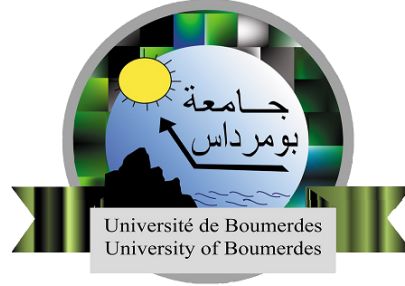


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Final year Master Project Report in Telecommunication

report Title
In-home PowerLine Communication

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Abstract

This report presents an overview of the major features and characteristics of PLC systems, discuss the broadband PLC access systems and their network components. So, there is no new cabling or infrastructure, instead of leveraging the long established power grid provided by electrical companies and In-Home BPL adapters utilize the existing house wiring to provision a Local Area Network (LAN) that can be used throughout the home, discuss different type of noise existing in powerline channel, simulation of the Transreciever and the powerline channel then design the device which performs the broad band over power lines which is called power line modem (PLM) and use it in exchange files between two PCs in the same building and remotely controled PV (photovoltaic) installation.

By applying this project the cost and expenditure in the realization of new telecommunications networks are reduced. In addition to providing Internet Services by means of the Transmission Control Protocol/Internet Protocol (TCP/IP) protocols, these protocols can support voice, data, and video services.

Acknowledgements

Our deepest gratitude goes to God who has provided all that was needed to complete this project and the program for which it was undertaken for. There was never lack or want. Throughout this entire study, He took care of everything that would have stopped us in our tracks and strengthened us even through our most difficult times.

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Thank you.

"I dedicate this project to God Almighty my creator, my strong pillar, my source of inspiration, wisdom, knowledge and understanding. He has been the source of my strength throughout this program and on His wings only have I soared. I also dedicate this report to our fathers, who taught us that the best kind of knowledge to have is that which is learned for its own sake. It is also dedicated to our mothers, who taught us that even the largest task can be accomplished if it is done one step at a time."

Adel HENNA

"In the name of Allah, the most beneficent and merciful. I devote this work to my parents with whom I share my joys and sorrows, my family and friends who believed and supported me".

Mohamed Amine BOUKELLAL

LIST OF ABBREVIATIONS

PLC	power Line Communication.
EMI/C	ElectroMagnetic Interference/Compatibility.
IEEE	Institute of Electrical and Electronics Engineering.
LAN	Local Area Network.
WAN	Wide Area Network.
BS	Base Station.
QoS	Quality Of Service.
OFDM	Orthogonal Frequency Division Multiplexing.
BPL	Broad band Over Power Lines
DSL	Digital Subscriber Line
PLM	Power Line Modems
TCP	Transport Control Protocol
IP	Internet Protocol
ADC	Analogue to Digital Converter
DAC	Digital to Analogue Converter
SIPO	Serial In Parallel Out

Chapter 1

Introduction

1.1 Introduction

The usage of telecommunications systems has increased rapidly. So there is a need for the development of new telecommunications networks and transmission technologies. The direct connection of the customers/subscribers is realized over the access networks, and the costs for realization, installation and maintenance of the access networks are very high and longer time is needed for paying back the invested capital. An alternative solution for the realization of the access networks is offered by the PLC (Power Line Communications) technology using the power supply grids for communications. PLC systems applied in the access area that ensure realization of telecommunications services with the higher QOS requirements are called “broadband PLC access networks”.

The power lines are spreaded in large areas in Algeria and used for transferring the electricity only, and Algeria is a poor country, so by using broadband over power lines, the costs for realization, installation and maintenance of the access networks will be reduced. The local area networks in home and small offices by using in home plug will be less cost and more availability.

Broadband over Power Lines (BPL) is a term used to describe the use of existing electrical lines to provide the medium for a high speed communications network. Power Line Communications (PLC) is achieved by superimposing the voice or data signals onto the line carrier signal using Orthogonal Frequency Division Multiplexing.

There are two main categories of BPL: in-house and access.

In-house BPL is broadband access within a building or structure using the electric lines of the structure to provide the network infrastructure. HomePlug is an alliance of several vendors of in-house BPL products. which has authored a standard for device compliance. Products conforming to the Home Plug standard have been commercially available. An adapter which connects an existing router (which accepts the in-coming broadband from Cable or DSL) to the electric lines of the house. Other computers in the building can then connect to the network simply by attaching their computer’s network card to an adapter plugged into a wall outlet.

Access BPL is the use of the electrical transmission lines to deliver broadband to

the home. Access BPL is considered a viable alternative to Cable or DSL to provide the 'final mile' of broadband to end users. A BPL coupler placed at the pole converts the transmission medium from fiber (originating at the substation) to medium voltage power lines. Broadband signals traverse the medium voltage power lines, bypassing transformers, with repeaters placed every mile along the transmission path. At the final pole, a BPL wireless device can deliver the broadband to home-installed BPL wireless receivers, or the signal can be sent to the individual homes via the low-voltage electrical lines and made available through any BPL wired receiver [1].

1.2 Advantages of PLC Systems

The concept of using the power lines for high speed data communication is not new. Communication over power line has been investigated since 1980's [1], however, it was never seriously taken into account because of harsh channel characteristics. For several years, power line communication (PLC) has been used for low data rate transmission with the data rates up to a few kilobits per second. However, recent trend in PLC requires the transformation of the electricity network into high data rate communication medium due to its inherent advantages. Advantages of PLC systems can be listed as follows [2]:

- The existence of the infrastructure and the unrivalled ubiquity of the network, which virtually reaches anywhere in the world, makes the PLC medium very promising for many communication applications such as Internet, data and voice transmission.
- Due to the ubiquity of the existing infrastructure, low-cost broadband may become a reality in areas that cannot get DSL, cable or wireless broadband. Even homes in extremely remote areas could now potentially get broadband communication access by PLC systems instead of satellite broadband communications which suffer from high latency problem.
- PLC systems will allow broadband Internet access from every socket in every room which provides the availability to have the access to the Internet everywhere.
- Since the system does not need any additional installations, PLC systems are introduced as plug-and-play devices which are very cost effective and very easy to install.
- PLC systems are accepted as one of the most promising communication opportunities for smart home applications. It will provide the opportunity to remotely control the Internet-enabled household appliances without any additional installations. With this system, it will be possible to control your refrigerators, heating

systems, smoke and fire alarm systems from the Internet. This idea will aid people with mobility problems.

1.3 Disadvantages

Some disadvantages of the PLC are given as:

- Minimum-security levels: power lines do not necessarily provide a secure media .
- Data attenuation: due to the presence of numerous elements on a power line network, data attenuation is likely to be an issue
- Noise: the greater amount of electrical noise on the line limits practical transmission speed (vacuum cleaners, light dimmers, kitchen appliances and drills are examples of noise sources that affect the performance of a power line-based home network.

1.4 PLC Systems

A simple PLC system is depicted in Fig 1.1 . The transmitter is located at the left and the receiver is on the right. The important parameters that effect the communication medium are the PLC channel itself, the noise added to the signal, and the impedance mismatches that occur along with the propagation of the signal. In order to connect the PLC transceivers to the mains line, coupling circuits are used. These circuits are one of the must-have equipment for PLC systems. The coupling circuit placed between the transceiver and mains line to block the 50Hz or 60Hz frequency currents in order to protect the system from the mains line voltage.

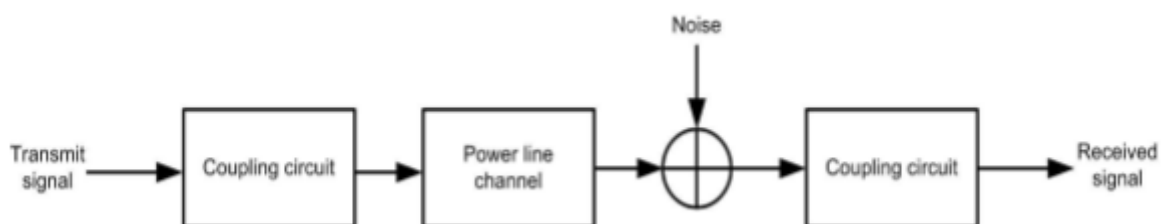


Figure 1.1: PLC system [28]

PLC systems are also vibrantly marketing their importance, because in-expensive and easier-to-use systems. There are several indoor and outdoor applications for PLC systems. Indoor power line applications can be listed as follows [3–6]

- Internet access for Internet protocol (IP) based devices.
- providing a home network for file sharing among computers, printers, cameras, televisions, speakers, gaming tools.

- Data file transfer medium for home control systems such as remote monitoring, alarm systems.
- Home automation systems for smart homes.
- Remote detection of illegal electric usage.
- Measuring the quality of power distributed to houses, communication tools for automated metering infrastructure (AMI) for smart grid systems.
 1. communication between electrical home devices and AMI for smart home applications.
 2. Communication from house to the central access unit for smart grid systems.

for outdoor application the PLC can be used for:

Automatic meter reading: In this technology, data from energy meter is automatically collected and transfer to the central database for bill and analysis. The main aim for the automation of meter reading is not to reduce labor cost but to obtain data rate that is difficult to obtain. In most of the places, users have demanded that their monthly bill be based on actual reading, instead of the bill which is based on prediction. This is the technology which saves periodic trip and billing is based on the real consumption not estimated.

1.5 Project Objectives:

The objective of this project can be summarized as follow :

- Study of the possibility and feasibility of power line communication as a solution of sending and receiving data.
- Simulate the function of powerline adapter and powerline channel.
- Design of powerline adapter.
- Using the power line modems in different applications like exchange data between two PCs.
- Remote control PV (photovoltaic) installation.

This report is organized as follows:

Chapter 2:This chapter covers an over view of the power grid and the broadband over power line.

Chapter 3:This chapter covers different mathematical analysis of the powerline system.

Chapter 4: In this chapter, we simulate the function of the transmitter and receiver and the subchannels using Matlab and the proceder of implementation and testing.

Chapter 6:conclusion

Chapter 2

Broadband over Powerline overview

2.1 Introduction

Just when we thought high-speed Internet access was limited to cable television and the local telephone company, we now have an additional option to consider. Broadband over power lines (BPL) represents an emerging technology that enables electric utilities to provide support for high-speed data communications over their infrastructure into our homes and offices. To paraphrase Barry Goldwater, we now have a choice instead of an echo.

There are two basic means of providing communications services: wireless or wireline. On the wireline side there are currently three means of providing broadband services: digital subscriber line (DSL) through telephone company telephone lines, cable modem through cable company coaxial cable lines, and fibre to the X (FTTX) through optical fibre lines to home or business to deliver broadband services. With the advent of broadband over power lines (BPL), a fourth wired option is emerging that uses electric utility power lines. Power lines are attractive for communications purposes because they have an omnipresence that reaches most homes and businesses, even in the most rural areas. This ubiquity implies a possible reduction in both time and cost for broadband deployment. In this sense, power lines, like Radio Frequency (RF) spectrum, can be considered a very valuable national resource, or even a national treasure. And of course, there is the inside-home power line wiring that can literally turn every outlet plug into a broadband communications access port. BPL is still a new technology in the communication fields by which broadband services can be provided throughout the country, as the power line network is thought to be ubiquitous. In Algeria especially the rural areas, where broadband services are still not available will have a chance to access broadband services through the BPL technology.

Wireless broadband services are similar to wired broadband in that they connect to an internet backbone usually a fiber-optic trunk; however they don't use cables to connect to the last mile or business/residences. Instead they use Wireless Fidelity (Wi-Fi) connections or radio waves.

Wi-Fi

Wi-Fi, short for Wireless Fidelity, Wi-Fi networks operate on an unlicensed basis in the 2.4 and 5 GHz radio bands and provide multiple data rates up to a maximum of 54 Mbps. The bandwidth is shared among multiple users. Wi-Fi enabled wireless devices, such as laptop computers or personal digital assistants (PDAs), can send and receive data from any location within signal reach of a Wi-Fi equipped base station or access point (AP). Typically, mobile devices must be within approximately 300 feet of a base station [8].

WiMax

Wireless Local Area Networks (LANs) based on the IEEE 802.11 or Wi-Fi standards have been quite successful, and therefore the focus in wireless is moving towards the wide area. While Wi-Fi dominates in the local area, the wide area market is still very much open. WiMax, short for Worldwide Interoperability for Microwave Access, refers to any broadband wireless access network based on the IEEE 802.16 standards. Internationally, a European Telecommunications Standards Institute (ETSI) initiative called HIPERMAN addresses the same area as WiMax/802.16 and shares some of the same technology. WiMax includes fixed systems employing a point-to-multipoint architecture operating between 2 GHz and 66 GHz. WiMax based broadband wireless access (BWA) or, also known as wireless DSL, will offer data rates between 512 Kbps and 1 Mbps. The key will be to deliver low-cost indoor, user installable premises devices that will not have to be aligned with the base station i.e., the antenna in the premises equipment would be integrated with the radio modem. WiMax is designed to deliver a metro area broadband wireless access (BWA) service. The idea behind BWA is to provide a fixed location wireless Internet access service to compete with cable modems and DSL. WiMax systems could support users at ranges up to 30 miles and is intended as the basis of a carrier service [8].

Broadband over Power Line (BPL) is an alternative means of providing high-speed Internet access, Voice over Internet Protocol (VoIP), and other broadband services to homes and businesses by using the existing medium voltage (MV) and low voltage (LV) power lines.

Our project is based on the technology of data exchange through electrical power lines. The main point of this project is the design of the device which performs the broad band over power lines which called power line modem (PLM) and use it in exchange data between two PCs, remote control photovoltaic and discuss the broadband PLC access systems and their network components. So there is no new cabling or infrastructure, instead leveraging the long established power grid provided by electrical companies. and In-Home BPL modems utilize the existing house wiring to provision a Local Area Network (LAN) that can be used throughout the home.

2.2 BPL Overview

Broadband over power line or BPL theoretically has the ability to enable data to be transmitted over power lines into homes and offices at data rates between 500 kilo bits per second (kbps) and 3 mega bits per second (Mbps), which is equivalent to most DSL and cable modem transmission rates [2]. So, BPL provides an emerging alternative to conventional methods of obtaining high-speed Internet access. The key reason for the excitement concerning BPL technology is the fact that virtually every home and office is connected to a power grid and contains electrical wiring. Thus, any mechanism that provides the potential to transmit high-speed data over existing electrical wiring has the potential to provide a truly pervasive method to access the Internet.

On April 23, 2003, the FCC adopted a Notice of Inquiry (Inquiry)¹, expressing enthusiasm about the potential of the BPL technology to enable electric power lines to function as a third wire into the home, and create competition with the copper telephone line and cable television coaxial cable line. The Commission subsequently issued a Notice of Proposed Rulemaking (NPRM)² in February 2004 based on the comments received in response to the Inquiry. Both the Inquiry and NPRM discusses two types of BPL: 1) Access BPL, and 2) In-house BPL

2.2.1 Access BPL

Access BPL is a technology that provides broadband access over medium voltage power lines. Medium voltage power lines are the electric lines that you see at the top of electric utility poles beside the roadways in areas that do not have underground electric service. Typically there are three electric lines (called phases A, B and C), each carrying several thousand volts. One phase is usually enough to power the houses on a residential street, two or even three phases can be joined together to power the big electric motors in an industrial or commercial area. (You also may see a fourth wire that is the ground wire) [7].

2.2.2 In-house BPL

In-house BPL is a home networking technology that uses the transmission between computers and different LAN devices. In-house BPL products can be used to access the internet in the presence of Modem(router). This technology uses the home electrical wire as medium to exchange data.

