ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY
SCHOOL OF ELECTRICAL ENGINEERING AND COMPUTING
DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

BROADBAND OVER POWER LINE (BPL)
AN ALTERNATIVE TECHNOLOGY FOR ETHIOPIA BROADBAND SERVICES

By

Daniel Asmelash

A thesis submitted to the department of electrical and computer engineering of Adama science and technology University in partial fulfillment of the Degree of Masters of Science in Communication Systems engineering

Advisor:
Dr. Sultan Feisso

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Declaration

I, the undersigned, declare that this MSc thesis is my original work, has not been presented for fulfillment of a degree in this or any other university, and all sources and materials used for the thesis have been acknowledged.

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This thesis work has been submitted for examination with my approval as a university Advisor.

Dr. Sultan Feisso ___________________

Advisor's Name Signature

Abstract

In Ethiopia 15.4 % [1] of total population have access to internet including mobile internet users.to increase internet users in Ethiopia broadband over Power Line (BPL) is an additional 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.

This thesis provides a comprehensive understanding about BPL with its implementation prospects in Ethiopia. In this context, the existing power grid infrastructures are discussed elaborately. BPL system functionality with its components and its benefits over other access technologies is also pointed out. Implementation scenarios for various deployment options are illustrated, and market survey are conducted to highlight the major vendors and products available in BPL networking area.

This thesis presents recent developments on PLC channel modelling and its transfer function. For data communication over any medium, it is necessary to determine the characteristics of the communication channel. In this thesis, the power line is approximated as a transmission line and the transfer function is derived based on the lumped-element circuit model, using scattering matrix method. The model is capable of determining the line characteristics under different network topologies. The approach allows not only taking into account the cable characteristics, but also the number and length of the branches.

This thesis is also analyzed problems related to electromagnetic compatibility of broadband power line communications. The study comprised theoretical analysis to do so PLC networks were modeled and simulated with Matlab/Simulink and Numerical Electromagnetics Code (4NEC2).

Based on the simulated results the feasibility of BPL deployments in Ethiopia has been also comparatively analyzed between several broadband accesses technologies. BPL is now a growing communication network technology which is quite fast hitting the competitive market of broad band internet services in international telecom environment. The simulated results shows with the help of some more researches and upgrading distribution line, BPL may also be an effective viable additional choice for providing broadband in Ethiopia.

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First of all, I would like to thank the Almighty **God** for His provision of Grace to overcome trials and temptation to complete the entire work.

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LIST OF ABBREVIATIONS

BPL	Broadband over power line
VoIP	Voice over Internet protocol
MV	Medium Voltage
LV	Low Voltage
AC	Alternating currently
DSL	Digital Subscriber Line
FSK	Frequency shifting key
CDMA	Code division multiple access
OFDM	Orthogonal Frequency Division Multiplexing
EMI	Electromagnetic interference
RFI	Radio frequency interference
MTL	Multi-conductor transmission line
TL	transmission line
EHV	Extra High Voltage
HV	High voltage
BPLC	Broadband over power line communications
NGN	Next Generation Networks
ACSR	Aluminum Conductor Steel Reinforced
BPL	Broadband over Power line
CFS	Carrier Frequency System
CPE	Customer Premises Equipment
CVT	Coupling Capacitor
EFIE	Electric-Field Integral Equation
EMC	Electromagnetic Compatibility

CHAPTER ONE

INTRODUCTION

1.1 Background

According to latest available data the world internet usage and Population statistics, only 31.2% of people in Africa use the internet in comparison to the 88.1%, 80.2% and 69.6% in North America, Australia and Europe, respectively [1]. In Ethiopia 15.4% use internet in 2017 [1] with penetration rate 4.7% 2017 [1]. However 30.56% of total population has power line in Ethiopia according to World Bank data 2017 [3].This statistics further show that the world internet resource usage in Africa, Europe and North America are 3.0%, 28.6% and 21.2%, respectively, despite the 16.6%, 10.9% and 4.8% world population in these three regions, respectively. In 42 of the 55 African countries where the latest statistics were conducted 10% or less persons have internet, and in 28 of these 42 countries only one person or less among 500 have the Internet [1]. These statistics verify the deliberation that countries categorized as least-developing are also those where the internet and other broadband penetrations are the lowest. Therefore, there is a good cause to look for all sorts of available resources to increase the percentage of internet penetration in developing countries.

