Hardware and Software interface for power line communication

A report submitted in partial fullfilment of
our thesis project

Bachelor of Technology

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CERTIFICATE

This is to certify that the work contained in this thesis entitled

Hardware and Software Interface for
power line communication

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for the award of the degree of Bachelor of Technology,carried out in the Department of Electronics and Electrical Engineering,Indian Institute of Technology Guwahati under my supervision and that it has not been submitted else where for a degree

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Abstract

Our aim is to implement power line communication through Hardware *and* Software *interface.In the first phase we have studied PLC environment which contains different types of noises and the removal of those noises.*
We have implemented PLC model by transmitting random binary data through OFDM transmission model and passing it through different types of channels (AWGN noise ,random impulse noise).We have calculated the bit error rate *of PLC system in both the cases and implemented notch filter for impulse noise detection and adaptive filter using LMS algorithm for impulse noise removal from the PLC system.*
In second phase we have studied and implemented hardware interface by establishing communication between two PLC modems *through power line channel using arduino micro-controllers.The micro controller at the transmitter end trasmits the data serially to the* PLC modem *which in-turn transmits the data into the power line channel,the other* PLC modem *at the receiver end receives this serial data and tarnsmits to the micro controller at the receiver end from which* user *can retrieve the information.*

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Nomenclature

AC Alternate Current

AWGN Additive White Gaussian Noise

BER Bit Error Rate

FEC Forward Error Correcting

FFT Fast Fourier Transform

IDFT Inverse Discrete Fourier Transform

IFFT Inverse Fast Fourier Transform

LMS Least Mean Square

OFDM Orthogonal Frequency Division Multiplexing

PLC Power line communication

QAM Quadrature Amplitude Modulation

SNR Signal Noise Ratio

1 Introduction and Outline

1.1 Introduction

Unlike traditional electric grids,smart grids use two way flow of information to create an intelligent energy delivery network.Several communication technologies came to existence to facilitate data throughout the grid,mainly in two cases :outdoor communications between local utilities and customers,and indoor communications for home area networks.Power line communication have been attractive as a solution for smart grid communications

PLC is a communication technology which uses existing power cables for the transmission of data.Like any other communication model,transmitter modulates the data before it passes through the channel and receiver demodulates the data.PLC uses existing power cables for transmission of signals.So,the *installation cost* is less than other communication approaches.

In PLC system,data is transmitted using OFDM technique.OFDM is a multicarrier modulation technique which is adaptable for harsh channel conditions.So,the PLC system uses OFDM modulation for reliable communication.Noises produced in the power line channel can be categorized into background and impulse noises.In the real PLC environment,some electrical appliances will produce this impulse noise at a fixed frequency with the power spectral density usually exceeding that of all received signals.These noises are modeled as the periodic impulsive noise and the background noises are modeled as AWGN.These noises interfere with the transmitted OFDM signal and affect system performance.So,these noises must be removed to improve the performance of PLC system.

1.2 Proposing Idea

For implementation of PLC system through software interface,our idea is to transmit the data through the OFDM transmission model.Since background noises can be modeled as AWGN, we added AWGN in *measured* sense to the input stream just before the receiver design.We modeled impulsive noises in two different methods : adding impulse noise in randomized data intervals and,adding impulse noise in fixed data intervals.

For hardward interface,we are trying to establish communication between two computers (*transmitter* and *receiver*) through power line channel.We establish this communication by transmitting the serial data using arduino micro controller to the PLC modem at the transmitter end which transmits the data into power line channel and receiving the data by PLC modem at the receiver end.The received serial data is then passed to the arduino at the receiver end which uses suitable decoding code to decode the information.

1.3 Outline

Chapter 2 deals with OFDM model for PLC system.In 2.1 we discussed about the functioning of transmitter end,In section 2.2 we discussed about the power line channel and different types of noises present in it.
In chapter 3 we looked at the calculation of BER for transmitted signal.In chapter 4,we dealt with the Impulse noise detection and it's removal.In section 4.2, we discussed about the implementation of LMS algorithm which is helpful in removal of impulse noise.
In chapter 5,we had a outlook at the **simulation** results.In chapter 6 we focused on hardware implementation of PLC system.In 6.1 we had deeper understanding of PLC modem and in 6.3 about the circuit implementation and basic code implementation.