2.3 Overview of Grid Structure and Topology

A power grid basically consists of power plants or generators, transmission substations, transmission lines, power substations with transformers to change voltage levels, and distribution lines that collectively generate and carry the electricity from power plants all the way to wall plugs Fig 2.1. Power plants are basically spinning electricity

generators. Spinning can be performed by a steam turbine, and steam can be created by burning fossil fuel or from a nuclear reactor. A generator's output is three-phase alternating current (AC) power at voltage levels in the thousands. The three single phases are synchronized and offset by 120 degrees. Power P , transferred over lines and delivered to customers, is equal to the product of voltage V and current I ($P = I.V$). Power loss in the line grows with the square of the current, that is,

$$P_{loss} = R_{line}.I^2$$

where R_{line} is the line resistance and depends on the line material and increases with the length of the line. For a given generated P and a given R_{line} , to reduce P_{loss} , current I must be made as small as possible. This means that the line voltage must be made as large as possible, especially for long-distance transmissions. Transmission substations located next to power plants use large transformers to step up generator output from thousands of volts to hundreds of thousands of volts (typically between 155,000 and 765,000 volts), thus allowing megawatts of power transmission over distances of 300 miles or more [7]

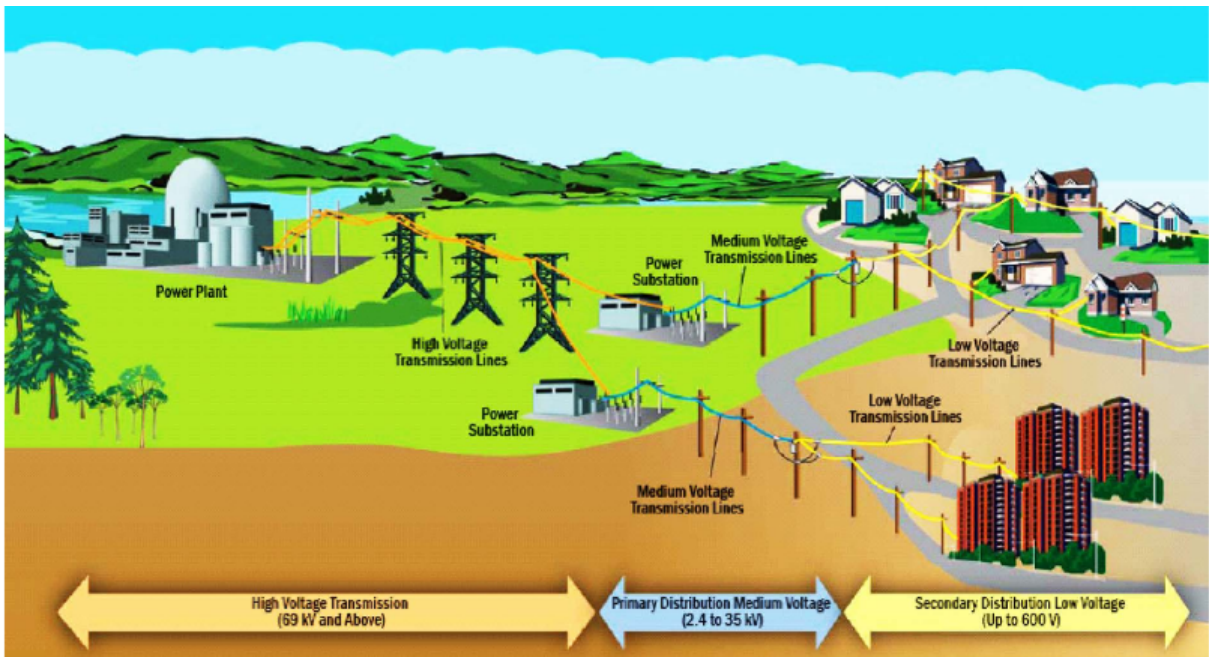


Figure 2.1: Typical electric power grid [2]

At power substations, voltages are stepped down and lines are branched out to cover larger areas. This is performed successively, transforming and branching out from extremely high voltage (EHV, typically 155 to 765 kilo volts or kV) to high voltage (HV, typically 45 to 155 kV), and then from HV to medium voltage (MV, typically 2 to 45 kV), and finally from MV to low voltage (LV, typically 100 to 600 V) for delivery to homes or businesses. The result is a tree-structured power distribution hierarchy. Basically, EHV and HV are used to transmit AC electric power, and MV and LV are used to distribute it Fig 2.2 .

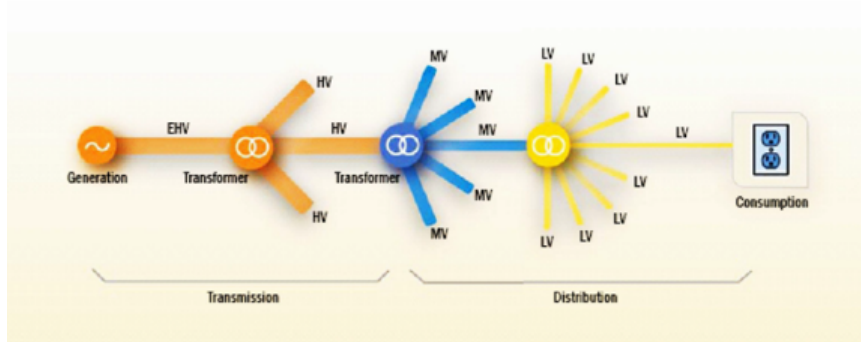


Figure 2.2: power grid hierarchies [2]

There are several different approaches to overcome the hurdles presented when transmitting data through power lines. When power leaves the power plant, it hits a transmission substation and is then distributed to high voltage transmission lines. When transmitting broadband, these high-voltage lines represent the first hurdle. The power flowing down high-voltage lines is between 155,000 to 765,000 volts. That amount of power is unsuitable for data transmission. It's too noisy. Both electricity and radio frequency (RF) are used to transmit data vibrating at certain frequencies. To transmit data cleanly from point to point; it must have a dedicated band of the radio spectrum to vibrate without interference. Hundreds of thousands of volts of electricity don't vibrate at a consistent frequency. That amount of power jumps all over the spectrum. As it spikes and hums along, it creates all kinds of interference. If it produces a spike at a certain frequency that is used for radio frequency data transmission, then it will cancel out that signal and the data transmission will be dropped or damaged on route [9]. (Figure 2.3).

BPL bypasses this problem by avoiding high-voltage power lines all together. The system drops the data off of traditional fibre-optic lines downstream, onto the much more manageable 7200 volts of medium-voltage power lines through injector/concentrator. Inside the injector, there are transmitter and receiver sections as well as a signal converter. The transmitter and receiver operate on different frequencies, which in effect enable full duplex transmission over the power line. The injector converts the signal on the fibre or metallic T1 line into the signal format used for transmission over the medium-voltage power line. Once dropped onto the medium-voltage lines, the data can only travel so far before it degrades. To counter this, special devices are installed on the lines to act as repeaters. The repeaters take in the data and repeat it

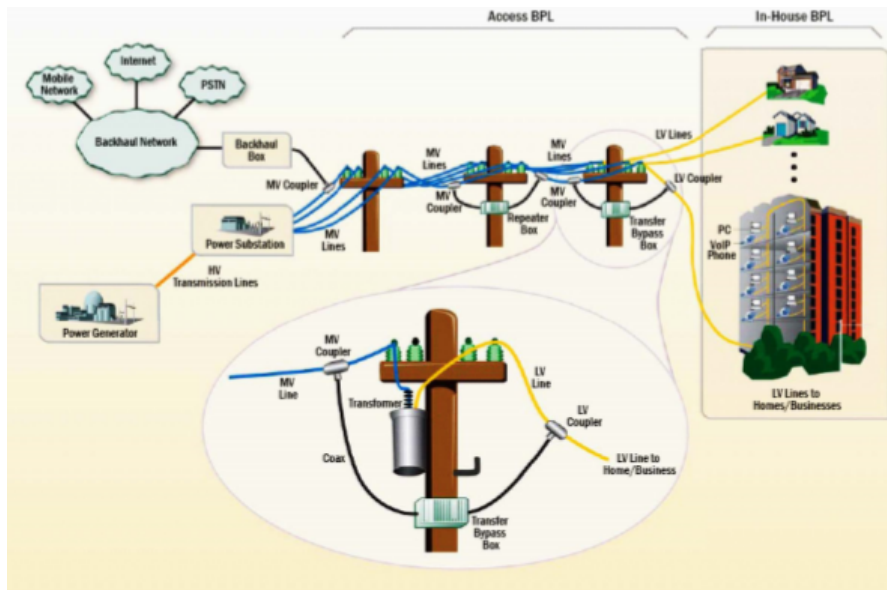


Figure 2.3: An overview of the BPL system [2]

in a new transmission, amplifying it for the next leg of the journey. The BPL repeater is installed approximately every 1000 to 2500 ft. along the medium-voltage power line. The coupler allows the data on the line to bypass transformers, and the bridge, a device that facilitates carrying the signal into the homes.

The transformer's job is to reduce the 7200 volts down to the 220 volt standard that makes up normal household electrical service. There is no way for low-power data signals to pass through a transformer, so a coupler is needed to provide a data path around the transformer. With the coupler, data can move easily from the MV line to the LV line and into the house without any degradation. The last mile is the final step that carries data into the subscriber's home or office. In the various approaches to last-mile solutions for BPL, some companies carry the signal in with the electricity on the power line, while others put wireless links on the poles and send the data wirelessly into homes. The Bridge facilitates both. The bridge mounted on a utility pole containing a transformer may also include one or more communications functions such as: data routing, managing subscriber information, Dynamic Host Configuration Protocol (DHCP), assignment of Internet Protocol (IP) addresses, encryption, symmetric data transmission to all electrical outlets in subscriber home or office. The signal can be received by a powerline modem that plugs into the wall. Inductive couplers are also used to connect BPL modems to the medium voltage power lines to extract information signal. The modem sends the signal to the computer. BPL modems use silicon chipsets specially designed to handle the work load of pulling data out of an electric current. Using specially developed modulation techniques and adaptive algorithms, BPL modems are capable of handling powerline noise on a wide spectrum [5] From the end user's perspective, BPL technology works by sending high-speed data along medium or low voltage power lines into the customer's home. The signal traverses the network over medium and low voltage lines either through the transformers or by-passes the transformer using bridges or couplers. The technology transports data,

voice and video at broadband speeds to the end-user's connection. The user only needs to plug an electrical cord from the BPL modem into any electrical outlet then plug an Ethernet or universal serial bus (USB) cable into the Ethernet card or USB interface on their PC. Any Internet Service Provider (ISP) can interface with the BPL network and provide high speed Internet access. The data signal can also interconnect with wireless, fibre or other media for backhaul and last mile completion.

2.4 Different Deployment Options

The MV and LV line portions of the BPL are usually referred to as the access BPL, while the portion inside home or office using the inside wiring is called the in-house BPL. BPL can be deployed either as end-to-end BPL or as hybrid BPL, using one of the three options illustrated in Figure 2.4 [7]. An end-to-end BPL system uses both access BPL and in-house BPL, i.e., power lines are used all the way from the power substation to the end user. Two of the three BPL deployment options involve the access BPL portion of an end-to-end system, and then the BPL signal can either (1) bypass the MV/LV transformer or (2) go through the transformer. For these two options, bypass boxes and LV couplers must be installed on all LV lines, and in-house BPL modems are required. The third BPL deployment option is hybrid BPL. In this option, typically only the MV lines are used, and a fixed wireless network replaces the LV lines and in-house BPL. In hybrid BPL Architecture, the bypass box does not couple the broadband signal to/from the LV line but converts it to/from a wireless format and delivers it to the wireless access point (AP) also located on the pole. For hybrid BPL, bypass boxes with wireless conversion boards, wireless APs, and existing standard wireless user modems are required.

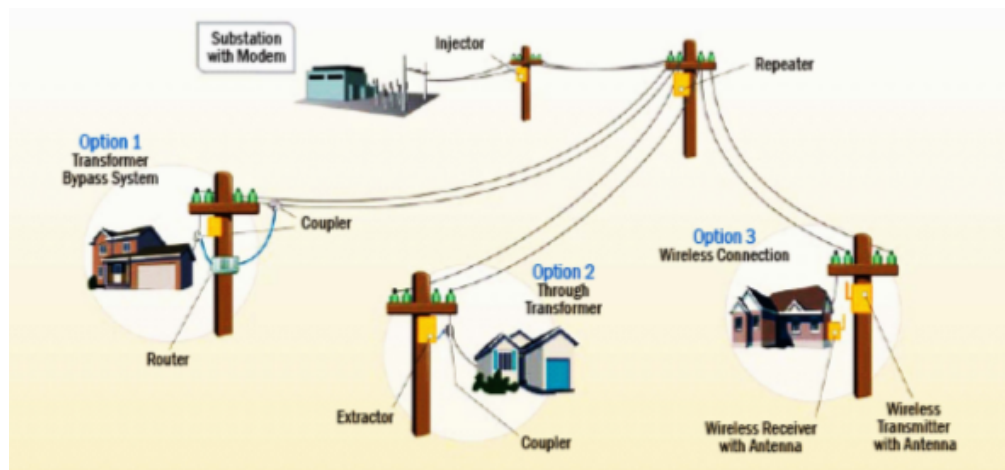


Figure 2.4: BPL deployment options [2]

2.4.1 Architecture 1

(Option 1) employs Orthogonal Frequency Division Multiplexing (OFDM) to distribute the BPL signal over a wide bandwidth using many narrow-band subcarriers.

At the BPL injector, data from the Internet backbone is converted into the OFDM signal format and is then coupled onto one phase of the MV power line. An injector also converts BPL signals on the MV power lines to the format used at the Internet backbone connection. The twoway data are transferred to and from the LV lines, each feeding a cluster of homes, using BPL extractors to bypass the LV distribution transformers. The extractor routes data and converts between access and in-house BPL signal formats. The subscribers access this BPL signal using in-house BPL devices. To span large distances between a BPL injector and the extractors it serves, repeaters may be employed. In this architecture, injector and extractors share a common frequency band (F1) on the MV power lines, different than the frequency band (F2) used on the LV lines by the subscriber's inhouse BPL devices. In order to minimize contention for the channel, Carrier Sense Multiple Access (CSMA) is used with Collision Avoidance (CA) extensions. This type of system is designed to accept some amount of co-channel interference between quasi-independent BPL cells without the use of isolation filters on the power lines, as all devices on the MV lines operate over the same frequency band. The BPL signal may be sufficiently tolerant of co-channel BPL interference to enable implementation of two or three of these systems independently on adjacent MV power lines. This architecture couples BPL signals into one phase line [2].

2.4.2 Architecture 2

This architecture also uses OFDM as its modulation scheme, but differs from Architecture 1 in the way it delivers the BPL signal to the subscribers' homes. Instead of using a device that uses LV power lines, this architecture extracts the BPL signal from the MV power line and converts it into an IEEE 802.11b WiFi signal for a wireless interface to subscribers's home computers as well as local portable computers. Technologies other than WiFi might also be used to interface to subscribers's devices with the BPL network, the important point being that BPL is not used on LV power lines in this system. This architecture uses different radio frequency bands to separate upstream (from the user) and downstream (to the user) BPL signals, and to minimize co-channel interference with other nearby access BPL devices. To span large distances between a BPL injector and the extractors it serves, repeaters may be employed. Like the injectors, BPL repeaters transmit and receive on different frequencies, and they use different frequencies from those used by the injector and other nearby repeaters. In this architecture repeaters may also provide the capabilities of an extractor when outfitted with a WiFi transceiver. This system/architecture couples BPL signals onto one phase of the MV power line [2].

Architecture 2 is option 3 in the picture. For deployment options, as mentioned in the Fig 2.4 we've discussed only 3 deployment options: Option 1 and 2 are point to point and both are a wired technique, besides a BPL modem is required. Option3 is wireless.

