Design and Development of a Multi-Channel Plug-in Type Wireless Data Logger for Energy Measurement

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***Abstract*—Increasing demand of electrical energy and its rising prices have enforced the need of managing usage of electrical energy more efficiently. This requires regular monitoring of electrical appliances to timely identify inefficient energy consumption due to faulty conditions, inefficient designs, user negligence, etc. In this paper, design and development of a multi-channel wireless data logger is presented that aims to accurately measure the value of energy and related parameters like V_{RMS}, I_{RMS} and instantaneous power from more than one single phase application in real time. The proposed data logger is aimed to be low cost and to be a plug and play type device that can easily be introduced between mains and the appliance for energy monitoring. Data collected from various appliances are communicated to a central computer over a Bluetooth wireless link. The computer hosts a simple graphical user interface (GUI) based application that allows user to log the data as and when required. The proposed data logger is designed using CS5460A single phase bi-directional power/energy IC from Cirrus logic interfaced with AVR ATmega32 microcontroller. A wireless link between is established using AUBTM-20 Bluetooth modules from Austar Technology. Serial EEPROM is also included in the proposed design to store the data locally on the board for later use. GUI for the data logger has been designed using MATLAB. The works presented is a part of on going research towards development of a low cost Home Energy Management (HEM) system.**

***Index Terms*—data logger, energy monitoring, bluetooth, embedded system, real time monitoring**

I. INTRODUCTION

Home as well as industries consumes much more electric energy than required mainly due to inefficient designs, faulty devices and user's negligence. Studies show that about five to fifteen per cent of energy can be saved if devices are monitored and handled efficiently [1]-[2]. However, the normal energy metering system that generally exists only give the total amount of energy consumed and thus user is not able to monitor the amount of electricity being used by individual appliance and are also not able to timely identify any drastic difference in power consumption due to faulty condition in the appliance. This proposes a need of a low-cost system that can be easily interfaced various electric appliances in a premise and helps to measure the consumption of electric energy by each appliance in real time.

In this paper design and development of a multi-channel plug-in type data logger is discussed that is capable of accurately measuring energy and related parameters like V_{RMS}, I_{RMS} and instantaneous power in real time from number of single phase applications operating in time multiplexed mode. The data logger is equipped with a Bluetooth based wireless communication module that is capable of neatly communicating the sampled data to a computer without any wired interface. Thus the design becomes a plug and play type multi-channel wireless energy meter that is very simple and flexible to use. Researchers and industries have developed such real time energy monitoring systems, however these requires additional setup and are little less economic [3]-[5]. The proposed design aims to serve two purposes. The first is to provide plug and play type solution for real time data logging from multiple sources that can be used either for testing or continuous monitoring. The second is to develop a low-cost system that can ultimately be converted to full featured Home Energy Management (HEM) system that can gather energy consumption data from number of appliances over a premise and also perform local control based on command signals issued from HEM system [6]. Use of such system would help to implement programs like demand side management at customer premises enabling them to play a proactive role in efforts towards energy conservation and also towards the goals of smart grid [7]-[9].

The rest of the paper is organized as follows. In section 2 design requirements and proposed system architecture is discussed. In section 3 and 4 details of hardware and

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software involved in the design of the system are discussed at length. This is followed by discussion on experimental results in section 5, future direction of work in section 6 and conclusion in section 7.

II. Design Requirements and System Architecture

Following design requirements were proposed to be met by the system.

1. Compatible to any single phase application connected to standard 16A source.
2. Able to monitor energy and related parameters, like V_{RMS}, I_{RMS} and instantaneous power, in real time from more than one appliance by operating in time multiplexed mode.
3. Measured data to be logged into local memory as well as central computer acting as a master of multi-channel network.
4. Data communication between appliance and central computer to be wireless avoiding the use of additional cables.
5. A simple GUI based application to run on central computer for easy user access.
6. Low cost and simple to add and remove.

