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SMART COMPONENTS FOR A SMART ENERGY METER

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Abstract: *The developments in the day to day life have led to smartness in everything, including technology. Smart devices are those devices which are controlled by receiving the signals either directly by the user or by another device. One such smart device is the Smart Energy Meter which provides the electricity consumption measurements and time-of-use information to the utilities and consumers. The requirements for these smart devices are also complex and increase in complexity day by day. In this paper, the components required for the development of the Smart Energy meters are being portrayed along with their specifications and descriptions. .*

Keywords: *Smart Meter, Smart Components, Sensors, Energy, Power, Efficiency, Linearity.*

1. Introduction

Smart devices are those devices which control and co-ordinate with other devices upon receiving the signals either from the coordinating device or directly by the user. So, as the smart meters provide the overall power consumption measurements, intimate the users on a timely basis. Failure to widely and successfully deploy such advanced metering technologies and related services to every home will increase the gap in between the energy supply and the demand that is to be met. The "Smart Devices" can facilitate the reductions or shifts in the overall energy consumption by averaging out the energy that is being consumed on a regular and a timely basis. The usage of the power can be recorded on a database over the internet where the customer can access his account using the credentials given to him. There are signals that act as indications such that the extra energy other than the energy that is averaged out can be utilized at some other place. Not only the devices, there are various algorithms that are deployed over these smart devices (Ex: Microcontroller, ARM Devices) to facilitate the different smart operating modes. The designs of these complex products will have to deal with issues such as reliability, cost and scalability. This is where semiconductor products come into picture. The costs are primarily high due to the complex set of communications and communication-related features such as encryption, load profile-storage, multiple two-way secure communications, interfaces to the communication and operating devices, displays as well as the remote disconnect/connect relays and additional printed circuit boards. The electric power industry's traditional rate based meters with inclusion of coil, magnet, etc. are outdated and this lead to the time-of-use billing and automatic meter-reading (AMR), microcontrollers (ARM-boards), GSM/ GPRS modules (SIM 300 / SIM 900),Liquid Crystal Displays (LCDs), Real Time clocks (RTC) and other peripherals which led to the elimination of the old traditional power measurement. Some of the smart components are being discussed here.

2. Current Transducers

Current Transducers are those devices which convert the current into proportional voltages that is required for further processing.

2.1 LA 55-P Current Transducer

The LA 55-P is a current transducer that senses current at the input side and gives relative stepped down output current. This is from a company called LEM. This device is used for the electronic measurement of AC, DC, pulsed currents with galvanic isolation between the primary high power circuit and secondary electronic circuit. This device features an excellent instantaneous output with an accuracy of nearly 0.9%. This device is a closed loop (compensated) current transducer that makes use of the Hall Effect. This device has a very good linearity with low temperature drift operating in the range of - 40oC to 85oC. It has an excellent and optimized response time lying in the range of 500ns and 1µs. This component has a very wide bandwidth of about 200 KHz for DC having no insertion losses and highly immune to external interference and current overloading capacity. The device primarily works on the nominal RMS current of 50A with its measuring range lying in the

range 0 to 70A. This component is designed to work for 2 range of voltages i.e. +/- 12V and +/-15V. The device has an excellent conversion ratio of 1 : 1000. The transducer provides a nominal secondary RMS current of 50mA. The current transducer is used in applications such as AC variable speed drives and servo motor drives, battery supplied applications, Uninterruptible Power Supplies (UPS), static converters for DC motor drives, switched mode power supplies (SMPS) and welding applications.

Figure 1. LA 55-P Current Transducer

2.2 ACS712 Current Sensor

It is a fully-integrated, hall- effect based linear current sensor IC with a low resistance current conductor. The device consists of a low-offset, precise, linear hall sensor effect with a copper path of conduction located near the surface. To the current flowing in it, it generates a proportional equivalent voltage. The device accuracy is close to the proximity of the magnetic signal to the Hall Transducer. This is a 8-pin IC in which pins 1 to 4 are primary copper path for the current flow. The internal resistance of this conductive path is about 1.2mΩ providing a low-power loss. The output path is the path from 5-8 which produces a proportional voltage. The disadvantage of this IC is that it can measure currents only up to 30A.