2.4.3 Potential Architectures And Their Financial Attractiveness

BPL providers anticipate a wider range of applications that may be offered to their subscribers. High quality, multi-channel video, audio, voice over Internet Protocol (VoIP), and on-line gaming applications are expected to rapidly increase the demand for additional bandwidth. To support the typical subscriber at 1 Mbps, BPL systems are expected to operate at speeds of 100 Mbps or more on the MV power lines in the near future. A number of comments filed in response to the NOI indicate that the BPL industry is already preparing for this growth. A number of BPL vendors have suggested use of frequencies up to 50 MHz. At least one vendor is considering use of 4 MHz to 130 MHz, while excluding frequencies that are actively in use by certain licensed services. One solution put forward in an attempt to mitigate interference with licensed services is to attenuate or “notch” BPL signals in frequency bands where licensed services are in nearby use. Future BPL systems may be able to accomplish this automatically without system operator intervention. To implement this solution while simultaneously maximizing the useable bandwidth, BPL systems are expected to use new modulations that can support more sub-carriers that are more finely spaced. As data rates and bandwidths requirements grow, the BPL systems may require operation at greater transmitted power levels but not necessarily with higher power density than is used today. BPL vendors may employ techniques to dynamically adjust the power level to maintain a minimum signal-to-noise ratio (SNR) over the entire BPL spectrum, while limiting emissions to levels compliant with Part 15. One vendor has proposed such a solution for adjusting transmitted power to maintain a constant SNR across the BPL spectrum, with a hard limit based on Part 15 rules. The challenge will be to develop the control mechanism that can maximize transmitted power while simultaneously limiting the radiated emissions, perhaps in conjunction with frequency agility. Nortel has developed and patented a filter that blocks BPL signals while concurrently passing medium-voltage AC power. The judicious use of such blocking filters will enable optimal segmentation of BPL networks into cells of various sizes having low conducted co-channel interference from neighboring cells. This will enable a greater level of frequency reuse than what is currently available. Another BPL technology utilizes the 2.4 GHz and 5.8 GHz unlicensed bands. An implementation using multiple IEEE 802.11b/g WiFi chips sets has been used to demonstrate the concept of carrying data over medium-voltage power lines at rates exceeding 200 Mbps. Consistent with the three Architecture types, the following are three distinct BPL systems [11].

2.5 BPL Business Models

In addition to resolving regulatory issues, each utility has to figure out the right BPL business model to pursue, which varies according to an electric utility’s business and economic objectives. The business model selection is experimental and fluid right now. Some utilities may make their lines available to a third party that would then

install BPL equipment. Others may decide to offer broadband directly. It depends on their risk/reward appetite. There are a number of variations to the following three fundamental business models available to electric utilities.

2.5.1 The Landlord Model

This model emphasizes partnering with an existing communications company who would give an electric company immediate access to operations and marketing expertise and personnel without having to invest in either the expenses or the personnel. The value brought to the table by the electric company, of course, would be its broadband network. Cautious utilities that want to avoid capital or operating exposure will look to enter into such partnership arrangements as part of a landlord strategy. The landlord business model is a very stable structure and can be risk-free if positioned correctly. This model allows for small returns for small investment and effort [11].

2.5.2 The Developer Model

This model involves building the infrastructure and offering wholesale access. Utilities seeking to leverage their core competencies in building and maintaining networks will look to this model. Those electric companies that are reluctant to incur the marketing costs associated with selling retail broadband services may want to consider marketing to a smaller group of customers—traditional broadband companies. Traditional broadband companies are those that primarily or exclusively sell communications services, such as broadband. There are many companies that already have personnel experienced in the marketing and selling of broadband services but that have failed to thrive due to the high costs of building networks. In fact, many of these companies must rely on ILECs to provide broadband service to their customers. BPL presents electric companies with the opportunity to sell broadband services to these companies. By upgrading their electricity networks to include broadband capabilities, electric companies could make ready-made last-mile broadband networks for competitive broadband companies that seek to eliminate their dependency on ILECs, which are their direct competitors for customers. According to the report drafted by the Shpigler Group and UTC Research, “the developer will be equally involved in network construction as a service provider but will trade in lower operational burdens for diminished financial returns.”

2.5.3 The Service Provider Model

This model is one in which the utility interfaces with the customer. Aggressive utilities seeking to offer retail broadband services may consider the service provider model. The service provider business model involves the highest risk, but can feature tremendous upside. Electric utilities are certainly poised to provide this service because they already own the poles and lines that access virtually every residential and business customer in the United States. Providing broadband service to these customers would

simply require adding equipment to their wires. The feature of BPL that would make it more attractive than DSL or cable modem is that BPL customers would immediately have in-house networks without having to purchase and install additional wiring in their homes. The challenge with providing retail service, however, is that there are marketing costs that some companies may be unwilling or unable to absorb. The cost of advertising to create market share where none exists can be overwhelming. An electric company deciding to enter this retail market would also have to hire or retrain staff with expertise in marketing broadband services. Any utility interested in pursuing the service provider model will need to address market, operational, and network build issues [8].

Function / Business Model	Landlord	Developer	Service Provider
Allow Access to Network	Yes	Yes	No
Network Construction	No	Yes	Yes
Network Maintenance	No	Yes	Yes
Network and Customer Operations	No	No	Yes

Functional Activities by Business Model source UTC research ,The Shpigler group

2.6 Benefits of the BPL over Other Access Methods

The benefit of the BPL can be summarized into two forms :

2.6.1 Benefits for Service Providers

A major advantage for the utility companies is that most of the infrastructure is already in place because the technology relies on the existing power grid. This enhances the cost-effectiveness of rolling out power line communications. Only the substation server equipment and customer conditioning service units need to be installed in order to establish a digital power line network [10]. Another important aspect to consider for providers is that of coverage; the power grid is everywhere. The low voltage power grid has a unique feature; it is comprised of an already existing networked infrastructure to billions of private customers as well as businesses. The power grid has the greatest availability of any other solution that exists today.

2.6.2 Benefits for the End Users

The equipment needed to set up BPL in home is cheaper on average than that of other broadband solutions such as DSL and cable modem. The equipment uses existing power outlets in the home making it a lot easier to set up and is very simple as it is plug and play. There is no need for complicated wiring and additional installations; and it is possible to move computers and appliances anywhere. The uplink and downlink speeds are similar. This is especially important for the uplink as the speed is higher than the DSL and Cable. For users in rural areas who cannot receive DSL or cable modem services, BPL can provide an all-in-one service-telephone, cable television and high-speed data.

2.7 Implementation Challenges

Power lines were not designed for data transmission; they were created to deliver power at 50 to 60 hertz (Hz). Broadband data are transmitted at different frequencies, so the data and electricity can travel in the same wire; however, several obstacles have to be overcome to enable high-speed and long-distance transmission of data on powerlines [12].

2.7.1 The Nature of the Power Grid

The most obvious challenge to implement BPL arise from the fact that power line grids were originally developed to transmit electrical power from a small number of sources (the generators) to a large number of sinks (the end customers). Power grids were neither designed nor devised for communications purposes. The main challenges to BPL are the extremely harsh unpredictable nature of power grid and the time and location variable characteristics of the power line channel, and potential interference arising from the power grid [2]. Because power lines are not twisted and have no shielding, they can produce electromagnetic radiation that is easily detected by radio receivers. For the same reasons, power lines can also easily pick up nearby radio frequency signals. Thus, addressing mutual interference is not only a challenge, but becomes a valid regulatory concern.

2.7.2 Power Line Noise

The power line noise is typically time, location, and frequency dependent. Time-variable behaviour is mainly due to the dynamically changing nature of the load connected to the power lines. Line branching, the number and types of branches, the lengths of line segments, the types of power line equipment connected (such as capacitor banks and transformers), and the kind of loads connected, all affect power line characteristics.

2.7.3 Channel Attenuation

Attenuation or reduction of signal strength occurs either on longer lengths of distribution feeders, or when a given feeder changes configuration several times such as from overhead to underground or from cross arm to a more compact configuration. Attenuation must be overcome to enable long-distance data transmission. Higher frequency data signals are typically attenuated much more seriously than lower frequency signals. Signals lose energy as they propagate for several reasons including the change in impedance on the line at every connection, splice, taps, standoff or even a location where the line is close to something else.

2.7.4 Attenuation Problems at the Distribution Transformers

Low frequency signals, obviously including electricity at 60 Hz can easily pass through the distribution stepdown transformer. But high frequency signals, which for BPL are typically in the 2 to 80 mega hertz (MHz) range, are obstructed or severely attenuated by the transformer [6]. Although some of the signals get through signal components can be so weak that they are difficult to detect or reconstruct. Accordingly, many BPL technology suppliers simply bypass the transformer.

2.7.5 Potentially Harmful Radio Frequency Interference (RFI)

Radio frequency interference has been one of the most serious potential obstacles to BPL. BPL systems have been shown to produce RF interference with nearby radio receivers, within up to 75 meters for mobile radios and 150 meters for fixed radios, according to the American Radio Relay League (ARRL). Also, various elements or structures in or near the powerlines readily become radiator or antennas at the high frequencies at which BPL data are transmitted. This presents a problem of interference with a variety of radio services.

2.7.6 Overcoming Technical Challenges

Conditioning the grid can improve power line performance by minimizing impedance mismatches, terminating stubs, filtering noise, etc. These options may deteriorate or diminish the advantages of power line grids. A better approach is to use modulation and coding schemes robust enough to work in the hostile power line channel environment. Currently, most BPL products use orthogonal frequency division multiplexing (OFDM) well known for its excellent robustness against channel distortions such as multipath and impulsive noise and for its good spectral efficiency, reasonable cost, and ability to avoid certain bands [2]. In BPL systems, multiple user modems are connected in a bus or star topology. Some type of medium access control (MAC) protocol must be implemented to provide communications through shared bandwidth on power lines. To provide the necessary quality of service (QoS) for applications that require bandwidth and performance guarantees, such as video streaming the carrier sensing multiple access/collision avoidance (CSMA/CA) protocol may be used.

Chapter 3

Theory

3.1 Introduction

The main point of this project is to simulate the function of powerline modem and design it. The design of the transceiver which is the main part of *powerline – modem* "PLM" based on Orthogonal Frequency Division Multiplexing process. The key behind using ofdm is to achieve high data rate also to eliminate the effect of *inter – symbol – interference*(ISI) caused by connected loads and the powerline channel.

A power-line channel is characterized by a multipath fading environment similar to wireless networks. This is due to a number of concentrated (distributed) branches and different connected load impedances, including line length (both direct and branched lengths). The delayed signals due to connected loads (i.e. refrigerators, computer power supplies, transformers, etc.) and branches (either concentrated at a node or distributed) interfere with the direct waves and cause inter-symbol interference (ISI), which degrades the network performance. Because the delayed waves interfere with the direct waves and degrade the systems, the delay must be eliminated as far as possible; the only means is to use equalization techniques. However, achieving equalization at megabits per second is more cumbersome. OFDM is based on parallel transmission broadband data which reduces the effects of multipaths and leads to unnecessary equalization techniques [13,14].

3.2 Orthogonal Frequency Division Multiplexing

Orthogonal Frequency Division Multiplexing (OFDM) is a digital multi-carrier modulation scheme that extends the concept of single subcarrier modulation by using multiple subcarriers within the same single channel. Rather than transmit a high-rate stream of data with a single subcarrier, OFDM makes use of a large number of closely spaced orthogonal subcarriers that are transmitted in parallel. Each subcarrier is modulated with a conventional digital modulation scheme (such as PSK , QAM, etc.) at low symbol rate. However, the combination of many subcarriers enables data rates similar to conventional single-carrier modulation schemes within equivalent

bandwidths. OFDM is based on the well-known technique of Frequency Division Multiplexing (FDM). In FDM different streams of information are mapped onto separate parallel frequency channels. Each FDM channel is separated from the others by a frequency guard band to reduce interference between adjacent channels. The OFDM scheme differs from traditional FDM in the following interrelated ways:

- Multiple carriers (called subcarriers) carry the information stream.
- The subcarriers are orthogonal to each other.
- A guard interval is added to each symbol to minimize the channel delay spread and intersymbol interference.

The Figure 3.1 illustrates the main concepts of an OFDM signal and the inter-relationship between the frequency and time domains. In the frequency domain, multiple adjacent tones or subcarriers are each independently modulated with complex data. An Inverse FFT transform is performed on the frequency-domain subcarriers to produce the OFDM symbol in the time-domain. Then in the time domain, guard intervals are inserted between each of the symbols to prevent inter-symbol interference at the receiver caused by multi-path delay spread in the radio channel. Multiple symbols can be concatenated to create the final OFDM burst signal. At the receiver an FFT is performed on the OFDM symbols to recover the original data bits [16, 17].

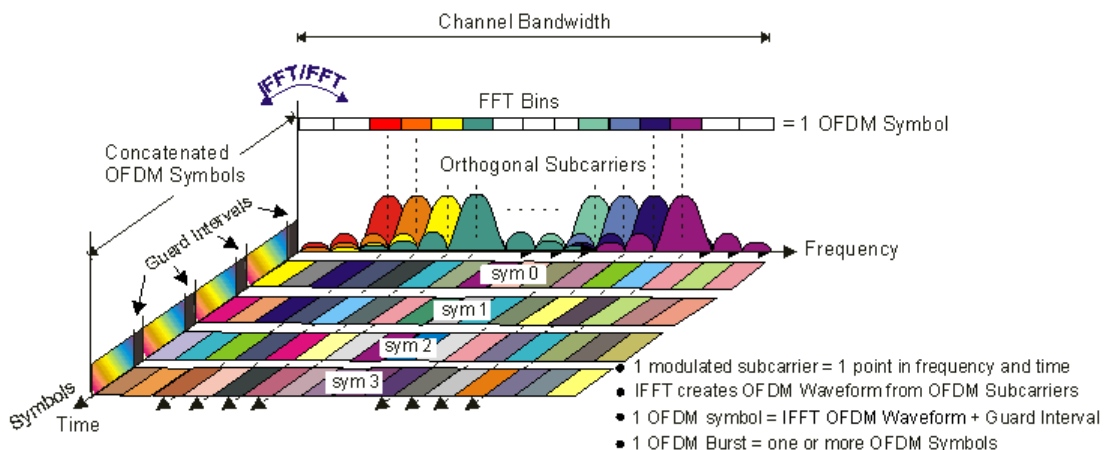


Figure 3.1: Frequency-time representation of an OFDM signal [15]

3.2.1 The need of digital modulation

The digital data are usually in the form of a stream of binary data, i.e., a sequence of 0s and 1s. Regardless of whether these data are inherently digital (for instance,

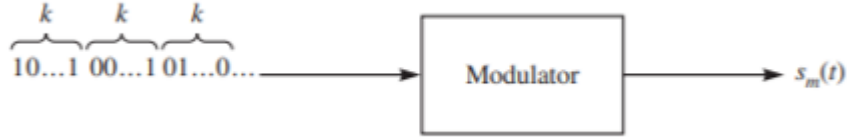


Figure 3.2: Digital modulator operation [18]

the output of a computer terminal generating ASCII code) or the result of analog-to-digital conversion of an analog source (for instance, digital audio and video), the goal is to reliably transmit these data to the destination by using the given communication channel. Depending on the nature of the communication channel, data can suffer from one or more of certain channel impairments including noise, attenuation, distortion, fading, and interference. To transmit the binary stream over the communication channel, we need to generate a signal that represents the binary data stream and matches the characteristics of the channel. This signal should represent the binary data, meaning that we should be able to retrieve the binary stream from the signal; and it should match the characteristics of the channel [18]. The process of mapping called digital modulation.