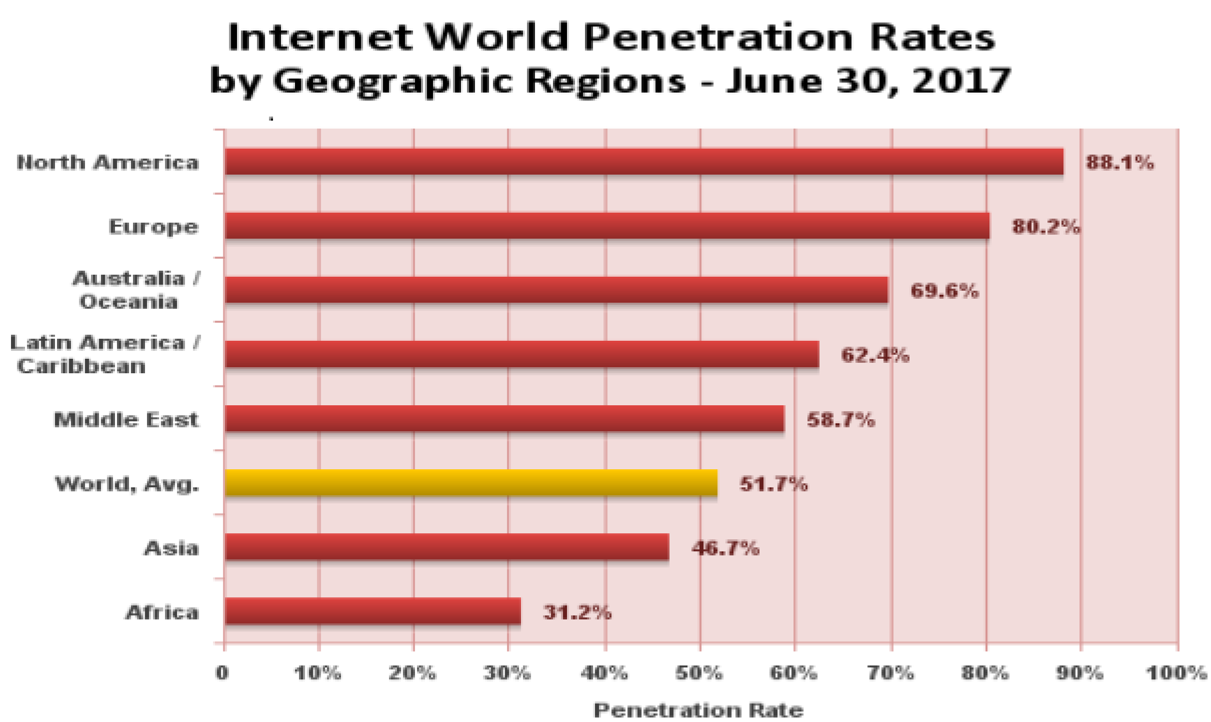

Figure 1.1: internet world penetration rate [1]

Table 1   world internet usage and population statistics [1]

World Regions	Population (2017 Est.)	Population % of World	Internet Users 30 June 2017	Penetration Rate(% Pop)	Growth 2000-2017	Internet Users %
Africa	1,246,504,865	16.6	388,376,491	31.2	8,503.1 %	10.0
Asia	4,148,177,672	55.2	1,938,075,631	46.7	1,595.5 %	49.7
Europe	822,710,362	10.9	659,634,487	80.2	527.6%	17.0
Latin America/Caribbean	647,604,645	8.6	404,269,163	62.4	2,137.4 %	10.4
Middle East	250,327,574	3.3	146,972,123	58.7	4,374.3 %	3.8
North America	363,224,006	4.8	320,059,368	88.1	196.1%	8.2
Oceania/Australia	40,479,846	0.5	28,180,356	69.6	269.8%	0.7
World Total	7,519,028,970	100	3,885,567,619	51.7	976.4%	100

Many Ethiopian urban, sub-urban and rural residents and entrepreneurs don't have access to Wireless, wired or other broadband communication medium. It is because of absence of well installed infrastructures and expensive cost of services. But most urban, sub-urban and now a days some rural area users in Ethiopia have the power lines. 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.

