Analog Input Expansion Board Based on I2C Communication with Plug-and-Play Feature, Applied to Current Measurements

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Abstract

Current measurement is a crucial feature of any energy monitor based equipment, either in the case of domestic applications or for building energy management systems. This work presents the design and technical features implementation of an expansion board, used to increase reading capabilities of electrical current measurement sources. Using a single microcontroller, it uses Inter-Integrated Circuit communication (I2C) to increase the number of analog reading channels. With this expansion board, an entire electrical frame with several circuits can be read without the need of additional microcontrollers and their associate communication network, with the advantage of adding plug and play capability.

Keywords — *I2C Communications, Analog to Digital Interfacing, Current monitoring, Smart Energy Monitor, Building Energy Management Systems.*

I. INTRODUCTION

The search for more efficient, accurate, and lower cost solutions for energy monitoring has been a research field that has attracted much attention in the research community, either at hardware, software, or firmware level. New architectures have been proposed to enhance actual platforms, through the use of distributed and scalable architectures [1] and new machine to machine (M2M) protocols, such as Message Queuing Telemetry Transport (MQTT) [2] replacing Representational State Transfer (REST), based on Hypertext Transfer Protocol (HTTP).

The applications of this type of solutions are vast, from domestic and building management [3], to industrial maintenance [4], among others.

Most proposed system architectures rely on having a point of measurement with communication capabilities, which send information to a central server that has the role of processing, storage and visualization. Power meters rely mainly on GSM, WLAN, ZigBee™ and Power Line [5], where communication issues are one of the largest limitations, due to the limited number of measuring equipment that can be installed, either because of their costs or because of privacy issues, considering that network connectivity is one of the essential functions for this kind of equipment.

In terms of communication, several solutions can be found, from Ethernet [6], GSM [7]–[10], GSM coupled with Zigbee [11], PowerLine [12], RFId [13], to WLAN [14]–[16]. The number of analog channels of the main processor limits the ability of all proposed platforms to perform energy readings. Despite the fact that they can be scalable, adding sensor nodes will involve additional communication capabilities, with the increase of the corresponding cost and complexity.

The communications protocol Inter-Integrated Circuit (I2C) [17]–[19] has been widely used in the past, mostly as an internal board bus for integrated circuits [20], but also as an interconnection external board bus [21], [22].

The aim of this work is to present the design, implementation and commissioning of an analog input expansion board, based on I2C communication, to expand sensor reading capability, without the use of other more complex means of communication. The board is designed with conditioning circuits for current measurements and plug and play features provided by firmware. Notice that an electric frame from a small building can easily have several dozen of electrical single phase or three phase circuits. Without the ability of reading all circuits, or at least, main power ones, load management based on desegregation is not possible, or will be very complex in terms of hardware installation.

The paper is organized as follows. In II the board schematics are presented and explained. III discusses the PCB layout. IV provides a description of the firmware developed; Section V shows commissioning details and VI summarizes the main conclusions and offers possible directions for future work.

II. EXPANSION BOARD SCHEMATICS

The expansion board described in this work can be divided into several functionalities, as a block diagram. The main block is an analog to digital converter with 8 channels and an I2C interface. There can also be found a power signalling and filtering block, terminal resistor block, address switch block, signal conditioning blocks and input and output communication terminal blocks (Figure 1).

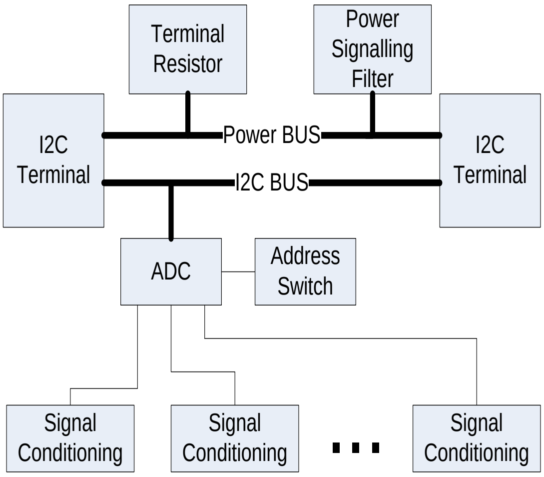

Figure 1 – Block Diagram of the Expansion Board

A. Analog to Digital Converter

This block is composed by a MAX127 8 channel ADC with I2C interface. Voltage references are set internally by capacitors C_{12} and C_{11} and power down mode is disabled through pin 13. The integrated circuit (CI) is powered by 5v, meaning that I2C signals will work with TTL standard voltages 0-5v (Figure 2).