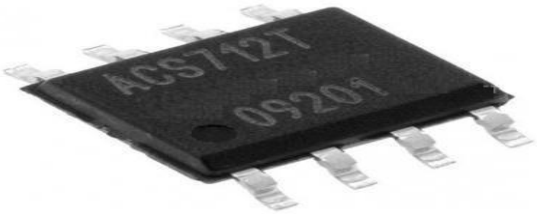

Figure 2. ACS712 Current Sensor IC

2.3 WINSON WCS1500

This transducer or current sensor provides precision and economical solution for both DC and AC current sensing for domestic and industrial purposes. This device has a wide sensing range of about 0 to 200A for DC and 0 – 150A for AC. It has very high sensitivity of about 11mV/A with wide operating range of about 0-12V. The device has a low operating current of only about 3mA and has an isolation voltage of about 4000V. The device basically works on the Hall-effect and provides a bandwidth of 23KHz.

Figure 3. WINSON WCS1500 current transducer

2.4 SCT - 013 – 000

This is a non-invasive AC current sensor whose core is made up of a ferrite material. The input current ranges from about 0 to 100A whereas it gives the output current as in the form 0 to 50mA. The input to the output ratio is about 20000:1. The input frequency ranges from about 50Hz to about 150 KHz. The device

works within a temperature of about -25^{o}C to about 70^{o}C.

Figure 4. SCT-013-000 Current Transducer/Sensor

Some other single input channeled, Hall-effect based, open-loop type current sensors for measuring AC/DC currents operating in the range of -40^{o}C to 150^{o}C whose measurement is as per ratiometric-voltage are very accurate.

3. Global System for Mobile Communication (GSM) SIM300 / SIM800/ SIM 900 Modules

The power consumption information that is being captured by the stepping down and multiplication of the current and the voltage sources is to be transmitted to the customer for notification. The captured and the calculated information should also be transmitted to the database for the generation of the bill and the generation of the due date. This transmission of information can be done with the help of GSM module. Ex: SIM300, SIM800 or SIM900.

3.1 SIM300 Modem

SIM300 module is a plug and play device which is very simple to serially interface. The device can be used to send SMS, receive and make calls and do other GSM operations by controlling it using simple AT commands from computers and microcontroller boards. This device comes in with a inbuilt standard RS232 interface which facilitates the interfacing very easily. The SIM300 modem consists of all the required external circuitry such as power regulation, SIM holder, external antenna, etc. This device provides a serial TTL interface for direct and easy interface with the microcontrollers. A special feature of this module is that a 3V onboard Lithium battery holder is been provided for power backup whenever necessary. SIM300 module facilitates the adjustment of the serial baud rate from 1200 to 115200bps with 9600bps being set as default baud rate. The modem works within an operating voltage of 7V – 15V AC or DC with a rectifier being present on board. The SIM300 module consumes a current of 0.25A during normal operation and about 1A during transmission.

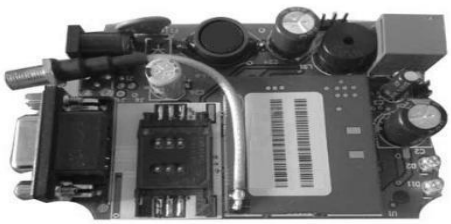

Figure 5 SIM300 GSM Modem

3.2 SIM800 Modem

SIM800 GSM Module is a Quad-band complete GSM/GPRS solution which can be easily embedded into the customer applications. This device supports quad-band such as 850/900/1800/1900MHz. This module is capable

of handling the transmission of voice, SMS and data information with least power consumption. It is very much slim and very compact as per the customer demands of designs. It allows total cost savings and fast time to market for various customer applications. This device can be connected using a USB to serial connector by setting a default Baud Rate of 9600 and can be controlled using AT commands through the Hyper-Terminal on the computer or through the commands when it is being interfaced with the microcontroller. This device provides a class 2/10 GPRS data connection. The operating range of this device is in the range of 3.5V to 4.4V and consumes very less power. The operating temperature of this device is in the range - 40^{o}C to $+80^{o}$C.