2 OFDM model for PLC system

An OFDM system consists of transmitter,channel and a receiver.OFDM is a multicarrier modulation technique in which available spectrum is divided into
several sub carriers.The channels are orthogonal to each other which eliminates the cross talk between co channels.The main advantage of OFDM over single carrier modulation is its robustness to narrow-band interference and its adaptability to several channel conditions.

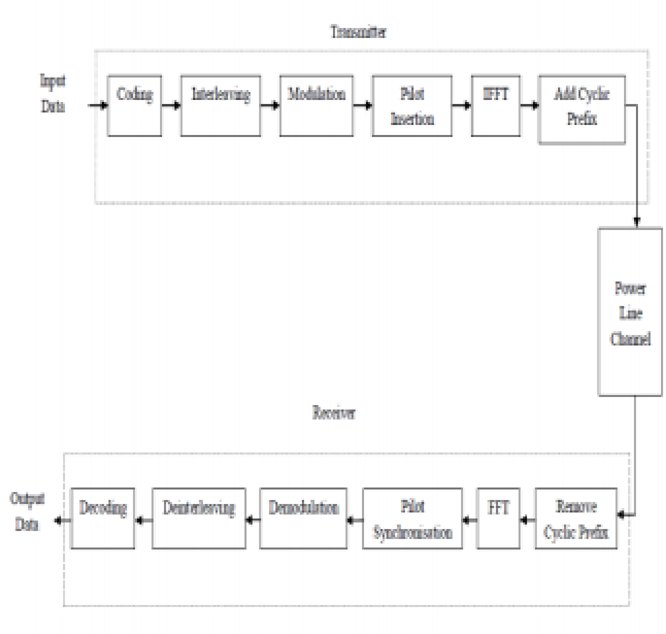

Figure 1: OFDM transmission system for PLC.

2.1 Transmitter

Encoding and Modulation :- The input stream is randomly generated and transmitted through OFDM transmitter.Some redundant bits are added to the input stream for coding purposes.These bits are useful for forward error detection and correction.There are so many FEC codes avaliable for OFDM system such as turbo codes,block codes and convolutional codes etc.We used *polynomial convolutional encoding* as our FEC scheme.These symbols are converted into decimal bits and then modulated using *16-QAM modulation.*

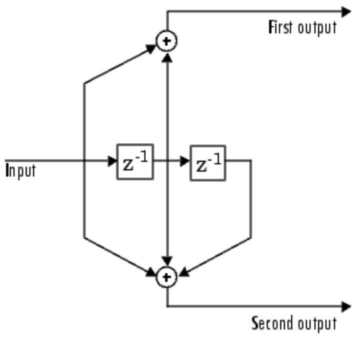

Figure 2: A feedforward Convolutional Encoder

A feedforward polynomial convolutional encoder has two components.They are Constraint length and Generator polynomial.The figure below shows a feedforward convolutional encoder that has one input,and two outputs.
The 16 QAM modulation is also the first rectangular QAM constellation.These rectangular constellations can be easily demodulated compared to other non-square constellations.Pilots are added to modulated data to maintain synchronization between data bits.

IFFT and Cyclic prefix addition :- FFT is an algorithm to compute DFT and its inverse.The advantage of FFT is that it takes O(nlogn) time to compute.

$x_0, x_1, x_2....x_n$ *are complex numbers.Then, its DFT is given by*

$$X_k = \sum_{n=0}^{N} x_n e^{-i2\Pi k \frac{n}{N}} \quad where \;\; k \; = 0, 1, 2...N-1$$

By using IFFT scheme the transmitted data is converted into orthogonal streams.Cyclic prefix is then inserted to prevent interference between overlapping channels.This also reduces inter symbol interference(ISI).