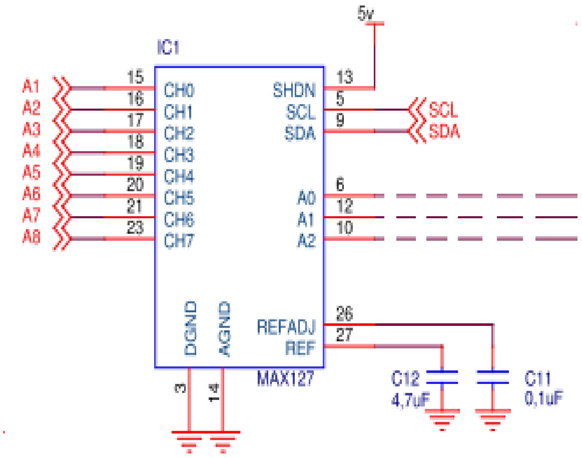

Figure 2 - Analog to Digital Converter MAX127

B. Signal Conditioning

Signal conditioning consists of a burden resistor that may be omitted when the current transformer already has one integrated. This is true for small current transformers like the range SCT-013 transformers used in this application, but in the case of higher currents, usually big scale transformers need an external resistor. Secondly, the circuit adds a 2.5v offset voltage through R_9 and R_{10}, since the ADC input range will be proximally 0-5v. Capacitor C_{10} will form a low pass filter coupled with equivalent impedance of the input circuit (Figure 3).

Notice that this circuit will be replicated for each analog input. In the case of the MAX127, the circuit is replicated 8 times, meaning eight input connectors, 8 voltage dividers and 8 low pass filters.

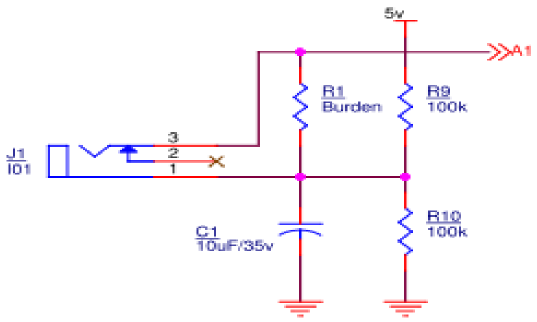

Figure 3 - Channel Input Circuit

C. Power Signalling and Filtering

In order to determine the online state of the board, a Light Emitter Diode (LED) was considered where R_{25} controls the current applied to the LED. Low and high frequencies are considered for power filtering through C_{13} and C_{14}; C_9 is a decoupling capacitor that must be soldered as close as possible to power pins of the MAX127 (Figure 4).

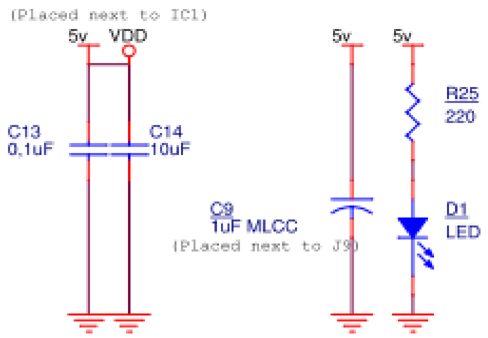

Figure 4 - Power Signalling and Filter

D. Terminal Resistors and I2C Terminals

I2C terminals are placed in each side of the PCB in order to connect a maximum of 8 boards.

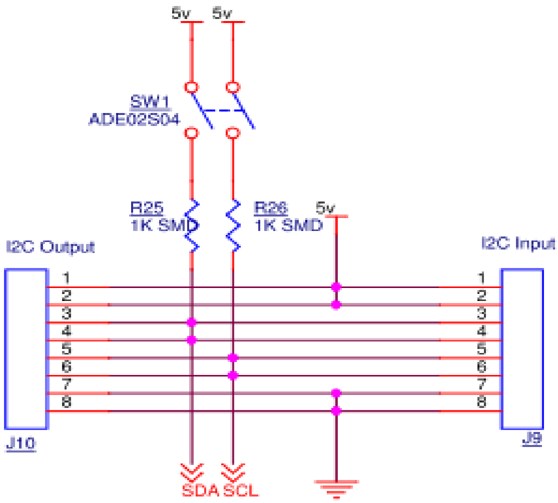

Figure 5 - Terminal Resistors and I2C Terminals

In order to comply with I2C specifications, two terminal resistors are considered, with an on/off switch, which must be set at the last board of the bus.