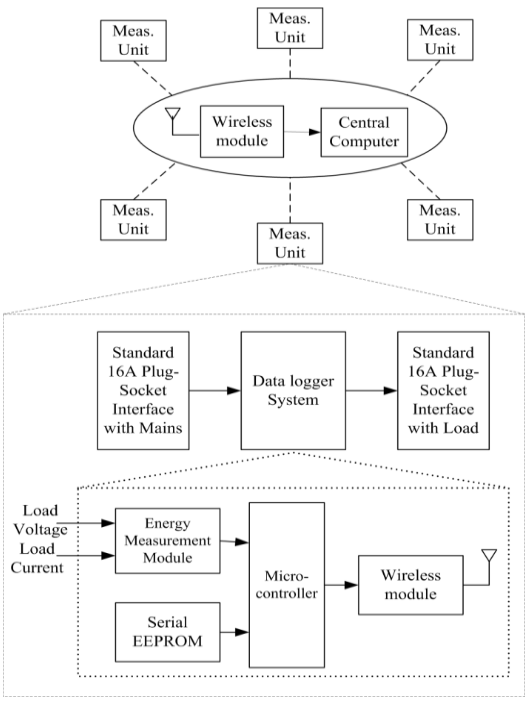


Figure 1. System architecture

To meet the mentioned requirements the proposed system architecture is shown in Fig. 1. System will consist of number of measuring units each interfaced with the appliance to be monitored. All such measuring units will be connected through a wireless link to a central computer that is responsible for data logging. Measuring unit typically will be a plug and play type of device. On the input side it will be connected to mains through a standard 16A plug-socket interface and a similar plug socket interface will be available on the output side for connecting the appliance whose energy monitoring is intended. In the measuring unit the module responsible for energy measurement and data logging will be a microcontroller based unit with energy measuring module, EEPROM, wireless module for communication and other interfacing modules. Here, energy measuring module performs the task of measuring energy and related parameters continuously. Microcontroller will fetch this data at regular interval, update the data in local memory and also forward it to wireless module to communicate it to central computer if wireless link is active. Central computer will act as a master of the network and will be responsible for making or breaking connection with any of the measuring unit for enabling or disabling communication of data.

III. System Hardware

System hardware designed as per the proposed architecture discussed in section 2 is discussed in this section. It consists of two modules: one for data measurement and transmission, which in Fig. 1 referred as measuring unit and another for data reception and logging on a central computer. This is shown in Fig. 2(a) and Fig. 2(b) respectively.

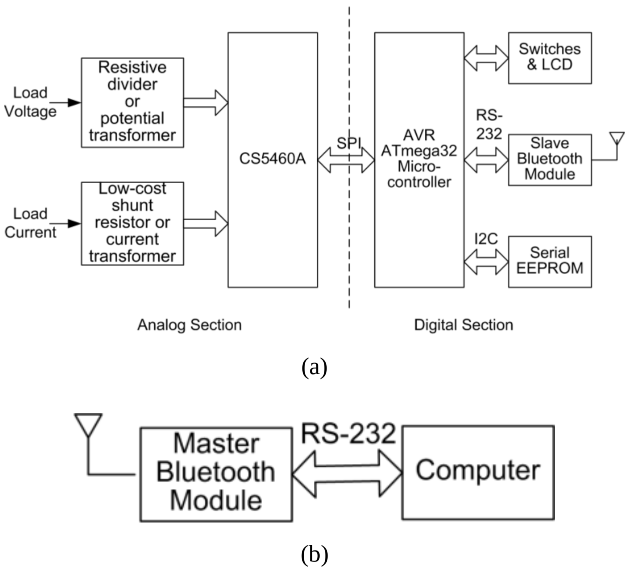
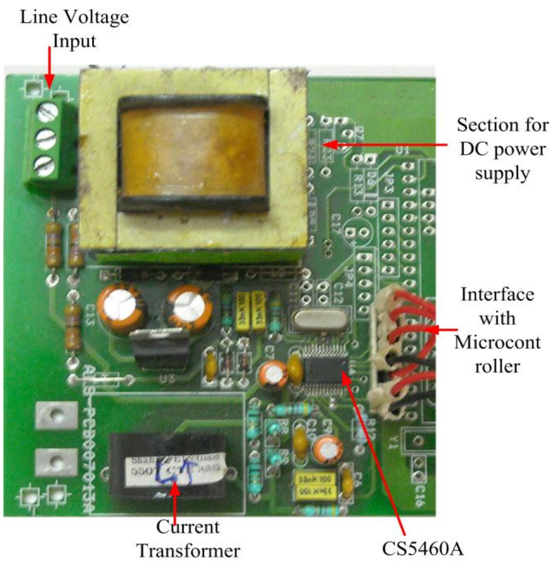