$x^{'} = [x[0], x[1], x[2]...x[N-1]]^T$ *be symbols obtained by IDFT.*

prefixing with cyclic prefix of length $L-1$ *we get ofdm code*

$X = [x[N-L+1], ...x[N-2], x[N-1], x[0], x[1, x[2]...x[n]]^T$

.

2.2 Power Line channel

The OFDM code is transmitted through PLC channel.Like any other communication systems,PLC channel also contains external and internal noises or disturbances.
Power line noises are classified into five categories :-

- Colored background noise - It is caused by simulation of multiple sources of noises with low power.Its power spectral density decreases with increasing frequencies.
- Narrow band noise - It consists of amplitude modulated sinusoidal signals which is caused by broadcasters,radio stations etc.
- Periodic impulsive noise asynchronous to main frequency - This type of impulsive noise is caused by switched mode power supplies.
- Periodic impulsive noise synchronous to main frequency - It is mainly caused by switching actions of rectifier diodes found in many electrical appliances.
- Asynchronous impulsive noise caused by switching transients in network.
  The first two comes under background noises and last three comes under impulse noises.

2.3 Receiver

At the receiver end,the cyclic prefix is removed and signal is transformed into frequency domain using FFT scheme.Downsizing is performed which is followed by pilot removal.After that,the data is demodulated followed by decoding to produce output data.The received data is expected to be same as that of transmitted data without any fault.

3 Calculation of BER for AWGN and impulse noise

We calculate the power of input signal and then we add the noise to the signal with desired SNR.At the receiver end, we use XOR function to calculate number of errors per sub carrier.

$$SNR_{db} = 10log_{10}(\frac{P_{signal}}{P_{noise}})$$

In case of impulse noise,we randomize the interval of impulse noise and then calculate the power of each peak according to desired SNR.

4 Impulse noise detection and removal

Noise detection and removal consists of two stages.

4.1 Detection of impulse noise

The received signal consists of original data,background noise and impulsive noise.Background noise can be modelled as AWGN and the periodic impulse noise.The periodic impulse noise interferes with transmitted data and reduces the performance of PLC system.The OFDM system is simple and effective method to remove this periodic impulse noise in frequency domain.

The OFDM signals are sent to *noise detection algorithm.*A threshold value is set and maximum value of all the signals are calculated.If the maximum value of a signal is greater than threshold value ,then presence of impulse noise is confirmed.

4.2 Removal of impulse noise

For impulse noise removal,there are so many methods which are in use.We are using adaptive LMS flitering which is optimal for our purpose.The principle behind adaptive filtering is that the reference signal is adaptively filtered and it is subtracted with input signal to produce the *estimated signal.*
In PLC systems,the transmitted OFDM signals interfered with periodic impulse noises in power line cables.These corrupted signals can be recovered by using adaptive filtering which uses Least Mean Square (LMS) algorithm.

Implementation of LMS algorithm:- LMS algorithm is used for cancellation of noise which is interfere with transmitted OFDM signal.It consists of two inputs mainly primary input signal d(n),and reference input signal x(n).The algorithm is as follows :-

- When intialized,the filter coefficients are set to zero and error signal e(n) is calculated using the following equation.

$$e(n) \ = d(n) - y(n)$$

- It updates the filter coefficients by using the following equation.

$$w(n+1) \ = w(n) + \mu.e(n).u(n)$$

$$where\ \mu\ is\ the\ step\ size\ of\ adaptivefilter$$

$$where\ w(n), w(n+1)\ are\ the\ filter\ coefficients$$

5 Simulation Results

Our simulation is done in matlab.The input stream is randomly generated binary data.We used convolution coding for coding the input stream as they are one of the powerful and efficient error correcting codes for detecting and correcting burst errors.

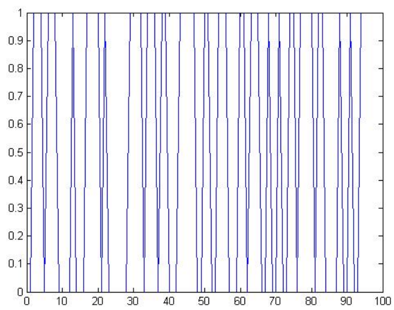

Figure 3: Input data.

