Microcontroller Based Magnetometer for Smart Meters Used in Electrical Energy Measurement

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***Abstract**: In this paper is presented the implementation of a versatile magnetometer which is designed for applications in the field of electrical energy measurement, especially for smart meters used in advanced metering infrastructure. The magnetometer is the key element in a smart meter, performing contactless current sensing for precise power consumption computation. The proposed system uses a magnetic sensor with a sensitivity of 2.5 mV/Gauss and a measurement domain of 0−1000 Gauss. All the initial processing of the signal generated by the magnetic sensor, as well as other specific functionalities required by the magnetometer's operation, like calibration and self testing, are realized with PIC16F876A microcontroller and few other complementary analog conditioning circuits. The connectivity of the equipment is ensured by a local RS232 interface and a Telit GE864 GSM/GPS module that allows the integration of the proposed microsystem into a larger smart grid. The innovative design of the proposed magnetometer relies on the intrinsic flexibility and reconfigurability offered by the microcontrollers technology, correlated with the advantages of the GSM interface which resulted in a efficient implementation solution that facilitate the development of intelligent electricity metering networks.*

1. INTRODUCTION

The increasing demands for energy saving and for the introduction of new and advanced services like power quality monitoring and real time notification of residential and industrial customers for consumption optimization involve a significant upgrade of the existing metering infrastructure [1].

Basically, the smart metering concept refers to a group of emerging technologies that allows accurate measurement and remote transmission of data regarding the consumption of various utilities like electrical energy, thermal energy, water, gas, etc. The most targeted application for the smart metering concept is in the field of electricity distribution systems where it can ensure an extended set of information for customers and for power grid operators enabling the improvement of overall energetic efficiency. The principle of power consumption measurement involves the existence, in any type of electrical energy meter, of voltage and current sensing capabilities which are of primary importance. Especially, the implementation of the current sensor rise complex problems because of the stringent requirements regarding the dynamic measurement range and frequency response. The implementation of the current sensor relies mainly on the solutions like: current shunts, current transformers, Hall effect and magnetoresistances. Although the current transformers and magnetoresistances allows noncontact measurement and represents robust methods with many practical advantages, the performances offered by the Hall effect sensor makes him the most suitable candidate for metering applications because it offers an extended frequency response and is capable to operate with very large currents. In this context, this paper presents the design and also the practical implementation of an innovative, Hall sensor-based magnetometer that is intended for applications in the smart metering domain [2], [3].

2. The Structure of the Magnetometer

The general structure of the proposed design is depicted in Fig. 1. The magnetometer is used for the challenging task of non-contact accurate monitoring of the current through a conductor. As can be observed in this diagram, the magnetic field is detected by a Hall effect sensor who's output signal is applied to an adjustable gain amplifier and then is band-pass filtered for removing any unwanted noises or other spurious or high frequency components that could interfere with the analog-to-digital conversion process performed by the internal converter existent in the PIC 16F876A microcontroller. The self calibration and testing procedures are performed with a dedicated test coil and the subsequent blocks that ensure variable external magnetic field on sensor. The configuration menu of the software application that runs on the microcontroller can be accessed through the local keyboard and also through the serial interface. The proprietary algorithms for calibration, testing and usual measurements contain innovative software procedures that offer improved performances for the proposed system [4].

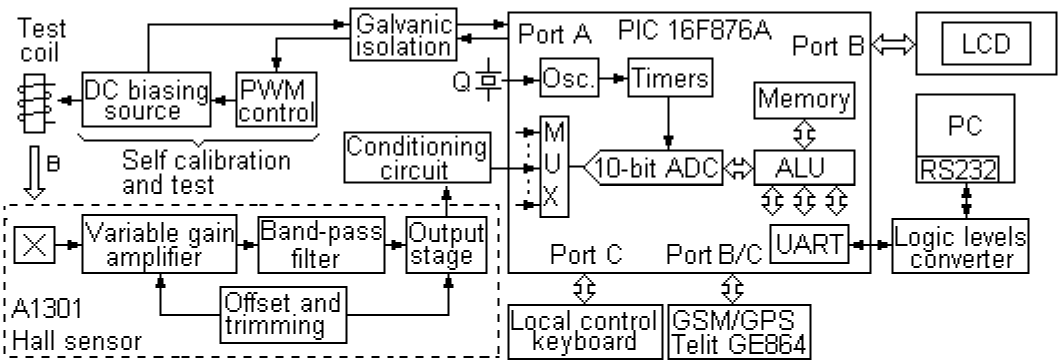

Fig. 1. The structure of the microcontroller-based magnetometer for smart metering applications.