The first step of mapping the binary sequence into analog signal is to pare the binary sequence into subsequence of length K , for each mapped sequence we generate a signal $S(t)_m$. As shown in Fig 3.2 We end up with $M = 2^k$ signals transmitted each one on period of time and for each one represents one symbol. We assume that these signals are transmitted at every T_s seconds, where T_s is called the signaling interval. This means that in each second:

$$R_s = \frac{1}{T_s} \quad (3.1)$$

Symbols are transmitted. Parameter R_s is called the signaling rate or symbol rate. Since each signal carries k bits of information, the bit interval T_b , i.e., the interval in which 1 bit of information is transmitted, is given by [18]:

$$T_b = \frac{T_s}{k} = \frac{T_s}{\log_2(M)} \quad (3.2)$$

The bit rate R given by:

$$R = k.R_s = R_s.\log_2(M) \quad (3.3)$$

The general form of the transmitted signal given by [18]:

$$s_m(t) = \sqrt{\frac{E_g}{2}} \cos\left(\frac{2\pi}{M}(m-1)\phi_1(t)\right) + \sqrt{\frac{E_g}{2}} \sin\left(\frac{2\pi}{M}(m-1)\phi_2(t)\right) \quad (3.4)$$

Where:

$$E_g = 2 \sum_{m=1}^M p_m E_m = 1 \quad (3.5)$$

E_m :represents the enrgy of the generated signal.

p_m : indicates the probability of the appearance of m^{th} signal [18]

$$\phi_1(t) = \sqrt{\frac{2}{E_g}} g(t) \cos(2\pi f_c t) \quad (3.6)$$

$$\phi_2(t) = -\sqrt{\frac{2}{E_g}} g(t) \sin(2\pi f_c t) \quad (3.7)$$

Where: $g(t)$: is the signal pulse shape [18]

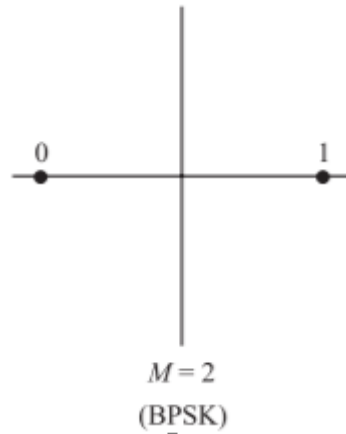


Figure 3.3: Signal space diagrams for BPSK (binary PSK, $M = 2$)

The corresponding waveform is the output of PSK modulator

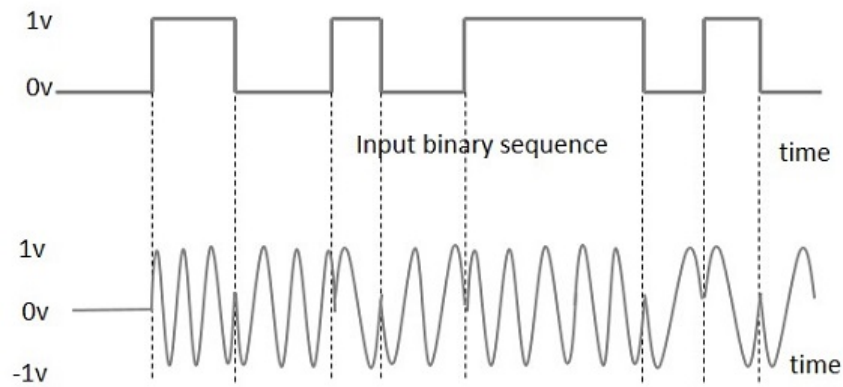


Figure 3.4: BPSK modulated output wave [19]

3.2.2 ofdm operation

OFDM consists to divide large bandwidth into small sub bandwidth which space between subcarrier Fig 3.5. If the bandwidth B , and N is the total number of subcarrier then:

$$F_0 = \frac{B}{N} \quad (3.8)$$

Where:

F_0 is the fundamental frequency of the system

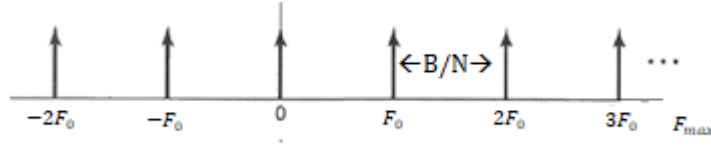


Figure 3.5: Subcarrier separation [20]

In each sub band we place subcarrier centered at $kF_0 = k\frac{B}{N}$. The K^{th} subcarrier and The K^{th} symbol represented as $e^{j2\pi kF_0 t}$, X_k respectively. There for the transmitted signal on the K^{th} subcarrier given as:

$$x_k(t) = X_k e^{j2\pi kF_0 t} \quad (3.9)$$

The net multicarrier transmitted signal [20]:

$$x(t) = \sum_k X_k e^{j2\pi kF_0 t} \quad (3.10)$$

Generating this signal is difficult because of the large number of subcarriers ,we need large number of oscillators placed exactly at $\{\dots, -2F_0, -1F_0, 0, F_0, 1F_0, 2F_0, \dots\}$ to satisfy the principle of orthogonality between subcarrier. It is challenging to have precise spacing between subcarrier with large number of oscillators in physical system [20].

The maximum frequency [21]:

$$F_{max} = \frac{B}{2} \quad (3.11)$$

Since the signal is bandlimited can be sampled at Nyqest rate which equals to twice of the maximum frequency [21]:

$$Nyqest - rate = 2F_{max} = 2\frac{B}{2} = B \quad (3.12)$$

$$Sampling - interval = \frac{1}{sampling\ frequency} \quad (3.13)$$

$$T = \frac{1}{B} \quad (3.14)$$

l^{th} sampling instant:

$$lT = \frac{l}{B} \quad (3.15)$$

Try to evaluate $x(l) = x(lT)$ [20]:

$$x(lT) = \sum_k X_k e^{j2\pi k F_0 l T} \quad (3.16)$$

We substitute T from 3.14 and F_0 from 3.8

$$x(lT) = \sum_k X_k e^{j2\pi k l \frac{B}{N} \frac{1}{B}} \quad (3.17)$$

$$x(lT) = \sum_k X_k e^{j2\pi k l \frac{1}{N}} \quad (3.18)$$

$$x(l) = \sum_k X_k e^{j2\pi k l \frac{1}{N}} \quad (3.19)$$

We need IDFT or IFFT in the transmitter and DFT or FFT in receiver to recover the sequence X_k instead of large number of oscillators to generate the OFDM signal.

3.2.3 OFDM block diagram

The general configuration of an OFDM transmission system is shown in Fig 3.6, where the transmitted high-speed data is first coded and interleaved and then mapped. Afterwards, the data are distributed as parallel data transmission in several channels, in which the transmitted high-speed data is converted into slow parallel ones in several channels. Increasing the number of parallel transmission channels reduces the data rate that each individual sub-channel must convey. The transmitted data of each parallel sub-channel is modulated by either M-ary phase shift keying (PSK) or M-ary QAM (M-QAM). The data are fed into an inverse fast Fourier transform (IFFT) circuit and then the OFDM signal is generated. The signal is fed into a guard time insertion circuit to reduce ISI then into a power-line communication (PLC) channel [13, 14].

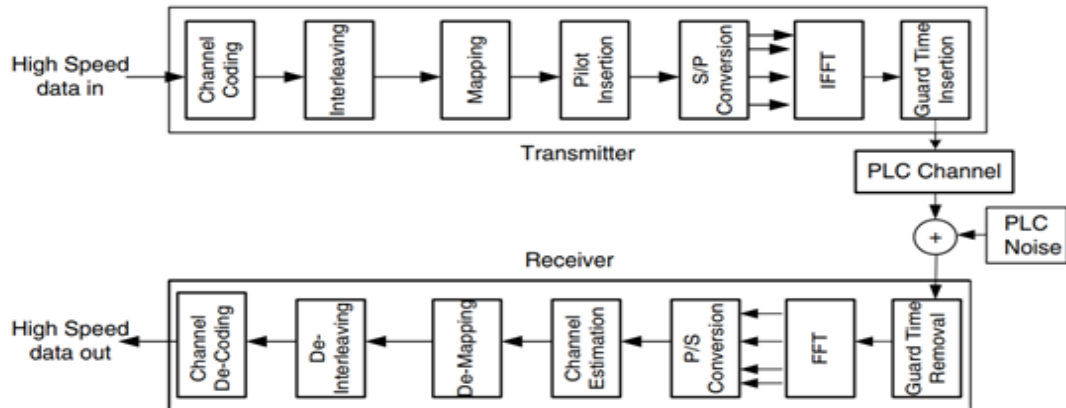


Figure 3.6: General configuration/scheme of an OFDM transmission system [28]

3.3 Powerline channel

Low voltage powerline is known to be a harsh environment for high-frequency signal. The main known noise for this type of channel is the additive white gaussian noise (AWGN) which is considered as the background noise in addition to impulsive noise [22]. The impulse response that models the powerline channel given by [23]:

$$h(t) = \sum_{i=1}^N |\rho_i| e^{-j\phi_i} \delta(t - \tau_i) \quad (3.20)$$

$|\rho_i|$: Amplitude of the complex attenuation factor that is given as [25]

$$\rho_i = |\rho_i| e^{-j\phi_i} \quad (3.21)$$

$$\phi_i = \tan^{-1} \left(\frac{\Re\{\rho_i\}}{\Im\{\rho_i\}} \right) \quad (3.22)$$

τ : the path delay given by the following .

$$\tau_i = \frac{d_i \sqrt{\epsilon_r}}{c_0} \quad (3.23)$$

where:

c_0 : the speed of light in free space.

ϵ_r : material's dielectric constant.

d_i : is the length of a path.

impulsive noise in PLC channel is modelled by using *Poisson-Gaussian* process According to this model, the overall noise sample z_k may be expressed as [24]:

$$z_k = g_k + i_k, k = 0, 1, 2, 3, \dots, N - 1 \quad (3.24)$$

where g_k is the AWGN, which represents the background noise and i_k is the impulsive noise sample given by [24]:

$$i_k = b_k \cdot w_k, k = 0, 1, 2, 3, \dots, N - 1 \quad (3.25)$$

where w_k is the Poisson process. The probability density function (PDF) of the noise z_k is

$$P_{z_k}(z_k) = (1 - p) \cdot D(z_k, 0, \sigma_g^2) + p \cdot D(z_k, 0, \sigma_g^2 + \sigma_i^2) \quad (3.26)$$

where σ_g^2 , σ_i^2 are the AWGN and impulsive noise variances, respectively. $D(\cdot)$ is the Gaussian PDF given by

$$D(z, 0, \sigma_z) = \frac{1}{\sqrt{2\pi}\sigma_z} e^{-\frac{(z-\mu)^2}{2\sigma_z^2}} \quad (3.27)$$

3.3.1 Impulsive noise reduction through OFDM-based PLC

New approaches to deal with the impulsive noise reduction is a dynamic impulsive noise compensator INC in the time domain, it utilizes a new adaptive clipping/blanking function to estimate and detect the impulsive peaks based on the estimation of the signal to impulsive noise power ratio (SINR) and the peak to average power ratio (PAPR) of the received noisy signals. Second, it estimates the impulsive bursts in the time domain after channel equalization and OFDM demodulation, which make it more accurate in the detection process and more effective for impulsive bursts suppression. As shown in Fig 3.5 [25].

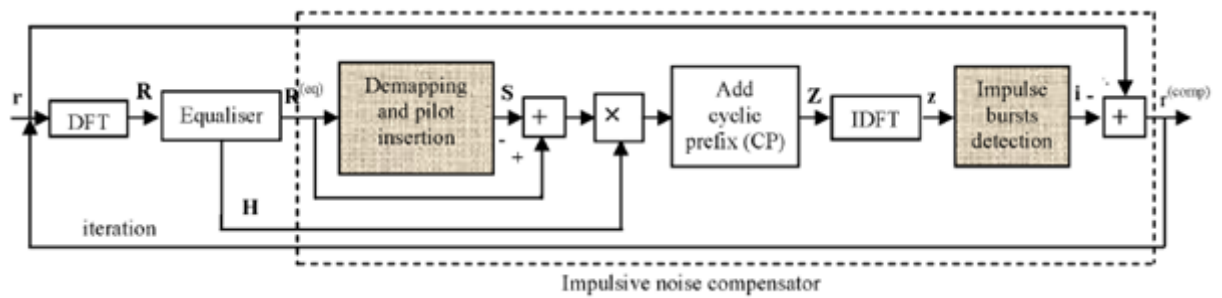


Figure 3.7: Block diagram of the recursive impulsive noise compensator [25]

Chapter 4

Simulation and Methodology

4.1 Introduction

The function of an OFDM transceiver can be modeled and simulated in different methods (HDL code, FPGA, simulink(Matlab), Matlab code...). This simulation is based on Matlab code which is formed from 4 main parts :

1. Part A: Setting Parameters
2. Part B: The Transmitter function
3. Part C: The AWGN Channel
4. Part D: The Receiver function

4.2 Matlab code simulation

4.2.1 Setting Parameters

Define parameters size of each ofdm block , length of cyclic and number of fft point prefix using matlab code from appendix part I.

4.2.2 Transmitter function

The input data is a serial stream of binary digits. By inverse multiplexing, these are first demultiplexed into parallel streams, and each one mapped to a symbol stream using some modulation constellation (QAM, PSK, etc.). Note that the constellations may be different, so some streams may carry a higher bit-rate than others. An inverse FFT is computed on each set of symbols, giving a set of complex time-domain samples. These samples are then passed through parallel to serial then adding cyclic prefix. In our case, we used :

1. Input data = 128 Kb= 128000 bit.
2. BPSK modulation.

3. Serial to parallel.
4. 8 points for the FFT/IFFT.
5. parallel to Serial.
6. Cyclic prefix. Following this process and Matlab code we can generate OFDM signal.

4.2.3 Awgn channel

AWGN considered as the background noise of the powerline communication system. We can generate the Additive White Gaussian Noise using matlab code from appendix part III.

4.2.4 Receiver function

The receiver picks up the OFDM signal,remove the cyclic prefix then the signal is forwarded to FFT which is used to convert back to the frequency domain. This returns parallel streams, each of which is converted to a binary stream using an appropriate symbol detector(BPSK in our case). These streams are then re-combined into a serial stream, which is an estimate of the original binary stream at the transmitter. We can build up the receiver using matlab code from appendix part IV.