OFDM modulation is preferred because it gives good performance in channel with harsh characteristics.The OFDM data is transmitted in power line channel which contains impulse noise and background noise.The background noise can be modelled as AWGN noise.The corrupted OFDM data is as follows

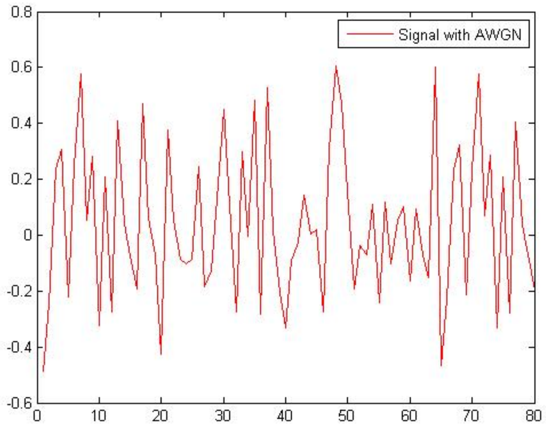

Figure 4: OFDM data corrupted with background noise.

Then corrupted OFDM data gets interrupted by impulse noise which is present in the power line channel.We calculate the bit error ratios of the received data for channel which contains AWGN alone and for the channel which contains both.The following is the BER of signal when passed through channel of AWGN

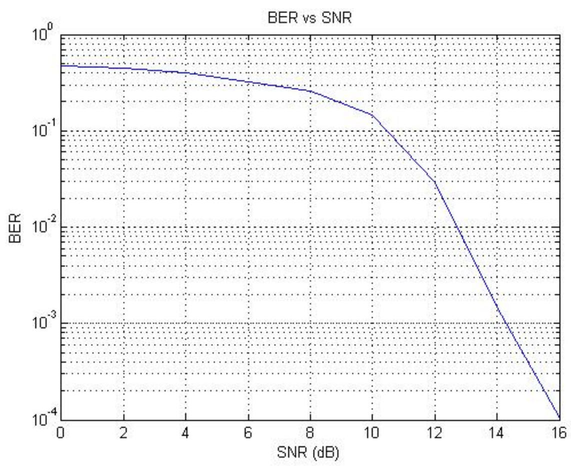

Figure 5: BER for signal in channel with AWGN

In order to add the impulse noise to the OFDM data,we simulated the addition of impulse noise both in randomized data intervals and fixed data intervals,which is why our BER ratio of the OFDM data is not as good as expected.