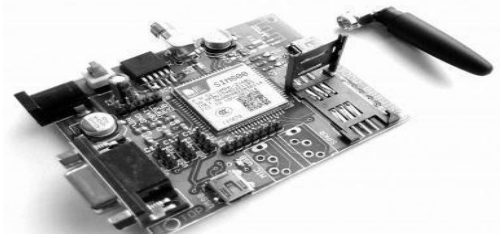

Figure 6. SIM800 GSM Modem

3.3 SIM 900 Modem

This modem is a dual band supporting two frequencies for communication. i.e. 900/1800MHz. The interfacing with the computer or microcontroller can be done with the help of a RS232 port. The baud rate of the SIM900 modem is configurable from 9600-115200. This GSM modem is having an internal TCP-IP stack which enables the user to connect to the internet via GPRS. It is suitable for data applications, messaging and voice communications. It has an onboard power supply connector which allows the user to connect it with 12V/2A DC. The operating temperature of this device varies from -20^{o}C to about +55^{o}C.

Figure 7 SIM900 GSM Modem

Either of the modem can be used for the communication purpose in between the customer and the smart energy meter.

4. Stepping Down the Voltage

Basically the voltage that is being used within the circuit is always about 230V. This voltage has to be stepped down to the voltage with which a circuit works.

4.1 LM317

This device is an adjustable 3-terminal positive-voltage output regulator which has the capability of supplying more than 1.5A over an output voltage range of about 1.5V to about 37V. The manufacturer of this device id Texas Instruments (TI). This device requires 2 resistors that are to be externally connected to set the output voltage. This device features a typical line regulation of about 0.01% and typical load regulation of about 0.1%. The specific features of this component are that it is current limiting, provides safe operating area protection and also provides thermal overload protection. The thermal overload protection continues to function even if the ADJUST terminal is disconnected. The device provides an input-to-output differential voltage of about 40V at the maximum.

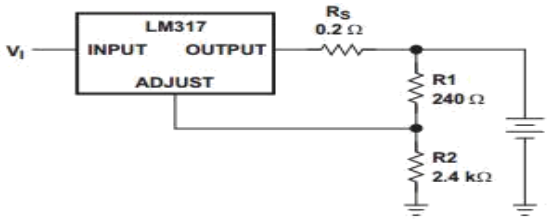

Figure 8 Circuit of LM317 IC

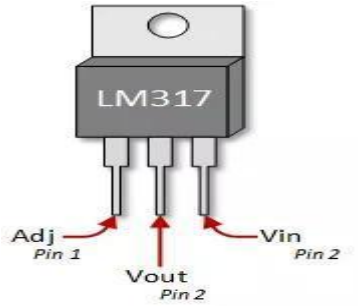

Figure 9 LM317 IC

4.2 Step Down Transformer

A step down transformer is the one whose secondary turns are very much less than the primary windings such that the secondary side gives a stepped down output than the input. Here the step down transformer converts high-voltage low current power into low voltage, high current power. The larger- gauge wire in the secondary turns side is very much necessary due to the increase in the current. There are various transformers of different ratings available in the market. The only disadvantage of the step down transformer is a slight fluctuation with respect to the design.

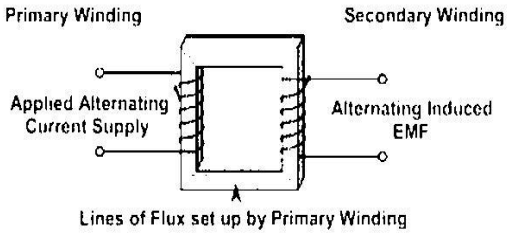

Figure 10 A Step down Transformer

5. Voltage Regulation

Voltage regulation is very much necessary to maintain a very stable voltage which in turn is necessary for the device to work efficiently and provide accurate results.

5.1 78xx Regulator

As the name indicates, this family is an extremely popular in the category of the voltage regulators. These devices are 3-pinned regulators wherein pin 1 is for input voltage, pin 2 is for output voltage and pin 3 is grounded. The devices are very specifically designed as 7805 which gives an output of +5V, 7812 regulator giving an output of +12V and 7815 regulator gives an output of +15V. The only constraint is that the minimum voltage that is to be given as input should be greater than the required output. The 78XX series of regulators provides a very stable, constant output voltage over the varying input voltage with upto 1A of output current. The 78xx series of regulators are designed to include the on-chip protection circuitry that will shut down the

voltage regulator even before the circuit gets heated up. The maximum input voltage for the regulator can be upto +35V.

