Stand Alone Merging Unit

A Dissertation

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In

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Declaration

I hereby declare that the work which is being presented in this dissertation entitles as, **'Stand Alone Merging Unit'** in partial fulfillment of the requirements for the award of degree of Master of Engineering in Electronics Instrumentation and Control Engineering, Thapar University, Patiala, is an authentic record of my own work carried out under the supervision and guidance of **Dr. Suraj Kumar Pardeshi Sr. Manager Technology Global R and D, Crompton Greaves Ltd.** and **Mr. Moon Inder Singh Assistant Professor Thapar University Patiala** and refer to the other researcher's work which are duly listed in the reference section.

The matter embodied in this thesis has not been submitted to any other University/Institute for the award of any Degree or Discipline.

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(Vipul Bhardwaj)

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Abstract

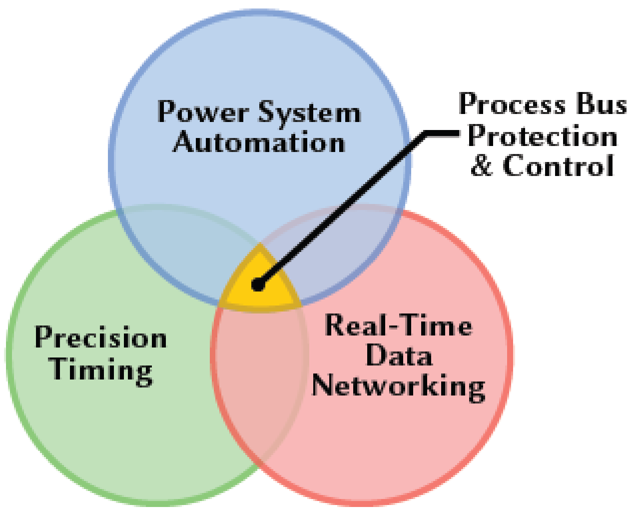
The ever increasing demand for power in the world has put immense pressure not only on power generation but also on distribution grids. So, the world has started moving from conventional grid to smart grid in order to reduce distribution losses. This also brings a level of automation, for real time control of digital substation. Digital substation extends the intelligent protection, measurement and monitoring to the process level in substation; as compared to conventional subsystem where it was restricted to the station level. Digital substation automation(DSA) has brought in a pool of intelligent electronics devices for measurement, monitoring and controlling the process. This thesis looks into the design of one such smart digital product for monitoring instrument transformer parameters, named Stand Alone Merging Unit (SAMU). The device continuously samples the data from instrument transformer and provides it over the ethernet. The device is based on electrical ratings taken from the standard International Electrotechnical Commission (IEC) 60044-8 and communication profile from IEC 61850. Interfacing of SAMU with instrument transformer is governed by IEC 61869-9, defining the sampling rates, conformance class, accuracy and rated error. An effort has been made to provide a network based solution for Stand Alone Merging Unit using a microcontroller based design. Design uses a simple dsPIC based starter kit for sampling and then transfer these values over ethernet with the help of ENC28J60, an ethernet control IC. It also publishes the data provided by the device over the webpage using dynamic variables in a webpage.

Interfacing these two controllers and using a state of the art control algorithm the prototype was able to provide the sampled data over the ethernet. Sampled data was visible over the network bus and can be accessed on any computer placed in the network.

Chapter 1

1 INTRODUCTION

This chapter provides an introduction to the field of substation automation and describes the motivation for undertaking this research. This research sits at the intersection of three fields: power system automation, precision timing and real-time data networks (*figure 1*). Substation automation is comprised of two disciplines: protection and control.



1: Research domain [1]

Protection: Protects electrical equipment from damage due to an electrical or mechanical fault, or due to certain conditions of the power system.

Control: A means of monitoring and controlling the operation of the power system.

Control can be considered to be the deliberate actions that take place in the power system, while protection responds to exceptional events. These two disciplines i.e. protection and control strives to provide a safe and secure power system.

1.1 Background

The high voltage power grid is playing an important role in the day to day life, with its interconnected network of transmission lines and substations; it powers the utilities like telecommunication and water supply. Ever increasing demand for power has created a deficit between demand and supply, putting immense pressure on power transmission. Increasing demand for electricity and limitations on the building of new power lines have led to increased operating voltages. High operating voltages increase the size of substations and impose greater stress on the instrument transformers used to measure currents and voltages.

In the power transmission system, the substation plays a significant role since it transfers the voltage from low to high or the other way around by utilizing the power transformer. In a substation the cost of copper cabling to connect current transformers (CTs) and voltage transformers (VTs) in switchyards to control rooms is increasing due to the quantity of the cable required and rising commodity prices. Aged oil filled instrument transformers (CTs in particular) are prone to explosive failure. Modern CTs are insulated with sulphur hexafluoride (SF6) gas rather than oil; however SF6 is the most potent of the known greenhouse gases. The measurement technology used for protection and control has not fundamentally changed since CTs and VTs were introduced in the early twentieth century.
To overcome this deficit, production is to be increased with modernization in sector of power generation and transmission. The architecture should be changed from the bottom. A multilayer information and control system architecture is proposed for the future power grid. In the substation, the monitoring, control, protection and other automation functions are provided by the Substation Automation System (SAS). New technology for both the measurement of primary currents and voltage and transfer of these measurements to substation control systems enables significant improvements to the design and operation of substations. Digital distribution of measurement data simplifies the implementation of substation-wide monitoring systems, with many signals multiplexed into a single data connection. The flexibility that networked connections between high voltage switchyards and control rooms provide will facilitate many new substation automation functions that are not feasible with conventional analogue connections.

With modernization in the technology, new control and automation methods are being implemented in the power distribution system. Digital control methods are used for implementing conventional and modern control algorithm.

1.2 Smart Grid

The demand of electricity generation is increasing largely. At the same time, the environment issues such as reducing carbon dioxide emissions and minimizing the effects of climate change are more and more concerned by public as well. As a result, the renewable and clear energy is preferred and a lot of green energy power plant is under construction. The increasing of demand and more distributed generation requires a more intelligent power grid in the future which can control and distribute the energy flow efficiently. The smart grid is the vision of future power grid.

The smart grid is a fully automated power delivery grid which allows bidirectional flow of the information and electricity. It has distributed intelligence and equipped with broadband communications and automated control systems which enable the real-time management. The smart grid also seamless interfaces among all the actors in power grid which include the industrial users, end-user customers, building automation system, industrial plants, energy storage installations and the electric network.

1.3 Digital Substation

As the technology developing, the electromechanical relay is introduced to replace the fuse. In a modern substation, the old electromechanical relay is replaced by the microprocessor-based relay which is one type of Intelligent Electronic Devices (IEDs). IEDs can provide more features and capabilities like protection, monitoring, data logging etc. than the devices based on the old technology. To protect the power equipment, a lot of parameters such as the current and voltage needs to be measured from the system and the IED should be able to get the measurement to perform the protection functions. Furthermore, the bay level IEDs in the substation need to communicate with each other in order to execute interlock functions and other complicate tasks. In the substation the SAS provides monitoring, control, protection, communication and other automation functions.

More compact switchgear is available from several manufacturers that combine the functions of previously separate items of plant, and this reduces the foot-print of a substation. An example of this is the Disconnecting Circuit Breaker that achieves space savings of up to 50%, which combines a circuit breaker, isolator, earth switch and optical current transformer. Networking technology such as Ethernet, widely used in other industrial applications, is now being considered for connections between the 'process level' in the switchyard and the `bay level' control room. *Figure 2* shows the hierarchy of the station, bay and process levels in a substation, along with the 'station bus' and 'process bus' connections between levels [19].

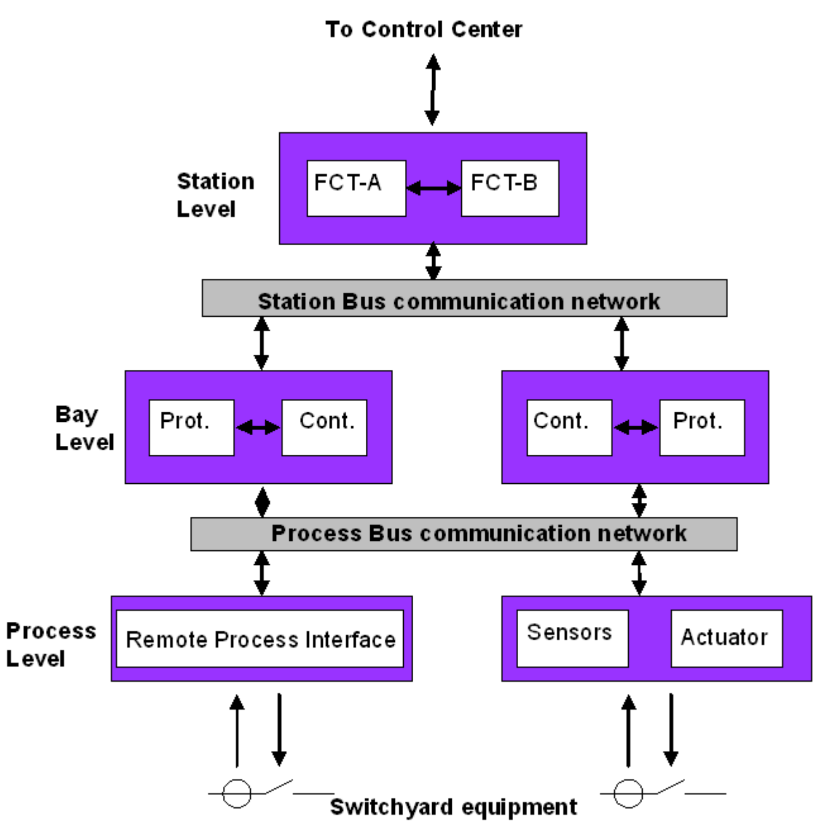


Figure 2 Substation Automation System [19]

1.4 Standardisation efforts for smart grid applications

The US Electric Power Research Institute (EPRI) launched the Utility Communications Architecture project in 1986 to develop architecture for substation communication that would incorporate protection, control, diagnostics and monitoring using object-oriented philosophies adopted from the information technology industry (IEEE PSRC Working Group H6, 2005). The Utility Communications Architecture Version 2.0 (UCA 2.0), produced in 1999 by EPRI and the Institute of Electrical and Electronic Engineers (IEEE), was intended for use by electricity, gas and water utilities (IEEE Standards Association, 1999). Technical Committee 57 (TC57) of the International Electro-technical Commission (IEC) had been working since 1994 on a proposal to standardise communications in substation automation systems (IEC TC57, 2003a). EPRI and TC57 agreed in October 1997 to merge the European and North American approaches to avoid duplication of standards, and as a result the IEC 61850 series of standards build upon UCA 2.0, and are accepted worldwide.

The first release of IEC 61850 was named "Communication networks and systems in substations". New standards, and updates of existing standards, in the IEC 61850 family are now named "Communication networks and systems for power utility automation" to reflect the wider scope of the standards, and their adoption by the wind, hydroelectric and distributed energy industries. Use of IEC 61850 is not limited to traditional transmission system operators, with the oil and gas industry now recognising the benefits of a consistent communication system.

IEC 61850 introduces a range of 'performance classes' and this reflects the wide range of applications for which the standards can be used, and that each application can have different performance requirements. Protection systems are defined by the three classes in IEC 61850-5, and these determine other performance standards such as communication transfer times (IEC TC57, 2003b).

The IEC and US National Institute of Standards and Technology (NIST) have both prepared 'roadmaps' for the standardisation of smart grids (SMB Smart Grid Strategic Group, 2010; Office of the National Coordinator for Smart Grid Interoperability, 2012). These roadmaps recommend that the IEC 61850 series of standards be used for future transmission smart grid development. While the term 'smart grid' is vague, it is generally accepted that the smart transmission grid will use a digital platform for substation automation. Two standards, IEC 61850-8-1 (Generic Object Oriented Substation Event, GOOSE) and IEC 61850-9-2 (sampled values), define communications services that map the abstract communications of the IEC 61850 object model to Ethernet, and have been adopted by a wide range of manufacturers. GOOSE and sampled values are used to implement the process bus. Both mappings are implemented using Ethernet frames with multicast (one to many) addressing to achieve fast transmission of their respective messages.

Digital data acquisition systems, including those in substations, require a sampling clock. A system-wide time reference is required when digitised signals from multiple sources are compared to one another. Sampling rates and offsets can vary, however alignment and resampling of measurements requires a single time reference to maintain phase accuracy. The IEC and NIST smart grid roadmaps [3, 4] also recommend the use of IEEE Std 1588 Precision Time Protocol (PTP) for highly accurate time synchronisation. IEC 61850 and IEEE Standard 1588 both use Ethernet, and therefore efficiencies can be made in the design and construction of substations through the use of a single network for multiple applications. Information technology is used to improve the operational response of utilities, and is a key feature of the smart grid in general.

1.5 Digital Substation and Merging Unit

Current transformers are relatively low in cost, but the consequence of their failure can be catastrophic. Explosive failures results in dangerous fragments of fractured porcelain insulation travelling a significant distance, which in turn poses a significant threat to nearby people and equipment. Non-Conventional Instrument Transformers (NCITs), such as capacitive voltage sensors and optical current transformers that are safer and pose less risk to the environment, are now commercially available. These sensors are air-insulated, rather than using the oil or SF6 gas insulation required by conventional CTs. Widespread adoption of NCITs has been limited due to the lack of a standardized interface and multi-vendor interoperability. This is changing with increasing numbers of manufacturers using IEC 61850-9-2 sampled values for the digital interface between NCITs and protection relays.

NCITs are not immune from manufacturing defects and the additional complexity of light sources and digital signal processing does reduce the inherent reliability of the product. NCIT instrumentation is self-monitoring and alerts operators to conditions that may impact performance. Redundant fibre drivers and secondary converters can be used to provide redundancy for the least reliable components. The explosive failure of a CT will destroy all cores, which in turn impacts the operation of all protection for the associated feeder or transformer. An NCIT failure will affect the connected automation equipment through loss of measurements, but will not result in collateral damage to surrounding plant.

The cost of complexity of CT and VT secondary cabling is significantly reduced through the use of GOOSE and sampled values over Ethernet. This process bus technology has been adapted to provide digital connections to conventional magnetic CTs and VTs, and is suitable for refurbishments of established substations. More than 100 copper circuits can be replaced by a single pair of fibre optic cables. An additional benefit of digital secondary cabling is that the hazards of high voltages from open circuit CTs and high voltages from VT secondary circuits are eliminated from substation control rooms.

The benefits achieved with digital process buses extend beyond the immediate cost savings and safety benefits described in the previous section. Sampled value data is readily aggregated and distributed by Ethernet switches. This simplifies the connections required for centralized substation automation functions, including disturbance recording, bus protection, and power quality monitoring and synchrophasor observations. The reduction in the cabling that is installed (in terms of quantity and physical size) and relaxation of cable distances (as voltage drop is not a concern) allows the design of substation control rooms to be rethought.

These advantages of the ethernet cabling are making a strong case for the digitalization of the substation. Digital Substation make use ethernet based substation communication and information exchange. The communication network within the substation is divided into three levels: process, bay and station. The process level includes the switchgear equipment, actuators and sensors. The process bus is the communication network between the process level and bay level IEDs.

Although in general the IEC 61850 is being widely used, the IEC 61850 Part: 9-2 process bus standard has only been applied in some pilot installations. The benefits of introducing the process bus are obvious. There will be a great reduction of the copper wiring requirement to interface to the process equipment compared with the traditional approach. In addition, with the digitalized information system, automated testing is possible which makes the implementation procedure easier.

The circuit breaker and current transformers are process level devices. To exchange information between electronic current transformer and the bay level equipment, Merging Unit is introduced. It is first defined in IEC 60044-8. It takes the analogue data from the Electronic Current/Voltage Transformer (ECT/EVT) is converted to digital form first and the MU is responsible for collecting the digital data synchronously and transmitting these measurements to bay level devices. In this project, the synchronization is not implemented.

Chapter 2

2 Literature Review

This chapter provides a summary of historic and current research in the fields that relate to this thesis, along with details of trials by utilities, product information and grid code requirements. As a result, the source material includes manufacturers' product specifications, international standards and regulatory documents in addition to traditional peer-reviewed sources.

Section 2.1 discusses the substation automation in general, with emphasis on the applicable standards. Section 2.2 provides information about time synchronization and related standards. Section 2.3 gives an insight into technical specifications and compares the different available products from various automation companies.

2.1 Substation Automation

This section discusses the brief history of digital substation and power system protection devices. IEC 61850 family and substation automation has been developing simultaneously. A conventional substation comprises of three levels [20] [*figure 3*], where process level is connected to bay level through copper wires. Devices at bay level and station level are connected over the network. Metering devices take value from the copper wire through sensor and actuator and these values are passed on to the station bus through copper wires. Automation and intelligence is restricted to the bay level and station level devices thus it cannot be called an intelligent grid.

Conventional substation works in the hierarchal manner where the substation control works at the top and the protection devices followed. The protection devices with measurement devices isolate the station control from any failure from the process level. The three layer structure is inter-connected using the copper wire.

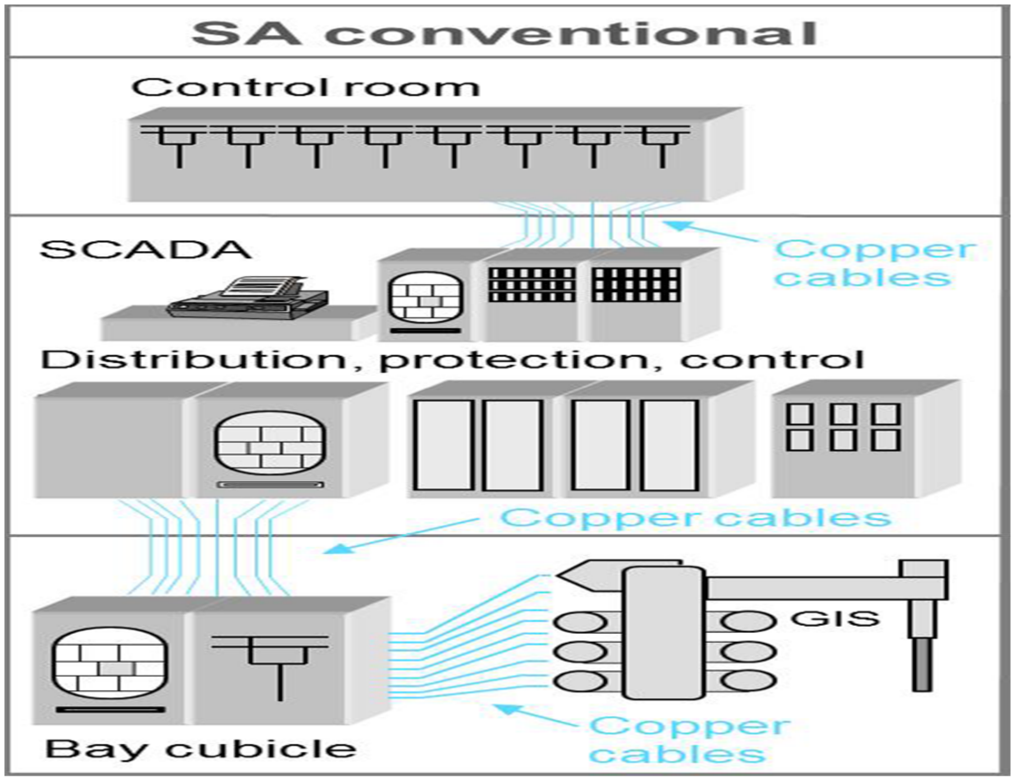


Figure 3 Conventional Substation [20]

(1) The functions of devices in process level are related to primary equipments, such as switch signal acquisition, analog sampling and control order receiving & sending, etc. These devices communicate with bay level equipments through the process level network.

(2) The functions of devices in bay level are for protection, measure and control, which is similar to the traditional substation. However, the media to transmit switch signal and electrical dada is changed from electric cable to optical fiber cable.

(3) There is no difference in function of devices between digital substation and traditional substation. The communication with bay level devices is achieved thorough Ethernet in accordance with IEC 61850.

Digital substation is inspired from the conventional system and continues with the three tier system but the interconnection for information exchange is Ethernet based bus architecture *figure 4*. This makes transfer of information faster, safer and cost effective.

The IEC 61850 standard mainly defines the information about device parameters, information exchange between devices in the network and configuration for protection, monitoring and control in the substation. The IEC 61850 is listed as a related standard for achieving smart grid vision. With the IEC 61850, the modern Information and Communication Technology (ICT) is utilized as the communication solution. IEC 61850 incorporates the information about data classes, attributes, datasets, logical nodes and mapping of data with frame formation and publication over the Ethernet.