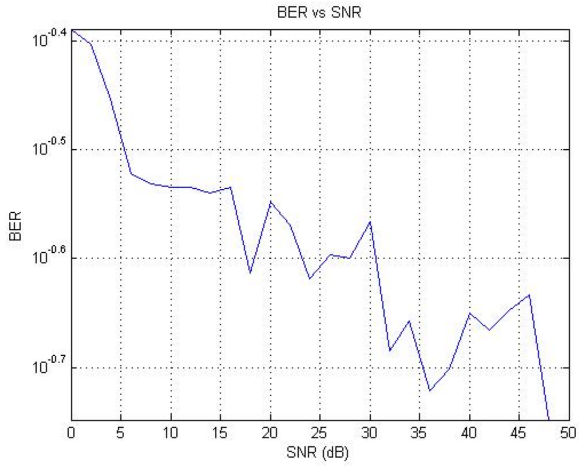

Figure 6: BER for signal for impulse noise in random data intervals

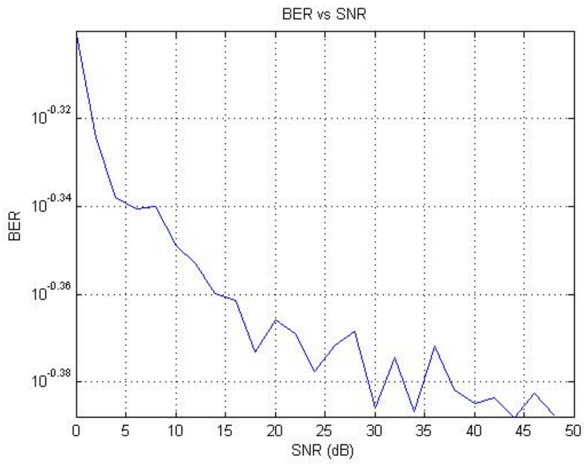

Figure 7: BER for signal for impulse noise in fixed data intervals

We can see the plots of BER in both random and fixed data intervals,we used a notch filter (basically a band stop filter) to filter these impulse noise.

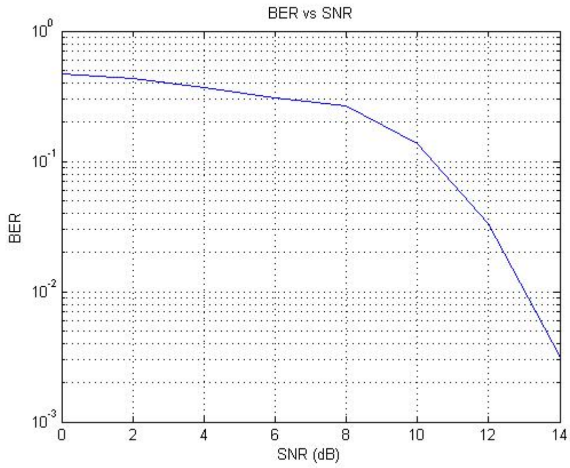

Figure 8: BER for signal with notch filter

The input data stream is divided into parallel streams using IFFT and they are recovered at the receiver by using FFT.Channel coding techniques,estimation is done before IFFT and FFT which improves performance of the given PLC system.

6 Hardware Implementation of Power line communication

As a part of hardware implementation, we are building a circuit by which we can transmit the data between two PLC modems over a power line channel using arduino micro controllers.

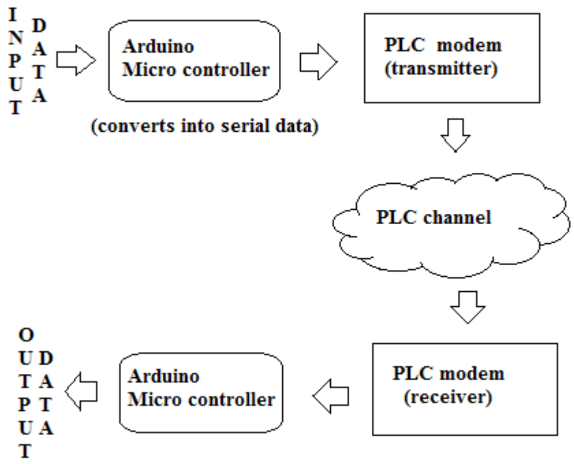

Figure 9: block diagram of the hardware interface

6.1 PLC modem

PLC modem is an essential block of our circuit.It is useful to send and receive the serial data over existing power line cables.It has high resistance to electrical noise which is present in the power line and also built in error checking so it never gives out corrupted output data.The modem is in form of ready to use,which is capable of bi-directional data communication at baud rate of 9600.

The module provides bi-directional half duplex communication over the power line channels of voltage upto 250V AC and for frequency 50 hz or 60 hz.half duplex communication means it can transmit the data and receive the data but not both at the same time.At the transmitter end,the serial data is transmitted on its RX-IN pin,it transmits the data into power line channel.The transmission of the data is indicated by *red* LED.At the receiver end,the reception of the data is indicated by *green* LED which is on its TX-OUT pin.

