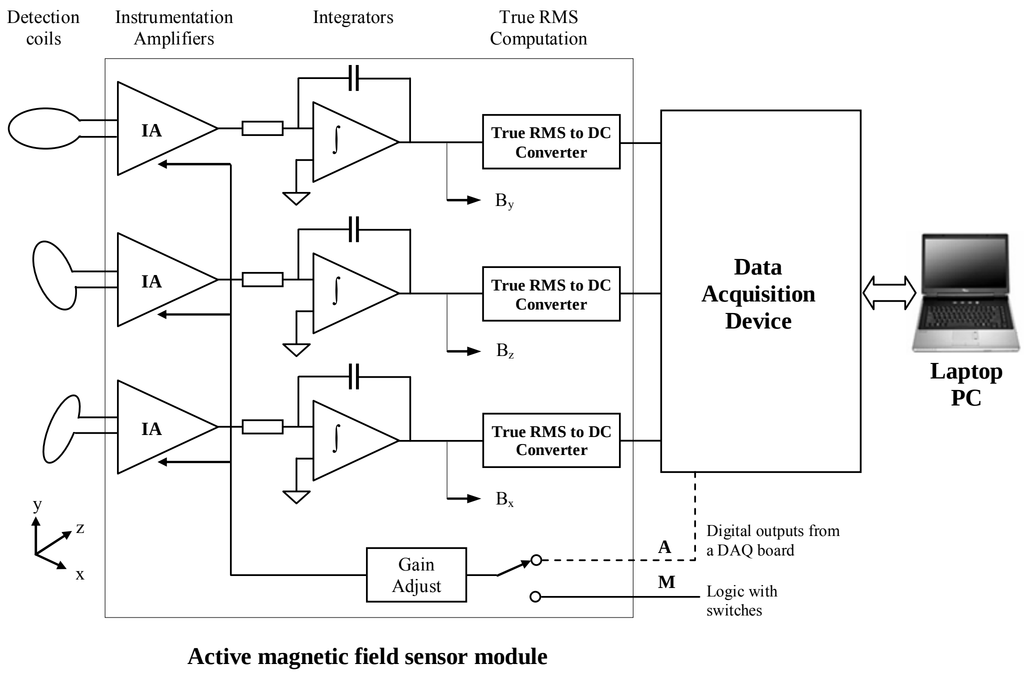

Figure 1. The simplified block diagram of the magnetic field measurement system

The calculation is done using the following equation:

$$B = \sqrt{B_x^2 + B_y^2 + B_z^2}\ , \tag{1}$$

where B_x, B_y and B_z are the r.m.s. values of the three orthogonal components of the magnetic field vector [1], [2], [3]. Rotating the probe will not result in a changing field indication, as long as the magnetic field is constant across the surface of the three coils.

The voltage induced into each detection coil is taken differentially using a very low-noise programmable instrumentation amplifier (IA), considered a better option than making an "unbalanced" measurement employing an operational amplifier in one of the standard configurations. Since the physical movement of the sensor within the earth's magnetic field can generate very low-frequency components, the output of each instrumentation amplifier is connected to a second order high-pass filter, which sets the low limit for the frequency domain at 40 Hz.

In order to retain a flat frequency response for the harmonic components of the magnetic field, each voltage signal is applied to the input of an integrator amplifier. After filtering and time integration, a high precision, wideband RMS-to-DC converter computes the true r.m.s. value of any complex magnetic field, a crest factor compensation scheme in the converter allowing measurements of signals with crest factor up to 10 with less than 1 % additional error. However, independent outputs are available for conducting time-domain and frequency-domain measurements if desired.

In the RMS-to-DC converter, the deviation from ideal r.m.s. value is due to an averaging error, comprised of an AC and DC component. Both components are functions of the input signal frequency and the averaging time constant. The AC component, ripple, can add a significant amount of uncertainty to the accuracy of the measurement being made. This uncertainty can be greatly reduced through the use of a post filtering network or by increasing the value of the averaging capacitor.

When increasing the value of the averaging capacitor, there are two major disadvantages: first, the value of this capacitor will become extremely large, and second, the settling time of the converter increases proportionally to the value of the averaging capacitor. For this reason, we used a 5 Hz, 3-pole, Bessel ripple post filter to enhance the accuracy of the true RMS-to-DC converter for low level inputs. Additionally, an external buffer preamplifier is used to drive the RMS section of the converter instead of the internal unity-gain buffer, which, in this case, is used by the ripple post filter and, generally, is recommended for applications where 100 kHz bandwidth is adequate. Moreover, the input signal for the RMS-to-DC converter is AC coupled so any DC offset from the previous stages will be removed.