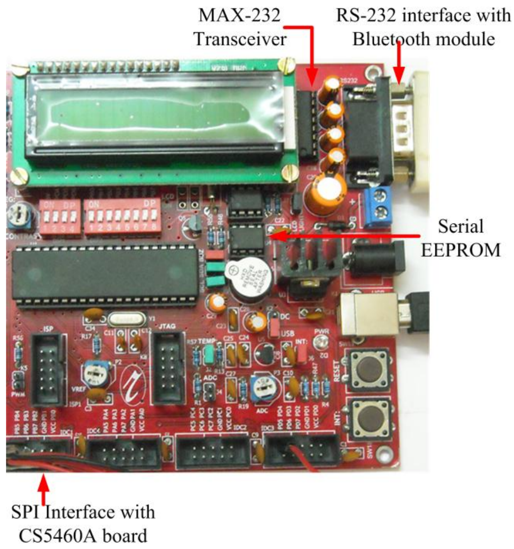
Figure 2. System hardware: (a) Measurement and transmission module (b) Receiver module

The first module, more complicated of the two, can be partitioned into two main sections: analog and digital as shown in Fig. 2(a). Analog section in the transmitter module, responsible for energy measurement, is designed using CS5460A. The CS5460A consist of two 24 bit ΔΣ ADCs, high speed power calculation functions with digital filters for signal conditioning and a serial interface all on a single chip. It is designed to accurately measure and calculate: energy, V_{RMS}, I_{RMS} and instantaneous power for single phase 2 or 3-wire applications. It meets accuracy specification for IEC 687/1036, JIS [10]. It can be interfaced using a simple resistive divider or potential transformer to measure voltage and with low-cost shunt resistor or current transformer to measure current. It supports auto-boot feature to function as stand-alone device as well as a standard bi-directional three wire serial interface (compatible to SPI and Microwire) for communication with microcontroller. The CS5460A also supports on-chip facility for AC or DC system-level calibration for both voltage and current channel. It has internally around twenty 24-bit registers related with configuration, calibration, status and data that can be read or written by microcontroller. A board designed for this analog section is shown in Fig. 3(a). Voltage input to the board is through a resistive divider network and current input is through current transformer. SPI interface is used to connect it with microcontroller.

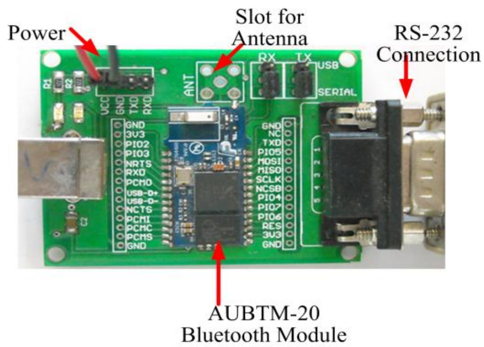
Digital sections consist of AVR ATmega32 microcontroller, AUBTM-20 based Bluetooth module, serial EEPROM 24c04, LCD and few switches. In addition to the general advantages that ATmega series microcontroller has, the reasons for selecting ATmega32 is that it supports all the three type of serial interface required in this design [11]. These are three wire serial interface required in interfacing with CS5460A, two wire serial interface required in interfacing of serial EEPROM and standard USART for RS232 interface required for Bluetooth module. Bluetooth module connected with each of the measuring unit is configured as a slave and the one connected with a central computer is configured as a master. When connection is established by the master, the slave will pass the measured data to the master. Once master and slave are connected, to disconnect the link it is required to reset the slave module. This is achieved in the design by use of a simple hardware that enables power to Bluetooth module under the control of ATmega32 microcontroller. The role of on-board serial EEPROM is to store the total energy consumed over the time since the beginning of the measurement. Switches and LCD are provided mainly for debugging and on board monitoring. Board representing the digital section is shown in Fig. 3(b) with Bluetooth module in Fig. 3(c).



(a)



(b)



(c)

Figure 3. (a) CS5460A based energy measurement module (b) ATmega32 based microcontroller module (c) AUBTM-20 based Bluetooth module

IV. System Software

Systems software consists of two main programs: microcontroller program for measuring units and GUI application program on central computer.