E. Address Switch

The analog to digital converter has three input address selectors, which provide the ability of selecting 8 different addresses, which can be recognized through the firmware. For connecting a maximum of 8 boards, 8 different addresses must be selected (Figure 6).

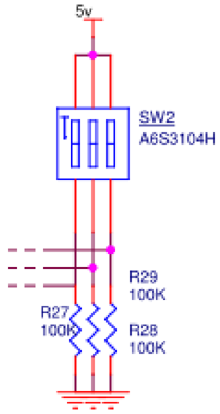

Figure 6 - I2C Address Switch

III.EXPANSION BOARD PCB LAYOUT

In terms of component placement, board layout was designed with the requirements that all inputs should be aligned in one the board's outline, and both I2C connectors placed at opposite sides. The terminal resistor switch should be placed near the I2C terminal at the left side of the board, and the power LED next to the input I2C terminal at the right side of the board. Coupling capacitors, with exception of C_9, should be placed next to the I2C input connector. C_9 should be placed next to the MAX127 power pins.

A two layer board was designed, though without a power and ground layer. Power planes were considered in the top and bottom layer, surrounding connection tracks, with the precaution of not creating closed circuits that would induce leakage currents. Figure 7 and Figure 8 shows the final PCB design with external measures of 102x39mm.

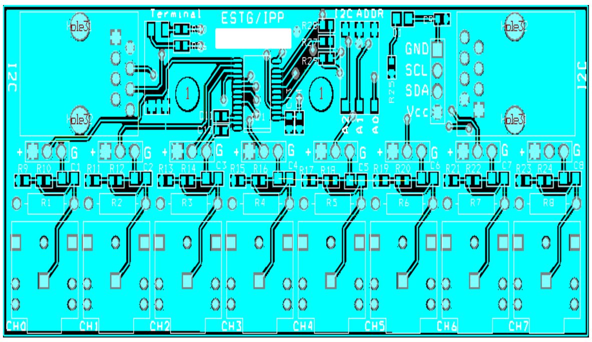

Figure 7 - PCB TOP Layer

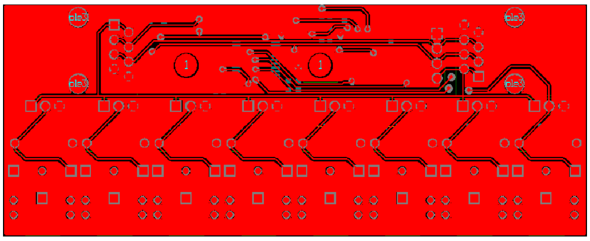

Figure 8 - PCB Bottom Layer

The PCB was assembled mainly with SMT components in order to keep the size to a minimum, since its final purpose is to be enclosed in an electrical frame, connected to 8 other boards.

Figure 9 - Assembled PCB

IV.FIRMWARE AND PLUG AND PLAY ABILITY

Firmware was developed in an Arduino based platform, using an Arduino UNO. The plug and play feature consists of incorporating in the main cycle a function that will scan for all possible addresses in the bus, and fill an array with the found responses from the devices. The following source code implements the scan procedure[1].

```
void check_if_exist_I2C() {
  byte error, address;
  int nDevices;
  nDevices = 0;
  for (address = 1; address < 127; address++) {
    Wire.beginTransmission(address);
    error = Wire.endTransmission();
    if (error == 0) {
      Serial.print("Device found at address 0x");
      if (address < 16)
        Serial.print("0");
        Serial.print(address, HEX);
        Serial.println("  !");
        nDevices++;
      }
    else if (error == 4) {
     Serial.print("Unknow error at address 0x");
      if (address < 16)
        Serial.print("0");
        Serial.println(address, HEX);
    }
```

[1] https://github.com/jainrk/i2c_port_address_scanner/blob/master/i2c_port_address_scanner/i2c_port_address_scanner.ino

```
    } //for loop
    if (nDevices == 0)
      Serial.println("No I2C devices found");
    else
      Serial.println("*********************\n");
}
```

The remaining firmware just has to consider the array and perform all measurements depending on the addresses found. Since each main cycle will sweep the bus, any board that is placed on the bus will be immediately recognized, without the need of any reset, downloading information or any hardcoded variable.

Figure 10 shows the structure of a generic firmware that would use the routine presented above.

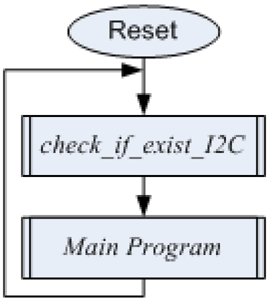

Figure 10 - Main Firmware Structure

V. IMPLEMENTATION RESULTS

For testing proposes, an Arduino UNO was used to read several interconnected boards and channels in order to evaluate ADC reading. The I2C bus was set at 100 KHz and measurements were performed to check reading stability and the ADC linearity.