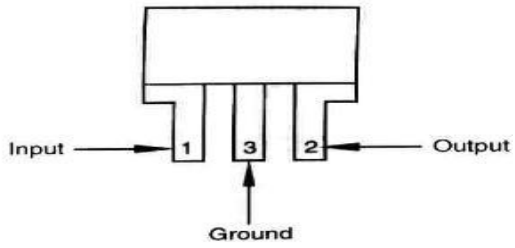

Figure 11 78xx Regulator

The same voltage regulator can be designed to provide a constant output current wherein the resistor is to be connected at the load side of some resistance R which can be obtained by the following formula.

Output Current = Output Voltage / R

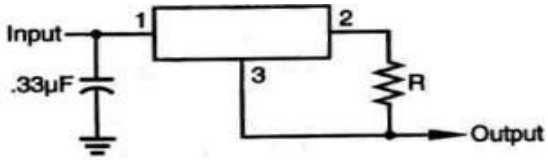

Figure 12 78xx as a Current Regulator

The voltage regulators can also be used as a part of the switching regulators. In the circuit where the regulators are used as switches, a pass switch is rapidly switched on and off to reduce any heat generation and duty cycle. Thus a square wave is obtained which is smoothened by an inductor. The output frequency is too high due to the rapid switching, the smoothing is relatively easy. The output voltage is set by the voltage regulator and the maximum current output is approximately 4A.

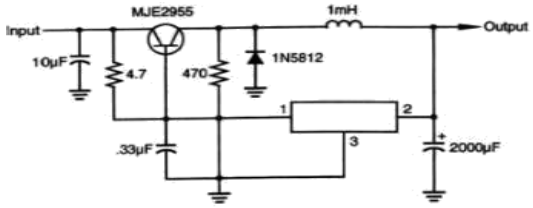

Figure 13 Switching Regulator

6. Development Boards

6.1 8051 Development Board

With this development board, any prototype can be developed using the 40pin IC. The RS232 onboard driver facilitates the easy connection with the PC or any other embedded hardware device. The board has status LED's and user buttons. The presence of the onboard bridge-wave rectifier facilitates the board to be powered with both AC and DC power supply adapters. There is a presence of RS232 Transmission and Reception with MAX232 IC on socket. Presence of DIL40 ZIF Socket onboard to reduce the microcontroller damages. The 8051 development board works on the crystal frequency of 11.0592MHz. 89v51RD2 Flasher can be used for input and output programming using the flash magic software . The best feature is that the board has onboard regulated supply of about 5V and 12V. The board also contains a LCD onboard of 2 lines x 16 charactered. A 24Cxx I2C EEPROM can be used as a backup to store the power consumption details when the power goes off. The board has an onboard analog to digital converter and a real-time clock DS1307. To facilitate the input obtained due to the current sensing and the voltage signals, 32 I/O lines are being provided.

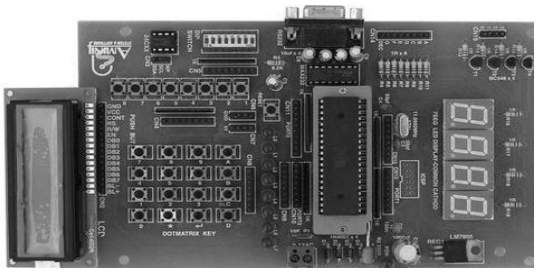

Figure 14 8051 Development Boards

6.2 PIC Development Boards

The PIC microcontrollers are one of the best 8-bit microcontrollers available in the market. PIC microcontrollers are a 40-pin IC with RJ11 socket for the programming through PIC PROG, PIC PLUS and PICICD2. Facilitates easy debugging and testing. The board has onboard regulated power supply of 5V and 12V. There is a presence of RS232 Serial Port, LCD Display of 2X16, a 24Cxx EEPROM for storing the data of the power consumed during a power cutoff. A Real time clock DS1307 is present on board. There is a presence of the onboard Analog to Digital Converter.