4.3 Results

After running matlab code we get the following result :

Data generator:

We generate random sequence of binary data of length 128000 points. The output of the generator for the first 35 data points shown in Fig 4.1

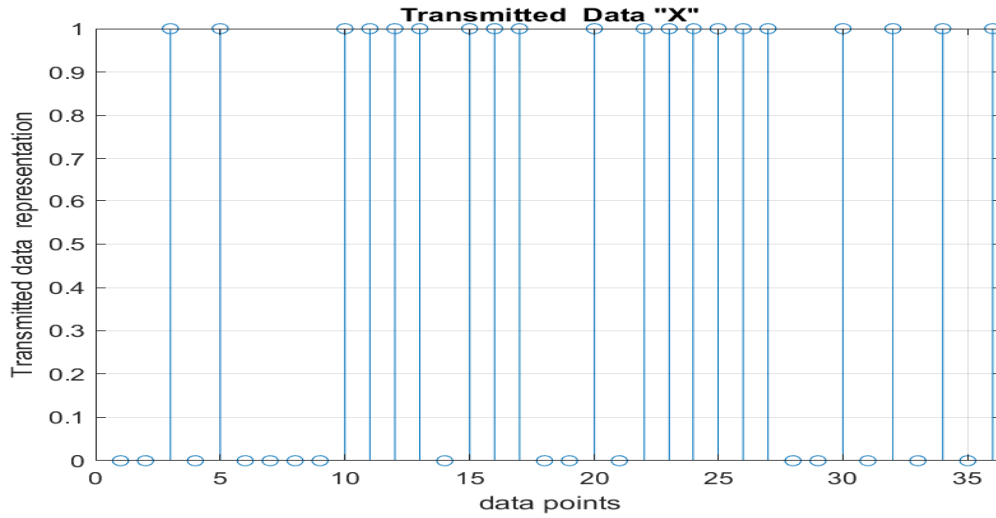


Figure 4.1: First 35 points of transmitted data

Modulated Data:

The output of BPSK modulator shown in Figures 4.2 and 4.3 We can see that for the input sequence of data for 6 points $\{0\ 0\ 1\ 0\ 1\ 0\}$ modulated into $\{1\ 1\ -1\ 1\ -1\ 1\}$. Where: The zero mapped into $1(\sqrt{E})$, The one mapper into $-1(-\sqrt{E})$

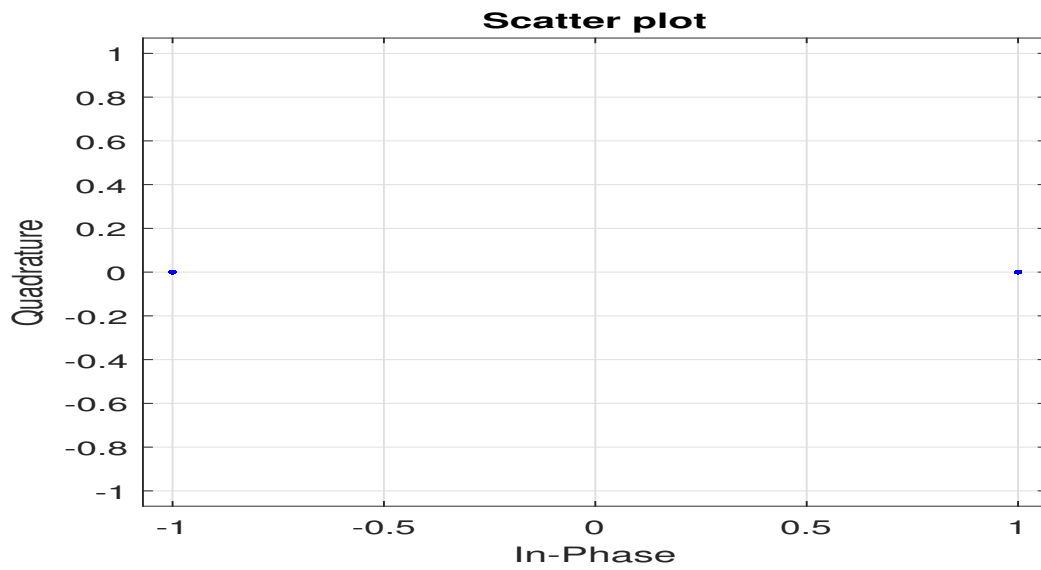


Figure 4.2: Constellation map of modulated data

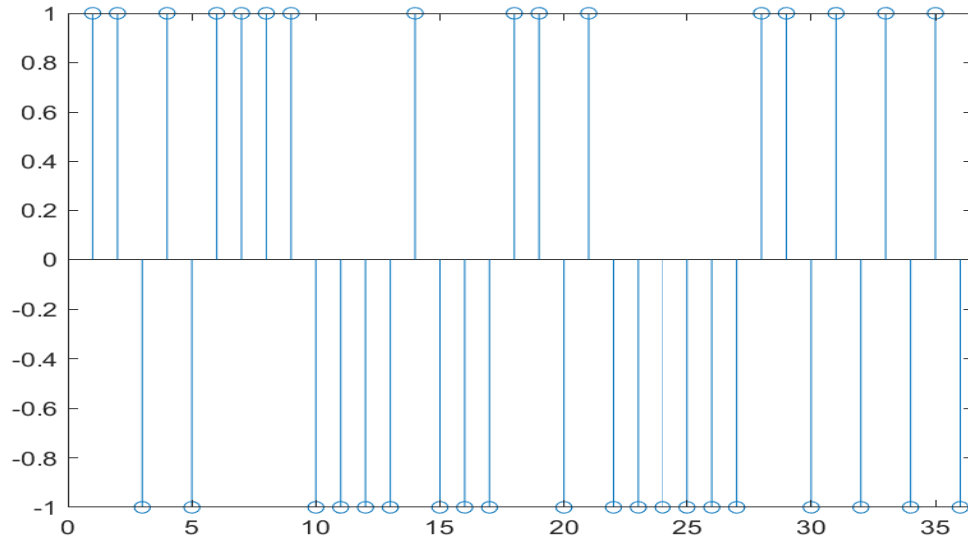


Figure 4.3: Modulated data

Serial to parallel / IFFT / parallel to Serial:

In this part we Convert the modulated signal from the serial form into parallel, then pass it through IFFT to generate subcarriers which are multiplied with the parallel signal and summed together, then convert to serial form to generate the OFDM signal which is shown in figure 4.4.

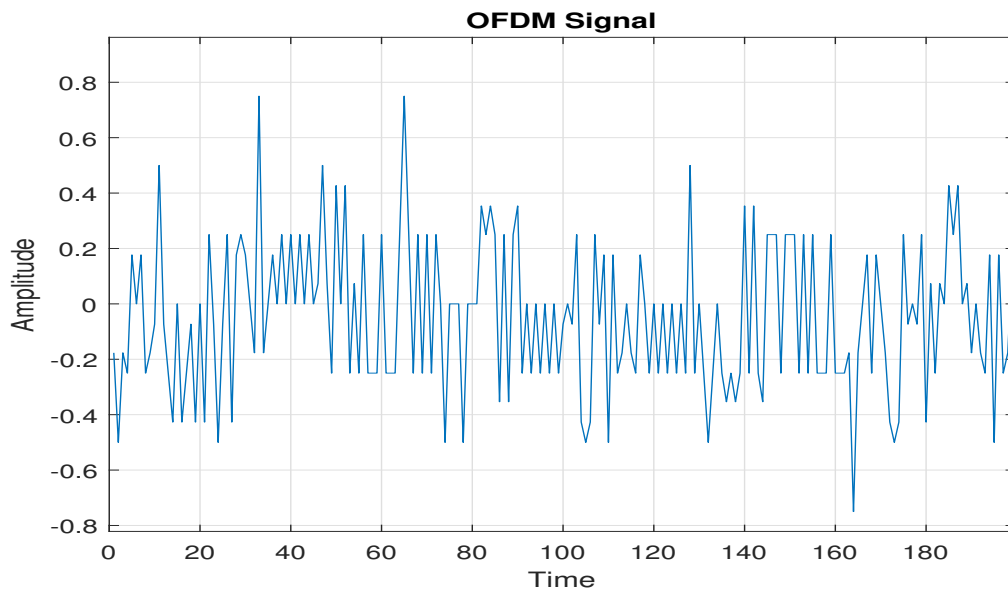


Figure 4.4: OFDM signal generate by the transmitter

Received OFDM signal:

Passing the OFDM signal through AWGN channel results noisy signal as shown in figure 4.5 . Using the syntax:

$Out = awgn(in, snr, signalpower)$

We can see that the signal is not smooth as the previous one in Fig 4.4. Increasing the value of SNR (signal to noise ratio) results small value of BER (Bit to Error Ratio) which leads to less error bit In this example we set:

$Snr = 5$

$Signalpower = 'measured'$.

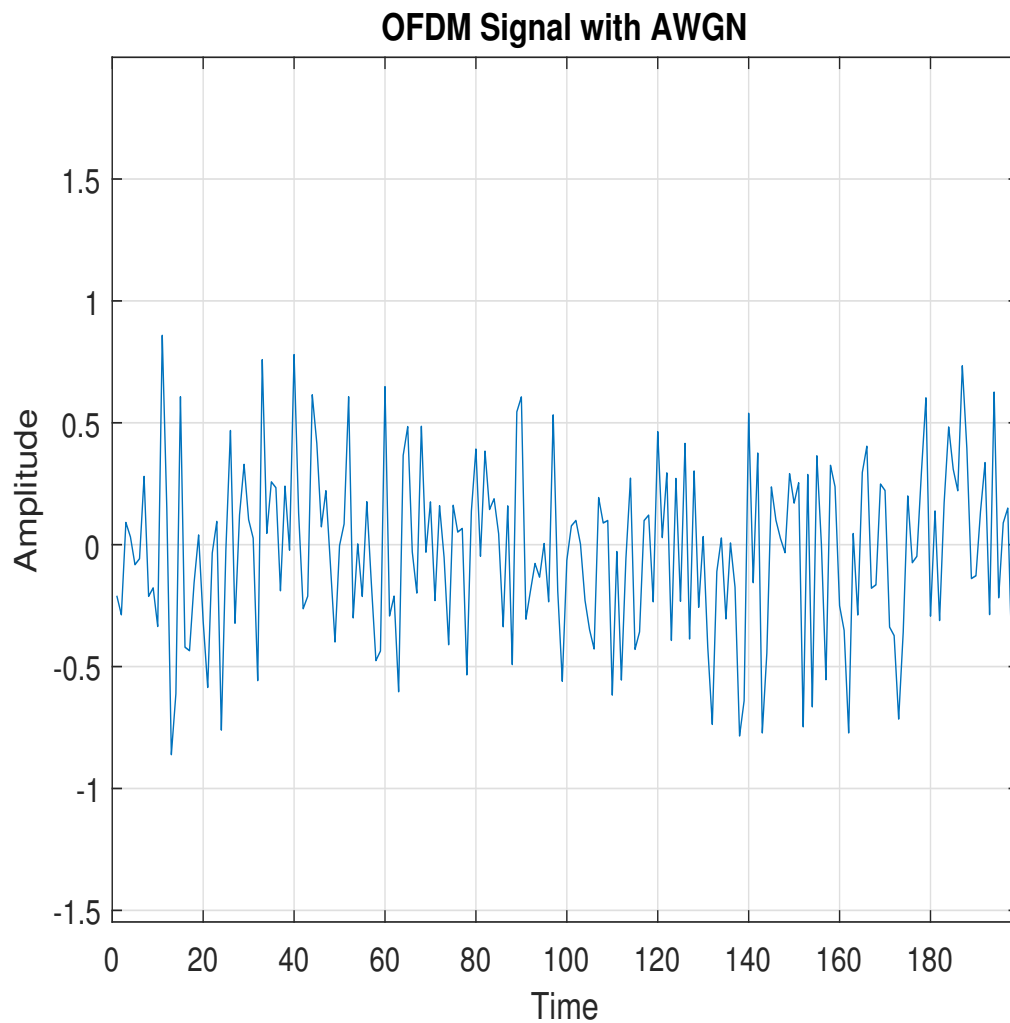


Figure 4.5: OFDM signal recieved at receiver

parallel to Serial / FFT / Serial to parallel:

Convert the received signal from serial form to parallel then pass it through FFT to detect the subcarriers and extract the modulated data, next convert the data into serial form. After displaying the constellation map , we can see a lot of disturbance around the point of interest -1 ,1 this due to the existence of AWGN noise.

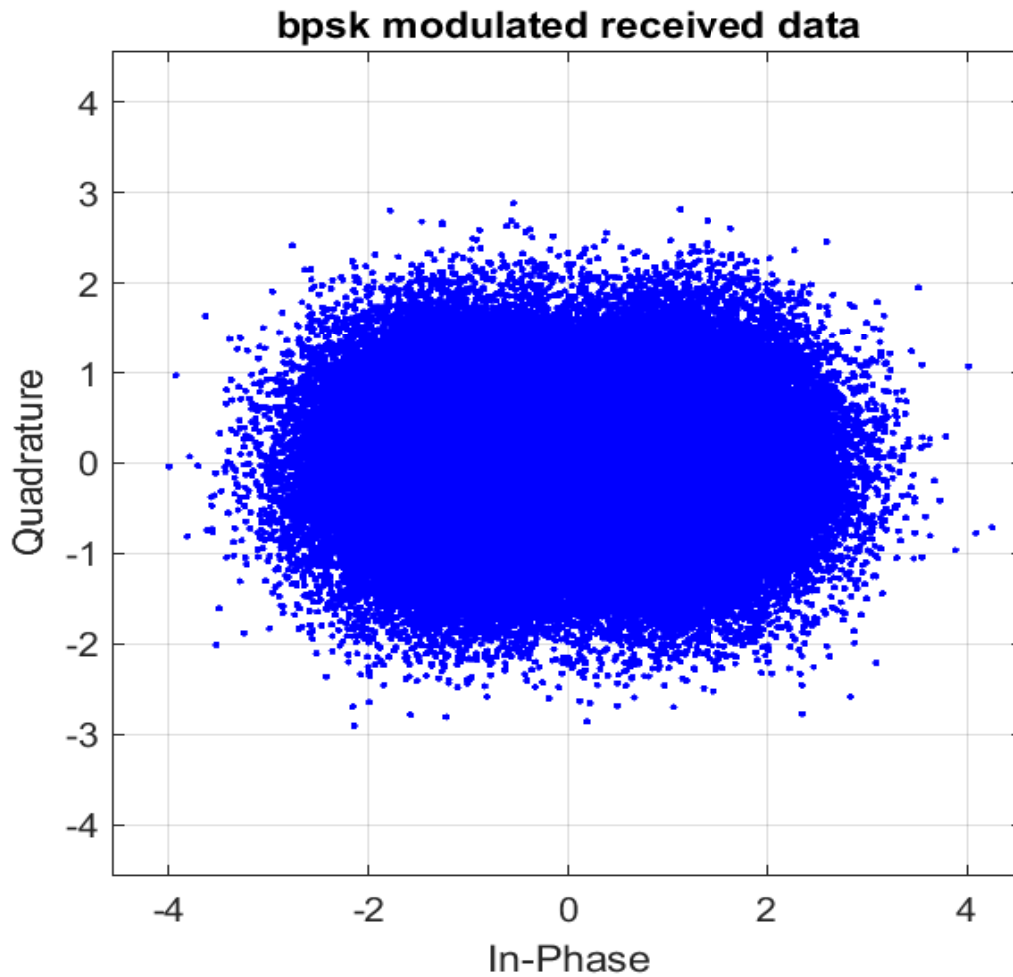


Figure 4.6: Constellation map of received data

Received Data:

After demodulating the received signal using BPSK demodulator we obtain the stream shown in Fig 4.7. We can remark that the first 35 bit are not the same as the transmitted data (existence of some errors bit). To calculate the number of error bits we use the function:

```
numerrs = biterr(data,demoData)
numerrs= 742 Fig 4.8
```

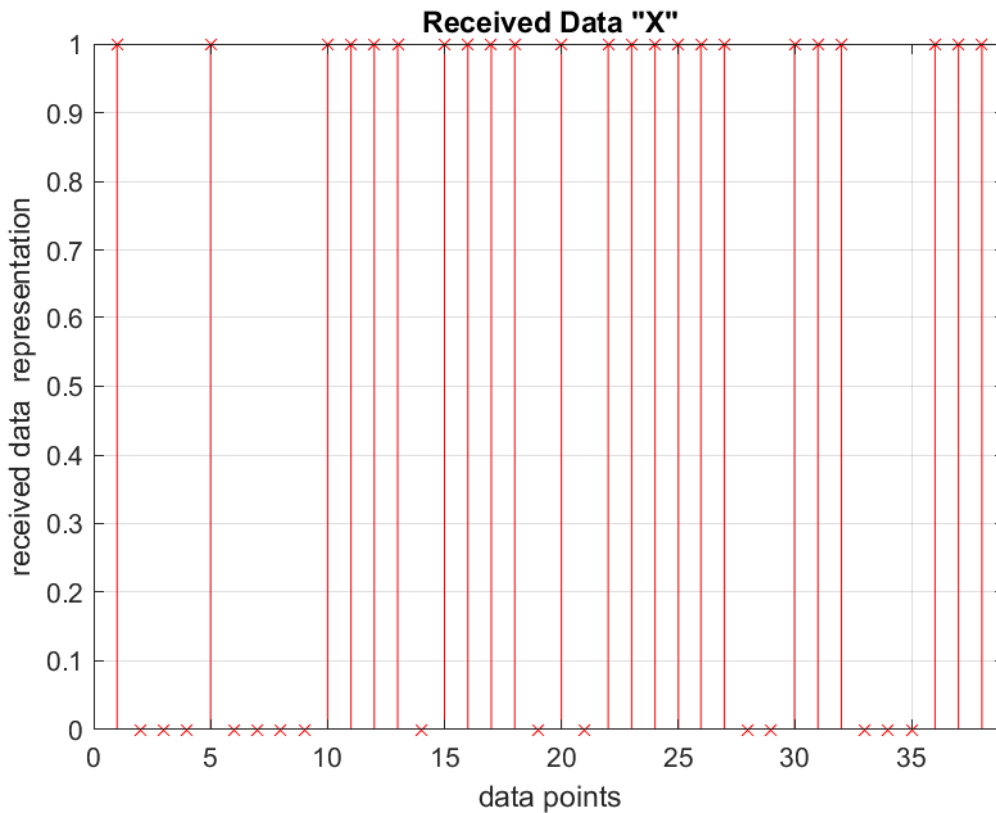


Figure 4.7: First 35 points of received data

```
0 |
1 | - numerrs = biterr(data,demoData)
-----
mmmand Window

numerrs =
    742
```