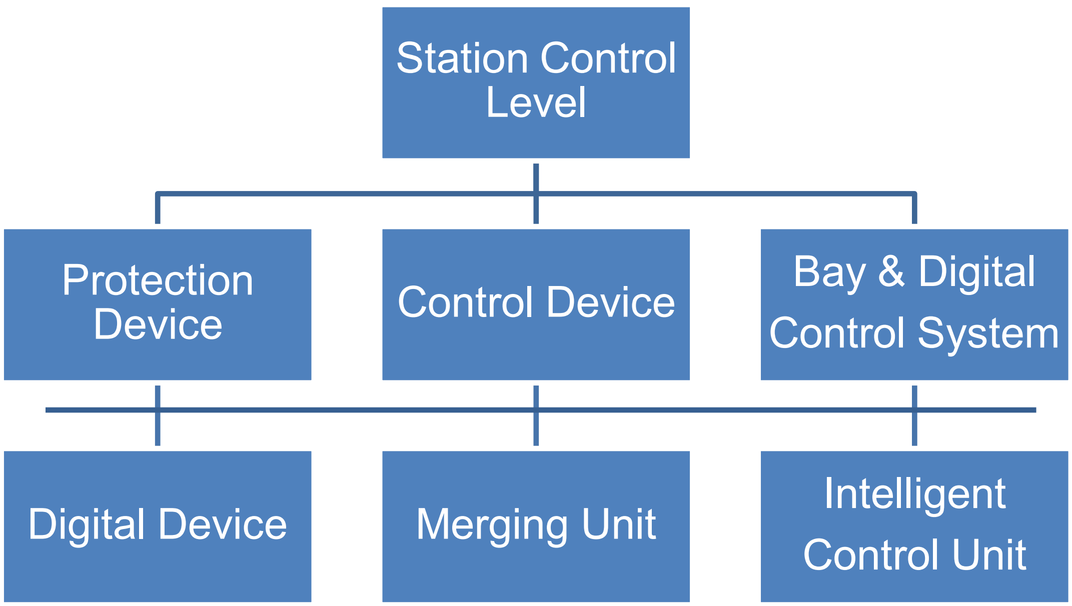


Figure 4: Digital Substation

Digital substation as shown *figure 4* includes intelligent devices at the different levels of automation; for a substation to be called as digital, the digital control devices are incorporated in the process level. Process level devices are the equipments which directly measure and monitor the parameters of process. Process level devices include circuit-breaker, phasor measurement devices, merging unit, disconnector, non-conventional instrument transformer. Communication between these devices and the substation is defined by the IEC 61850.

Subsequent parts of IEC 61850 assert different aspects of communication in the network of automated devices.

1) IEC 61850-7-2 defines the data class related to substation communication, dataset and logical nodes.
2) IEC 61850-7-2 based data classes are used by IEC 61850-7-3 to define the dataset related to automation processes like sampling, measured value, phase, harmonic value, harmonic error.
3) Dataset are part of the logical nodes defined in IEC 61850-7-4 for mapping of information from the process to the ethernet frame. Logical nodes are essential for mapping of information; they play crucial part in information exchange between devices.
4) IEC 61850-9-2 is applicable for publishing the sample value over the bus and defines the application and transport profile for services.

2.2 Time Synchronization

Digital substation has many devices working simultaneously on different process. These devices share information among them. For accurate information exchange among devices at different level the data has to be coherent. Digital substation devices work in real time environment where time accuracy is needed not only on amplitude value but in time as well. In devices like Stand Alone Merging Unit where sampling is done at every second microsecond there is a need for devices to be accurate at microsecond level.

There are possibility in digital substation architecture that there are multiple devices performing sampling and publishing them at the network level. These devices produce bulk data and differentiating between this data is impossible task. Thus we need data to be time stamped therefore providing an attribute to distinguish one data to another. Intelligent Electronic Devices (IED) generally has their local clock which is used to time stamp the data being published. Multiple devices in the network may not have clock which are coherent to other clock. In such situation the data being shared may not be time accurate leading to wrong interpretation of data, misinformation. To reduce the anomaly on the time front, local clock in IED's should be synchronised to each other, maintaining time and frequency at microsecond level.

Synchronization for clocks can be done in two manners:

1. Directly synchronizing clock from a universal source
2. Synchronizing clock over the network where the network uses a single universal clock.

2.2.1 IRIG-B

Inter-Range-Instrumentation-Group (IRIG) has developed standard for synchronization in 1960 for direct synchronization of the devices. This standard provides time in the binary straight coded format, which enables direct comparison of time for local clock with universal source. IRIG-B became popular for device synchronization for its simplicity and ease of execution.

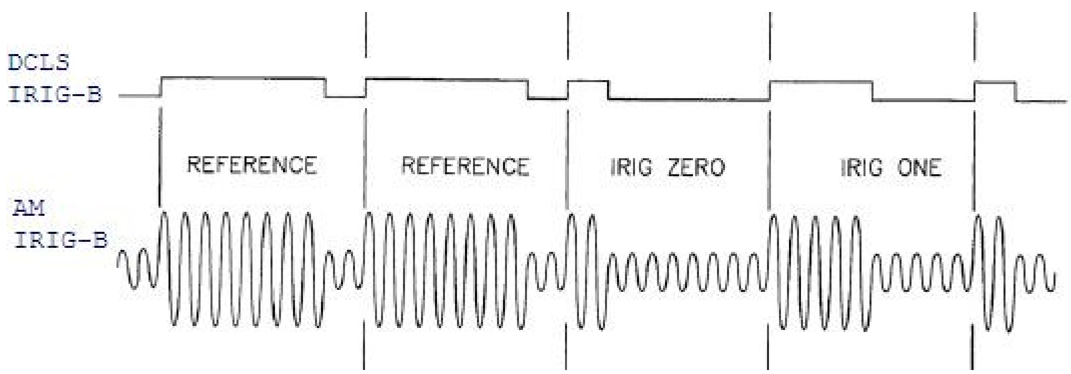


Figure 5: Modulated IRIG-B Signal [11]

IRIG-B uses coded binary signal to represent year, month, day, time. These binary code are DC level shift, pulse-width coded signal ("unmodulated IRIG-B") or as an amplitude-modulated signal based on a sine wave carrier with a frequency of 1kHz. *Figure 5* shows modulated IRIG-B signal.

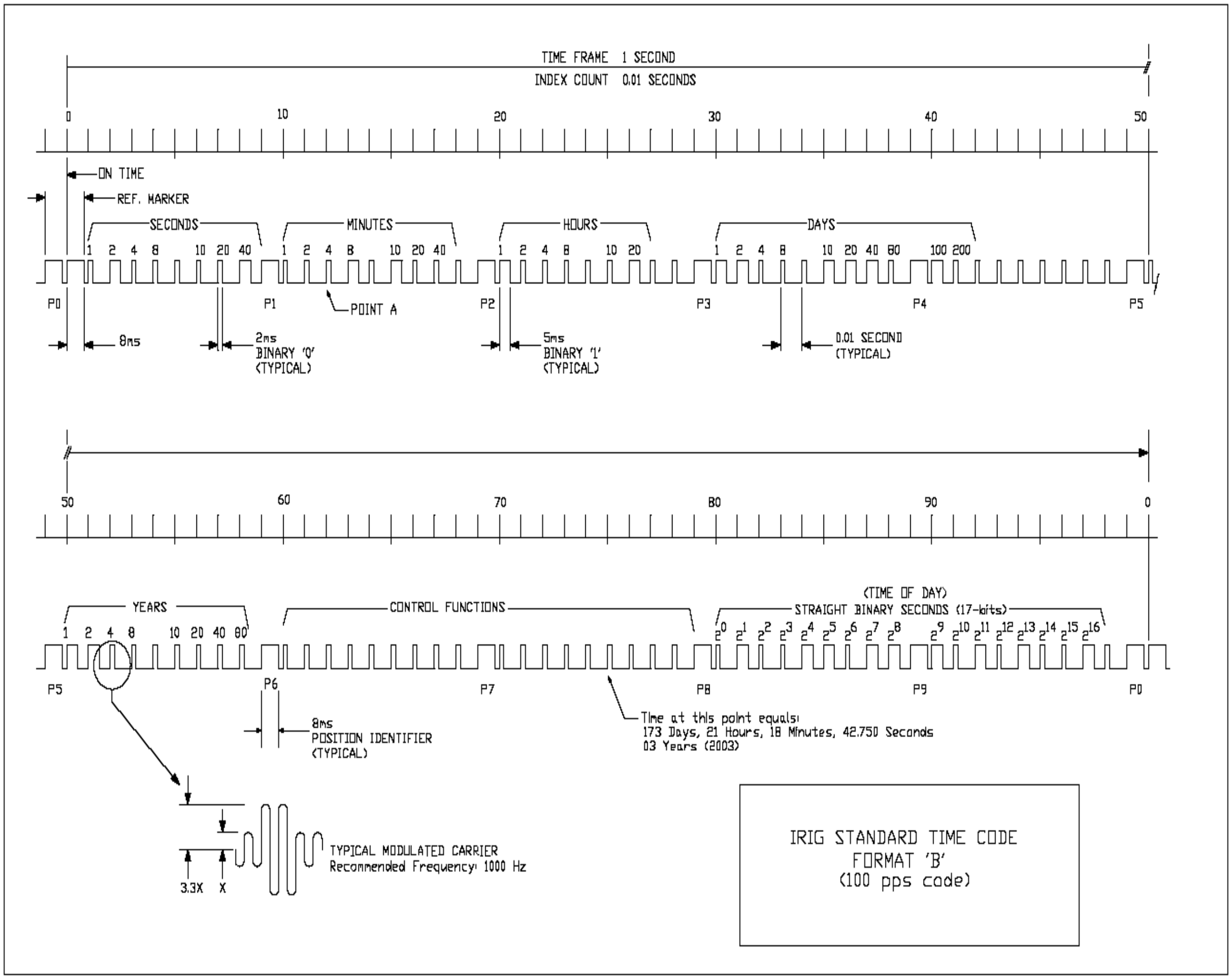


Figure 6 IRIG-B 100 bit coded signal [11]

IRIG-B Code consists of three bit as zero, one and reference marker. Zero and one represent low and high value respectively, whereas the reference marker shows start of new time frame. IRIG-B consists of 100 bit code which is produced every second as shown in *figure 6*. These 100 bits contain 74 bits specifically for time related entities like hour, minutes, second and day, time quality information. These coded bits are categorised majorly in three form as; BCD for time information, Straight binary second for sub-second values, and Control Function quality, parity and other information.

2.2.2 IEEE 1588

(IEEE) came up with standard to synchronize different clock in the network, while achieving an accuracy of microsecond level. IEEE published a standard in 2009 known as the IEEE 1588; further a C37 profile was introduced in 2013. These standards state and define clock different network clocks on the basis of their function.

Synchronization over the network is needed; as a single oscillator cannot be used by multiple devices due to following reasons:

- High frequency clock signal delivered over long distant cannot be assumed reliable.
- Characteristic of oscillator changes with change in operating conditions.

Network based synchronization method like Network Time Protocol (NTP) can be used to synchronize the clock. The regular network synchronizing methods are limited by their accuracy; NTP has an accuracy level in millisecond. Real time control applications are time dependent thus they need time accuracy to the level of microsecond. To cater to these needs of modern control system IEEE came up with IEEE 1588 in 2002. Different parts of the standard are being updated regularly since its publication and new edition was published in 2009.

2.2.3 Function of IEEE 1588

IEEE 1588 is also as Precision Time Protocol (PTP); it is based on Secure Network Time with Multiport (SNTP), it also uses User Datagram Protocol (UDP) packet to provide time synchronization. It provides better result than SNTP as it proposes the hardware based time stamping as well. IEEE 1588 defines different type of the clock based on their function and operation in the network. IEEE 1588 mention grandmaster clock, master clock, transparent clock, slave clock, boundary clock, one-step clock, two step clock, etc.

2.2.4 Function/ Definition of Clock in IEEE 1588

Grandmaster clock: Within a domain, a clock that is the ultimate source of time for clock synchronization using the protocol.

Ordinary clock: A clock that has a single Precision Time Protocol (PTP) port in a domain and maintains the timescale used in the domain.
One-step clock: A clock that provides time information using a single event message.
Two-step clock: A clock that provides time information using the combination of an event message and a subsequent general message.
Transparent clock (TC): A device that measures the time taken for a Precision Time Protocol (PTP) event message to transit the device and provides this information to clocks receiving this PTP event message
Boundary clock: It is a multi port device that bridges between PTP domains; that is a slave clock on one side, and a master clock on the other side.
Slave-only clock: An ordinary clock that is not currently capable of Precision Time Protocol (PTP) Master state.

2.2.5 Best Master Clock Algorithm

PTP knows different types of clocks and acts as a master to slave protocol. A clock in an end device is known as an ordinary clock, a clock in a transmission component like an Ethernet Switch is a boundary clock (BC) or transparent clock (TC). A master which is controlled ideally by a radio clock or a GPS receiver, synchronizes the respective slaves connected to it. In a network with multiple devices with individual clocks and some clock acting as bridge have individual frequency with inherent accuracy or inaccuracy. Among these clocks a device with time nearest to the GPS source time is selected as grand master clock. All other clocks in the system act as slave to the grand master clock. Accuracy of a clock is determined on the basis of the time difference between master clock and the time from GPS.
Once a grandmaster clock is selected, other clocks in the network are synchronised with respect to the grandmaster. If the grandmaster clock is removed or best master clock algorithm calculate it to be no longer as a clock with highest quality; then the algorithm find and assign grandmaster clock status to another clock and all other clocks are synchronized according to it.

2.3 Existing product's comparison and benchmarking

Digital Substation automation devices have made many strides in last decade. Many company and organization has invested heavily in research and implementation of Smart Grid. Organization like GE, Alstom, Vizimax, have developed a range of product for operation need of different part of grid. This section deals with the comparison of the various Merging units from companies all over the world.

2.3.1 Alstom Merging Unit

Alstom after acquiring NxtPhase technologies also bought the Non-Conventional Instrument Transformer technology. They introduced merging unit as a part of the NCIT for digital interface. Later the merging unit was also introduced as an independent stand alone device. Alstom calls its merging unit as Agile AMU series [6].

MU Agile AMU: Stand Alone Merging Unit (SAMU) – Digitalising conventional 1A\5A and 100\200V analogue secondary circuit.

MU Agile XMU 800: Modular numerical Merging Unit – Interfaces with multiple primary converters in the field

MU Agile XMU 820: Modular Merging Unit – Interfaces with numerical and conventional transformers

MU Agile NXMU: Modular Merging Unit – Interface with non-conventional optical CT and conventional VTs.

Features of Analogue Merging Unit from Alstom are:

- Stand alone device which can be interfaced with conventional and modern digital substation.
- It can accommodate four current and four voltage transformer
- Device is configurable with MiCom PC toolsuit
- IEC 61850-9-2 based sampling of 80 sample per cycle
- It has USB port for configuration setting and event logging.
- Four LED's to show IED's status.
- Ethernet port to support a fibre optic LC ethernet connection for sample value publication

- Fibre optic port for GPS real time signal of 1 PPS for time synchronization

Figure 7: Alstom Agile Merging Unit [6]

Specifications of Alstom MU Agile AMU:

Table 1

Standard	IEC 61850 -9-2 LE
Power consumption (VA for 5A)	2.5
Number of Current inputs	4
Nominal current	5 A
Max permanent Current	20 A
Max current (1 sec)	500 A
Alternate current setting	
Nominal current	1A
Max permanent Current	4A
Max Current (1sec)	100A
Number of voltage input	4
Nominal voltage	100/120Vac
Nominal Permanent voltage	100/120 Vac

Thermal Capacity	200/240 Vac
Nominal frequency	45-65 Hz
Interface	USB, Fibre Optic ethernet, 1PPS input
Synchronization	GPS based, 1PPS
ADC resolution	24 bits
Sampling Rate	4000 sample/sec @50Hz 4800 sample/sec @60Hz
Published Data	Va, Vb, Vc, Vn, Ia, Ib, Ic, In

2.3.2 Vizimax Analog Merging Unit

Vizimax's Analog Merging Unit acquires ac current and/or voltage from *conventional current and voltage transformers* (CTs and PTs) and publishes the measurements to an Ethernet LAN using a 100Base-T interface. [7]

Figure 8: Vizimax Analog Merging Unit [7]

Feature of Vizimax Merging Unit are:

- IEC 61850-9-2 based device with sampling rate of 80 sample per cycle
- 100 base-T fibre optic output for publishing data over ethernet.
- Clock synchronization can be done using both 1PPS or PTP (IEEE 1588)
- Web interface which can be used for both event logging, status check and configuring the device
- Sampling of three current and three voltage values

Specifications of Vizimax SAMU:

Table 2

Standard	IEC 61850 -9-2 LE
Power consumption (VA for 5A)	<1
Number of Current inputs	3
Nominal current	5/1 A
Max permanent Current	5 A
Max current (1 sec)	150 A
Alternate current setting	
Nominal current	1A
Number of voltage input	3
Nominal voltage	100/120Vac
Nominal Permanent voltage	115/200 Vac
Thermal Capacity	200/240 Vac
Nominal frequency	40-70 Hz
Interface	USB, Fibre Optic ethernet, 1PPS input, SD card

Synchronization	GPS based, 1PPS
ADC resolution	16 bits
Sampling Rate	4000 sample/sec @50Hz 4800 sample/sec @60Hz
Published Data	Va, Vb, Vc, Ia, Ib, Ic

2.3.3 Schniewindt Merging Unit

Schniewindt is a Germany based company provides a merging unit based on IEC 61850-9-2 LE. The IEC 61850 merging unit collects data from conventional instrument transformers and converts the analog signals into a digital protocol defined by IEC 61850-9-2.

- The Merging Unit transmits the converted signal through fibre-optics utilizing industrial grade Ethernet hardware.
- As being an IEC 61850-9-2 standard based device it has a sampling rate of 80 samples/cycle [8].
- The device takes four current and four voltage analogue inputs with current rating of 1/5V and voltage rating of 110V.
- Synchronization signal is provided through fibre optic as optical 1 PPS.

Figure 9: Schniewindt Merging Unit [8]

Specification of Schniewindt Merging Unit

Table 3

Standard	IEC 61850 -9-2 LE
Power consumption (VA for 5A)	<0.2
Number of Current inputs	4
Nominal current	5/1 A
Max permanent Current	5 A
Alternate current setting	
Nominal current	1A
Number of voltage input	4
Nominal voltage	110Vac
Nominal Permanent voltage	85/250 Vac
Nominal frequency	50-60 Hz
Interface	USB, Fibre Optic ethernet, 1PPS input, SD card
Synchronization	1PPS
ADC resolution	16 bits
Sampling Rate	4000 sample/sec @50Hz 4800 sample/sec @60Hz
Published Data	Va, Vb, Vc,Vn, Ia, Ib, Ic,In

2.3.4 ECIL Energia JADE Merging Unit

Brazilian company ECIL Energia came up with its IEC 61850-9-2 LE based product called JADE Merging Unit.

- This device support 4 current and 4 voltage analogue inputs which are sampled at 80 samples/cycle and 256 samples/cycle [9].

Figure 10: ECIL Energia JADE SAMU [9]

- It also supports time synchronization.
- ECIL's Jade stands out for its ruggedness and it toughness. It follows IP 67 rating thus making it protected against water, solid object, dust, lightening, shock resistant.

2.3.5 Reason Merging Unit

Reason is USA based company which provide digital substation product.

- The Anaolg Merging Unit is IEC 61850-9-2 LE based product which support upto 16 analog and 12 binary inputs.
- It support ethernet based PTP (IEC 1588) synchronization but IRIG-B based synchronization can be optionally provided [10].

Figure 11: Reason Merging Unit MU320 [10]

- Device is configurable through standardized SCL file.
- It has LED based alarm system for communication loss, synchronization, power, In-Service.
- It supports PRP based network redundancy protocol. It sample and publishes the value of three phase current and voltages with neutral for both current and voltage.
- It support two sampling rate of 80 samples/cycle and 256 samples/cycle. These samples are framed in the two multicast sample value control block for protection and quality.

2.4 Comparison and Benchmarking

As discussed in section 2.3 the market does have many IEC 61850-9-2 based merging unit with their own relative advantages and disadvantages. Alstom has the widest range of merging unit product with solution for conventional, non-conventional transformers. Alstom also offer its range of non-conventional optical output based instrument transformer with embedded merging unit. Vizimax has a merging unit which can be fitted with any conventional transformer. ECIL and Reason provide merging unit with dual sampling rate for measurement and protection class. ECIL's Jade stands out for its ruggedness and tough body which can sustain in harsh environment condition.