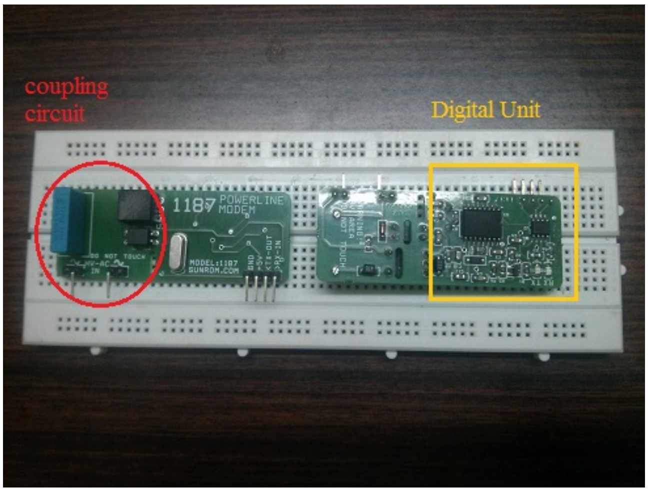

Figure 10: PLC modem

The transmission is based on byte by byte basis.Once we give one byte to module for transmission,we have to wait atleast 500ms before a new byte is given for transmission.For example,transmission of "HELLO" requires transmission of H,wait 500 ms and transmit E,wait 500 ms and transmit L,wait 500 ms and transmit L,wait 500 ms and transmit O,wait 500 ms.

6.1.1 PLC module hardware overview

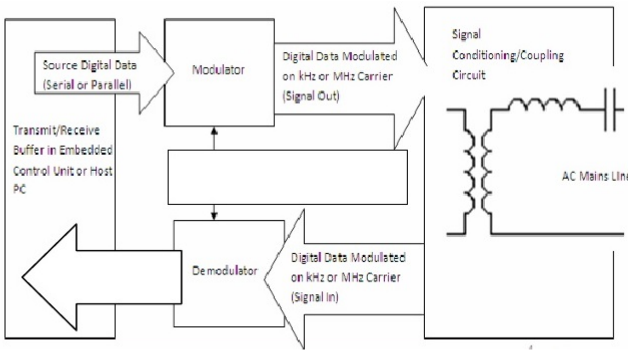

Figure 11: PLC modem hardware design

When the digital serial data is sent to a PLC modem,it modulates the serial data using *frequency modulation* and encodes the data which is sent to AC power lines through coupling circuit.

At the end receiver end, the encoded data is received through coupling circuit from AC power lines,which is then decoded and passes through the demodulator to retrieve the serial data.

6.1.2 Detail design of PLC modem

The design of a PLC modem is divided into *three* sub units,which is inclusive of power supply.The three sub units are as follows :-

1. Digital unit
2. Power supply
3. Coupling circuit

Digital unit consists mainly of modem IC and interface circuit.Modem IC is mainly responsible for transmitting and receiving the data bidirectionally via AC power lines.Modem IC functionality can be divided into three main sections such as : Transmitter section,Reception section,clock section.Interface circuit is responsible in creating a suitable interface for receiving and transmitting serial data.

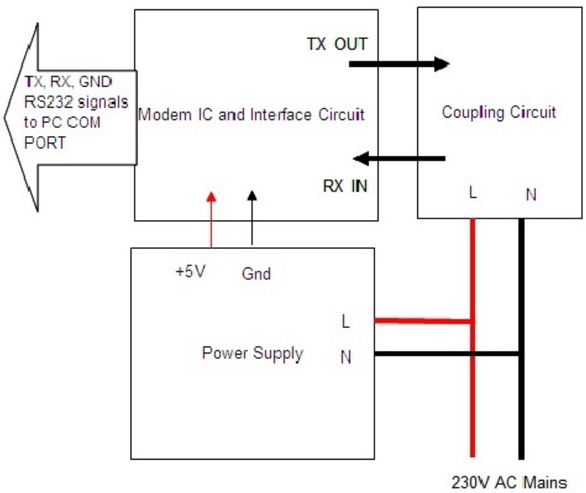

Figure 12: Signal and power connections of a PLC modem

A standard **power supply** of 5V is required for operation of the digital unit.This power can be produced by step downing the AC mains voltage of 230V into 5V DC or by directly connecting 5V DC power supply (batteries).