1.2 Broadband over power line (BPL)

Broadband over Powerline (BPL), also called Powerline Communication (PLC) is the technology of transmitting high frequency communication signals (voice, data, Video) on an existing electric supply network in addition to the 50/60Hz electric supply for which the network was primarily intended. Due to the higher penetration of electric network in any country, compared to the telecom penetration, utilizing the electric supply network as an alternative infrastructure to the provision of broadband services would exponentially increase the overall telecom penetration of any country.

BPLC deployments in different regions of the world show that BPLC is an easily deployable and cost effective broadband service for sub-urban and isolated rural communities, where major telecom infrastructure is not available. Even if the utilization of electric network as a narrow band information medium dates back to the beginning of the last century, the service was for long years limited within the utility company for controlling of substations, voice communications, and protection of high-voltage transmission lines. However, since BPLC has evolved to an alternative broadband infrastructure for IT service providers the advantage for the electricity utility companies in controlling and monitoring their electric grid is also improving.

1.3 Statement of the problem

Many Ethiopian urban, sub-urban and rural residents and entrepreneurs don't have access to Wireless, cable or other broadband communication medium. Only 15.4% [1] of total population users has internet access. It is because lack of well installed infrastructures and expensive cost of services. But mostly, about 30.56% [3] of total population in urban, sub-urban and now a days some rural areas users in Ethiopia have the power lines.

This lack of infrastructure and very high expensive cost of service affects both the service provider and (i.e. Ethiotelecome) and most Ethiopian population specially those who are in medium and low economic status.

These problem occurred in all over Ethiopia but this thesis only focused on areas with already installed power line infrastructure and access (i.e. 30.56% of total population).To solve this problem BPL technology is desirable option for those residents who want to get broadband service. And BPL may be used as another cheaper technology for broadband services in Ethiopia without the need of complex and costly infrastructure.

Because of this both the service provider and end users are beneficiaries. This thesis study feasibility of BPL to be an additional alternating technology solutions to the broadband service in Ethiopia.

1.4 Motivation

The majority of people in Ethiopia stay in sub urban and rural areas where some of them have access to electricity; it is 30.56% [3] of total population and even in all Ethiopian towns but majority of them do not have access to the internet, only 15.4% of total population [1]. Deployment of dedicated optical fiber, mobile and wireless network communications is not economically feasible because the return on investment is low for service providers due to the low purchasing power of the populace which is mainly poor. Therefore, the PLC channel would be a more attractive technology in such a case since its convenient outlets (power sockets) serve as connection ports from each room in a home, office or factory for the services such as internet, video conference, Voice over IP, Video streaming, and E-commerce connectivity, etc. Additionally, the fact that this communication technology uses the existing power network renders it very cost effective.

1.5 Objective of the study

1.5.1 General objective

- To study feasibility of the broadband over power line (BPL) to be an additional alternative broadband technology for Ethiopia broad band service.
- Propose indoor BPL communication channel transfer function model and analyze to validate the proposed model, and to model and analyze low voltage distribution line as a BPL communication transmission line for broadband service communication in Ethiopia.

1.5.2 Specific objectives

- Comparative analysis of BPL and several broadband access technologies for Ethiopia broadband services.
- To investigate elaborately the existing Ethiopian power grid infrastructures and distribution power line electromagnetic radiation.
- Illustrate implementation scenarios for various BPL deployment options and to study Home networking and power line networking technologies for Ethiopia.
- To simulate indoor channel transfer proposed model on Matlab/Simulink to explore the effects of different network topology and property on power line channel transfer function.
- To simulate low voltage distribution model on 4nec2 to explore the effects of wire separation and types of feeding as a BPLC transmission line.