The following table draws comparison between the merging unit from Alstom and Vizimax. Both these devices have proven history in market and illustrative specification sheet.

Table 4

SPECIFICATION	**ALSTOM**	**VIZIMAX**
	MU Agile AMU	**AMU**
Enclosure dimensions (mm)	154.2 x 177.0 x 248.4	482.6 x 177.0 x 299.1
Operating temperature	-40°C to 70°C	-40°C to 55 ◦C
Hardware		
Power consumption (VA for 5A)	2.5	<1
Number of Current inputs	4	3
Nominal current	5/1 A	5/1 A
Max permanent Current	20 A	5 A
Max current (1 sec)	500 A	150A
Alternate current setting		
Nominal current	1A	1A

Max permanent Current	4A	
Max Current (1sec)	100A	
Number of voltage input	4	3
Nominal voltage	100/120Vac	100/120 Vac
Nominal Permanent voltage	100/120 Vac	100/120 Vac
Thermal Capacity	200/240 Vac	115/200 Vac
Nominal frequency	45-65 Hz	Between 40 Hz and 70 Hz
Input connector	N/A	5.08 mm
Power supply		
Voltage range		
AC	100/120 Vac	100/120 Vac
DC	70 Vdc to 150 Vdc and 187 Vdc to 242 Vdc	66 V dc to 160 V dc
Maximum power consumption	60 W	< 20 W
Bandwidth (3db, 1A)	10 Hz to 6 kHz	0.5 Hz to 4 kHz
Standard	IEC 61850 -9-2 LE	IEC 61850 -9-2 LE
Voltage Precision	IEEE 0.2S	0.30%
Immunity to disturbances	As per IEC 60255 and IEC 61000	As per IEC 60255 and IEC 61000

Mechanical resistance to vibrations	EN 60255-21-1 Class 2	IEC 255-21-1 Class 2
Dielectric strength	IEC 60255-27:	IEC 255-5
DC inputs and I/Os	2 kV ac rms	2 kV ac rms
Communication	2 kV ac rms	1.5 kV ac rms
Impulse voltage (IEC 255-5)	5kV	5 kV
Electrostatic discharge	IEC 255-22-2	IEC 255-22-2
Air discharge	15 kV	15 kV
Contact discharge	8 kV	8 kV
Overvoltage supported	IEC 60255-22-1	IEC 60255-22-1
Common mode	2.5 kV	2 kV
Differential mode	1 kV	1 kV
Fast transient burst	IEC 60255-22-4 Class 4	IEC 60255-22-4 Class 4
Radiated RF immunity	IEC 61000-4-3	IEC 61000-4-6:
Modulated	10 V/m for150 kHaz to 80 MHz	10 V for 150 kHz to 80 MHz 10 V for 80 MHz to 2.7 GHz

Communication		
Flash Memory	√	√
RS 232	X	X
Ethernet (RJ-45)	√	√
LAN transfer rate	100 Mbps	10-100Mbps
LAN interfaces type	Ethernet 100 BaseFx	100 Base-T (copper interface)
Voltage isolation level	N/A	1.5 kV
USB 2.0	√	√
Maximum speed	N/A	480Mbit/sec
Connector type	type B	type B
Voltage isolation level	ELV level	N/A
SD card 2.0	X	√
Connector type	N/A	SD/SDHC card
Voltage isolation level	N/A	N/A
Smpling rate	80/cyle	80/cycle
ADC resolution	24 bit	16 bit
Published value		
Va	√	√
Vb	√	√
Vc	√	√
Vn	√	√
Ia	√	√

Ib	√	√
Ic	√	√
In	√	√
Time synchronisation	1PPS GPS source	1PTP GPS source
Alarm Type	Synch Source loss, sample synch loss, Power indicator	No Synch source,Sample Synch lost, Network, internal fault

Chapter 3

3 Stand Alone Merging Unit

The electricity is generated by the power plant (e.g. nuclear power plant). The power generated needs to be delivered to the consumers. The substation is an important part of the power distribution grid. The early technology used the fuse to protect the power transformer in the substation. As the technology developed, the electromechanical relay was introduced to replace the fuse. In a modern substation, the old electromechanical relay is replaced by the microprocessor-based relay which is one type of Intelligent Electronic Devices (IEDs). IEDs can provide more features and capabilities like protection, monitoring, data logging etc. than the devices based on the old technology. To protect the power equipment, a lot of parameters such as the current and voltage needs to be measured from the system and the IED should be able to get the measurement to perform the protection functions.

Substation in a distribution system can be called as digital if the devices at process level are intelligent in nature and provide digital data. Digital substation consists of many intelligent electronic devices, performing the task of circuit breaking, measurement, protection relay, recorder, phasor measurement etc. These devices perform the task of measurement, control, quality check, protection and information exchange.

One such intelligent device is Stand Alone Merging Unit; this device was initially developed as a part of non-conventional Instrument Transformers. It acts as the digital interface of the instrument transformer. According to the IEC 60044-8 "Instrument Transformers- Electronic Current Transformer" **Merging unit** is physical unit used to do the time-coherent combination of the current and/or voltage data coming from the secondary converters. The merging unit can be part of one of the transformers in the field or may be a separate unit.

3.1 Placement of Merging Unit in Digital Substation

Digital substation architecture is a three level design where intelligent electronic devices perform various operations. MU, in a practical application, is the data recipient of primary devices and the data source of secondary devices, of which data processing module is of essential importance. According to the development of intelligent distribution substation, merging unit is designed to receive real-time power network information from both conventional electromagnetic instrument transformers and electronic transformers. Once the instrument transformer fails to work, the information is distorted, which would cause interference to the correct action of protection relays.

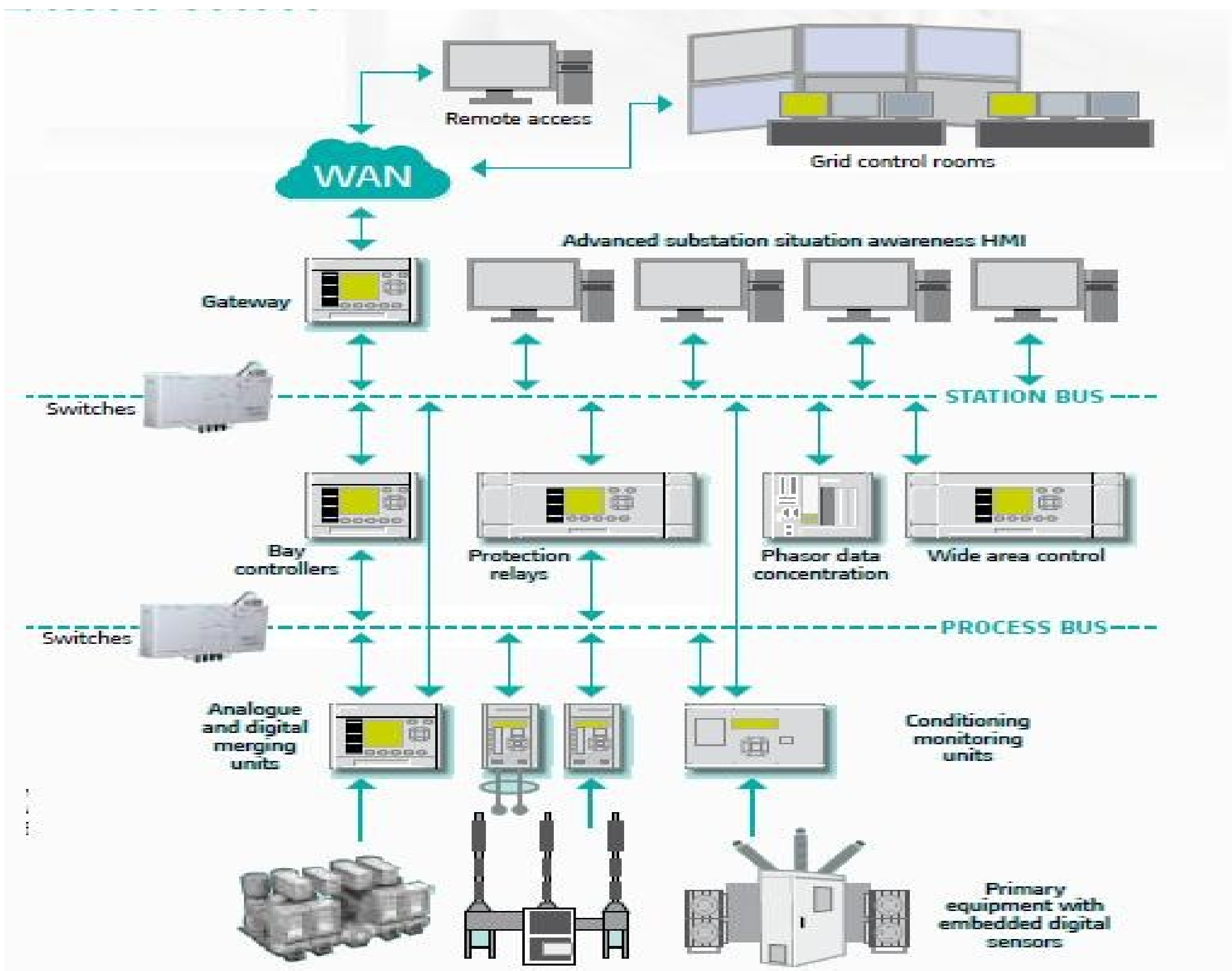


Figure 12: Digital Substation [6]

As shown in *figure 12* Stand Alone Merging unit is a process level device which works on instrument transformer secondary output. Merging Unit act as a monitoring and control device; feature of quality monitoring can be added with dual sampling. Position of the merging unit in substation is in the figure below.

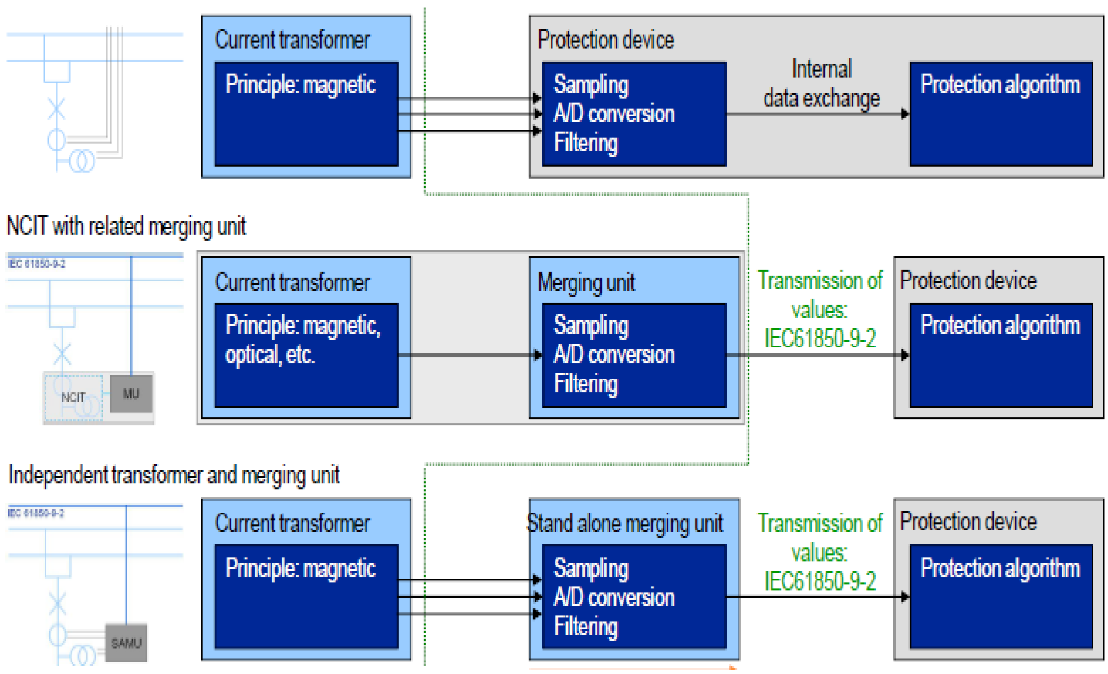


Figure 13: Placement of Merging Unit [20]

According to IEC 61869-9, a digital device when incorporated with a single instrument transformer is known as an Analog Merging Unit (AMU). Intelligent device which can be used with any instrument transformer or can be retro-fitted with a conventional transformer for digital interface is known as Stand Alone Merging Unit (SAMU). This has been illustrated in the *figure 13* where second image show measurement through AMU within an instrument transformer and third show an independent SAMU.

The first image in *figure 13* depicts conventional approach where protection device was used for measuring Instrument transformer data. Protection device is connected via parallel copper wires from the secondary of instrument transformer. Protection device is responsible for adequately converting the analog value to digital for transfer sample value with in the system. Conventional approach does not use digital data for information exchange between different devices. Digital data is shared and contained within the individual device only.

An instrument transformer with digital output as shown in the figure has merging unit as an integral part to the transformer. Here merging unit take the secondary output of the transformer through CT/VT‘s and publish sample value in digital format. Merging unit acts as a digital interface of the transformer. Sample value publication of three phase current and voltage value is governed by the standard IEC 61850-9-2 ‘Specific Communication Service Mapping – Sampled value over IEC 8802-3’. IEC 8802-3 is standard for Ethernet protocol based communication network. Implementation of IEC 61850-9-2 ensures publication of sampled value on the substation network. Sampled values over the Ethernet can be used by intelligent electronic device which support IEC 61850 based communication.

Figure show a stand alone merging unit as an independent device which can be used for any conventional instrument transformer. SAMU is independent of the type of instrument transformer and can be retro-fitted in any conventional transformer for digital communication. SAMU act as a measurement and monitoring device to the instrument transformer which samples the transformer current and voltage to be published over the substation network. SAMU’s electrical and design configuration are governed by IEC 61869-9, while its communication profile is derived from IEC 61850-9-2 communication network protocol. SAMU output are Ethernet frame formed according to IEC 61850 communication profile.

Electrical interface of the transformer were discussed in IEC 60044 where different chapter dealt with interface of various transformer. IEC 60044-8 defines merging as a physical device for digital interface for publication of sampled value. Electrical rating for current, voltages, error, and communication delay are provided in the IEC 60044-8. These electrical rating has inspired the merging unit design for IEC61869-6, for accuracy class and accuracy test. Accuracy test for merging unit provided in IEC 60044-8 is used by IEC 61868-9 and IEC 61869-6 for test circuit, accuracy class rating. Architecture of the SAMU can be derived from these standards, architecture of SAMU is not rigid but it does include some persistent parts which are mandatory for standard compliance. Architecture for SAMU is discussed in the following sections.

3.2 Stand Alone Merging Unit Architecture

Merging Unit (MU) has been defined in the IEC60044-7 /8 for the first time as shown in Figure. This new concept is put forward for digital output of electronic transformer. Its main function is to synchronously sample multiple ECT/EVT digital signals and send them to protection and control devices in accordance with format prescribed by IEC standards. In the intelligent distribution substation, merging unit is the process level device which provides input interface for multiple instrument transformers and synchronous signal, and receives real-time information of power network from the instrument transformer; at the same time, merging unit provides both serial output and Ethernet interfaces for communication with protection, monitoring and control devices in bay level.

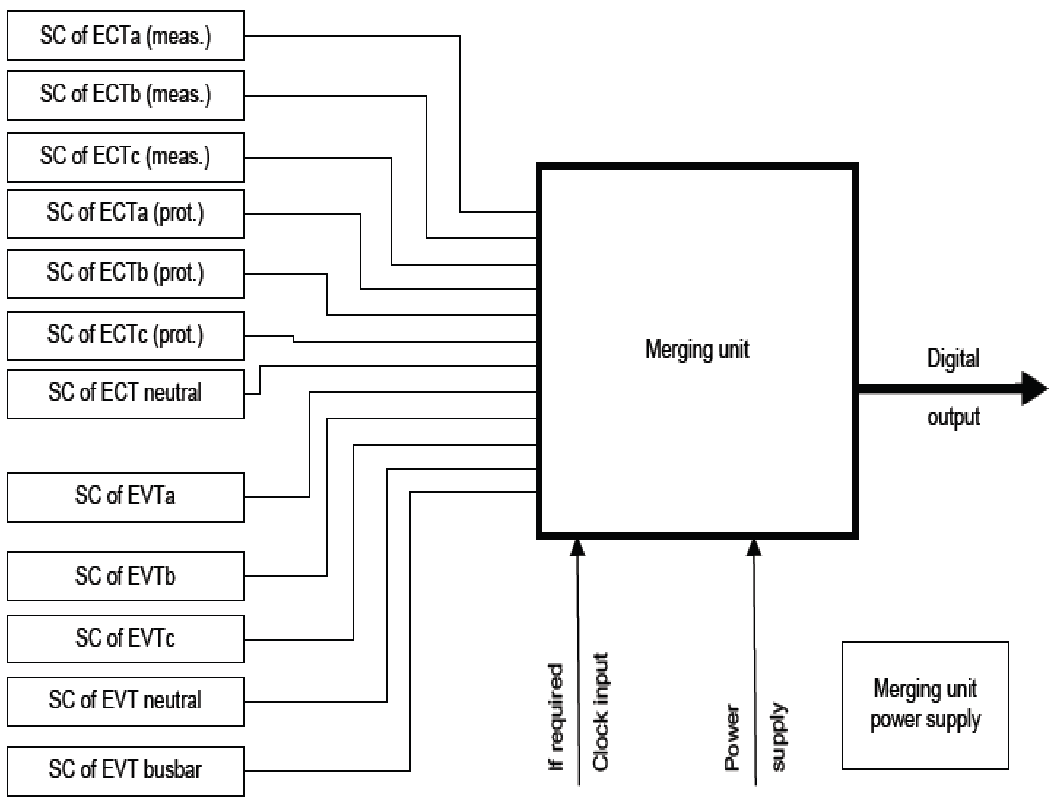


Figure 14: Merging unit Concept [2]

Figure 14 shows merging unit as a concept for sampling the current and voltage values and providing them over the ethernet. Merging Unit being device with flexible architecture can be implemented with a single controller, single controller with multiple core or as multiple microcontroller device.

Major function for SAMU can be listed as follow:

- Simultaneous sampling of three phase data
- Synchronization of device clock with network clock
- Time stamping of sampled value
- Publication of sampled value
- Frame generation for Ethernet

3.3 Electrical Rating based on IEC 60044-8

Electrical rating for SAMU are derived from IEC 60044-8 "Electronic Current Transformer". This standard gives us following feature for SAMU:

3.3.1 Electronic instrument transformer

Arrangement consisting of one or more current or voltage sensor(s) which may be connected to transmitting systems and secondary converters, all intended to transmit a measuring quantity in a proportional quantity to supply measuring instruments, meters and protective or control devices. In case of a digital interface this is done by using a merging unit for a set of electronic instrument transformers

3.3.2 Electronic current transformer (ECT)

Electronic instrument transformer in which the output of the secondary converter in normal conditions of use is substantially proportional to the primary current and differs in phase from it by a known angle for an appropriate direction of the connections

3.3.3 Primary terminals

Terminals through which the current to be measured flows

3.3.4 Rated frequency (*f*r)

Value of the fundamental frequency on which the requirements of this standard are based

3.3.5 Rated primary current (*I*pr)

R.M.S. value of the component of the primary current at rated frequency *f*r on which the performance of the electronic current transformer is based

3.3.6 Current error (ratio error) (ε %)

Error which an electronic current transformer introduces into the measurement of a current and which arises from the fact that the actual transformation ratio is not equal to the rated transformation ratio

For analogue output, the current error expressed in per cent is given by the formula:

$$\varepsilon\,\% = \frac{K_{ra}.U_s - I_p}{I_p} \times 100$$

where

*K*ra is the rated transformation ratio;

*I*p is the r.m.s. value of the actual primary current when *i*p res(*t*) = 0;

*U*s is the r.m.s. value of secondary converter output when *U*sdc + *u*s res(*t*) = 0.