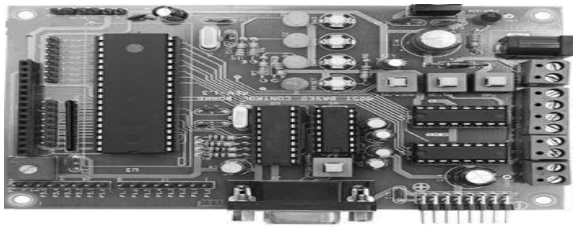

Figure 15 PIC Development Board

6.3 Arduino Development Boards

The Arduino board contains all the necessary peripherals that need to support the microcontroller onboard. It has a very simple interface with the computer such as USB. The Arduino board consists of an Atmel 16-bit, 8-bit or a 32-bit microcontroller (ATmega168, ATmega8, ATmega1280, ATmega328 and ATmega2560). The boards make use of a single-row pins that facilitate the connections for programming by interfacing it with the computer or incorporation it into other circuits. Presence of add-on modules onboard and stack-shields may be individually addressed via I2C Serial Bus. The Arduino boards work on a voltage of 5V by making use of the voltage regulator onboard. There is a presence of a crystal oscillator generating the frequency of 16MHz. The Arduino microcontrollers are preprogrammed with a boot-loader which facilitates easy uploading of the programs on to the on-chip flash memory. A program that is to be dumped on to the Arduino board can be done via a serial connection to the host computer. There is a level shifter and logical converter onboard to facilitate the logical conversion of voltages between RS232 and TTL voltages to make the devices compatible for functionality. The Arduino board exposes most of its microcontroller I/O pins for the use by other circuits. The Arduino has onboard 14 digital I/O pins, of which of them can produce PWM signals and 6-analog outputs which can be used as 6-digital inputs. Thus the Arduino board can be programmed to interface with the solder less breadboard.

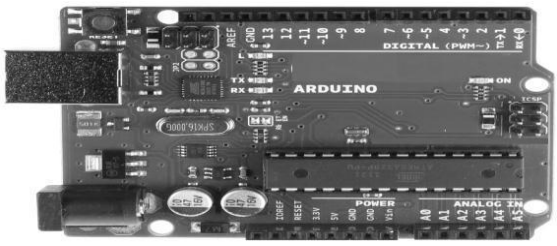

Figure 16 Arduino Development Board

6.4 MSP-430 Microcontroller Dev Board

The MSP-430 is a Ultra-Low Power microcontroller development board. It is a mixed-signal microcontroller originally manufactured by the Texas Instruments. It has a 16-bit CPU. The current drawn by MSP-430 in its idle mode is very much less than 1μA. The top CPU speed is 25MHz which can be throttled back again to the low power consumption. The MSP-430 uses 6 different low-power modes which can disable the unneeded clocks and the CPU. The best feature of the MSP-430 microcontroller is that it can wake up within less than 1μA allowing the microcontroller to sleep for a longer time and reducing its overall power consumption. This device has a variety of configurations including the internal oscillator, watchdog, timer including PWM, SPI, i2C, USART, 10/12/14/16/24-bit ADC's and a reset circuitry.

There are some exceptional peripherals on the device board such as the comparators and the signal conditioning opamps, LCD Driver, 12-bit DAC, DMA, USB and hardware multiplier. There is also a presence of the EEPROM and high volume mask ROM in-system which are programmable via JTAG or using UART or using USB. The MSP430 does not have an external memory bus and so the memory is limited to on-chip memory which may be too small. The following device works on a 12V AC/ DC power supply with an onboard rectifier for the conversion of AC to DC. There is also a presence of JTAG debugger on-chip.

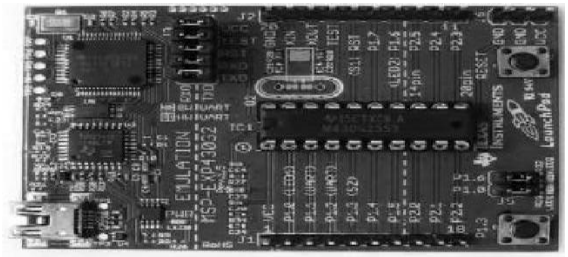

Figure 17 MSP430 Development Board

6.5 Renesas Development Kit

The Renesas kit is a user-friendly evaluation hardware kit. This hardware kit may be connected to the host PC using a very simple RS-232 serial connection or through a USB to UART interface. This is a 16-bit Single-Chip microcontroller with general purpose registers of 8-bit and 32-bit (8 bits- 8 registers and 4-banks). This development board has onboard ROM ranging from 2KB to 16KB and RAM ranging from 256bytes to 2KB and a data-flash memory of 32KB. There are different boards whose on chip oscillator frequency varies from 1MHz to 24MHz. A specific feature of the board is that it has a Single power supply flash memory system with the prohibition of the erase / writing function. This board provides an easiest way of debugging the program and also has power-on-reset (POR) and voltage detector circuit onboard. The I/O ports range from 18 pins to 26 pins. The device also has a on-chip clock output and a buzzer output and a on-chip BCD adjustment module.