The calibration of the tri-axis magnetic field sensor has been made, separately, for each of the three measurement channels, using the standard field method [4]. The frequency response of the active sensor, for a single axis, is shown in Figure 2. The two curves correspond to IA gains of 10 and 100, respectively.

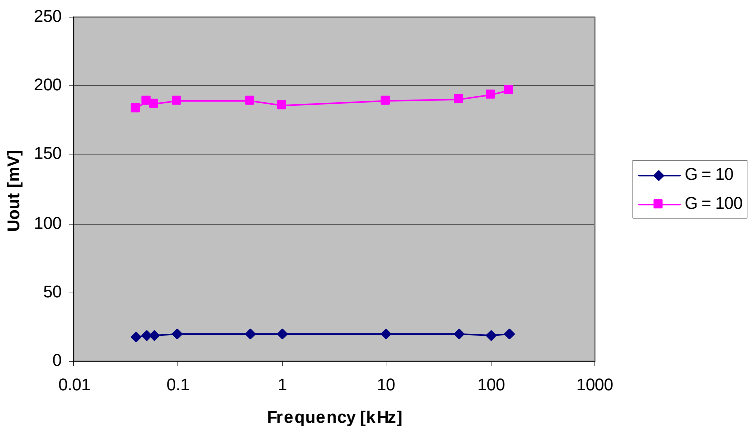

Figure 2. The frequency response of the magnetic field active sensor, for a single axis

For measuring the r.m.s. values of signals from the X, Y and Z detection coils, we designed a low-cost but yet accurate data acquisition system, based on a 12-bit, 8-channel data acquisition IC, that directly communicates with a laptop PC through a parallel port interfacing logic, as shown in Figure 3.

The specific software running on the PC is responsible for ensuring the system functionality and also provides capability for long-term survey of the magnetic field.

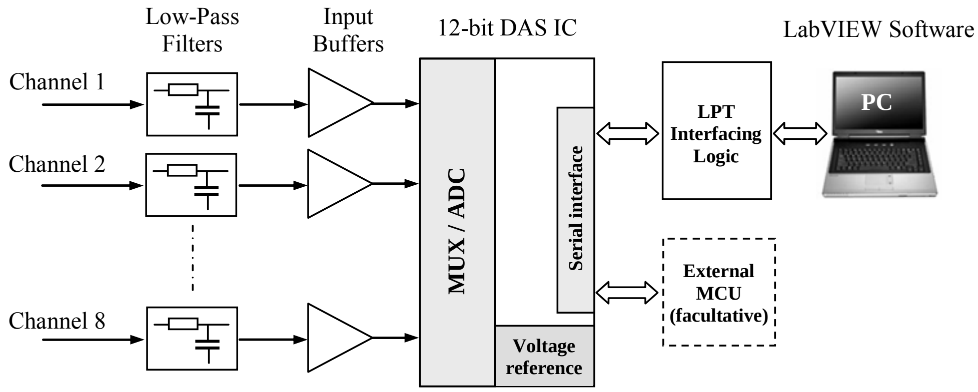

Figure 3. The block diagram of the LPT Data Acquisition System

It should be noted that three waveform outputs corresponding to the B_x, B_y and B_z are available for connecting to an external recorder device. Using a high-speed data acquisition card or a 4-channel digital oscilloscope with FFT functions and PC interface, these waveforms can be displayed, analyzed and stored in a variety of ways. For example, Figure 4 shows the three components of the magnetic field recorded with Fluke 192 Scopemeter when measuring at 1 meter distance from a power supply unit. However, because the entire system is modularly designed, the active sensor part can be used in conjunction with any external device, even a DMM, and the gains can be set manually.