For digital output, the current error expressed in per cent is given by the formula

3.3.7 Rated delay time (*t*dr)

Rated value of time needed e.g. for digital data processing and transmission

3.3.8 Accuracy class

Designation assigned to an electronic current transformer, the current error and phase displacement of which remain within specified limits under prescribed conditions of use

3.3.9 Digital output

The digital output is made up of an optical or an electrical output interface at the merging unit. It supplies measuring instruments, meters and protective or control devices with digitally coded time-coherent sets of current and/or voltage data

3.3.10 Merging unit clock input

Electrical or optical input of the merging unit that can be used to synchronize several merging units if required

3.3.11 Data rate (1/*T*s)

Number of current and/or voltage data sets transmitted per second

Accuracy class	± percentage current (ratio) error at percentage of rated current shown below				± phase error at percentage of rated current shown below							
					Minutes				Centiradians			
	5	20	100	120	5	20	100	120	5	20	100	120
0,1	0,4	0,2	0,1	0,1	15	8	5	5	0,45	0,24	0,15	0,15
0,2	0,75	0,35	0,2	0,2	30	15	10	10	0,9	0,45	0,3	0,3
0,5	1,5	0,75	0,5	0,5	90	45	30	30	2,7	1,35	0,9	0,9
1,0	3,0	1,5	1,0	1,0	180	90	60	60	5,4	2,7	1,8	1,8

Table 5 Standard accuracy class [18]

3.3.12 Standard accuracy classes

The standard accuracy classes for protective current transformers are:

5 P, 10 P, and 5TPE.

3.3.13 Limits of error

At rated frequency, the current error, phase error and composite error and, during application of specified duty cycle if transient performance is specified, the maximum peak instantaneous error shall not exceed the values given in table 6. The phase error indicated in the tables of limits of errors are the values remaining after the compensation of the rated delay time

Accuracy class	Current error at rated primary current %	Phase error at rated primary current		Composite error at rated accuracy limit Primary current %	At accuracy limit condition Maximum peak instantaneous error %
		Minutes	Centiradians		
5TPE	± 1	± 60	± 1,8	5	10
5 P	± 1	± 60	± 1,8	5	-
10 P	± 3	-	-	10	-

Table 6 Rated error for accuracy class [18]

3.4 IEC 61869-9 based requirement

The new standard from IEC discusses about the physical requirement for the SAMU similar to IEC 60044-8. It also incorporate the relevant communication profile, logical nodes and sampling rates as in the case of IEC 61850 series. IEC 61869-9 act as a complete guide for development of SAMU with guideline for synchronization, communication and physical interface being included in single standard.

The standard initially states physical realization of merging unit as a part of instrument transformer.

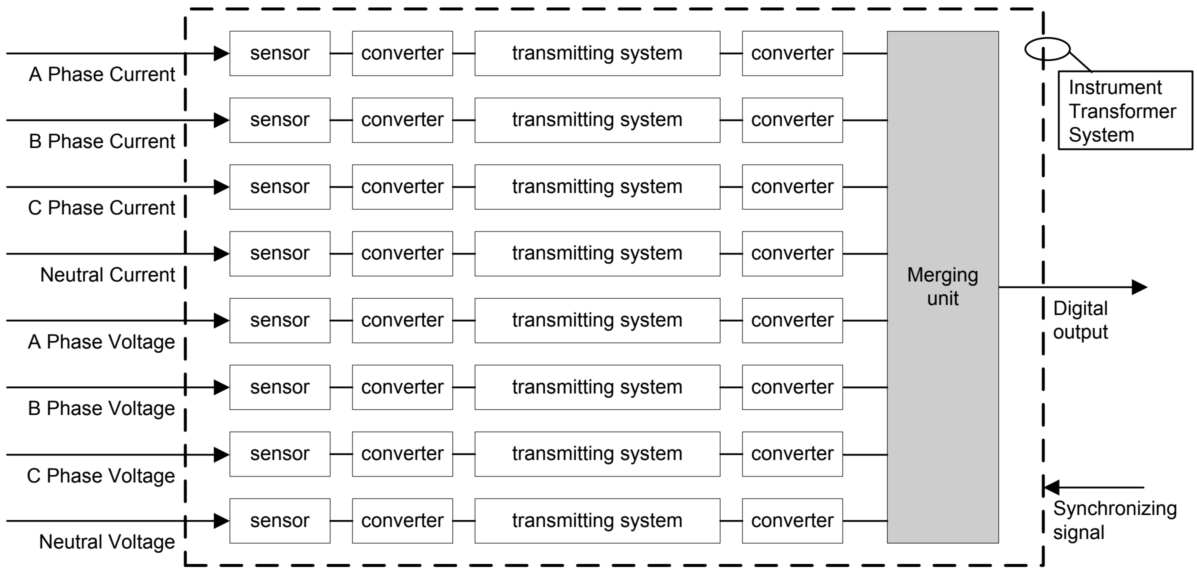


Figure 15 Merging Unit as part of Instrument Transformer [18]

It is not absolutely necessary that all parts shown in *Figure 15* be included. For example there may be a separate physical unit for each phase containing the primary voltage and/or current sensors, primary converters and primary insulation, with all secondary converters and the merging unit in a separate physical unit located in the control house.

Unlike the merging unit in an instrument transformer, a SAMU is a separate product. It accepts as inputs the outputs of instrument transformers, said outputs conforming to the specifications of one of the product standards in the IEC 61869 series. The number of inputs and their type (voltage or current) may be other than shown in *Figure 16*. Output produced by a SAMU and output produced by an electronic instrument transformer with built in merging unit should be indistinguishable from each other. A simpler version of SAMU is provided in *figure 17*.

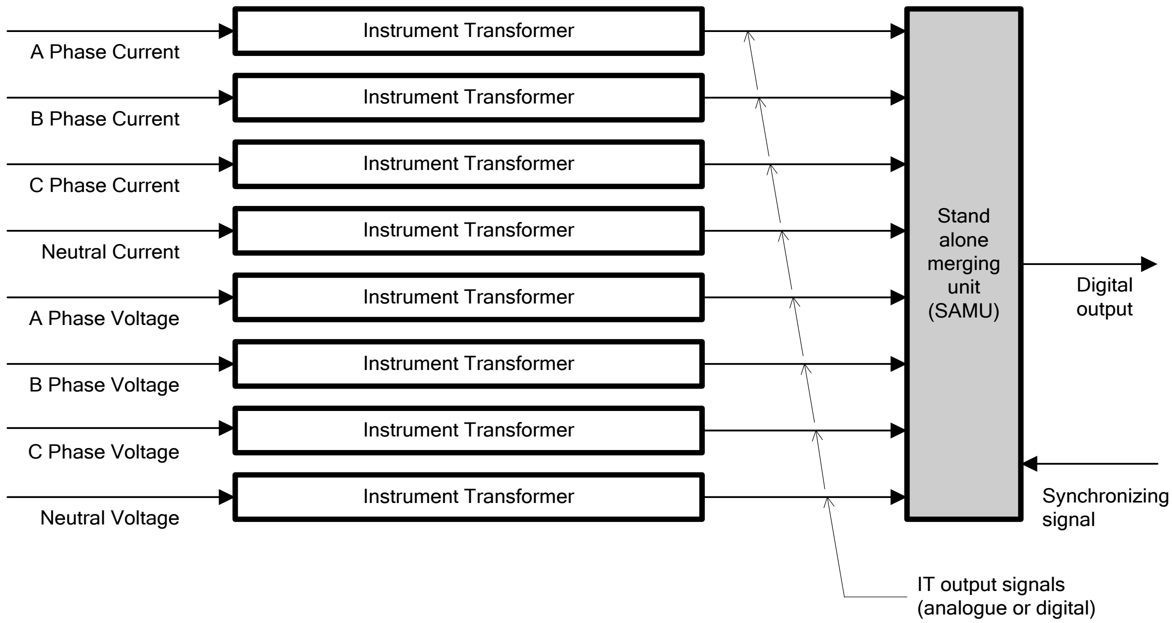


Figure16: Stand alone merging unit (concept example) [18]

IEC 61869-9 make some additional definition to already defined ratings:-

3.4.1 Rated holdover time

The rated duration over which the merging unit shall continue to send samples maintaining the sample timing required for the measuring accuracy class following loss of the time signal

3.4.2 Processing delay time tpd

The difference between the time encoded by the field SmpCnt in a digital output message and the time this message appears at the digital output

3.4.3 Maximum processing delay time

The longest processing delay time (tpd) under all rated operating conditions

3.4.4 Rated accuracy class

In the SAMU case accuracy of the digital output is calculated by cascading the separately given instrument transformer and SAMU accuracy specifications. Accuracy specifications directly incorporate all errors associated with time synchronization.
With regards to accuracy classes, instrument transformers with digital output shall be classified in two groups:

- Measuring instrument transformers
- Protection instrument transformers.

The dual rating requirement acknowledges the fact that protection rated instrument transformers are commonly also used for measurement and indication purposes. It establishes a proven, well understood method for documenting this performance and takes into account SAMU specific requirements.

Performance requirements

Electronic instrument transformers with digital output shall meet all the requirements defined in IEC 61869 specific product standards.

- Merging unit behaviour shall be well defined under all operating conditions
- If present, test signal generating capability shall by default be disabled
- All data included in the same ASDU (including quality bits) shall be mutually consistent and shall represent the same time instant.
- Data shall be synchronized to a common time reference

3.4.5 Maximum processing delay time requirement

Processing delay time (tpd) defined is the difference between the time encoded by the digital output message field SmpCnt and the time this message appears at the digital output. The time of the message appearing on the digital output shall be measured at the message timestamp point using the external clock supplied to the device synchronization input.

Maximum processing delay time shall be specified by the manufacturer and shall be within the limits specified in IEC 61869-9.
The maximum processing delay time limit is measured at the merging unit output and does not include external delays contributed by the process bus network components or network congestion.
Maximum processing delay time shall remain compliant with this specification, regardless whether the device is in the holdover mode or synchronized to an external time reference.

3.4.6 Rated conformance classes

Class a: the minimal set of services required to transmit MU data using sampled values;
Class b: class a capabilities plus the minimal set of services required to support GOOSE messages;
Class c: class b capabilities plus services required to implementation of the IEC 61850 series' information model with self-descriptive capabilities;
Class d: class c capabilities plus services for file transfer, buffered and unbuffered reporting

3.5 IEC 61850-9-2 based requirement

IEC 61850 series discusses network based communication in the substation. IEC 61850-9-2 handle the publication of sample value over ethernet in IEEE 0.802 format. This standard not only defines the legacy sampling rate but also the attribute, dataset and logical nodes required for publication.

3.5.1 Attributes

An entity that define and store a typical automation, protection or other function.

3.5.2 Logical devices

An entity that represent a set of typical automation, protection or other function.

3.5.3 Logical Nodes

An entity that represent typical automation, protection or other function.

3.5.3.1 Logical nodes LPHD

LPHD logical nodes shall be as specified in IEC 61850-7-4:2010, 5.3.2, except that the LPHD logical nodes shall be extended by the addition of the data objects defined in IEC 61869-9. The data attributes of these extended data objects shall be read-only.

Table 7 shows the attribute and their priority as mandatory or optional.

LPHD class				
Data object name	Common data class	Explanation	T	M/O/C
Data objects				
Descriptions				
PhyNam	DPL	Physical device name plate		M
Status information				
PhyHealth	ENS	Physical device health		M
OutOv	SPS	Output communications buffer overflow		O
Proxy	SPS	Indicates if this LN is a proxy		M
InOv	SPS	Input communications buffer overflow		O
NumPwrUp	INS	Number of power-ups		O
WrmStr	INS	Number of warm starts		O
WacTrg	INS	Number of watchdog device resets detected		O
PwrUp	SPS	Power-up detected		O
PwrDn	SPS	Power-down detected		O
PwrSupAlm	SPS	External power supply alarm		O
Controls				
RsStat	SPC	Reset device statistics	T	O
Sim	SPC	Receive simulated GOOSE or simulated SV		O

Table 7: Logical Node LPHD Attributes

LPHD class certain the physical attribute of the device. It also mention which features are mandatory and which attributes can be taken as optional.

3.5.3.2 Logical nodes TCTR

TCTR logical nodes shall be as specified in IEC 61850-7-4, except that the TCTR logical nodes shall be extended by the addition of the data objects defined in IEC 61869-9. The data attributes of these extended data objects shall be read-only.

Table 8 shows the attributes of the TCTR node and their inclusion as mandatory, optional or conditional.

TCTR class				
Data object name	Common data class	Explanation	T	M/O/C
LNName		The name shall be composed of the class name, the LN-Prefix and LN-Instance-ID according to IEC 61850-7-2, Clause 22.		
Data objects				
Descriptions				
EEName	DPL	External equipment name plate		O
Status information				
EEHealth	ENS	External equipment health		O
OpTmh	INS	Operation time		O
Measured and metered values				
AmpSv	SAV	Current (sampled value)		C1
Settings				
ARtg	ASG	Rated current		O
HzRtg	ASG	Rated frequency		O
Rat	ASG	Winding ratio of an external current transformer (transducer) if applicable		O
Cor	ASG	Current phasor magnitude correction of an external current transformer		C2
AngCor	ASG	Current phasor angle correction of an external current transformer		C2
CorCrv	CSG	Curve phasor magnitude and angle correction		C2
Condition C1: The data object is mandatory if the data object is transmitted over a communication link and therefore it is visible. Condition C2: If there are two or more correction pairs necessary, CorCrv should be used.				

Table 8: Logical Node TCTR Attributes

3.5.3.3 Logical nodes TVTR

TVTR logical nodes shall be as specified in IEC 61850-7-4:2010, except that the TVTR logical nodes shall be extended by the addition of the data objects defined in IEC 61869-9. The data attributes of these extended data objects shall be read-only.

Table 9 represent the TVTR logical node attributes and their inclusion as mandatory, optional or conditional.

TVTR class				
Data object name	Common data class	Explanation	T	M/O/C
LNName		The name shall be composed of the class name, the LN-Prefix and LN-Instance-ID according to IEC 61850-7-2, Clause 22.		
Data objects				
Descriptions				
EEName	DPL	External equipment name plate		O
Status information				
EEHealth	ENS	External equipment health		O
OpTmh	INS	Operation time		O
FuFail	SPS	TVTR fuse failure		O
Measured and metered values				
VolSv	SAV	Voltage (sampled value)		C1
Settings				
VRtg	ASG	Rated voltage		O
HzRtg	ASG	Rated frequency		O
Rat	ASG	Winding ratio of external voltage transformer (transducer) if applicable		O
Cor	ASG	Voltage phasor magnitude correction of external voltage transformer		O
AngCor	ASG	Voltage phasor angle correction of external voltage transformer		C2
CorCrv	CSG	Curve phasor magnitude and angle correction		C2
Condition C1: The data object is mandatory if the data object is transmitted over a communication link and therefore it is visible. Condition C2: If there are two or more correction pairs necessary, CorCrv should be used.				

Table 9: Logical Node TVTR Attributes

Logical nodes TVTR, TCTR, LPHD are necessary for mapping of SAMU data.

3.5.3.4 Quality

The quality attribute refers to the quality of the sampled value independently of any error in the sample time instant. For instance when in the free-run mode, wherein sample time error is arbitrarily large, sample quality may still be good and sampled values perfectly usable by subscribers that are not sensitive to the phase difference between these samples and samples from other instrument transformers. The quality of each sampled value in each ASDU shall be as represented by its quality value in that ASDU.

3.5.3.5 Dataset(s)

The datasets shall be as specified in IEC 61850-7-2:2010. Dataset members shall consist of AmpSv.instMag.i (current sampled value) or VolSv.instMag.i (voltage sampled value) attributes, each followed immediately by the corresponding AmpSv.q or VolSv.q (quality) attribute. The number of current sampled values and the number of voltage sampled values shall match the number of each specified by the variant code for the dataset.

For example Definition of Data Set PhsMeas

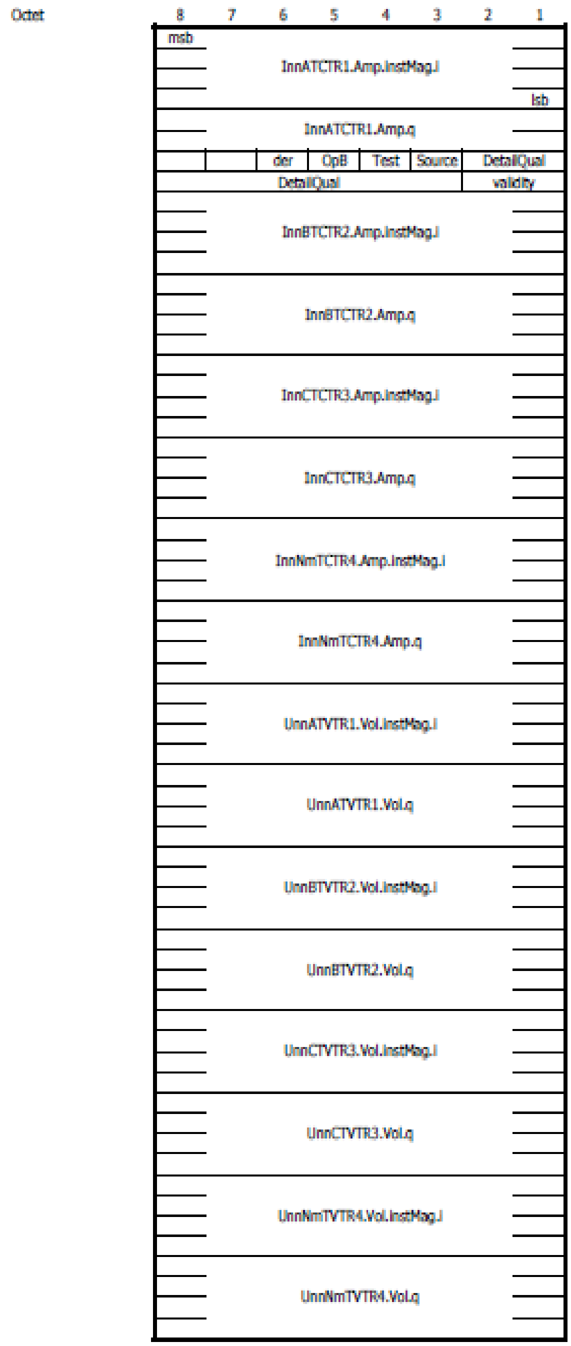


Figure 17: Dataset for PhsMeas

Using these dataset values Application Protocol Data Unit are formulated.

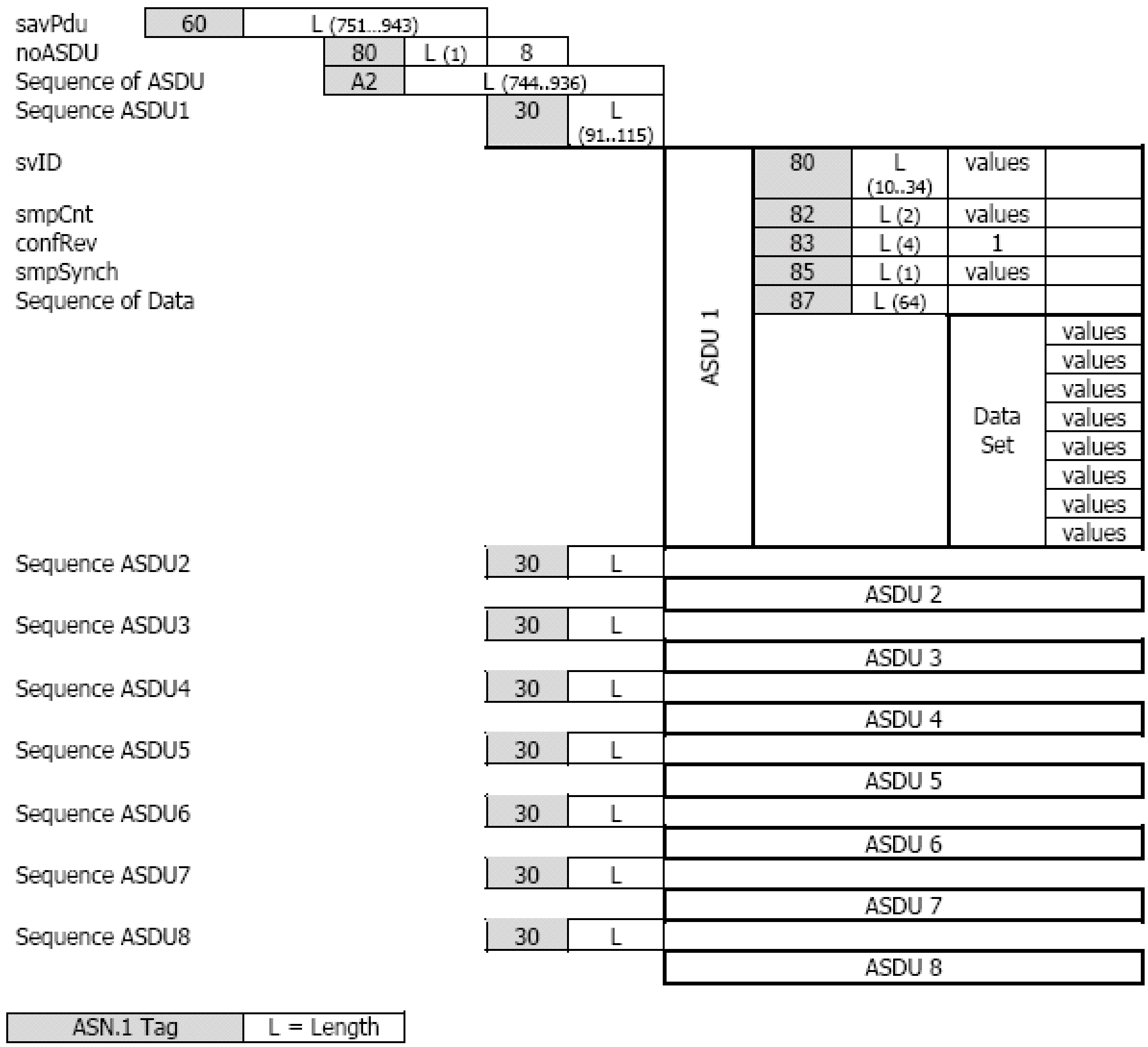


Figure 18: Sample Value APDU

Collection of APDU and ASDU (Application Service Data Unit) are used for Ethernet frame formulation.