Figure 4.8: Number of errors in received data

After that we run the matlab code again, we set the number of subchannels to $N=\{2,4,8,16,32,64,128,256\}$ first we fix N to one of those values and we vary the value of $\text{SNR}=\{0,1,2,3,4,5,6,7,8\}$, we can record the values of bit errors

for $N=2$

snr	0	1	2	3	4	5	6	7	8
number of bit errors	10228	7319	4749	2891	1615	783	319	100	32

For $N=4$

snr	0	1	2	3	4	5	6	7	8
number of bit errors	10208	7223	4829	2920	1614	772	332	94	32

For $N=8$

snr	0	1	2	3	4	5	6	7	8
number of bit errors	10085	7175	4859	3015	1580	743	316	85	24

For $N=16$

snr	0	1	2	3	4	5	6	7	8
number of bit errors	10075	7107	4807	2877	1630	750	310	89	23

For $N=32$

snr	0	1	2	3	4	5	6	7	8
number of bit errors	10044	7086	4818	2922	1553	737	295	84	21

For $N=64$

snr	0	1	2	3	4	5	6	7	8
number of bit errors	10015	7021	4665	2917	1549	706	279	82	19

For $N=128$

snr	0	1	2	3	4	5	6	7	8
number of bit errors	10037	7046	4824	2851	1600	805	287	98	22

For $N=256$

snr	0	1	2	3	4	5	6	7	8
number of bit errors	10035	7038	4754	2910	1612	793	301	96	23

Now we can determine the value of Bit Error ratio using the following formula

$$BER = \frac{\text{number of error}}{\text{total number of data point}} \times 100 \quad (4.1)$$

and summarize it in the following table:

SNR values \ N	2	4	8	16	32	64	128	256
0	7.99	7.957	7.879	7.871	7.847	7.824	7.841	7.84
1	5.718	5.643	5.6	5.552	5.536	5.485	5.51	5.49
2	3.71	3.772	3.796	3.755	3.764	3.644	3.77	3.714
3	2.259	2.281	2.355	2.248	2.283	2.278	2.227	2.273
4	1.26	1.26	1.234	1.273	1.213	1.21	1.25	1.26
5	0.612	0.564	0.583	0.586	0.576	0.551	0.63	0.62
6	0.249	0.259	0.246	0.242	0.23	0.217	0.224	0.235
7	0.078	0.073	0.066	0.069	0.065	0.064	0.076	0.075
8	0.025	0.025	0.01875	0.0179	0.0164	0.0148	0.0171	0.0179

Using these values we can plot the graph of variation of BER versus SNR as shown in Fig 4.9.

We can see that:

- Increasing the value of SNR will decrease the number of bit Errors.
- Increasing the number of sub channels will also decrease the number of bit errors for the same value of SNR.
- All the graphs have the same shape decreasing.
- The system with 64 sub channels is the best one for PLC medium since it has low Bit Error Ratio compared to other system.

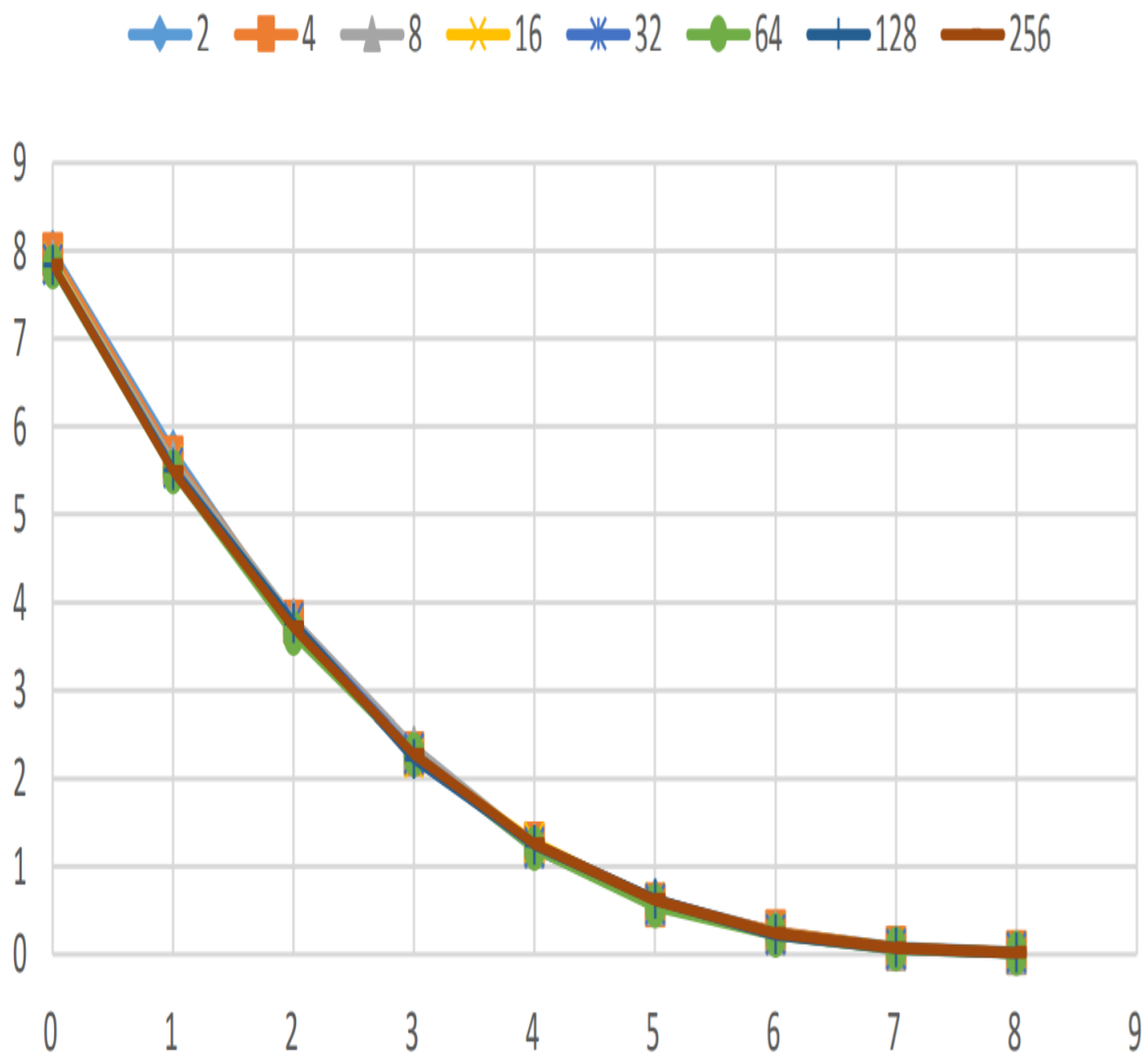


Figure 4.9: BER versus SNR

4.4 Circuit design

4.4.1 BPSK modulator

In psk system , a sinusoidal carrier wave of fixed amplitude A_c and fixed frequency of f_c is used to represent both symbols 1 and 0, except that the carrier phase for each symbol differs by 180° .

$$S(t) = \cos(2\pi f_c t) \text{ for symbol '1'}$$

$$S(t) = \cos(2\pi f_c t + \pi) \text{ for symbol '0'}$$

Using those equations we can design BPSK modulator using electronics device. The following circuit represents BPSK modulator.

We put a carrier signal as sinewave and message signal as pulse wave , we set the carrier as input to the collector of the transistors and the message to the base of the transistors. Transistors take two state on and off base on the input of the base. The transistor T1 operates as an “open switch:

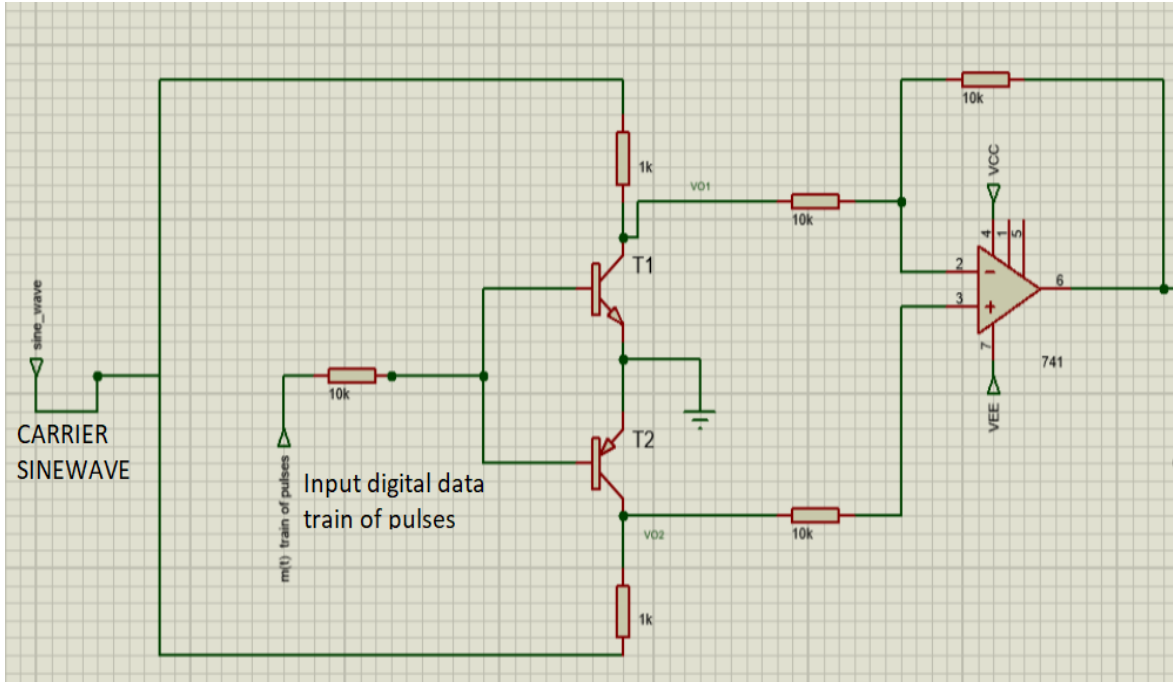


Figure 4.10: Circuit of the BPSK modulator

- The input and Base are grounded ($0v$).
- Base-Emitter voltage $V_{BE} < 0.7v$.
- Base-Emitter junction is reverse biased.
- Base-Collector junction is reverse biased.
- Transistor is “fully-OFF” (Cut-off region).
- No Collector current flows ($I_C = 0$)
- $V_{O1} = V_{CE} = V_{CC}$

For $V_{in} = 5v$

Here the transistor will be biased so that the maximum amount of base current is applied, resulting in maximum collector current resulting in the minimum collector emitter voltage drop which results in the depletion layer being as small as possible and maximum current flowing through the transistor. Therefore the transistor is switched “Fully-ON”.

- The input and Base are connected to V_{CC} .
- Base-Emitter voltage $V_{BE} > 0.7v$.
- Base-Emitter junction is forward biased.
- Base-Collector junction is forward biased.

- Transistor is “fully-ON” (saturation region).
- Max Collector current flows ($I_C = \frac{V_{cc}}{R_L}$).
- $V_{CE} = 0$ (*ideal saturation*).
- $V_{O1} = V_{CE} = 0$.
- Transistor operates as a “closed switch”.

For the second transistor T2 the operation Will be reversed

$V_{in} = 5v$ results $V_{O2} = V_{CE} = "V_{CC}"$.

$V_{in} = 0v$ results $V_{O2} = V_{CE} = "0"$.

For the op amp par that is used as subtractor

$$V_{out} = K(V_{O2} - V_{O1})$$

We can summarize the results as follow

$$V_{in} = 5 \Leftrightarrow V_{O2} = V_{c(Carrier)}, V_{O1} = 0$$

And

$$V_{out} = -V_{C(Carrier)} = -\cos(2\pi f_c t)$$

For:

$$V_{in} = 5 \Leftrightarrow V_{O2} = 0, V_{O1} = V_{c(Carrier)}$$

And

$$V_{out} = -V_{c(Carrier)} = -\cos(2\pi f_c t) = \cos(2\pi f_c t + \pi)$$

4.4.2 Serial into parallel

A serial-in, parallel-out shift register is similar to the serial-in, serial-out shift register in that it shifts data into internal storage elements and shifts data out at the serial-out, data-out, pin. It is different in that it makes all the internal stages available as outputs. Therefore, a serial-in, parallel-out shift register converts data from serial format to parallel format. So we use serial into parallel shift register 74LS164

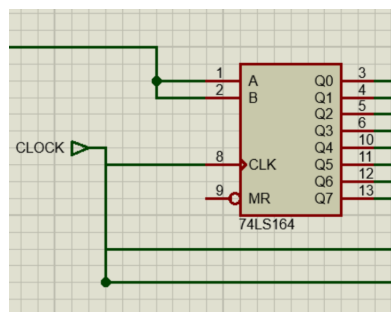
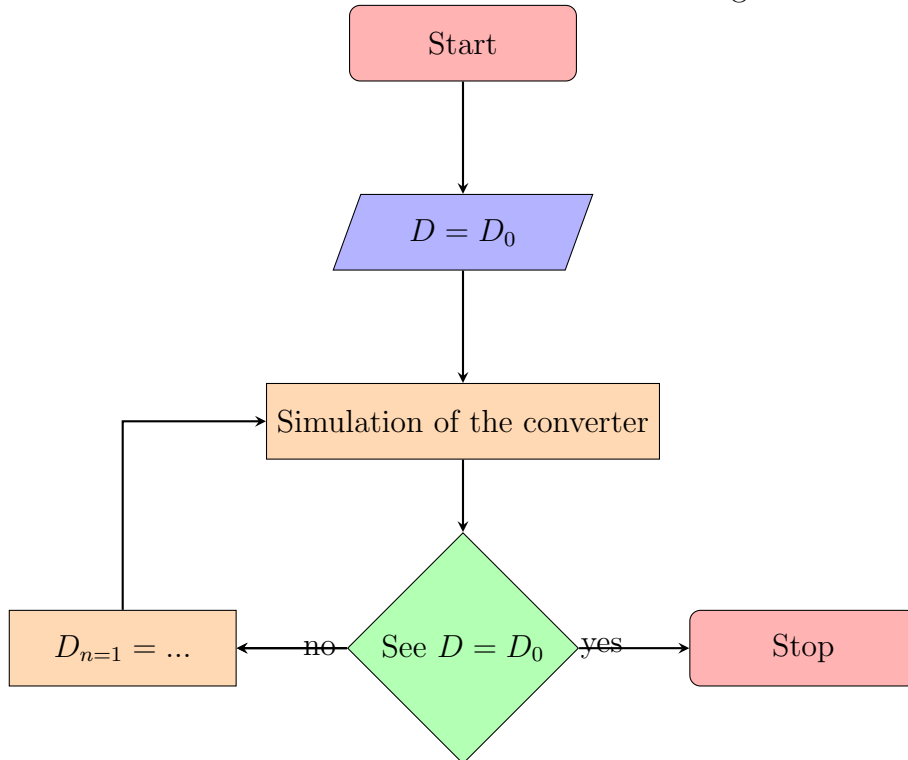


Figure 4.11: SIPO IC

the function of SIPO can summarized in the following flowchart



4.4.3 IFFT

Using Digital signal processing (processor TMS320F28027F) and c programming language we implement the IFFT process.