Program on microcontroller consist of two modules, one for initial calibration of CS5460A and second for real time measurements and data logging. Before using CS5460A for measurements for the first time, it has to be calibrated following a specific sequence and these calibrations values are then saved in serial EEPROM for later use during measurement. For both voltage and current channel there are calibration sequence both for AC and DC purpose. Calibration in AC or DC is primarily of two basic types: system offset and system gain. Depending on the specific metering application and accuracy requirements, some or all of the calibration sequences may be required to be executed. There are dedicated registers in CS5460A for specific calibration sequence. The steps for calibration process are shown in Fig. 4 with the recommended sequence in Table I. Calibration of each type requires applying appropriate inputs on the input channels, issuing calibration

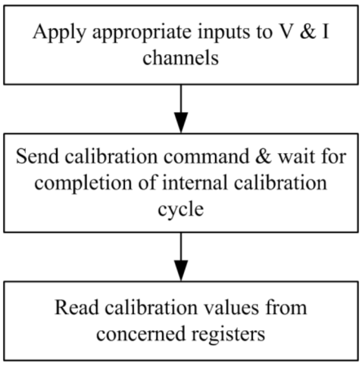


Figure 4. Steps in calibration process

TABLE I. CALIBRATION SEQUENCE

Preferred Sequence	Calibration Sequence	Inputs applied to V/ I channels
1	DC offset	Connected to ground level
2	AC offset	Connected to ground level
3	DC gain	DC signal equivalent to absolute peak full scale value of input
4	AC gain	AC signal with maximum possible RMS value of input

commands and reading result from the concerned registers at the end of calibration. As shown in Table 1, if both AC and DC calibration has to be performed then DC calibration should precede AC calibration and if both offset and gain calibration has to be performed then offset should precede gain [12].

Flow chart highlighting the sequence of major operations performed by microcontroller program for real time measurement of energy is shown in Fig. 5. On power-on CS5460A is required to be initialized. This involves two operations. First operation is to fetch calibration values that are stored in serial EEPROM and load them into concerned registers in CS5460A. Second is to define conversion cycle and computation cycle rate. Conversion cycle indicates the rate at which instantaneous voltage, current and power is obtained and computation cycle indicates number of these instantaneous values that are used to calculate V_{RMS}, I_{RMS} and energy over the period. For example, if conversions cycle is 4000Hz and computation cycle is set to one second, then V_{RMS} and I_{RMS} will be calculated using 4000 samples of instantaneous values of voltage and current respectively and energy over one second will be calculated summing 4000 samples of instantaneous power. These cycles are again defined by loading appropriate values in concerned registers. These values depend on the clock frequency of CS5460A.

After initialization of CS5460A the slave Bluetooth module connected with microcontroller is enabled i.e. powered ON. This is done by a simple arrangement where microcontroller enables a buffer that is responsible to provide power to the slave module. The reason for this arrangement is that on power ON Bluetooth module is in command mode but in the later stage when master and slave modules are connected for data transfer both enter into data mode and after this to disconnect them and bring them back in command mode when required; one of the modules has to be reset.