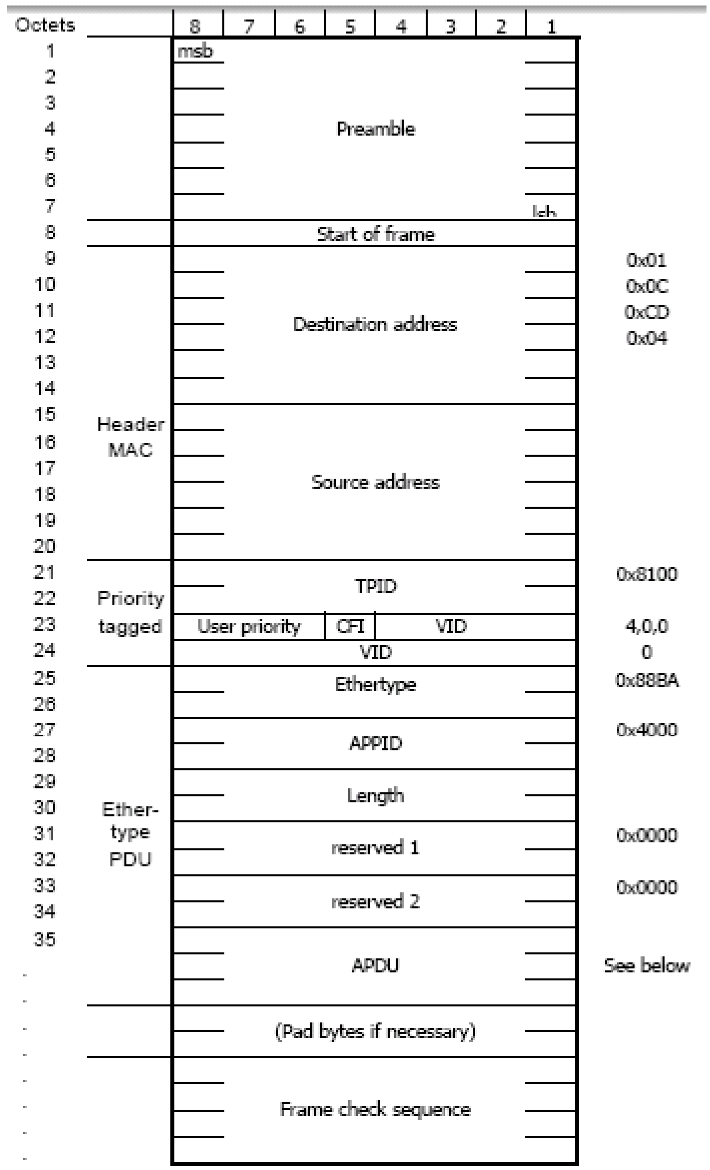


Figure 19: Sampled Values based Ethernet Frame of IEC61850-9-2

3.6 IEC 61588 based synchronization requirement.

Merging units shall have the capability to accept an external synchronizing signal, so that their sampling can be synchronized both to other merging units and to an external time reference. The preferred synchronization method is Precision Time Protocol specified in IEC 61588:2009 (PTP, also known as 1588.). The merging unit may use a one pulse per second (1PPS) input as specified herein instead of (or as an optional alternative to) PTP for legacy applications. In either case, the accuracy of the time signal (mean error from absolute time) is expected to be better than 1 μs for accuracy characterisation.

The merging unit shall contain an internal clock that is synchronized by the synchronizing signal. A sample counter (SmpCnt) shall be used to identify the samples within the present second and to code their sample times. The sample counter increments from zero to the nominal number of samples per second less one, then repeats. Sample times are those instants where the internal clock's fraction of a second equals the sample counter's count divided by the nominal sample rate.

Following are the standard based attributes which are essential for accurate operation of SAMU:

3.6.1 Precision Time Protocol Synchronization

Merging unit ports used for sample value transmission shall comply with IEEE Std C37.238™-2011 *Standard profile for use of IEEE Std. 1588™ precision time protocol in power system applications*, here referred to as Power Profile.

3.6.2 1PPS Synchronization

Merging units shall accept the following 1PPS signal on a dedicated clock input port:

- Signal type : optical on graded index 62,5/125 μm glass fibre
- Clock rate : must be one pulse per second
- Change of second : it should be on the rising edge from low to high
- Pulse duration t_h : 10 μs to 500 ms

Optionally, the merging unit may compensate for transmission delays in the time network by applying a user configurable time offset to the 1PPS signal.
Figure 20 shows the shape of the 1PPS signal graphically.

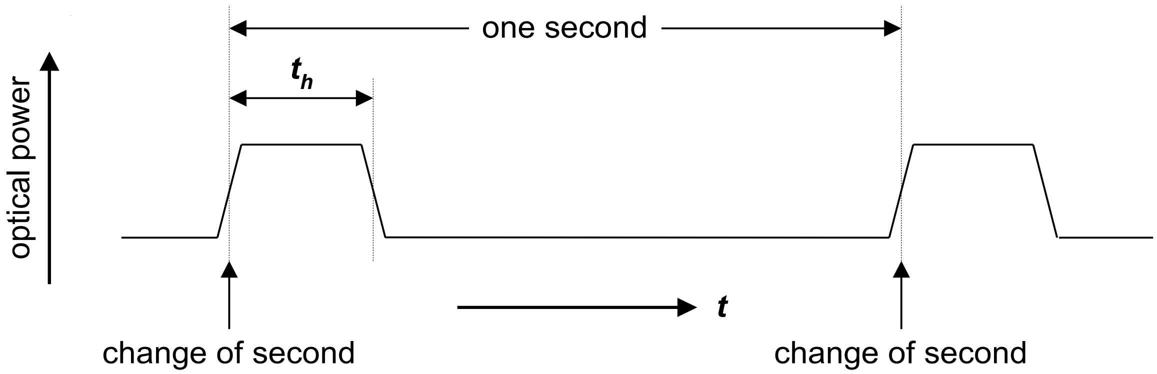


Figure 20 – 1PPS signal waveform at the merging unit clock input [5]

3.6.3 Sample value message (SmpSynch attribute)

Applications that are sensitive to the phase angle difference between different merging units require that the sampled values from those merging units be synchronized with each other. Such applications include protection, control, metering, and synchrophasors. Sampled values from different devices are synchronized with each other where each of the devices is synchronized to the same time source. The SmpSynch attribute provides information on the time source used to assist sample value subscribers in determining whether sampled values are synchronized to each other.

Sampled values are synchronized to a global area clock to the degree required to meet the measuring accuracy class phase displacement limit. A global area clock is a source that provides time that is traceable to the international standards laboratories maintaining clocks that form the basis for the International Atomic Time (TAI) and Universal Coordinated Time (UTC) timescales. Examples of these are Global Positioning System (GPS), NTP, and

National Institute of Standards and Technology (NIST) timeservers. All sampled values synchronized to any global area clock are synchronized to each other.

While sampled values are synchronized to a local area clock to the degree required to meet the measuring accuracy class phase displacement limit, the value of the "SmpSynch" attribute in the SV messages shall be the unique identifier of the specific local area clock. A local area clock is a source that provides time that advances at essentially the correct rate but which may have a time offset from global area clocks and other local area clocks.

The 1PPS signal does not contain information on the specific local area clock that is the source of the synchronizing signal. Merging units may optionally have a setting specifying the area clock (Local or Global) connected to the 1PPS input.

Figure B.1 shows a typical example of the signal processing and the individual sources of delay that make up the delay time. The time source may be either the 1PPS signal shown or Precision Time Protocol (PTP).

3.7 Problem definition

Real time measurement of instrument transformer is critical for substation operation. Measurement and control of conventional substation posed following problems:

1. Inefficient and costly measurement through copper wires.
2. Delayed control action: As substation process is situated far from the substation control.

To overcome these problems a device needs to be developed which can perform following functions:

1. It should be a standalone device which can be used independently with instrument transformer and retro-fitted in a conventional transformer.
2. It should obey IEC 61869-9, for sampling the current and voltages of instrument transformer at a rate of 4800 samples/ second (measurement class) and at a rate 14400 samples/second (protection class).
3. It should obey standard IEC 61850-9-2 in mapping the sampled data.
4. Sampled values should be published over the ethernet at a rate of 2400 frame/second.

Chapter 4

4 Proposed Hardware

According to the device requirements stated above SAMU require following basic modules to be included:

- A microcontroller which can fulfil following
  - A port for data acquisition
  - An analog to digital convertor unit for signal conversion
  - Support Ethernet (either at physical or software level)
  - High processing speed for calculation and conversion
- A hardware to support Ethernet
- Clocking system (internal or external) for synchronization and time stamping

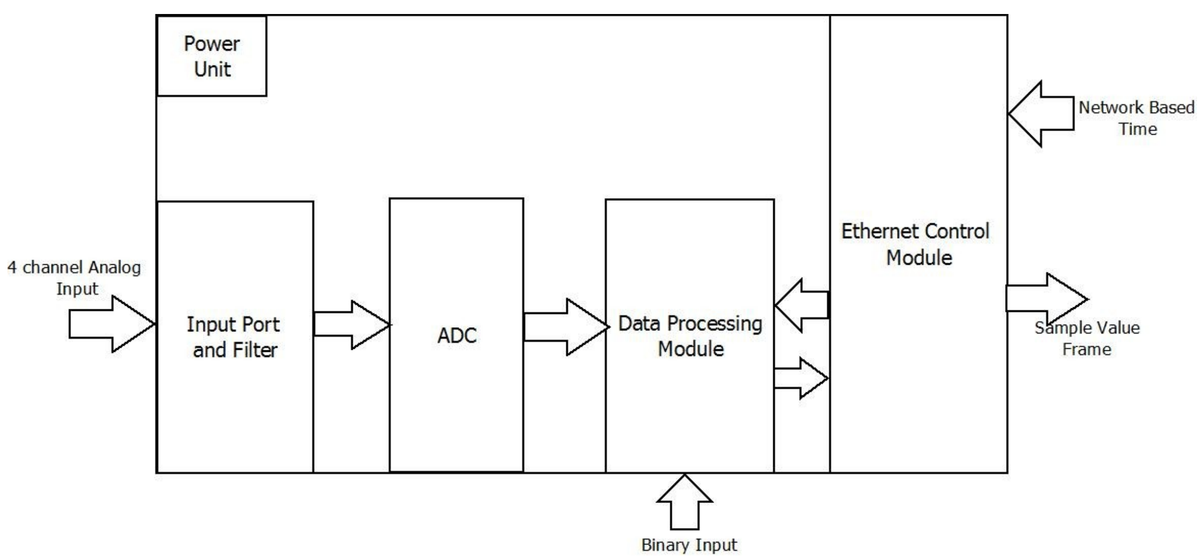


Figure 21: Block Diagram for SAMU

Figure 21 shows a block diagram of SAMU based on same modular approach.

4.1 Proposed Solution

For fulfilment of above said requirements, a dsPIC based system was chosen. A dsPIC33FJ256GP710A possesses following useful characteristics

- Its processor supports high processing speed of 80 mips
- Ease in signal acquisition and signal conditioning
- Inherent ADC module with multichannel simultaneous sampling
- It support ethernet solution through inclusion of TCP/IP stack
- Signal analysis features like fourier and digital filtering also exist which can be used for signal analysis.

With above mentioned advantages dsPIC 33FJ256GP710A based starter kit was selected for prototype development of SAMU.

4.2 Microcontroller

dsPIC 33FJ256GP710A has following features:

- 256 KB Program Flash Memory
- 30 KB RAM
- 9- 16 bit timer which can also be used in 32 bit mode
- 8 input capture
- 2 ADC with 32 channels
- 2 Modules each for SPI, I2C, UART and ECAN
- A maximum of 85 pins which can be used for input/output operation

These features are shown in the block diagram of the dsPIC33FJ256GP710A in *figure 22*.

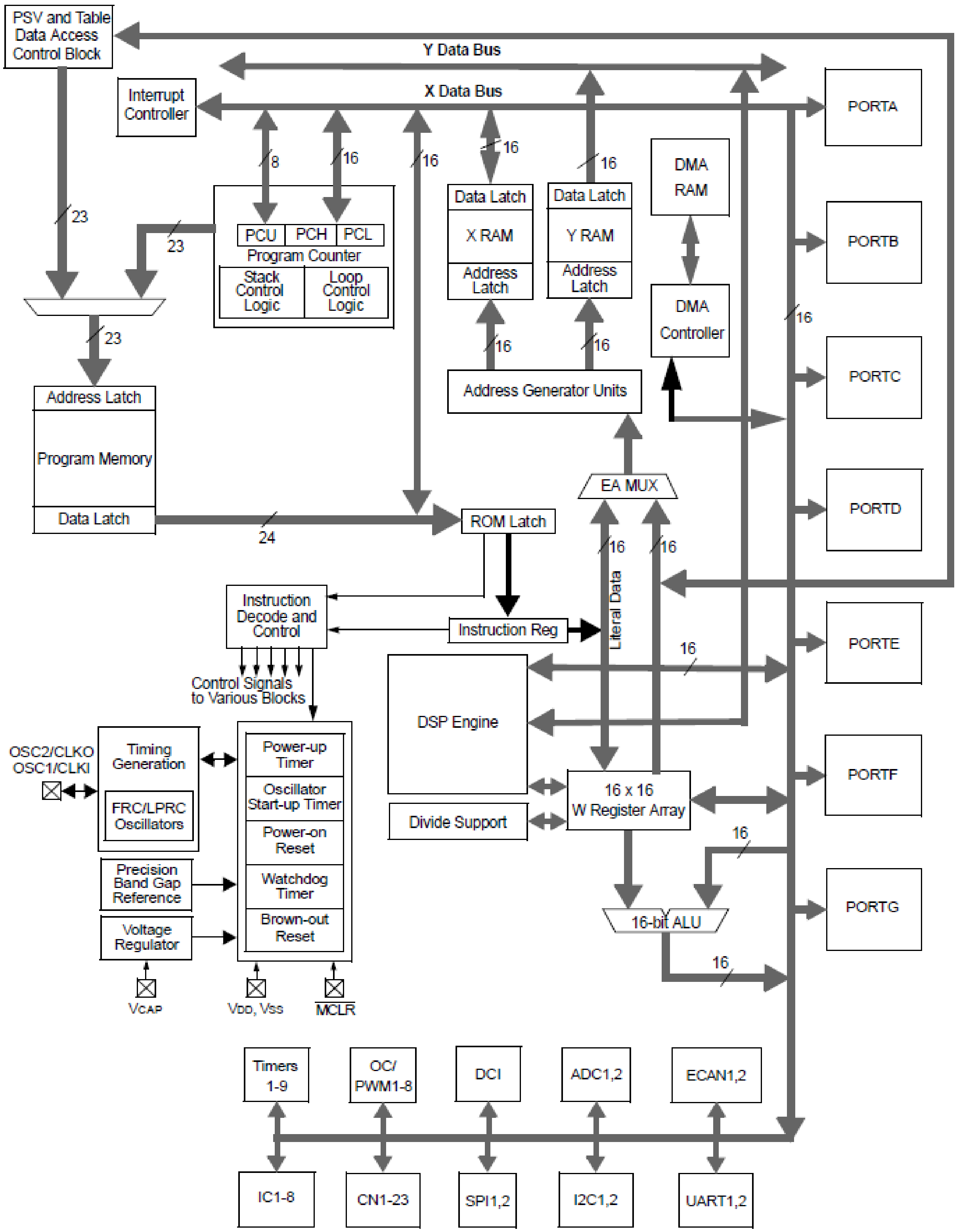


Figure 22: dsPIC 33 FJ256GP710A Block Diagram (Processor)[24]

dsPIC 33FJ256GP710A based Explorer 16 board[23] can be used in development of a device prototype for the ease of usage.

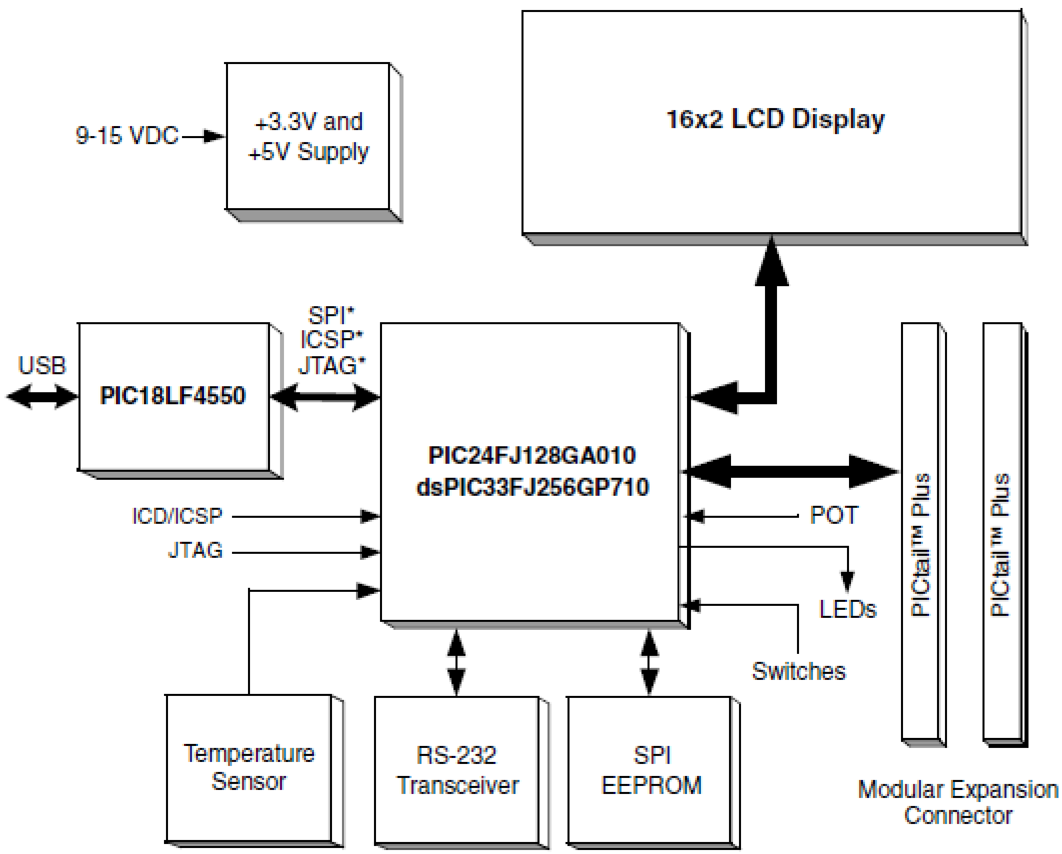


Figure 23: Explorer 16 block diagram [21]

dsPIC33F can support ethernet by using Microchip TCP/IP stack, but it does not have the hardware controller to support physical layer application of ethernet. Thus we can implement application layer and data transfer layer application like IP resolution, domain name server through dsPIC's TCP/IP stack solution. Physical level application like MAC address and physical interface can be done by using a separate device. There are many available ethernet based chips which support physical addressing of device and provide physical interface. One such IC is ENC28J60 from Microchip [22], which is ethernet controller with inbuilt MAC address and physical layer application. It can easily interfaced with any microcontroller through SPI communication.