4.4.4 Parallel to serial

Digital parallel and serial converters adapt data transmitted in a parallel port to a serial communication format using 74165. The input vector converted into serial data.

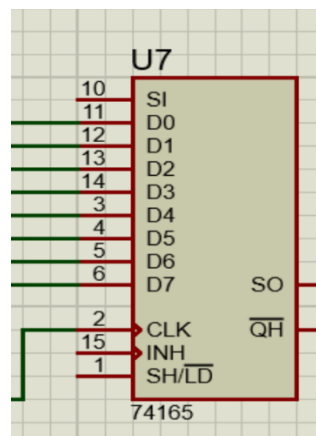


Figure 4.12: Parallel to serial IC

4.4.5 Digital to analogue converter

To put the data into the powerline we should make the serial digital data as analog sequence and feed it to coupler circuit .We use the following DAC:

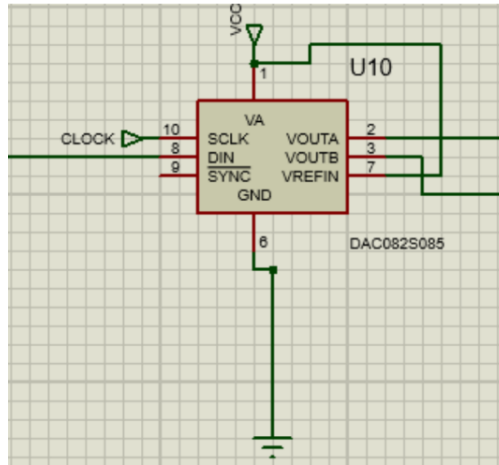


Figure 4.13: DAC IC

4.4.6 Coupler circuit

The coupler is the heart of the PLC system. The low voltage coupler shown in Fig 4.14 is suitable for userend distribution network (220 V - 440 V). on the 11 KV distribution network. The same coupler circuit is used for both transmitting and receiving data. For transmitting data live-neutral is connected to power line and data input side is connected to low voltage data source. Similar connection is followed for receiving data. For transmitting data through coupler circuit, data flows from data input side to live-neutral and data flows in reverse direction for receiving data.

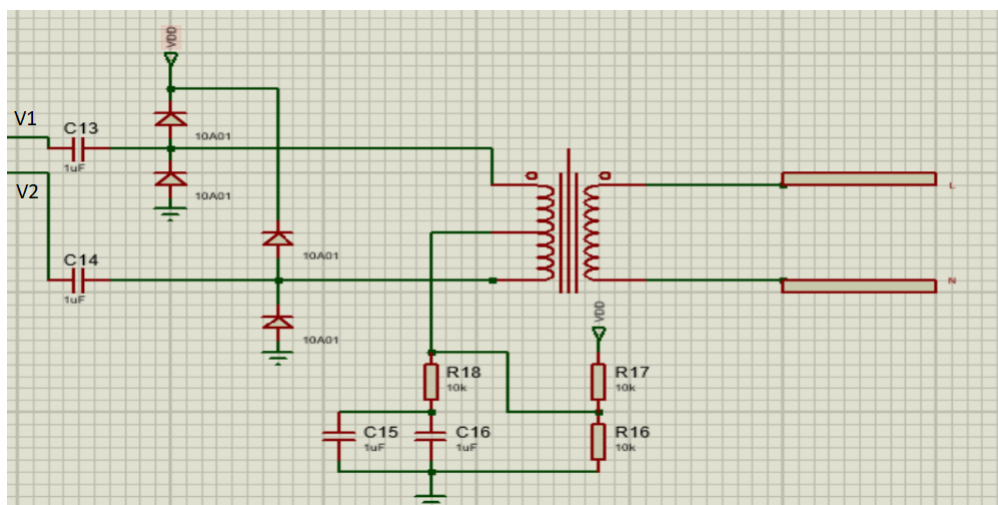


Figure 4.14: Coupling circuit

Transformer coupling circuits are extensively used in power line communication system because transformers provide galvanic isolation from power line and act as limiter when saturated by high voltage transient. The transformer with turn's ratio 20:1 is made of ferrite core because ferrite core introduces fewer losses at higher frequency than other cores. The combination of series capacitors and parallel inductors forms a high pass filter with cutoff frequency 1 MHz. This filter blocks 50 Hz and other noise signals present in power line but allow passing the message signals of higher frequency (5 MHz - 10 MHz). In addition, parallel resonant circuits can be used here to improve overall bypass effect. Back to back zener diodes are used here to clamp the voltage transients at the secondary side of the transformer and limiting any high voltage that may creep into the data circuit. A resistor is connected in parallel with the capacitor to discharge the capacitor in order to minimize the hazard of high voltage peaks caused by the stored charge in capacitor. The metal oxide varistor (MOV) protects the circuit from any incoming surge from the power line; basically the metal oxide varistor provides protection against very large transients on the power line.

4.4.7 The line trap

The line trap used here is actually multiple-T-filter configuration, which is made up of coils and capacitors. It is connected in series with the power line and presents high impedance to the carrier band of 1 MHz to 15 MHz. The T-filter configuration is chosen because of its advantage of working well in low impedance line. However, for a multiple filter such as double-T-filter, it will have a resonant rise lower in frequency than the trouble frequency. A RC- shunt is used to overcome this problem. A double-T-filter consists of two T- filter stages connected in series and symmetrical way. Typical design of such a trap circuit is shown in Figure 4.15. The output will be converted to digital using ADC and then entered to serial to parallel then to DSP.

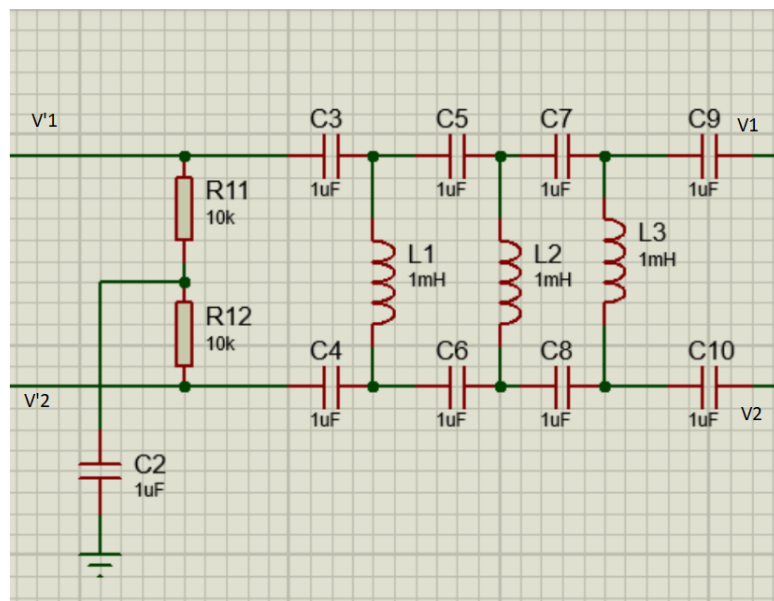
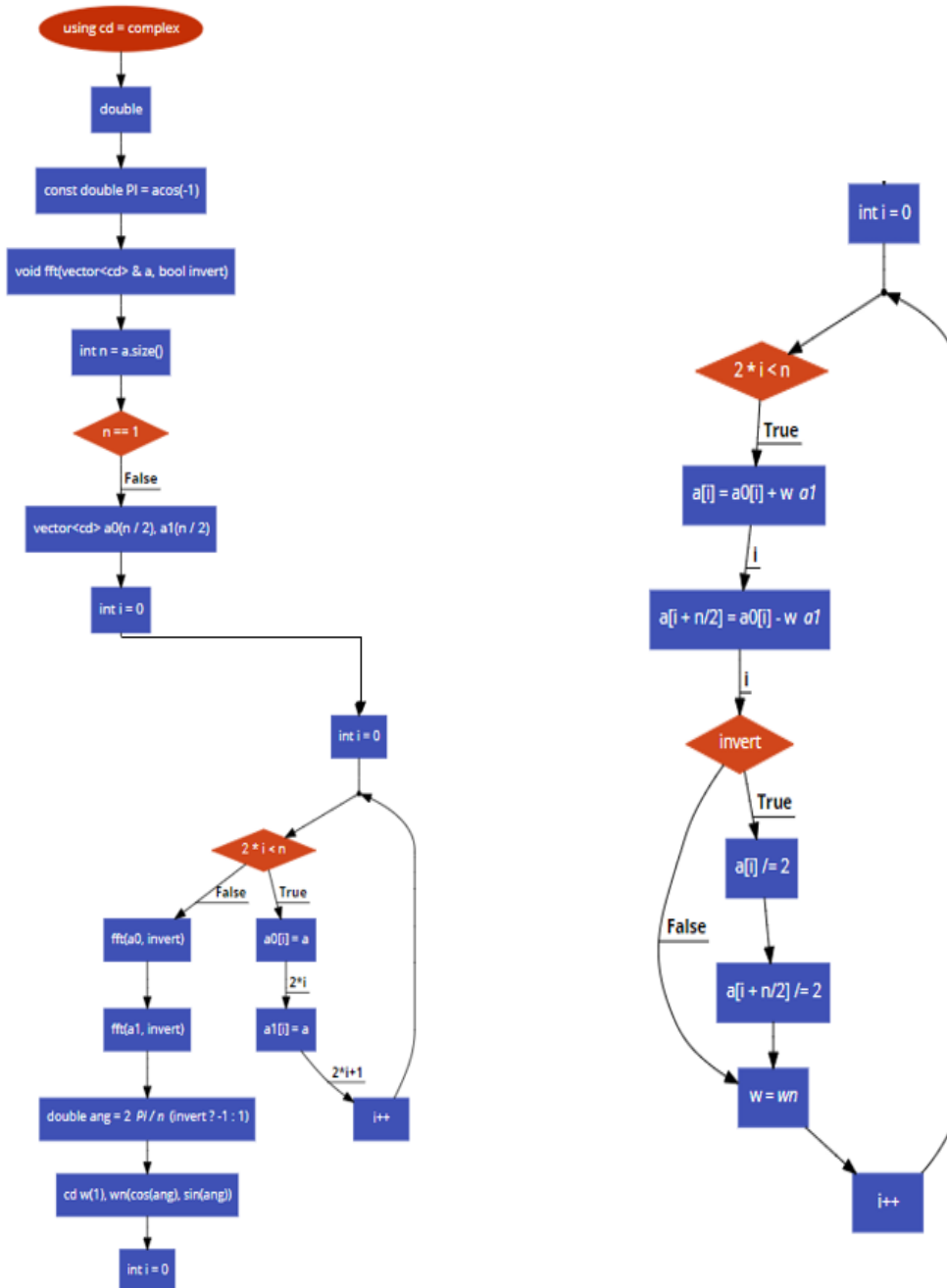


Figure 4.15: The trap circuit

4.4.8 Digital signal processing

Using digital signal processing (processor) and program it with C language and run on it th FFT algorithm we can recover the transmitted, modulated data and we feed it to parallel into serial converter. Using the following algorithm:



4.4.9 BPSK demodulator

the output of the DSP will be converted into serial using Parallel to serial converter and demodulate them using BPSK demodulator. The input signal to the bpsk modulator will be subtracted from the carrier if the $V_{carrier} = V_{psk}$ then the output will be zero

if else the output will be $2V_{psk}$ at the second op amp the result will be compared to V_{ref} so for $V_{carrier} = V_{psk}$ the output will be V_{CC} and for $V_{carrier} + V_{psk} = 2V_{psk}$ the output will be 0 v so we can recover our sequence of data.

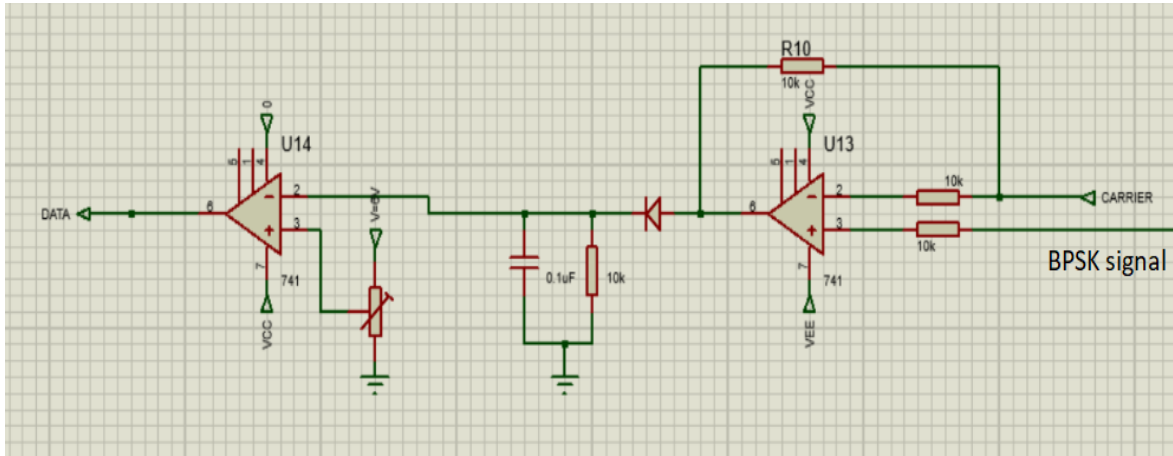


Figure 4.16: BPSK demodulator

4.5 Implementation

Here throughout this section we will focus on In Home PLC (indoor) network, which use internal electrical infrastructure as transmission medium. It makes possible the realization of PLC local networks within houses, which connect some typical devices existing in private homes telephones, computers and printers.

First step to realize the plc in home is the implimentation of PLM using MAX2982 and MAX2981. After that we will test the PLM functionality to control PV (Photovoltaic) system using Arduino and Servo-Motor.

4.5.1 Powerline Modem

One way to design high speed powerline modems is to use components provided by Maxim integrated company which manufactures ICs for typical industrial Broadband powerline modem as shown in Fig4.17 .

MAX2982 Typical circuit

The MAX2982 powerline transceiver utilizes state-of-the-art CMOS design techniques to deliver the highest level of performance, flexibility and operational temperature range at reduced cost. This highly integrated design combines the media access control (MAC) and the physical (PHY) layers in a single device. The MAX2982 digital baseband and its companion device, the MAX2981 analog front-end (AFE) with integrated line driver, offer a complete highspeed powerline communication solution fully compliant with HomePlug 1.0 Powerline Alliance Specification.