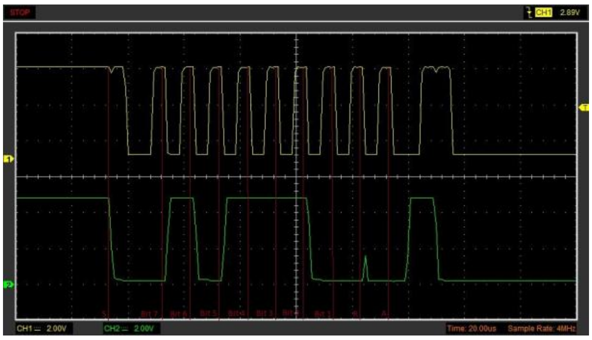

Figure 11 - I2C Reading Signals (SCL and SDA)

From Figure 11, acquired with a Pro Hantek 6022BE Oscilloscope, where the first signal is the bus clock and the second signal is the bus data, many standard validations can be done. Firstly, there can be seen that the clock is in fact generated at 100 KHz; secondly, the control byte sent to the MAX127 has the correct value 0x2E.

A. Readings Stability

In order to check for reading stability, 1000 reading were performed in different channels and boards. As an example, readings from channel 1 powered with 5v from a TTi EL302T power supply, has it histogram represented in Figure 12. An average value of 4,96106v was obtained, with a standard deviation of 0,000716v. Since the ADC has a 12 bit resolution, despising the ±3 LSB bits of offset error presented in the CI datasheet, 12 bit implies a 0,00122v resolution. The fact that the calculated standard deviation is lower than the expected resolution, results can be considered valid.

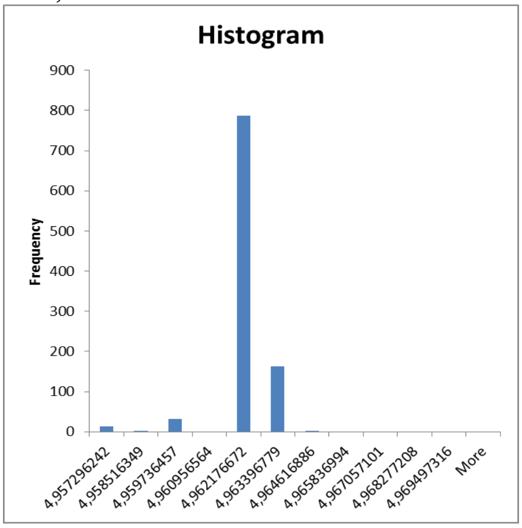

Figure 12 - Histogram for 1.000 reading at Channel 5

B. Linearity

To validate ADC linearity, 1.000 readings were performed at each channel, with input voltages from 0v to 5v with 1v step.

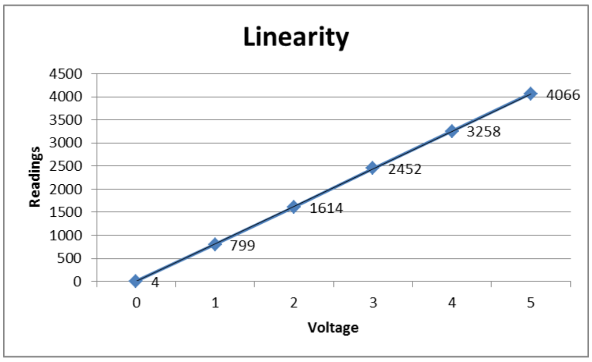

Figure 13 - Linearity Analysis for Channel 5

As can be seen from Figure 13, the ADC has a good performance. To validate the result, an interpolation line was overlapped with the data, showing a perfect linear equation.

VI. CONCLUSIONS

In this work, a new approach for a design board for monitoring analog signals, with several new features for a high number of inputs was described. With the use of its full scale capability, 8 boards can be connected, reading 8 channels each, meaning that a total of 64 current channels can be read in an electric frame with only needing one point of communication. Results have showed that analog channels have good performance characteristics in terms of repeatability and linearity. The compact design is suitable to encapsulate 8 boards in an industrial electric frame physically supported by DIN gutters. The proposed hardware solves the problem of having to install several platforms each with its communication capabilities, lowering installation cost and physical space, allowing reading much more electric circuits providing additional information for management tools.

For further improvement, the same architecture should be considered for voltage readings, with different I2C range address ADC, in order to add to the same bus another feature without the need of new communication mean.

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