1.6 Scope of the study

This study limited to how BPL will be an additional alternative technology for Ethiopia broadband services, it is also of interest to study BPL feasibility over other broadband technologies in Ethiopia, to propose models of BPL communication and to carry out indoor part of the proposed model simulation. Broadband over power line (BPL) is a communication technology that still needs deep and detail study and also it needs well organized standards and regulations to implement it effectively. It is not possible to investigate all of the possible circumstances relevant to the broadband over power line communication in this work.

1.7 Significance of the study

This thesis serve as a general and technical reference on the broadband over power line communication systems, specially concerning in Ethiopia context. Basically this work aimed at making significant contributions to this topic on broadband services in Ethiopia by showing alternatives (i.e. BPL) and it gives details about its implementation. This thesis has significance for both the service provider and end users.

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.

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 millions of private customers as well as businesses. The power grid has the greatest availability of any other solution that exists today.

The equipment needed to set up BPL in home is cheaper on average than that of other broadband solutions such as DSL. 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 up-link and down-link speeds are similar. This is especially important for the up-link as the speed is higher than the DSL. For users in areas who cannot receive DSL services, BPL can provide an all-in-one service-telephone, cable television, and high-speed data.

1.8 Thesis Organization

This thesis organized into six chapters. The rest of the document is organized as follows:

Chapter two is theoretical background, theoretical aspects of power line communication in general and broadband power line communication in specific, and the general worldwide electrical transmission and distribution power line are discussed.

Chapter three is literature review, related works about BPL channel transfer function modeling methods and there gap are shown. Details about broadband power line communication parts, types, deployment option, speed, standards, advantages, disadvantages, comparison with other broadband technologies and equipment vendors are discussed. And Ethiopian electric transmission and distribution system discussed comprehensively.

Chapter four system model description and analysis, broadband power line communication indoor power line channel transfer function modeling and effects of different network topologies, wire spacing, wire length, number of branches, branch line length and number of branches at a single point on channel transfer function frequency and phase response modeled and analyzed in Matlab/Simulink. Low voltage distribution line modeled using 4nec2 and simulated effects of wire spacing and types of feeding on electromagnetic field radiation.
Chapter five results and discussion, the Matlab/Simulink and 4nec2 simulation results are discussed

Chapter six conclusion, based on the results found by simulation the total work carried on this thesis conclusion is discussed.

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CHAPTER TWO

FUNDAMENTALS OF BPL

2.1 The Electric Network Structure

The electricity supply network in most of the developing countries is similar to that of the European network structure. In general, the High Voltage (HV) network of 380 kV, 230 kV or 132 kV connect either generation substations with other HV power substations or it connects different HV substations to form national electric grid. The HV is stepped down to medium voltages (MV), generally between 6 kV and 30 kV, at HV/MV power substations. The MV feeders, underground or overhead, can extend up to more than 100 km length to feed more than 50 distribution transformers which further step down the MV to a low voltage (380/220 V). The low voltage (LV) feeders (2, 3 or more) outgoing from a single MV/LV transformer feeds electric power to 100 – 200 households on the average. This means, a single MV feeder supplies electric power to thousands of households and, theoretically speaking, a high frequency signal injected to this single MV feeder can have the potential of reaching these thousands of households. Despite the different limitations related to transmitting high frequency signals over the electric network, it is therefore possible and practically proved that the electric infrastructure is feasible, already-in-place, resource for the much sought broadband service, in some cases it is the only available resource for providing broadband services.