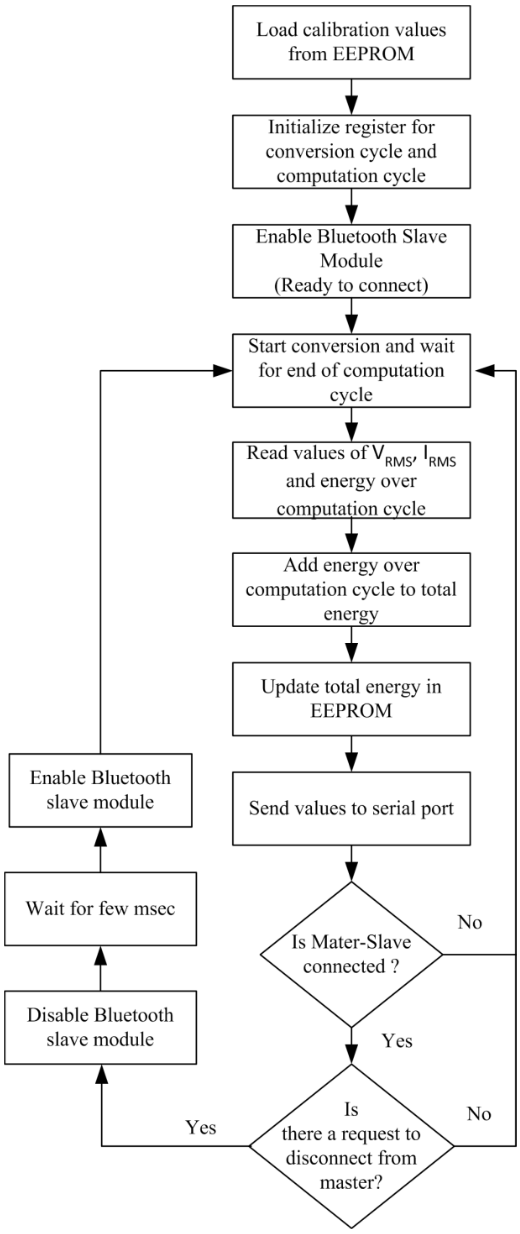


Figure 5. Process of acquiring measurements from CS5460A.

Further, before interfacing Bluetooth modules in the system they have to be configured for baud rate, mode of operation (master/slave), identification number, etc. This is done by sending series of AT command to Bluetooth module using some serial port utility. Various AT commands used for configuration as well as data transfer are discussed in Table II [13].

After initialization of CS5460A and enabling of Bluetooth module, the process of data measurement starts. Microcontroller handles this process in a polling mode. At end of each computation cycle value of V_{RMS}, I_{RMS} and energy are read. Energy over the period of each computation cycle (e.g. duration of 1 sec.) is accumulated to have the total amount of energy consumed and this count is updated in serial EEPROM. Further all the values measured over the computation cycle are by default sent to the serial port where the slave Bluetooth module is connected. Thus when master and slave Bluetooth link is active the measured data is transferred to central computer.

GUI based application is developed in MATLAB for data logging on a computer. A snapshot of GUI is shown in Fig. 6. The application supports following features

1. Receive the data from a specific measuring unit or from all active measuring units around in round-robin fashion.
2. Duration for which data has to be received from each measuring unit.
3. Total duration for which data has to be logged.

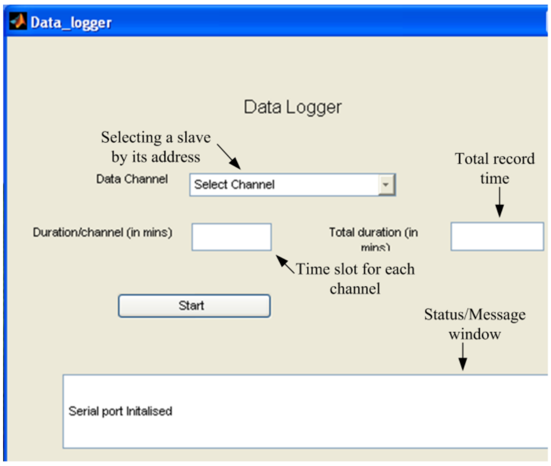


Figure 6.. Snapshot of GUI application for data logging on computer.

While operating in a round-robin fashion, master Bluetooth module is made to first identify all active slave modules associated with measuring units present in the vicinity. After this the application program commands master to connect with each slave, one at a time, and log the values V_{RMS}, I_{RMS} and energy as transmitted by the measuring unit. Data is logged from each measuring unit for specified duration after which master sends a command to slave to reset and disconnect the link. Once the link is disconnected master connects to the next slave in line and logs the data. This continues in round robin fashion for the total time specified. Measurements received by GUI are stored in from a matrix and remains available for off-line analysis also.

TABLE II. AUBTM-20 BLUETOOTH MODULE AT COMMANDS

AT Commands	Description
AT+SETUP	Shows current setting of module like baud rate, mode of operation, address etc.
AT+MODE	Define the mode of operation that can be Master, Slave or Auto Connect.
AT+PIN	Set PIN code for the Bluetooth module
AT+BPROFILE	Set current active profile that can be either serial port, head set or hands free
AT+INQ	Discover other Bluetooth modules in the neighborhood.
AT+CON	Create a connection with other Bluetooth device.