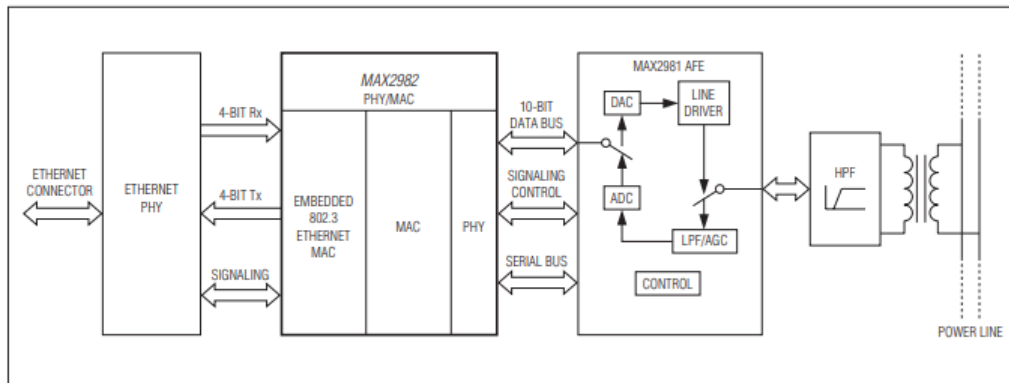


Figure 4.17: Typical Application Circuit

The MAX2982 offers reliable broadband communication for industrial environments. The PHY layer comprises an 84-carrier OFDM modulation engine and forward error correcting (FEC) blocks. The OFDM engine can modulate the signals in one of four modes of operation: DBPSK, DQPSK (1/2 rate FEC), DQPSK (3/4 rate FEC), and ROBO. The MAX2982 offers -1dB SNR performance in ROBO mode, a robust mode of operation, to maintain communication over harsh industrial line conditions. Additionally, advanced narrow-band interference rejection circuitry provides immunity from jammer signals [26].

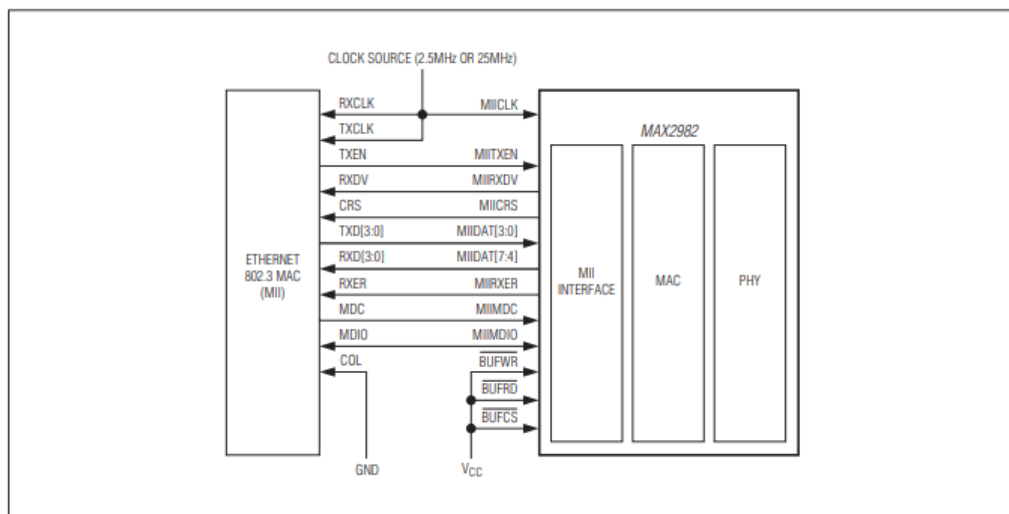


Figure 4.18: Ethernet MAC and MAX2982 Connection

MAX2981 Typical circuit

The MAX2981 powerline communication analog front-end (AFE) and line-driver IC is a state-of-the-art CMOS device that delivers high performance at low cost. This highly integrated design combines an analog-to-digital converter (ADC), digital-to-analog converter (DAC), adaptive gain control (AGC), filters, and line driver on a single chip. The MAX2981 substantially reduces previously required system components and complies with the HomePlug standard.

Combined with Maxim's integrated PHY/MAC digital baseband, the device delivers the most flexible and cost-effective solution. The advanced design of the MAX2981 allows operation without external control, enabling simplified connection to a variety of HomePlug 1.0 digital PHY ICs [27].

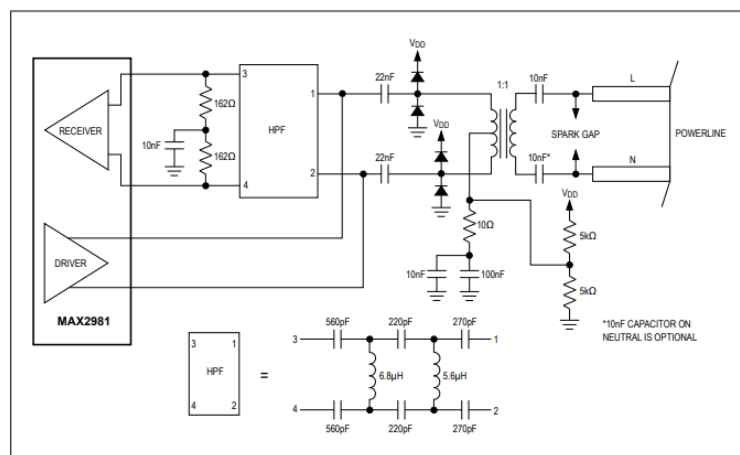


Figure 4.19: Typical Analog Front-End Operation Circuit

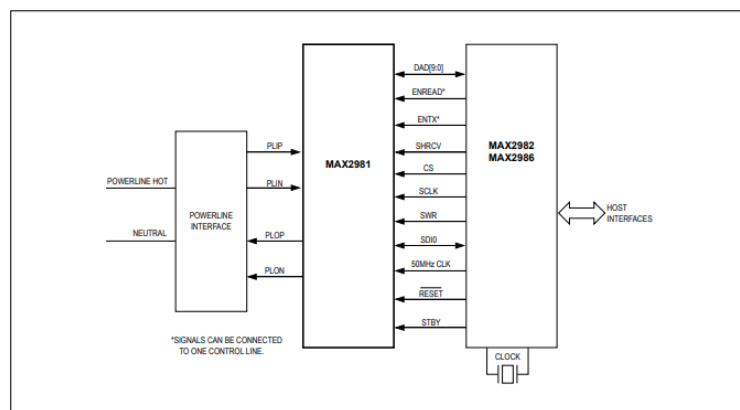


Figure 4.20: Interfacing the MAX2981 to the MAX2982

4.5.2 Control circuit

For this part we need :

1. Arduino board.

2. Servo-motor.
3. Small solar panel with rotation axis.
4. Jumpers.
5. Ethernet cables with Rj45 connectors (crossover cable).
6. Two powerline modems.
7. IDE arduino software.
8. Computer.

Ethernet Shield comes with different pins, provided for connections. We place this shield on Arduino board properly and connect the Ethernet Port with one PLM using Ethernet cable with Rj-45 connector then the PLM with power socket.

On the other side we connect the computer with the other PLM which is connected to other socket in building. Now we can access the arduino via Ethernet shield also we can perform different type of access method (ssh, telnet). We access the arduino using UDPSendRecieveString from the library of IDE arduino. We add the program of Servo-motor from library of IDE arduino. We connect the servo which is connected to the axis of rotation in solar panel, with *arduino + shield* then we can send instruction to rotate the servo and receive information about the current situation.

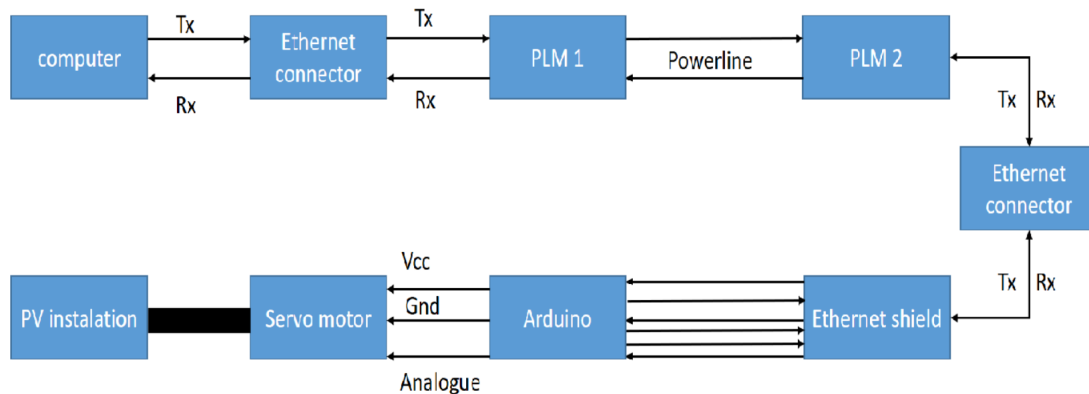
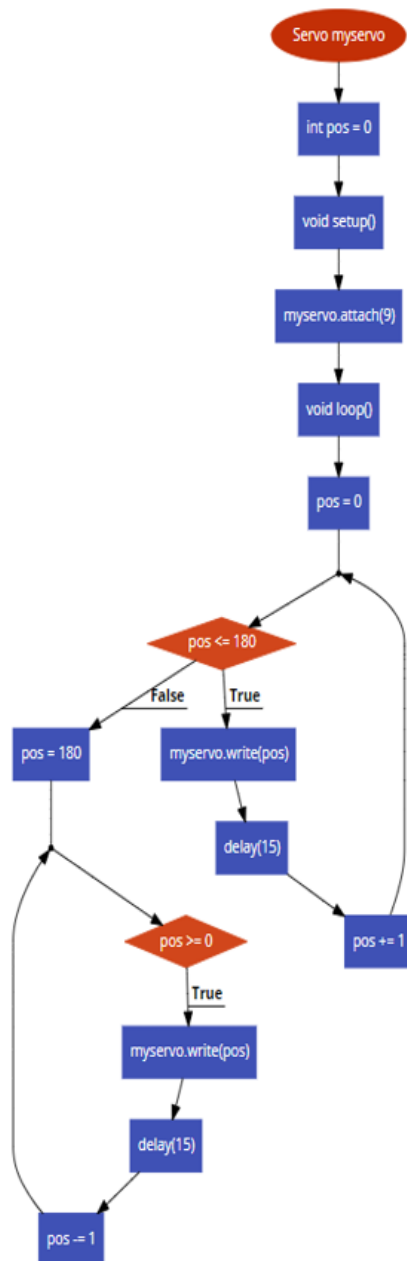


Figure 4.21: Testing system diagram

Once we finish the connection of devices and our computer establishes connection with the shield we use IDE arduino to programme the controller based on the following flowchart:



- Create servo object to control a servo.
- Variable to store the servo position.
- Attaches the servo on pin 9 to the servo object.
- Goes from 0 degrees to 180 degrees.
- Tell servo to go to position in variable 'pos', waits 15ms for the servo to reach the position.
- Goes from 180 degrees to 0 degrees.
- Tell servo to go to position in variable 'pos', waits 15ms for the servo to reach the position.

Chapter 5

Conclusion and future work

5.1 Conclusion:

- This project of broad band over power lines was successfully designed but was not implemented; also the project objectives introduced in chapter one were achieved except the implementation part.
- We expect this project will cost less because of the low price of equipments (MAX-ICs no more than 500 DA for each IC) and there is no need to establish a new network since it already exists for electrical power distribution purposes.
- The results of simulation prove that the electrical network has the ability of data transmission and receiving in addition to the main distribution function.
- One of the benefits of the network through power line communication will be the ability to connect to the network just by plug in the PLM to one of the available sockets, so it will be easy to make a small network in a house or any building using this effective feature.
- Based on the concept of medium and high voltage, we can allow remote locations to access the Internet at low cost.

5.2 Future work

1. First step in this part will be the implementation of the PLM and testing as shown in chapter five.
2. Study the characteristics of the medium and high voltage power line and use it as a transmission medium for an intranet that will use a local hosting site; implement different applications on local servers, Example: Using the power line, we connect all hospitals to the hosting site. We configure applications that manage the input of doctors about their patients, each patient has a complete medical file that covers different medical check-up, surgery, different blood tests.... This will make it easy for another doctor to examine the patient. In addition, it will improve the security of the local networks.
3. Smart Grid application: PLC technology is an important enabler to the vision of Smart Grid, at all grid power levels. HV power line protective relay systems are being revisited applying PLC systems ready to cope with their strict and demanding requirements. Broadband and narrowband PLC solutions are being deployed in MV and LV grids, which are integral parts of smart grid applications reaching to customers and meters. Smart metering is without doubt the current main focus for smart grid implementation and the application of PLC. Although broadband PLC systems are attractive for smart meter access, their application has mainly been demonstrated at large scale at the MV level, as a telecommunications backbone solution to transport the smart metering data collected at SSs. At the same time, from the SSs to the meters (LV grid) several HDR NB PLC technologies have emerged and been standardized, and some of them have been deployed in the field at a massive (millions of units) scale.

Appendix

Matlab code:

I. Setting Parameters:

```
% A: Setting Parameters

snr=5;
block_size=8;           % size of each ofdm block
cp_len = ceil(0.1*block_size); %length of cyclic
    prefix

no_of_ifft_points=block_size; % 8 points for the FFT/
    IFFT
no_of_fft_points=block_size;
```

II. Transmitter function:

```
% B: The Transmitter

% define BPSK modulator and demodulator

bpskModulator = comm.BPSKModulator;

bpskDemodulator = comm.BPSKDemodulator;

% generate binary random data

data = randi([0 1],128000,1);

% plot the data
figure(1)
stem(data)
grid on;xlabel('data points');ylabel('Transmitted data
    representation');title('Transmitted Data "X"')

% perform the BPSK modulation
```

```

modData = bpskModulator(data);

% plot the constellation map of modulated data

scatterplot(modData)

% plot the modulated data sequence
Tx=real(modData);
figure(3);stem(Tx)

% 3. Do IFFT on each block
% Make the serial stream a matrix where each column
represents a pre-OFDM
% block (w/o cyclic prefixing)
% First: Find out the number of columns that will exist
after reshaping

num_cols=length(modData)/block_size;
data_matrix = reshape(modData, block_size , num_cols);

% Second: Create empty matrix to put the IFFT'd data

cp_start = block_size-cp_len;
cp_end = block_size;

% Third: Operate columnwise & do CP

for i=1:num_cols,
    ifft_data_matrix(:,i) = ifft((data_matrix(:,i)),
        no_of_ifft_points);
    % Compute and append Cyclic Prefix
    for j=1:cp_len,
        actual_cp(j,i) = ifft_data_matrix(j+cp_start,i);
    end
    % Append the CP to the existing block to create the
    actual OFDM block
    ifft_data(:,i) = vertcat(actual_cp(:,i),
        ifft_data_matrix(:,i));
end

% 4. Convert to serial stream for transmission

```

```

[rows_ifft_data cols_ifft_data]=size(ifft_data);
len_ofdm_data = rows_ifft_data*cols_ifft_data;

% Actual OFDM signal to be transmitted

ofdm_signal = reshape(ifft_data, 1, len_ofdm_data);
figure(5)
plot(real(ofdm_signal)); xlabel('Time'); ylabel('Amplitude'
);
title('OFDM Signal');grid on;

```

III. Awgn channel

```

y = awgn(ofdm_signal,snr,'measured');
figure(6)
plot(real(y))

recvd_signal = y; ;xlabel('Time'); ylabel('Amplitude');
title('OFDM Signal with AWGN');grid on;

```

IV. Receiver function

```

% D: The Receiver

% Convert Data back to "parallel" form to perform FFT

recvd_signal_matrix = reshape(recvd_signal,rows_ifft_data,
cols_ifft_data);

% Remove CP

recvd_signal_matrix(1:cp_len,:)=[];

% Perform FFT

for i=1:cols_ifft_data,

% FFT

fft_data_matrix(:,i) = fft(recvd_signal_matrix(:,i),
no_of_fft_points);

```

```

end

%      Convert to serial stream

recvd_serial_data = reshape(fft_data_matrix, 1,(block_size*
    num_cols));

%disp(recvd_serial_data)

%      Demodulate the data using BPSK demodulator

R=recvd_serial_data.';

%      plot the constellation map of the demomodulated data

scatterplot(R);title('bpsk modulated received data')

demoData = bpskDemodulator(R);

% plot the constellation map before we demodulate data (the
    output of the fft)

scatterplot(R);title('bpsk modulated received data')

% plot the data

figure(7)

stem(demoData, 'rx');

grid on;xlabel('data points');ylabel('received data
    representation');title('Received Data "X"')

```

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