The **coupling circuit** is the main part of PLC modem which is responsible from blocking AC mains system and preventing it to reach the input of modem communication system.Another main purpose is to allow carrier frequency into Modem IC chipset and block other frequencies of power signals.

6.2 Arduino

Our PLC modem can only receive serial data for communication purposes.General micro controller sends parallel data instructions which in turn needs a multiplexer to convert this parallel data instructions to serial data.As it is very difficult to monitor this circuit,we are opting for *arduino* micro controller and as it can send instructions directly in serial data format.We are using *arduino* IDE for writing some set of intructions directly on the host computer which is accessed by the arduino micro controller and sent into power line channel through PLC modem.

6.3 Circuit Implementation

- At **transmitter** end,the TX pin of arduino micro controller goes into the RX pin of the PLC modem and the TX pin of PLC modem goes into the AC mains power line supply.Thus,transmitting the serial data into power line channel.
- At **receiver** end,the RX pin of PLC modem is connected to power line channel,thus receiving the serial data from power line channel and TX pin of PLC modem is connected to the RX pin of arduino micro controller.

6.3.1 Basic Code Explanation

At transmitter end,we need to set the baud rate of the serial transmission to the baud rate of PLC modem i.e, 9600.After transmission of each byte,we need to set the delay to 500 ms as PLC modem waits for 500 ms after transmission of each byte of data.The detailed code at transmitter end is shown below.

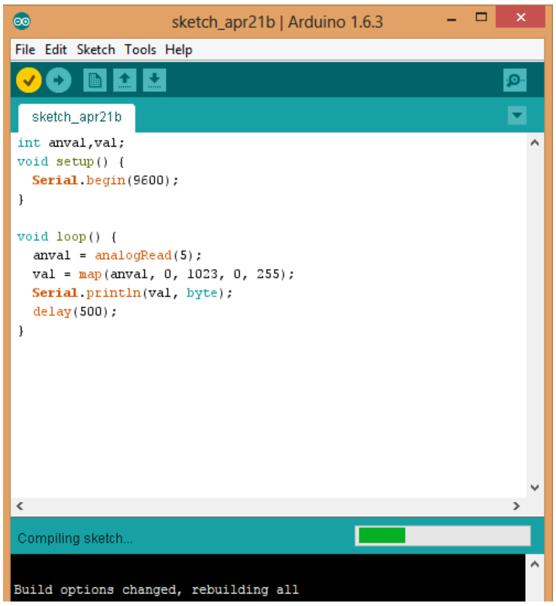

Figure 13: Arduino code at transmission end

At receiver end,we need to set the baud rate to the baud rate of PLC modem.Like that of transmission end, we need to wait for 500 ms after every transmission of single byte of information.The detailed code is shown below.

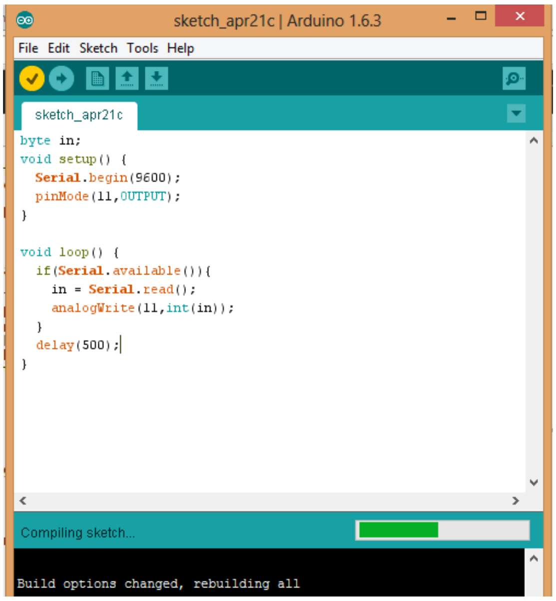

Figure 14: Arduino code at receiver end

7 References

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