3. The Software Application

The software program used for controlling the operation of the proposed system is realized in PCWH IDE Compiler which is a dedicated programming tool for PIC microcontrollers. The simplified architecture of the main software module stored in the internal flash memory of the PIC16F876A microcontroller is presented in Fig. 2. As can be seen, the first step is represented by the initialization of the internal variables, registers and communication ports. Also, in this stage is initialized the internal analog-to-digital converter (ADC) contained by the microcontroller. The local interaction between the user and the magnetometer is realized through a simple interface comprising a control keyboard and an alphanumeric display. When the system is started, after the predefined initializations, the second step which is performed is the displaying of the general menu of the application. Immediately after that are executed two key software modules: the self-testing and calibration procedure of the Hall sensor followed by the reading of the current value for the magnetic field. The usual operation of the magnetometer can be modified through configuration commands received either from the GSM/GPRS module or from the local keyboard. A special case is when the magnetometer is directly connected to an external PC through the RS232 serial interface. This particular method is intended to be used only when the other two methods mentioned above are not operational [5].

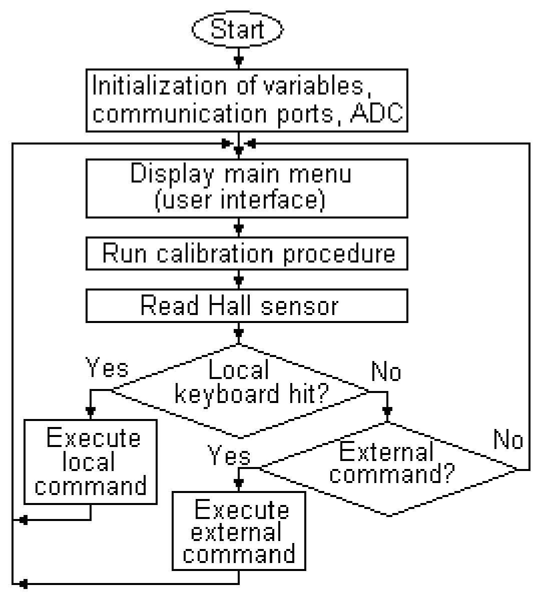

Fig. 2. The logic diagram of the software application for the PIC16F876A microcontroller.

4. Implementation and Results

The hardware design of the microcontroller-based magnetometer which is dedicated for the implementation of smart metering concept in electrical energy measurement systems is presented in Fig. 3. The preliminary tests were mainly focused on the accuracy and the operation correctness of the stand-alone magnetometer. After that, the module was also integrated into a classical energy meter, for sensing the current consumption of various types of loads, including inductive and capacitive loads. Also, different geometries were considered for the measurement setup, with multiple sensor placing positions, aiming to improve the accuracy of the system which is sensitive to the problems generated by the fact that the magnetic field distribution around the measured cable is not uniformly distributed. In the proposed design was used an A1301 Hall effect integrated sensor. The sensor was chosen because it has a continuous-time, linear operation with a good sensitivity of 2.5 mV/Gauss, a bandwidth of 20 kHz and an extended measurement domain of 0−1000 Gauss. The biasing circuits for the test coil and the magnetic sensor circuitry are both galvanic insulated from the rest of the system through high speed optocouplers.