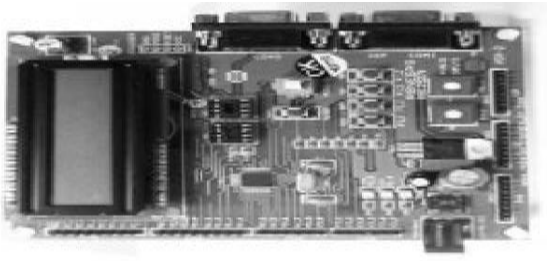

Figure 18 Renesas Development Board

6.6 ARM-32 bit Development Board

The ARM-32 bit single chip 16/32-bit microcontrollers with 512KB Flash/256KB Flash/128KB Flash. The device has a 4-channel 10-bit ADC. The device has onboard RS232 ports with Philips flash burner for the hex code downloading through the RS232 port. The board works on either 12V AC/DC with optional USB Socket for the purpose of power supply. The device has an onboard 2line x 16 Charactered LCD Display. An I2C EEPROM of 24Cxx is present onboard to keep a backup of data when there is a power-cutoff. It has a 16KB on-

chip RAM and the flash program memory supports upto a frequency of 60MHz. The ARM board has an In-Application Software and In-System Software that gets loaded every-time the boot loader loads up. The conversion time of the on-chip ADC is about 2.44ms. There is a presence of 2 UART's on boards supports a baud rate of 9600 bps -115200bps.

There are 2 SPI's and an I2C that support upto a speed of 400Kbps.The board has about 46 I/O Pins that are tolerant upto 5V. There is a presence of a crystal oscillator onboard which provides a frequency of about 1MHz to about 30MHz. This ARM-32 board supports 2 low-power modes: Power-down and idle mode. The CPU operating voltage is about 1.8V with a tolerance of +/-0.15V. The I/O pins are capable of supporting upto 3.6V ranging from 3.0V with the average voltage centered around 3.3V. The data transfer is very fast.

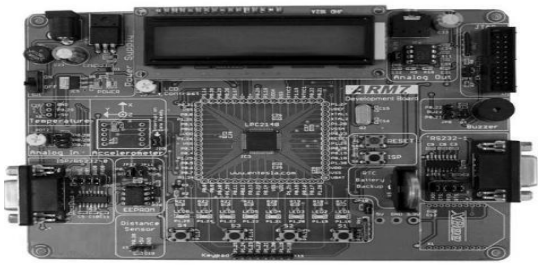

Figure 19 ARM 7 Development Board

6.7 ARM Cortex M Development Board

There are a lot many variations that are obtained in this category. This board is very much suitable for advanced applications such as Smart Energy Meter, etc. This board is basically an I/O pinout development board with options of onboard USB device and power. This board basically provides the JTAG connectivity for easy debugging purpose or programming purpose. This board usually has about 12MHz clock onboard and 38KHz is used for the internal clock purpose (RTC). The board has 2 on-chip UART's which supports the interfacing of the

GSM module for wireless communication and also can be used for the data transfer. This board works on a voltage of about 3.3V to about 5V. This device can be USB or externally powered.

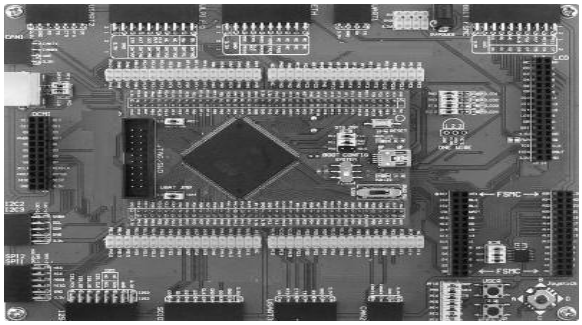

Figure 20 ARM Cortex M Development Board

7. Smart Power Meter IC's

Current transformers have drawbacks as they require extra copper wiring and are relative expensive. The parallel current sensors are less costly but can be used to only for single phase and single element systems. The voltages measured by these systems are too high and are non-maintainable by the maintenance-personnel. Thus smart-power metering IC's provide an alternative to the current transformers. Few are:

7.1 71M6541x:

It is a new system-on-chip (SoC) belonging to a smart-metering product family. This family features a digitally isolated current sensor and is basically based on data-access-arrangement (MicroDAA) technology. An inexpensive pulse transformer is interfaced to the isolated sensor IC which is then connected to a current sensing

shunt element. It is a 64-pin LQFPs with 32/64-kbyte flash memory options. This IC features much better than 0.1% accuracy over 2000:1 dynamic range and the presence of a unique programmable 32-bit metrology engine which adapts to meet the dynamically changing utility requirements. This IC is a copyright of Teridian Semiconductors.

Figure 21 71M6541x metering SOC IC

7.2 ADE77xx

The ADE77xx IC family is a highly accurate IC family used for electrical energy metering. This family of IC has a on chip oscillator used as a clock source an supports upto a frequency of 50Hz-60Hz. The best feature of this IC is that it facilitates error less than 0.1% over a dynamic range of 500:1. This IC gives only a positive only averaged real power on the frequency outputs f1 and f2. There is a logical detection from the IC if there is any potential miswiring or negative power. The very special feature of this IC is that it has on-chip power supply monitoring. This IC is facilitated by a single 5V DC supply. Using this IC costs very cheap to build the circuit. This component is a copyright of Analog Devices company.

Figure 22 ADE77xx Metering ICs.

7.3 STPMxx

Smart metering analog Front End (AFE) IC's offer high accuracy when measuring DC and AC energy even when extremely low currents are being measured. An accuracy of nearly 99% when using turns ratio of 5000:1. This family of IC's have an input channels ranging from 2 to 5. The best features of the IC's of this family are they are active, reactive, hardware registers to store the captured values of energy, voltage line frequency can be measured, hall-sensors supported, can measure Current and Voltages and are always anti-tamper.

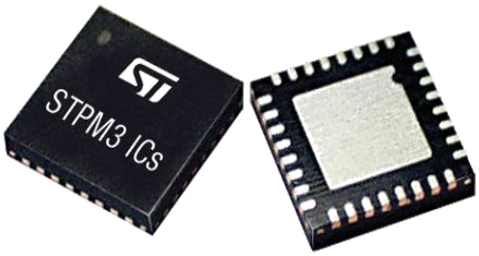

Figure 23 STPMxx ICs

7.4 MCP3909 IC

This device is an Energy-metering IC specifically designed as per the international metering standard. This IC can be easily interfaced serially and also produces Active Power Pulse Output. It has a 16-bit dual ADC output and a multi-bit DAC onboard. The energy measurement error is only about 0.1% when operating in the dynamic range of 1000:1. This gives out a frequency output that is proportional to the average active real power by simultaneously giving serial access to ADC. The output available is at 14KHz with 16-bit ADC output and 20-bit multiplier output words. A specific feature of this IC is that it provides a negative power indication. The device operates in the range of -40^{o}C to about +125^{o}C.

Figure 24 Microchip MCP3909

8. Advantages and Disadvantages of Smart Components

8.1 Advantages

There are various advantages of the smart components. Some of the few are being listed below:

- Reduced circuitry space.
- Less shock risks are involved.
- Reduced labor costs.
- Easier installation procedures.
- Highly accurate and reliable.
- Highly Efficient.
- Very much portable.

8.2 Disadvantages

- Components are a bit expensive.
- Replacement of the whole component is necessary when a part of it is damaged.
- Same type of component for replacement is not available most of the time.

9. Conclusion

The Smart components are very much advantageous as it saves much time for manufacturing as it is less complex and are highly portable. The less the complexity in the circuit, the more the efficient and portable is the circuit and the device. The more the efficiency of the device, the highly accurate results it provides and lasts for longer time duration. The smart components are highly linear, utilize low power and saturation. They are highly immune to noise and are highly flexible. Even though the cost of the components is comparably higher than the conventional components, the services they provide is extremely good and thus are reliable.

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