V. EXPERIMENTAL RESULTS

Designed data logger has been tested for varieties of load of different capacities and type. For example a fixed resistive load, variable resistive load, induction motor etc. Appropriate scaling factors were identified for ADC. This is required because measured value of V_{RMS} and I_{RMS} are available as 24 bit unsigned value in the range of $0.0 \leq V_{RMS}, I_{RMS} \leq 1.0$, whereas that of energy is available as 24 bit singed value in the range $-1.0 \leq E < 1.0$. Further, AUBTM-20 is a Version 1.2, class-2 Bluetooth module that as per specifications gives connectivity range of around 10 meters; however range of successful communication without antenna was found to be less than 2 meters and with antenna was around 8 meters.

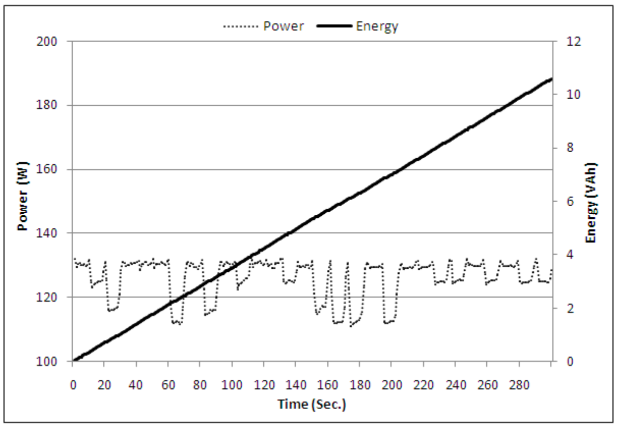


Figure 7. Power and energy measured over a single channel.

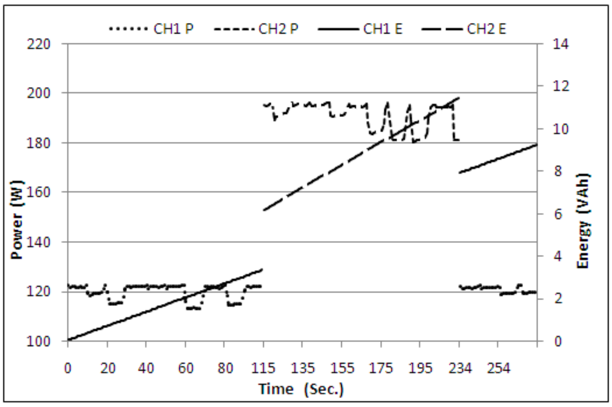


Figure 8. Power and energy measured over two channels.

Maximum bit rate supported by Bluetooth Version 1.2 is around 1 Mbits/s; however as the required bit rate in our case was well below the maximum possible this was not much of the concern. While attempting to use it in a multi-channel mode, the performance was verified with successful data logging from four measuring units. As per Bluetooth specifications maximum number of salves which a master can deal with are seven [14].

In Fig. 7 readings of power and energy recorded in a log file as received from a channel scanned continuously are plotted. Reading are taken every second and passed to the computer over Bluetooth link. In Fig. 8 reading from two channels are plotted. Each channel is scanned alternatively for period of 100 seconds and readings are logged. Changeover of channels takes approximately 10 sec. of time during which data is not available. Measurements obtained from the data logger were compared with those obtained from parallel connected KRYKARD portable load manager ALM32 from Manaco Energy Solutions Pvt. Ltd. The results were encouraging and very much within the acceptable limits of accuracy.

VI. Future Directions

Direction of the work that is intended to be followed as an ongoing part of the presented research work includes following

1. To review alternate technology for wireless link as Bluetooth technology has limitation in terms of communication range and number of nodes. One of the possible alternatives to be studied is Zigbee [15].
2. To develop a complete home energy management system that can be the part of the smart grid.

VII. Conclusion

Design and development of a plug-in type multi-channel wireless data logger for measurement of energy and related parameters for single phase applications has been discussed. The design has an advantage of being easy to use and low cost. GUI has been developed that supports single as well as multi-channel data logging on a central computer. Operation of the proposed design has been verified experimentally and has been found to be meeting acceptable limits of accuracy. Bluetooth technology has been used for wireless connectivity. This proves to be easy to use and low cost however its application is limited in terms of communication range and number of nodes that can be part of the network. Alternative technology like Zigbee can be used where this limitation are not acceptable. It is believed that availability of such low cost easy to use energy monitoring solutions will encourage consumers to use them. This will help them to manage their energy usage more efficiently and also to contribute towards goals of smart grid like efficient energy management and energy conservation. The presented work was part of the ongoing research towards design and development of a full-fledged low cost home energy management system.

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