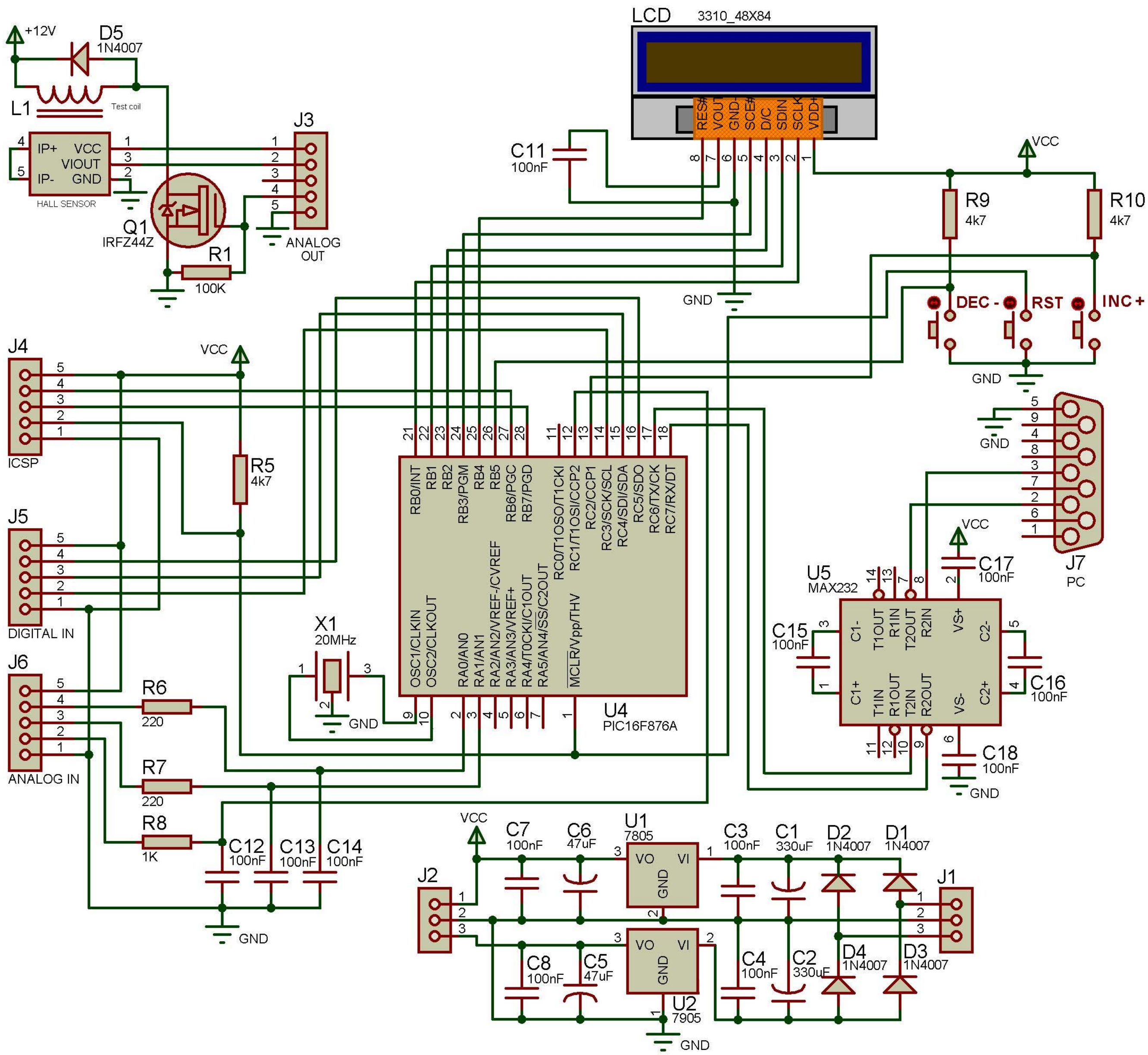

Fig. 3. The electronic diagram of the control module used for implementing the magnetometer.

The aspect of the implemented magnetometer is shown in Fig. 4. In this picture the magnetometer is displaying the level of the magnetic field generated by the test coil which is activated in the initial calibration process. For improved accuracy of practical determinations, the calibration of the proposed magnetometer was also realized with an ENVI PRO magnetometer. The extended tests revealed that the medium accuracy of the proposed magnetometer is around 0,5 Gauss. The measurement accuracy of the proposed magnetometer is primarily limited by the measurement precision of the integrated Hall sensor and by the resolution of the internal analog-to-digital converter which in the case of PIC16F876A microcontroller is of 10 bits [1], [2].

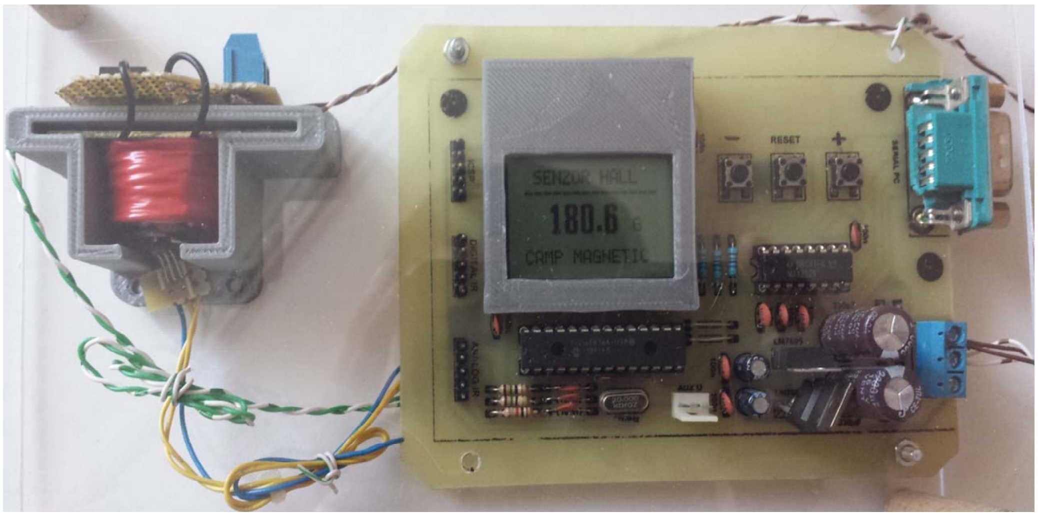

Fig. 4. The hardware implementation of the magnetometer displaying the measured magnetic induction generated by the test coil in the initial calibration process.

5. Conclusions

The implementation of reliable magnetometers using the Hall effect sensors offers many practical advantages regarding the robustness and simplicity of the measurement system.

Being a non-contact sensing equipment, the Hall effect-based magnetometer offers an increased flexibility in the installation of the measuring system, eliminating the need for separate access to the load's conductors and temporary interruption in power supply. The extended frequency response and the capability to operate with large currents represent other key advantages of the proposed design.

Acknowledgement

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