4.3 Microchip ENC28J60

This ethernet based chip support the following features:

• IEEE 802.3™ Compatible Ethernet Controller

• Fully Compatible with 10/100/1000Base-T Networks

• Integrated MAC and 10Base-T PHY

• Supports One 10Base-T Port with Automatic Polarity Detection and Correction

• Supports Full and Half-Duplex modes

• Programmable Automatic Retransmit on Collision

• Programmable Padding and CRC Generation

• Programmable Automatic Rejection of Erroneous Packets

• SPI Interface with Clock Speeds up to 20 MHz

• 8-Kbyte Transmit/Receive Packet Dual Port SRAM

• Configurable Transmit/Receive Buffer Size

• Hardware Managed Circular Receive FIFO

• Byte-Wide Random and Sequential Access with Auto-Increment

• Internal DMA for Fast Data Movement

• Hardware Assisted Checksum Calculation for various Network Protocols

• Loopback mode

• Two Programmable LED Outputs for LINK, TX, RX, Collision and Full/Half-Duplex Status

• Six Interrupt Sources and One Interrupt Output Pin

• 25 MHz Clock Input Requirement

• Clock Out Pin with Programmable Prescaler

• Operating Voltage of 3.1V to 3.6V (3.3V typical)

• 5V Tolerant Inputs

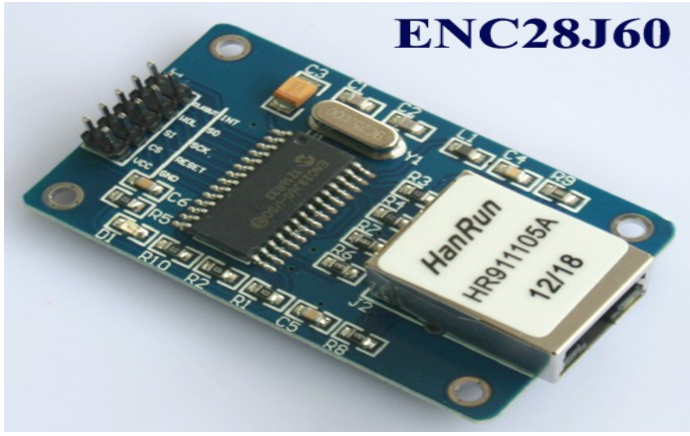


Figure 24: ENC28J60 board [25]

ENC28J60 board are available online as plug-in module (*figure 24*) which can be directly connected to the microcontroller. This chip acts as an ethernet controller which has MAC module, SPI interface and internal memory for storing address as shown in *figure 25*.

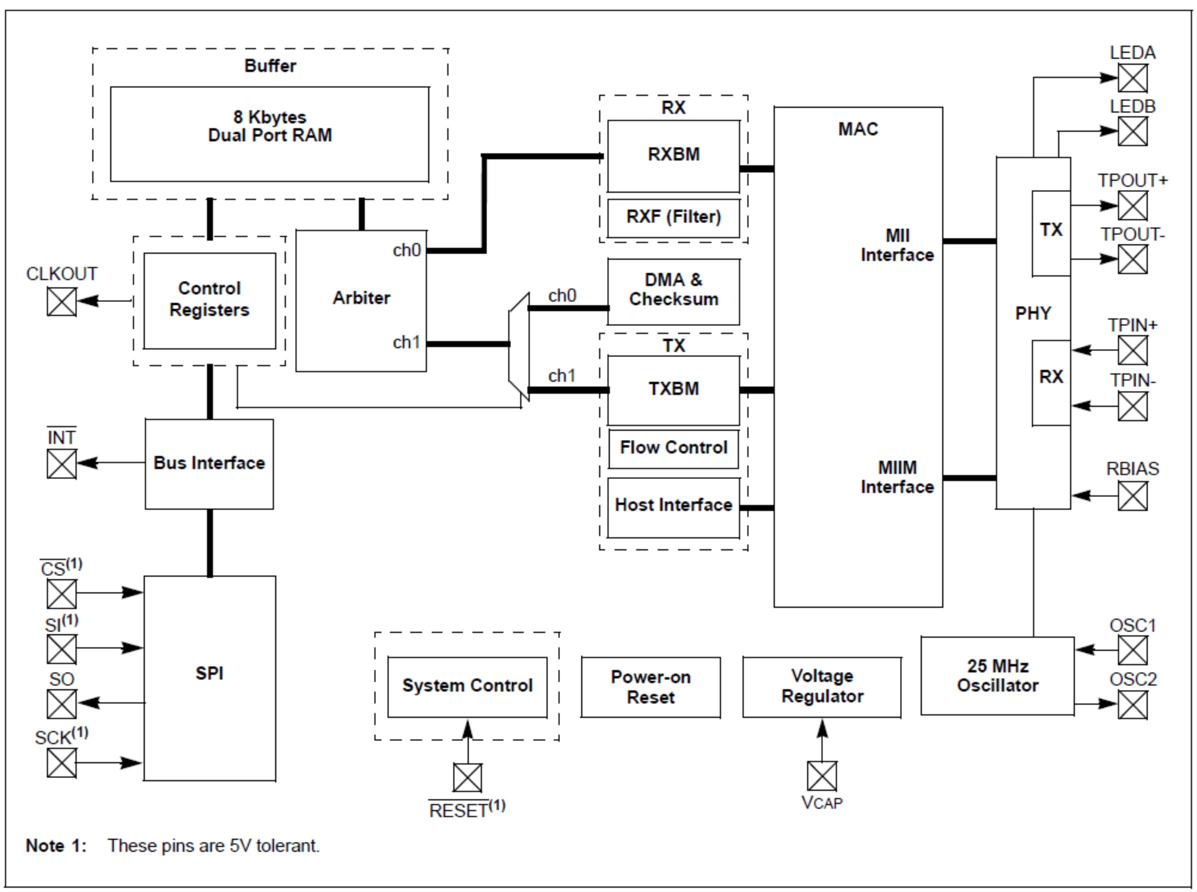


Figure 25: ENC 28J60 Block Diagram [22]

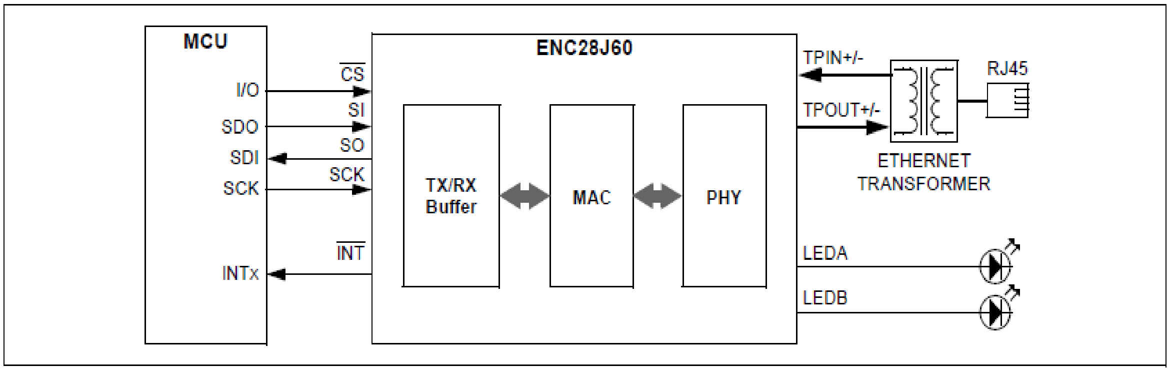


Figure 26: ENC28J60 based interface [22]

Figure 24 shows the ENC28J60 based board that can be mounted on the microcontroller prototype board. ENC28J60 chip act as an ethernet controller with internal memory and register as shown through block diagram in *figure 25*. *Figure 26* shows the interface between the ENC28J60 board and the microcontroller. Schematic of the ethernet chip is available online as they differ from one vendor to the other. The schematic for the ethernet board is provided in the section 4.4, *figure 27* show the schematic as shared by the vendor. *Figure 28* is the schematic developed for the interface of dsPIC and ENC28J60 IC's to develop the SAMU prototype. The *figure 28* shows the port pins used for interfacing the two boards. Following observations can be made from the schematic *figures 27, 28*:

- Microcontroller is connected with two crystal oscillator of 32.7 MHz and 8 MHz
- SPI 1 is used for the interface with ENC28J60 through plug-in connector
- Emulator for programming the microcontroller is connected connector J2
- ENC28J60 uses its on crystal oscillator of 25 MHz
- Ethernet port terminal (RJ45 terminal) is connected to the transformer circuit

4.4 Schematic

ENC28J60 Schematic

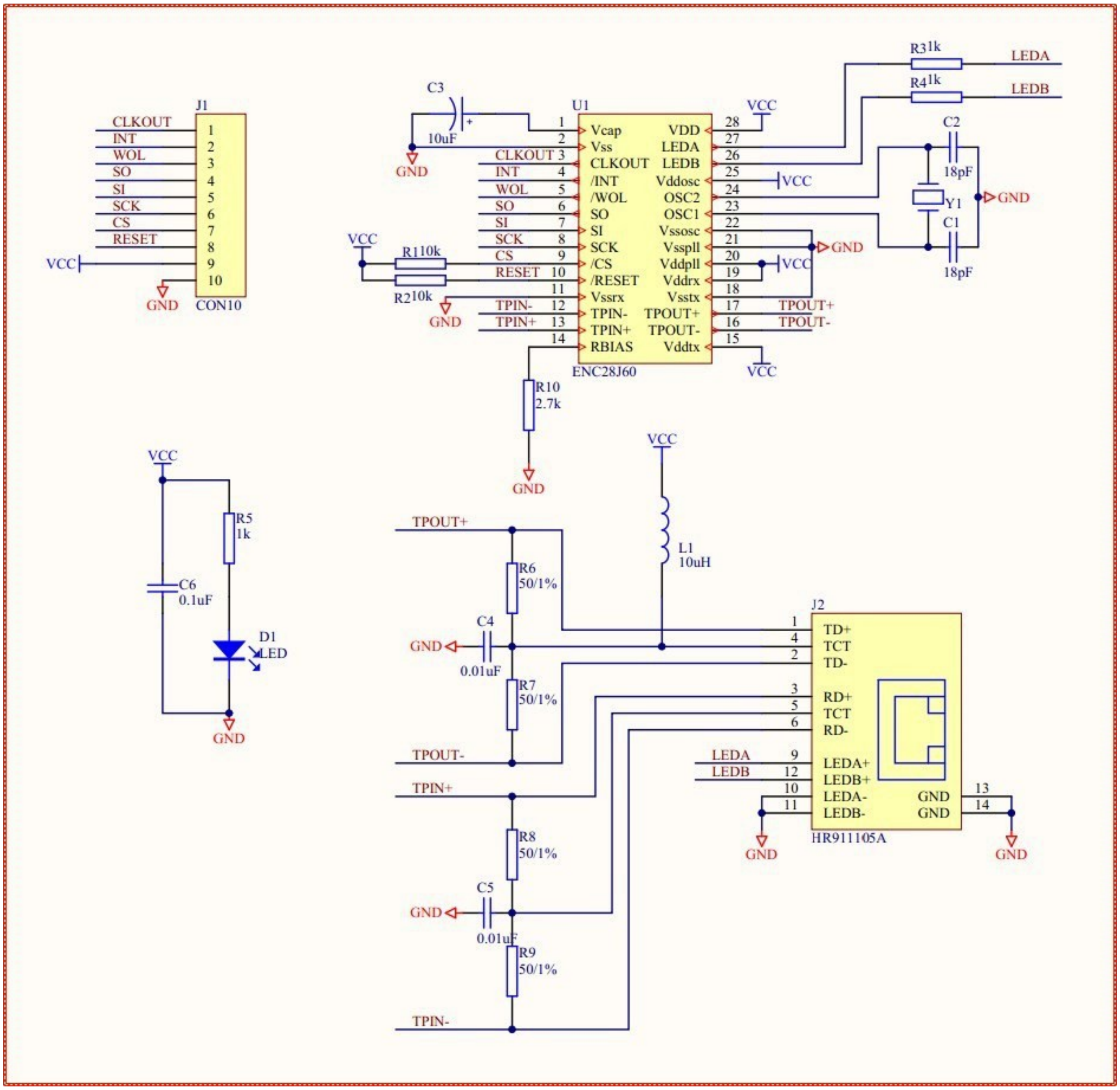


Figure 27: ENC28J60 Schematic [23]

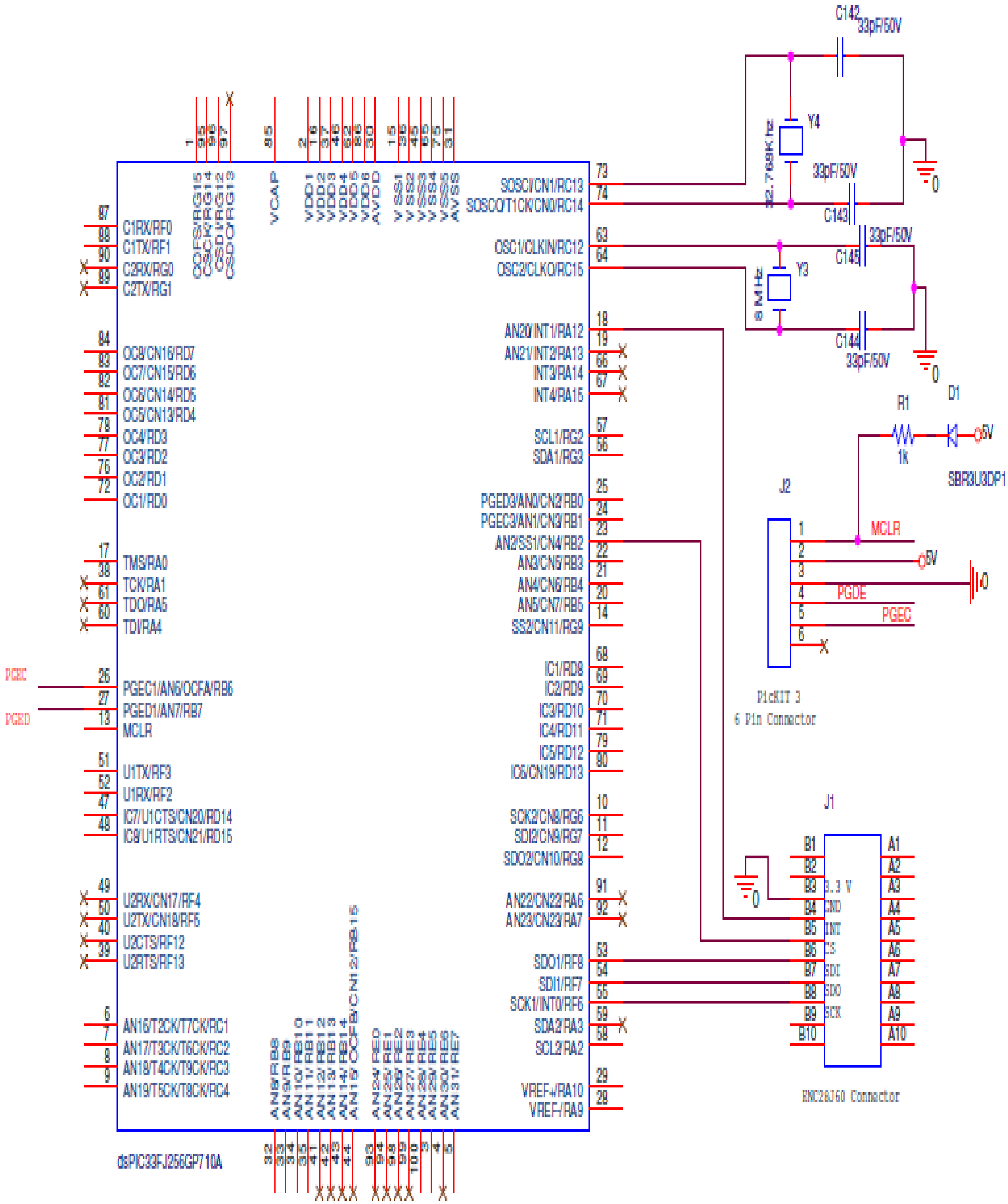


Figure 28: Hardware implementation of ethernet.

Chapter 5

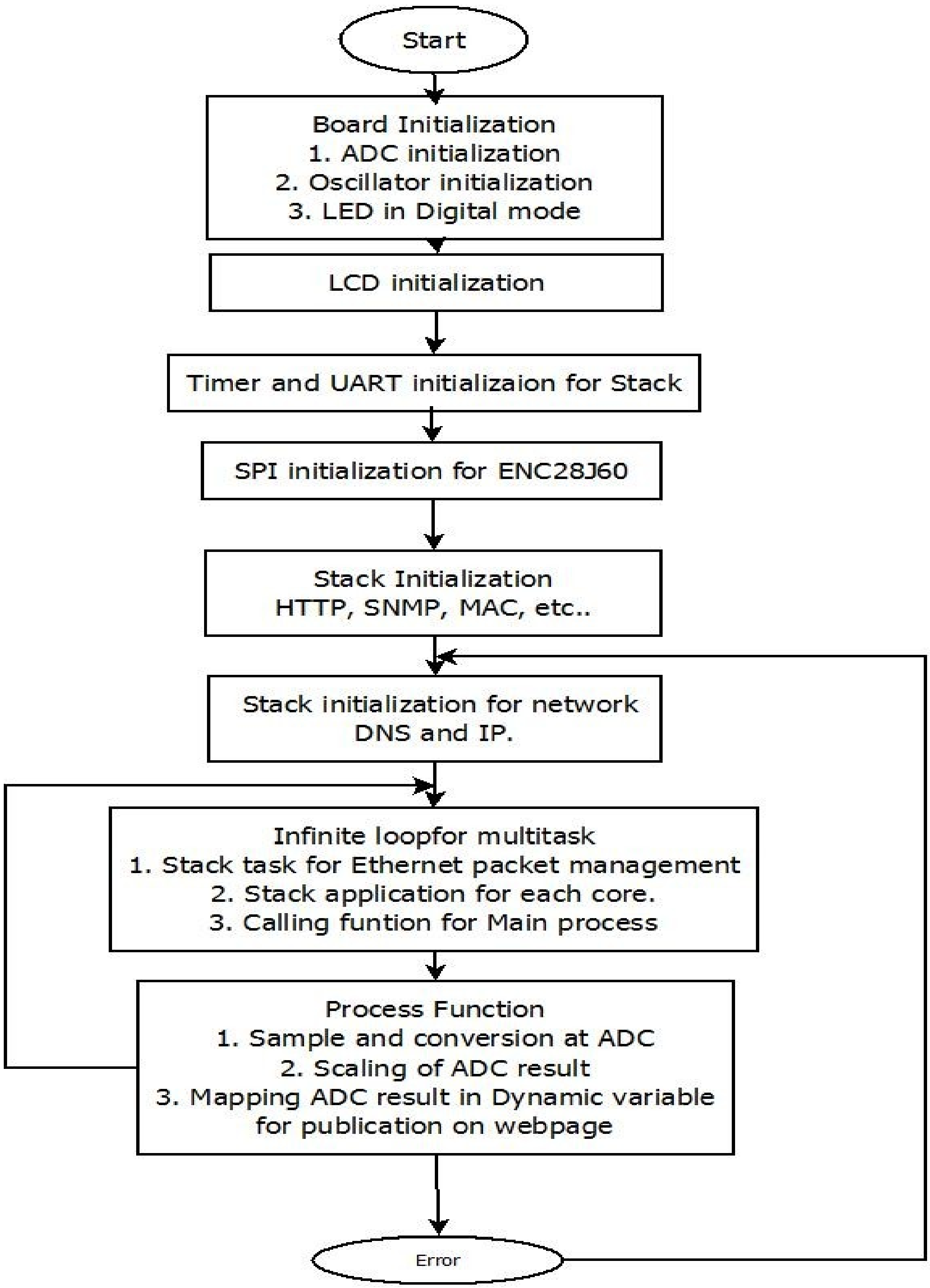
5 Software Stack

Software operation for SAMU can be easily defined based on the hardware solution described in the preceding chapter. Software solution for the SAMU can be done in modular form, where each module performs unique operation. Our software can be broken down into following operations;

- Microcontroller initialization with oscillator and clock settings
- Peripheral initialization
- Communication set between ENC28J60 and microcontroller
- Main program execution with sampling and frame formation
- Frame publication with dynamic variables

Microcontroller and peripheral can be initialized in the main function whereas the ethernet related operations are carried out in the TCP/IP stack. TCP/IP stack for the dsPIC with ENC28J60 is provided by Microchip which can be modified according to the application. TCP/IP stack has different layer for operations, which functions for data transfer, physical interface, ethernet frame formation and application for webpage. The following section shows the control algorithm; while section 5.2 discusses the various aspects of TCP/IP protocol.

5.1 Software Implementation



Software is based on a similar modular approach as the hardware; it distributes the SAMU operation to different functions and each function is called from the main program. Operations of main program are:

- Initializing the board and its peripherals in appropriate working mode and value
- Set up SPI connection between ENC28J60 and the dsPIC
- Repeatedly calling the function related to the TCP/IP stack like IP resolution
- Sampling the ADC channel simultaneously and perform conversion
- Mapping the sampled value in the specified memory location and dynamic variables of webpage

Explorer 16 kit is available with crystal oscillator of 32.7 KHz for timer and clocking whereas as an 8 MHz crystal for microcontroller clocking. The controller uses internal PLL loop and divider to achieve a rate of 80 million instructions per second.