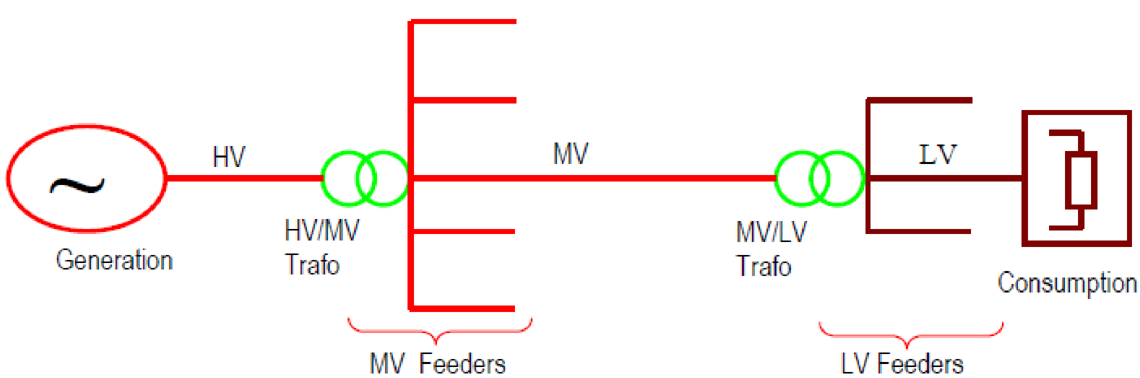


Figure 2.1 Electric Network structure

2.1.1 Ethiopian Electric Network

In Ethiopia, Ethiopian Electric Power, EEP generate electricity and it is distributed throughout the country via high voltage line at 161kV. EEP transmit power to Ethiopian electric utility, EEU via the 430kV high voltage power lines. EEU then distributes electricity to low power consumers such as households, companies, factories and etc. The power distribution system is made up of sub-transmission lines, power transformers, 33kV lines, 15kV lines, distribution transformers, LV Lines, etc. Distribution substations monitor and adjust circuits within the system. Currently Ethiopian Electric Power and Ethiopian Electric Utility power system have 400kV, 230kV, 132 kV primary transmission systems and 66kV, 45kV as sub transmission system and 33kV and 15kV as distribution system. At all the 66 or 45kV substations power transformers of various ratings like 25 /12 /6.3/3M VA are installed for step down of voltage to 15kV for feeding to distribution transformers. The outgoing feeders are connected in radial fashion. Mostly 33kV and 15kV overhead conductors are used for feeding 60 to 70 distribution transformers on each 33kV and 15kV feeder. The voltage is then further reduced by distribution transformers to the utilization voltages of 380 volts three-phase or 220 volts single-phase supply required by most users.

Substations are fenced yards with switches, transformers and other electrical equipment. Once the voltage has been lowered at the distribution substation, the electricity flows to industrial, commercial, and residential centers through the distribution system. Conductors called feeders reach out from the distribution substation to carry electricity to customers. At key locations along the distribution system, voltage is lowered by distribution transformers to the voltage needed by customers or end-users.

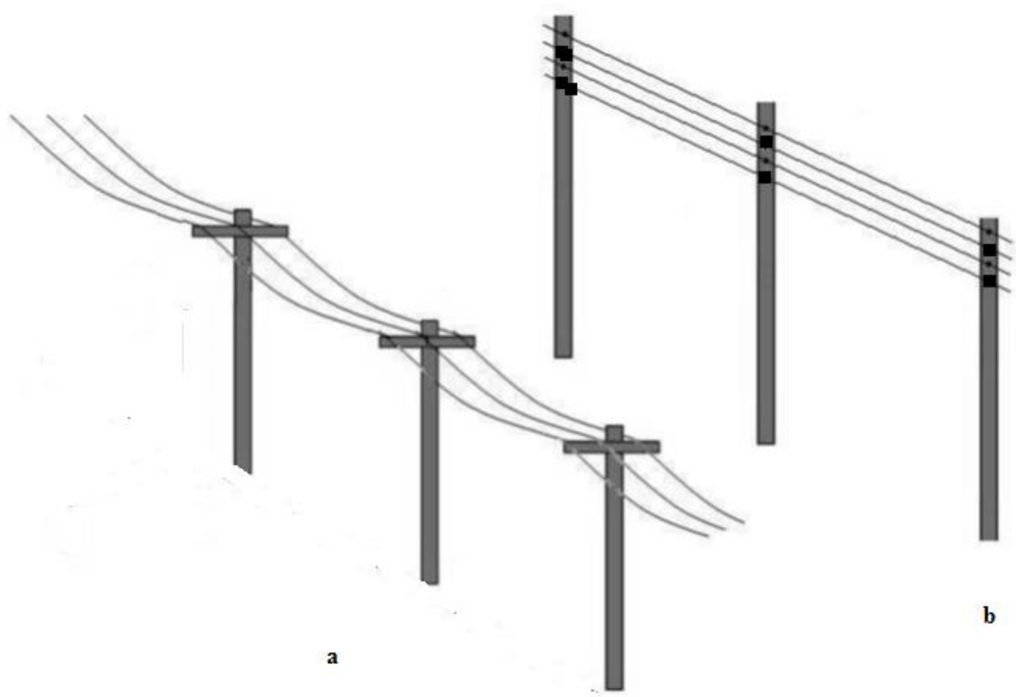


Figure 3.2 power line arrangement in Ethiopia [20]