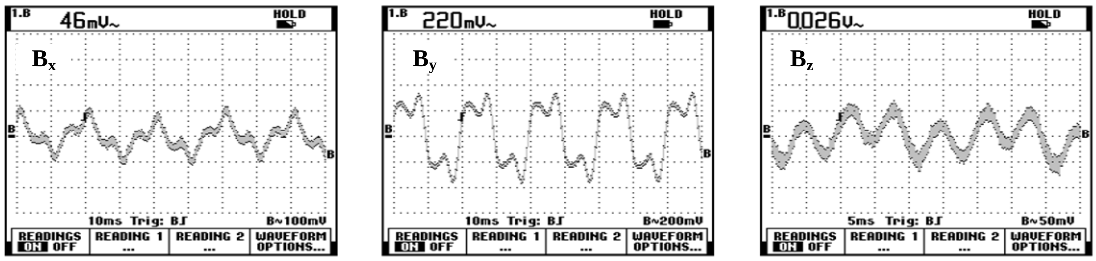

Figure 4. B_x, B_y and B_z components at 1 m distance from a power supply unit

Typically, the applications requiring electronic switching of gains need a multiplexer. Even if the instrumentation amplifier used in this application removes the classic problem of the multiplexer ON resistance, which appears in series with the gain setting resistor, the frequency response and settling time will be yet slightly affected by the ON resistance and internal capacitance of the multiplexer. For this reason, the switch resistance leakage current errors are reduced by using a relay-based gain circuitry. In automatic mode, when the active sensor module is used in conjunction with a data acquisition card, the measurement ranges are set via digital outputs under software control. In manual mode, when used in conjunction with a signal analyzing device, such as an oscilloscope, the gains can be set through a simple logic involving a multi-pole switch.

Figure 5 shows the front panel of the measurement software, developed under LabVIEW 8.0 graphical environment. It works with the LPT data acquisition system in Figure 3 and accomplishes specific tasks such as acquiring data from the active sensor module, computing and displaying the field magnitude based on calibration data and storing the measurement results.

Since the measurement software records all three orthogonal components of the field as well as its resultant value, this approach allows simplifying the identification of the major contributing source of the magnetic field in a complex multi-source environment.

For long-term measurements, the data logging sampling period can be programmed. The software displays the evolution in time of the magnetic field and, if desired, the results can be summarized with the arithmetic mean.

The presented system provides three measurement ranges (2 µT, 20 µT and 200 µT) and is useful for determining the magnitude of the electromagnetic fields generated by power lines, video display units, domestic appliances and many other similar devices.

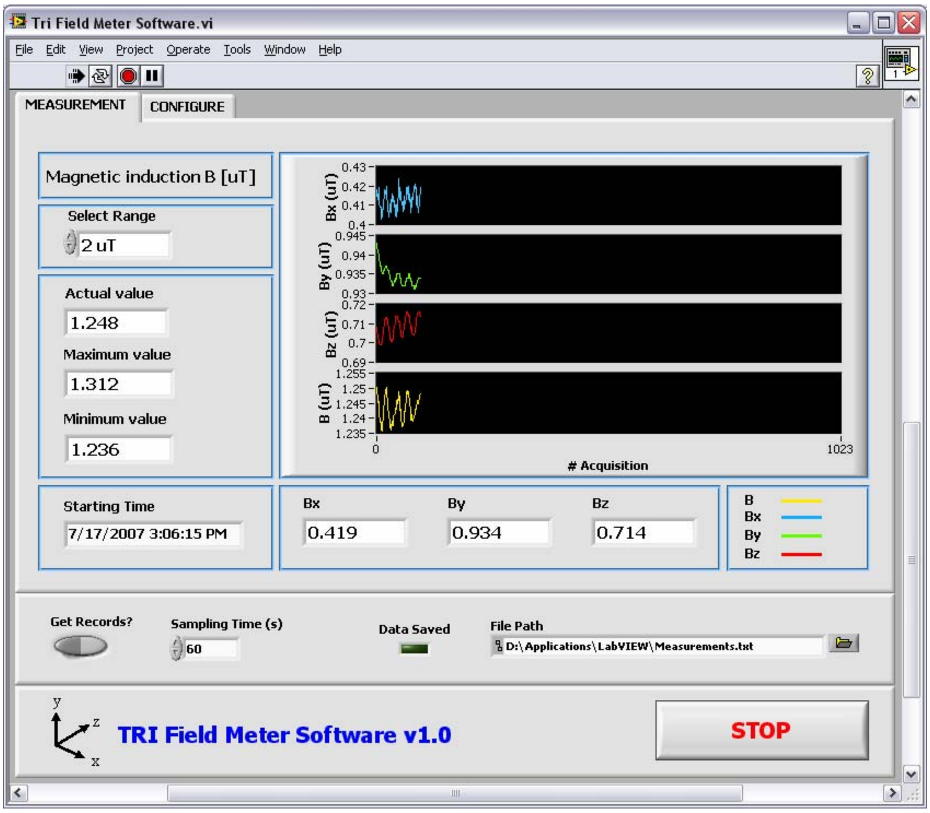

Figure 5. TRI Field Meter Software - user interface

III. Conclusions

A broadband tri-axis magnetic field measurement system with high sensitivity is proposed. The instrument can be used mainly for long term measurements in the wide frequency range from 40 Hz to 150 kHz, being recommended for applications regarding the biological effects of the low-frequency magnetic fields. The true r.m.s. of the three orthogonal components as well as the resultant value can be accurately displayed and stored if needed a possible mitigation work at a later stage.

Acknowledgements

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