Ports of the controller are initialized first and then the peripheral like Analog to digital convertor and LCD are initialized. ADC is set up in 4 channel simultaneous sampling mode (we are taking 4 inputs only) with timer to provide sampling instant. Timer register are configured to provide interrupt after every 70 microsecond (14400 sample per second), to trigger ADC sampling for protection class. Every third sample is used for measurement class sample (4800 sample per second).

TCP/IP stack provided by the microchip is used for the ethernet communication; it consists of application and transport layer function. These functions are to be called repeatedly for polling and ethernet communication essentials. These function calls are placed in a infinite loop of main function. A process function continuously samples the ADC data and copy it into the memory location allocated to the sampled data. Sampled data is also mapped into the dynamic variable for the webpage through Hypertext Transfer Protocol function.

The following section describes the various layer and function of TCP/IP stack.

5.2 TCP/IP

The stack is divided into multiple layers, where each layer accesses services from one or more layers directly below it. Per specifications, many of the TCP/IP layers are “live”, in the sense that they not only act when a service is requested, but also when events like time-out or new packet arrival occurs.

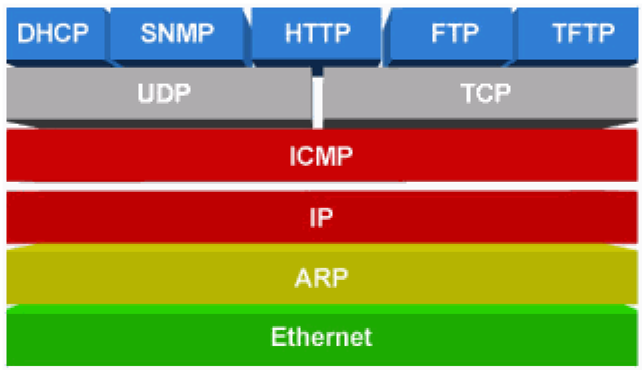


Figure 29: TCP/IP Stack

5.3 Network Interface Layer

5.3.1 Ethernet

Ethernet is a data link and physical layer protocol defined by the IEEE 802.3. specification. It comes in many flavors, defined by:

- Maximum Bit Rate (Mbits/s): 10, 100, 1000, etc.
- Mode of Transmission: Broadband, Baseband
- Physical Transmission Medium: Coax, Fiber, UTP, etc.

Frame Structure

Information is sent around an Ethernet network in discreet messages known as frames. The frame structure is quite simple, consisting of the following fields:

8 Bytes	6 bytes	6 Bytes	2 Bytes	0-1500 Bytes	0-46 Bytes	4 Bytes
Preamble	Destination Address	Source Address	Frame Length	Data	Pad	Checksum

Figure 30: Ethernet Frame

- The Preamble - This consists of seven bytes, all of the form "10101010". This allows the receiver's clock to be synchronised with the sender's.
- The Start Frame Delimiter - This is a single byte ("10101011") which is used to indicate the start of a frame.
- The Destination Address - This is the address of the intended recipient of the frame. The addresses in 802.3 use globally unique hardwired 48 bit addresses.
- The Source Address - This is the address of the source, in the same form as above.
- The Length - This is the length of the data in the Ethernet frame, which can be anything from 0 to 1500 bytes.
- Data - This is the information being sent by the frame.
- Pad - 802.3 frame must be at least 64 bytes long, so if the data is shorter than 46 bytes, the pad field must compensate. The reason for the minimum length lies with the collision detection mechanism. In CSMA/CD the sender must wait at least two times the maximum propagation delay before it knows that no collision has occurred.
- Checksum - This is used for error detection and recovery

5.2.2 MAC Addresses

A MAC address is a 48-bit (6-octet) number unique to every piece of Ethernet hardware. It consists of a 24-bit Organizationally Unique Identifier (OUI) and a 24-bit hardware identifier. OUIs are assigned by the IEEE to a particular company or organization (Microchip's OUI is 00-04-A3h), while hardware IDs are assigned by the owner of that particular OUI.

MAC address octets are transmitted high-order (Octet #1) first, while bits within an octet are transmitted low-order, Least Significant bit (LSB) first.

A MAC address whose Least Significant bit of Octet #1 is set as a multicast address is intended for one or more nodes. As an example, pause frames, which have an address of 01-80-c2-00-00-01, are considered multicast packets. A MAC address of FF-FF-FF-FF-FF-FF is a broadcast address, which is intended for all nodes.

The MAC sub-layer has two primary responsibilities:

- Data encapsulation, including frame assembly before transmission, and frame parsing/error detection during and after reception
- Media access control, including initiation of frame transmission and recovery from transmission failure

5.4 Network Layer Protocols

5.4.1 Internet Protocol (IP)

IP is the protocol that hides the underlying physical network by creating a virtual network view. The overall role of IP is the routing of the packet from the source to the destination. It is not responsible for quality of service (QoS). It does not keep track of numbers of packets or lost packets throughout the network. As with the MAC layer, the IP layer contains a source address, a destination address, and an FCS. It is more complicated than a MAC frame. Like the MAC frame, the IP frame includes a destination address, a source address, and an FCS. There is a difference, however. The destination and source addresses are the final end point addresses and are not the next addressable ports.

The total length field identifies the overall length of the information field. The overall length of the information field can range from 46 bytes to 1500 bytes.

Now that the IP layer has been added, there is another layer for the occurrence of events. It is obvious that the main goal of IP is transmitting packets from a beginning point (source) to the end point (destination). This is apparent from the basic IP frame format. If a user incorrectly addresses a packet, the packet will not arrive at the proper destination (like incorrectly addressing an e-mail). If the addressing scheme is flawed (the DNS server is not operating properly, for example), users will not be able to transmit their data to the destination. As discussed earlier, any errors at lower layers will corrupt the traffic in the layers above it. Therefore, it is critical that the physical and MAC layers are clean for IP to run properly.

5.4.2 Transport layer protocols

The most important and commonly used protocols of the TCP/IP transport layer are:

- User Datagram Protocol (UDP)
- Transmission Control Protocol (TCP)

The final layer of the OSI model prior to the actual desired data is the transport layer. There are two main protocols that reside over IP and are common transport protocols in an IP network. These protocols are Transmission Control Protocol (TCP) and User Datagram Protocol (UDP).

TCP – A Connection-Oriented Transport Protocol

TCP has six main responsibilities. They include:

- Basic data transfer
- Reliability
- Flow control
- Multiplexing
- Connection management
- Security

Basic data transfer and reliability: TCP, being a connection-oriented transport protocol, makes sure that all data gets from the beginning to the end of the network. Sequence numbers are built into the TCP overhead information of the TCP frame. These sequence numbers keep track of all of the information sent and the order in which it arrives. If any packets do not arrive, the TCP layer knows which packets didn't arrive and requests those lost packets. It is this layer that allows for small blips in local area networks and wide area networks to go unnoticed by the user.

– Flow Control: In addition to the sequence numbers discussed previously, there is another portion of the header that contains a value known as a "window size". A window size is effectively the amount of data each end point will receive prior to acknowledging its receipt of the data. A larger window size is more efficient than a smaller window size. The problem with a large window size occurs when there are lost packets. Because a larger window size indicates more data between acknowledgements, more data will need to be retransmitted for each error if there is an error in that time period.

– Multiplexing: Users are used to running multiple applications on their PCs simultaneously. Oftentimes they are checking e-mail and accessing one or moreWeb sites at the same time. TCP not only connects them to the other end point (Web site or e-mail), but it also manages which packets entering their computer are from the Internet or e-mail and makes sure that outbound packets are properly identified by the far end.

– Connection Management and Security: When two end points begin a conversation, the requesting end point requests a connection to the receiving end point. The receiving end point manages the connection and, if implemented, will attempt to confirm that the requesting end has the right to access the information.

UDP – A Connectionless Transport Protocol

UDP is a simpler protocol than TCP. UDP is designed with the following features:
– Basic data transfer
– Connection management

Based on this reduced feature set, the make up of the UDP frame provides a good understanding of how it works and why it has a reduced feature set (Table 11). The main use for UDP is for those applications that do not require the arrival of all of the data in order to work. More importantly, UDP is for those applications that cannot utilize the information unless it arrives in the sequence in which it was sent. Examples of UDP applications include VoIP and streaming video.

The UDP datagram has an 8-byte header, as described in *Figure 31*

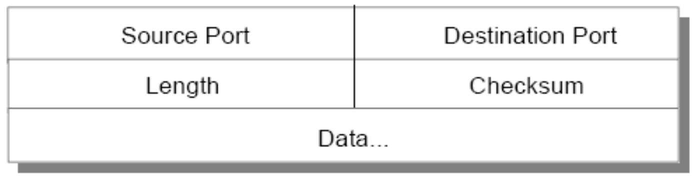


Figure 31: UDP: Datagram format

Where:

- Source Port Indicates the port of the sending process. It is the port to which replies are addressed.
- Destination Port Specifies the port of the destination process on the destination host.
- Length The length (in bytes) of this user datagram, including the header.
- Checksum An optional 16-bit one's complement of the one's complement sum of a pseudo-IP header, the UDP header, and the UDP data.

Application Layer Protocols

Hypertext Transfer Protocol (HTTP)

The Hypertext Transfer Protocol is a protocol designed to allow the transfer of Hypertext Markup Language (HTML) documents. HTML is a tag language used to create hypertext documents. Hypertext documents include links to other documents that contain additional information about the highlighted term or subject. Such documents can contain other elements apart from text, such as graphic images, audio and video clips, Java applets, and even virtual reality worlds (which are described in VRML, a scripting language for that kind of elements).

Overview of HTTP

HTTP is based on request-response activity. A client, running an application called a browser, establishes a connection with a server and sends a request to the server in the form of a request method. The server responds with a status line, including the message's protocol version and a success or error code, followed by a message containing server information, entity information, and possible body content.

An HTTP transaction is divided into four steps:

- The browser opens a connection.
- The browser sends a request to the server.
- The server sends a response to the browser.
- The connection is closed.

On the Internet, HTTP communication generally takes place over TCP connections. The default port is TCP 80, but other ports can be used. This does not preclude HTTP from being implemented on top of any other protocol on the Internet or on other networks. HTTP only presumes a reliable transport; any protocol that provides such guarantees can be used.

Following diagram (*figure 32*) shows where HTTP Protocol fits in communication:

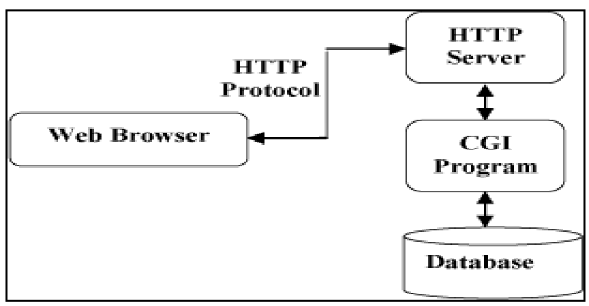


Figure 32: HTTP Protocol

Dynamic Variables

Dynamic variables allow the web server module to take data from our system, such as the value from a sensor or data in memory, and combine it into a template web page. The completed web page is then transmitted through a network or the Internet, and the system data is displayed on the user's screen.

6 RESULTS

Results of testing the solution are given here. The communication between the ENC28J60 and dsPIC was tested for information exchange. SPI communication between ENC28J60 and dsPIC33 was setup and signals were checked. Waveforms of SPI communication (/CS, SDI, SDO, SCK) were obtained at the SPI 1 (port F).

Resulted prototype hardware is shown in *figure 33*.

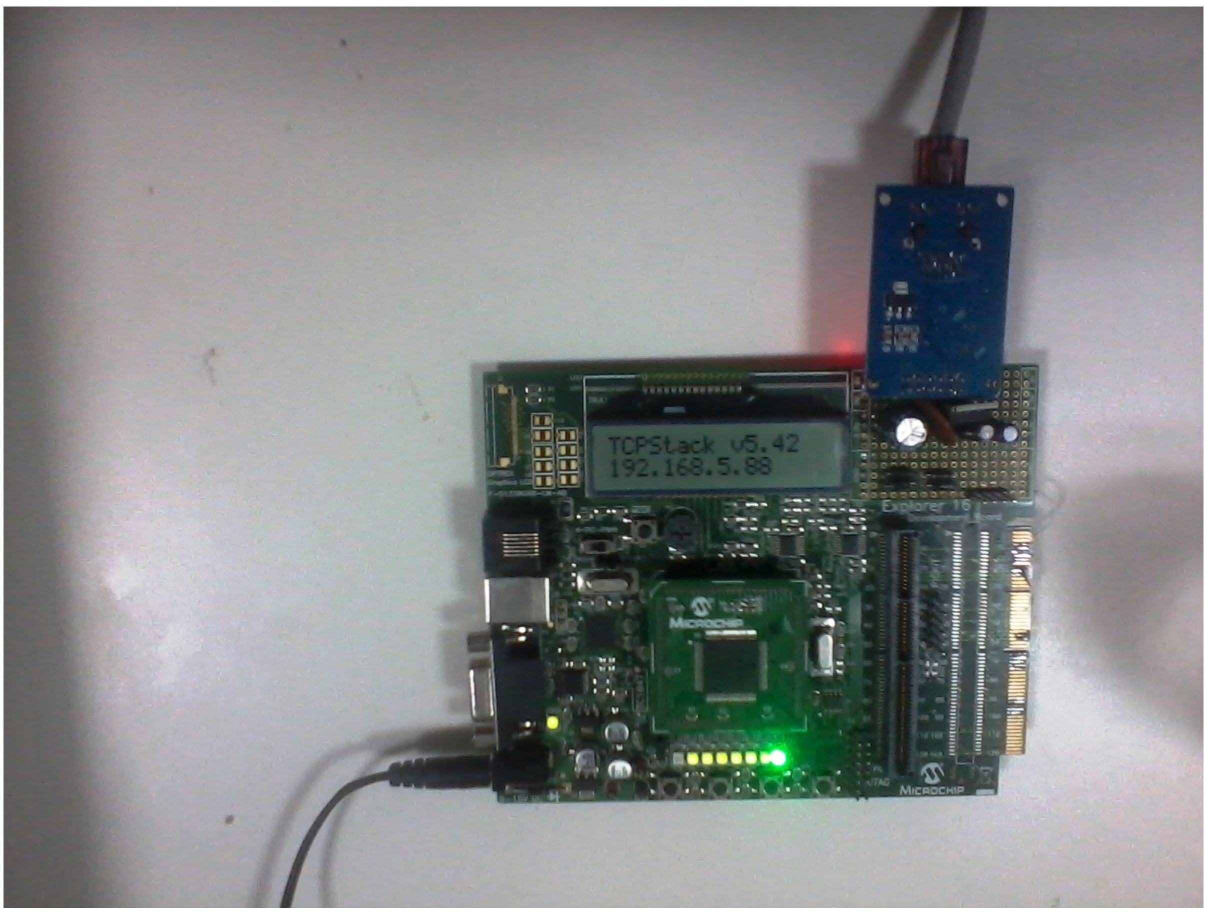


Figure 33: SAMU prototype hardware

The SAMU prototype was connected to the internal network with dynamic addressing (DHCP) enabled. The Device was able to connect to the network and it was assigned a legitimate IP address from the network. We were able to ping the IP address thus confirming connection to the network. It was also verified by the Microchip TCP/IP Discover Tool. Webpage images were uploaded in the setup and data from the SAMU was obtained in the webpage format.

6.1 Result Figures

Figure 34-37 show the SPI signal.

Figure 38 shows ping request

Figure 39 shows TCP/IP Discover tool result

Figure 40 shows webpage images.

SPI signal for CS

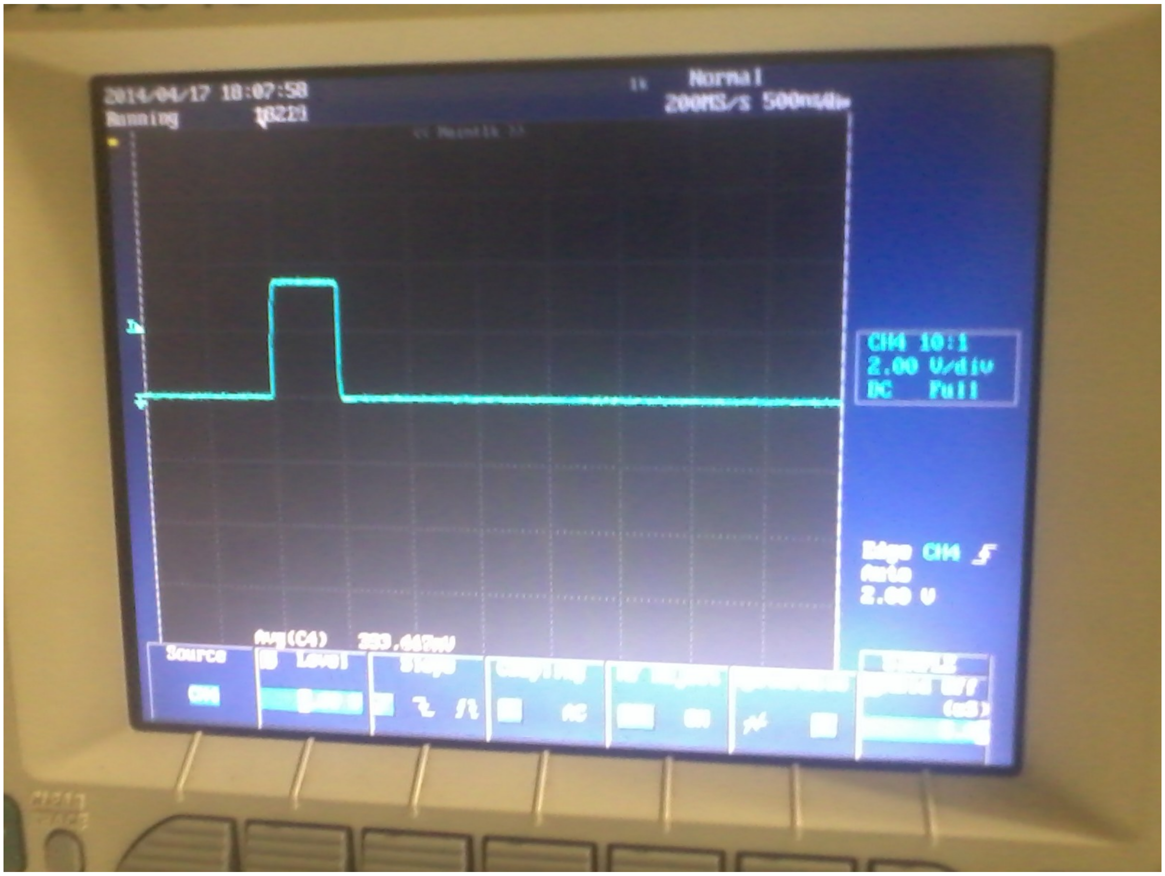


Figure 34

Chip select (CS) pin of the microcontroller show the triggering and start of serial communication. As the CS pin becomes low the serial clock and data pin start communication. As it can be seen in the *figure 34* the CS pin goes to low to felicitate the start of communication.

SPI signal for clock

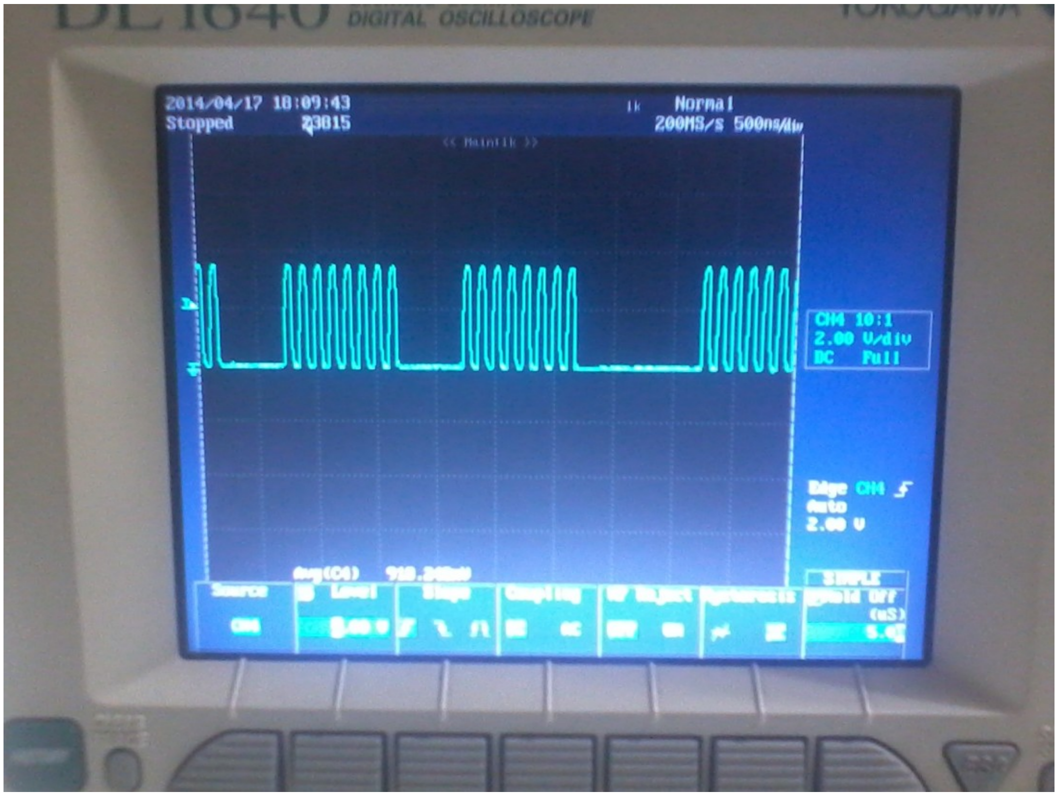


Figure 35

Serial clock in the SPI communication is initialized as the CS pin goes to low it start providing synchronous clock for transfer of data. As it can be seen in the *figure 34* clock is provided on the pin when the CS pin is low and data is to be transferred.

SPI Signal for SDO

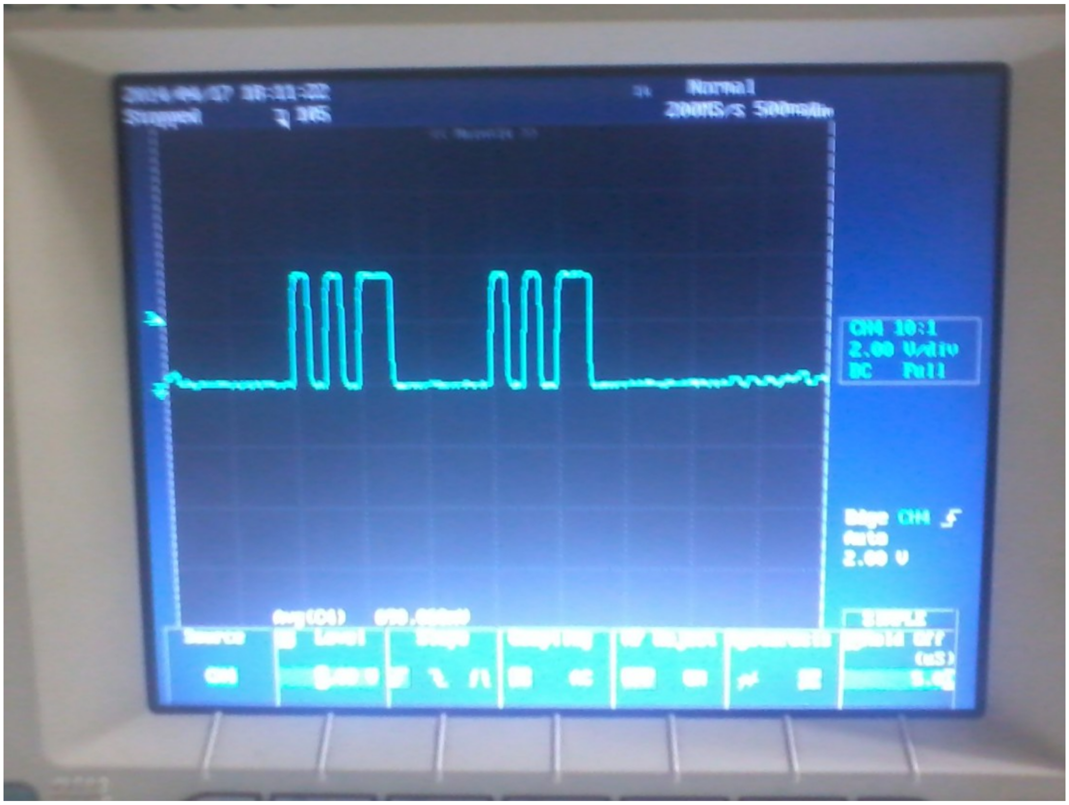


Figure 36

SDO pin of the microcontroller is connected with SDI pin of the ENC28J60, it act as the output for the microcontroller and as input to the ENC28J60 chip. SDO pin along with SDI pin felicitate the data transfer between the two boards. *Figure 36* shows the data bit being transferred from dsPIC to the ENC28J60 chip's SDI pin.

SPI signal for SDI

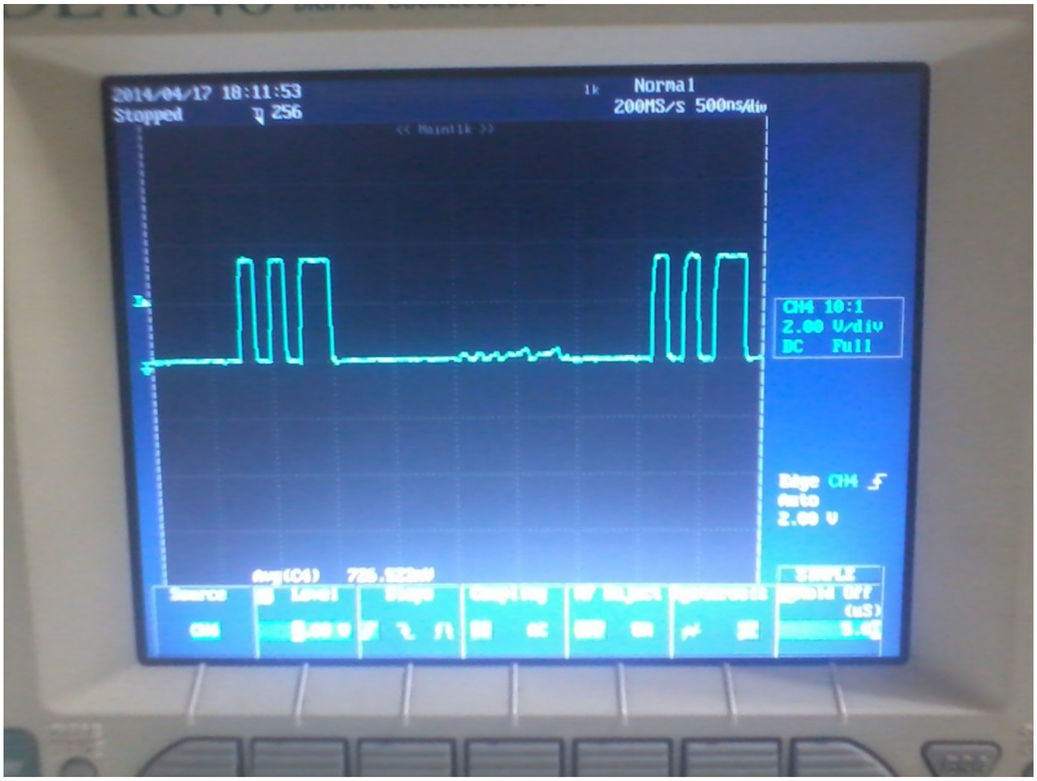


Figure 37

SDI pin work similar to the SDO pin as explained above, the signal between the two board were observed whenever the CS pin goes low and there is a healthy clock signal. The *figure 37* show data being received from the ENC28J60 board on to the microcontroller SDI pin.

Ping request

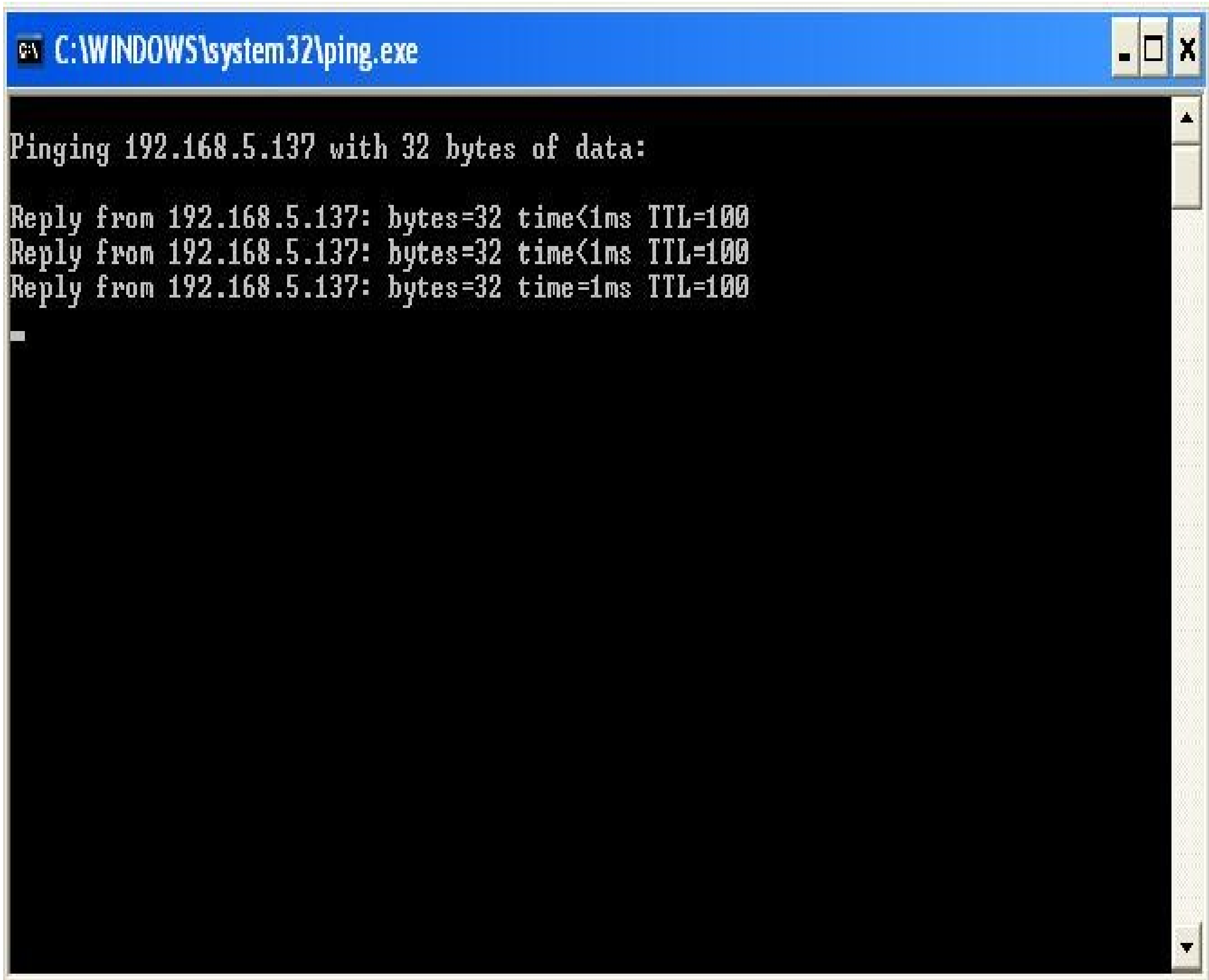


Figure 38

Ping request is a network operation which confirms a network connection between two devices. It indicates that device is connected to the network and it responds whenever request through IP is made. *Figure 38* show SAMU responding to ping request made from a computer on the network.

TCP/IP discover tool

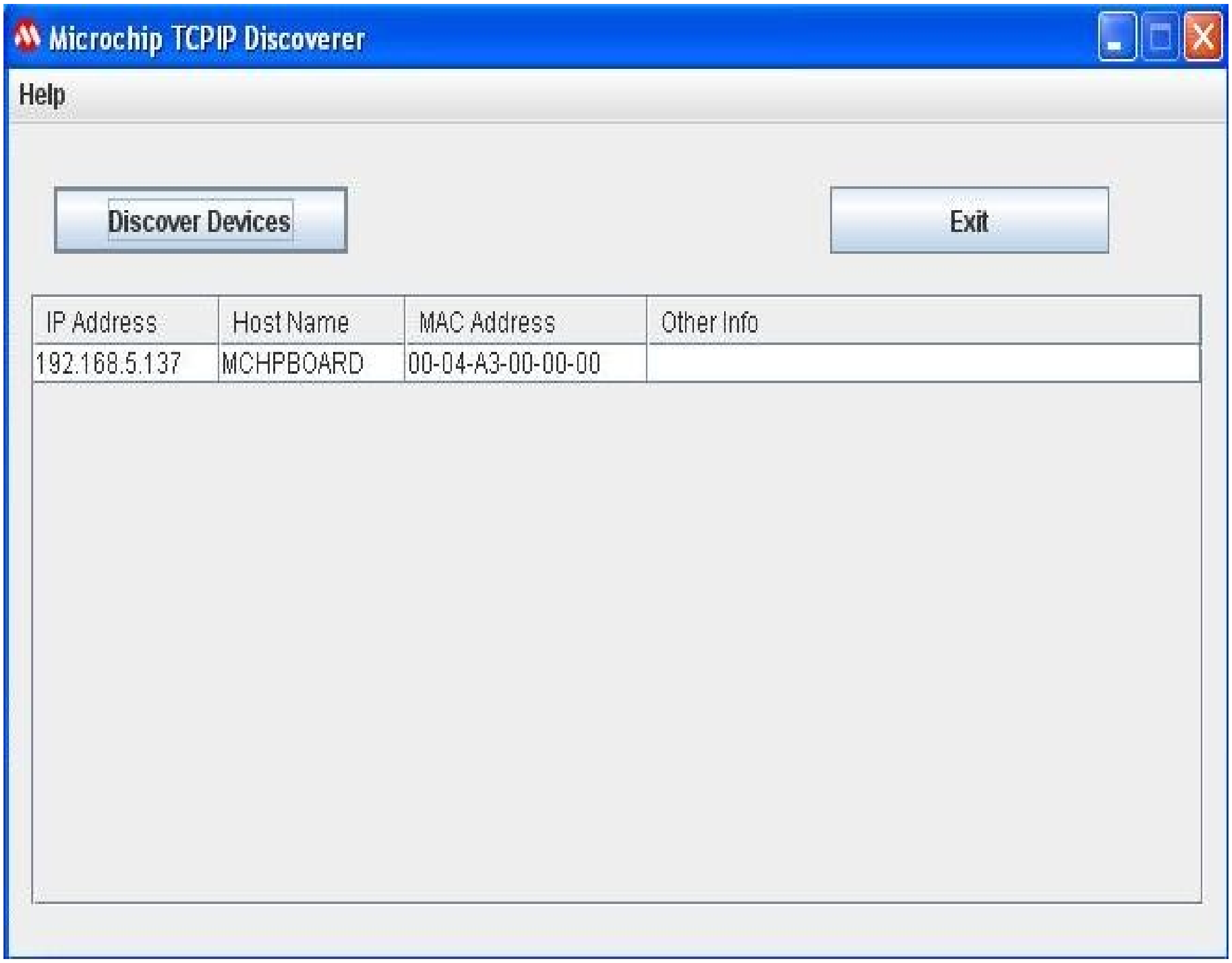


Figure 39

TCP/IP Discover is a tool provided with the TCP/IP stack, it checks for the devices connected to the network. Through this tool we can verify that the SAMU is connected to the network and a dynamic IP is assigned to it by the network server. *Figure 39* shows the SAMU being named as MCHPBoard and it has an IP 192.168.5.137 assigned to it.

Webpage

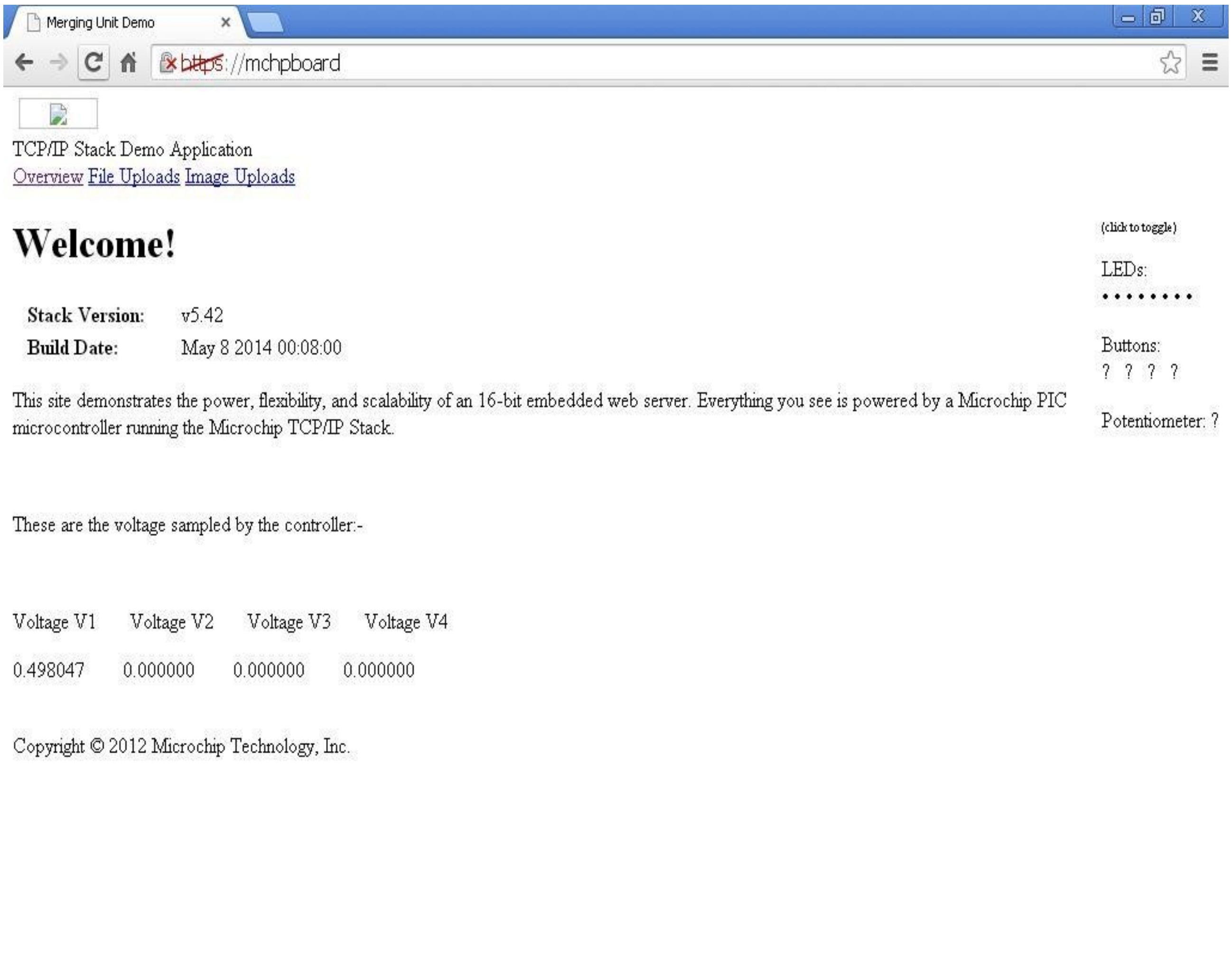


Figure 40 Webpage

Sampled values which are generated by the SAMU are to be shown on webpage so that it is easily accessible on the network. *Figure 40* show a demo webpage which shows the sampled values from a SAMU with single phase input.

7 Conclusion and Future Scope

SAMU proves to be an essential part of the digital substation for the process level automation.

We have developed a dsPIC based solution for the SAMU which can be used for sampling and publication of sampled values. The developed device provides a solution for SAMU with minimum architectural changes in the microcontroller starter kit, thus providing ease of implementation. Thus it fulfilled the requirement mentioned problem statement 1 of section 3.7.

In addition to this we successfully implemented sampling using single timer where it can be used to provide two different sampling rates for measurement and protection class as specified in IEC 61869-9. Hence it successfully solved the problem statement 2 of section 3.7. Sampled data is placed in the ASDU.

The sampled values were published on the ethernet using the dynamic variable for the webpages. It partially fulfilled the problem statement 4 by publishing sampled data through dynamic variable and not through framing.

Dissertation gave insight into the technical specifications and compared the available merging unit solution from different companies. It has also given a detailed comparison between the Merging Unit solution from the Alstom and Vizimax.

We could though publish the sampled value over the ethernet but does not analyse the sampled data. The digital signal processing feature of the microcontroller were not included here can be used for analysis of sampled data; these feature can be included in the future. It implements the synchronization through network solution of SNTP while IEEE 1588 and IRIG-B based solution can also be incorporated in future.

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