(a) Horizontal arrangement of MV line   (b) Vertical arrangement of LV line

In Ethiopia, a typical arrangement of medium voltage, MV power line consist of three (R,S,T) horizontal parallel Aluminum Conductor Steel Reinforced (or ACSR) wires which are about 12mm in diameter and 10m above the ground and uses wood and concrete poles to mount and steel bar to arrange the three lines horizontally as shown in figure. 2.2 (a). The conductors have a minimum line spacing of about 400mm. And that of a three phase low voltage, LV power line consist of four (i.e. Three phase as R,S,T and one neutral N lines) vertical parallel ACSR wires which are about 10 mm in diameter and 7 m above the ground. The arrangement of the lines are neutral line is always put above all three phase RST lines with up to 200mm separation each other and uses wood and concrete pols and uses hooks shown in figure. 2.2 (b).

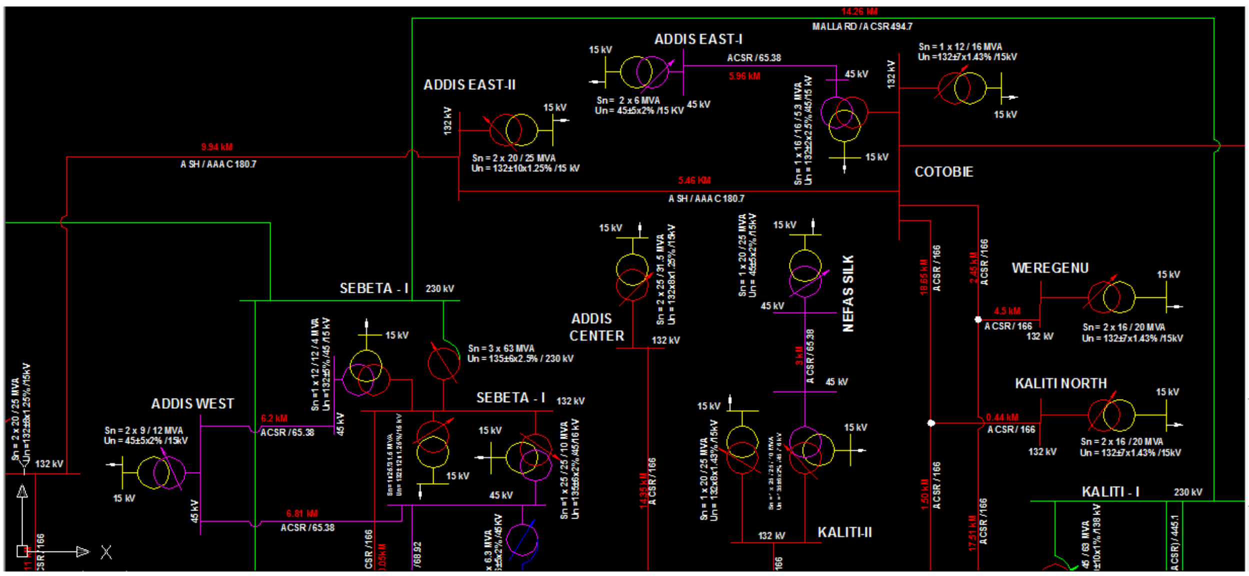


Figure 4.3 Single line diagram of Addis Ababa's substation [6]

The World Bank awarded Ethiopia last place in Africa, with power utilization of 45kWh per person in 2009, the year before GTP I was launched, as compared to South Africa, which ranks first with 4,532kWh. The Bank gave a slightly higher rating of 51.96kWh for 2011. Total power consumption in Ethiopia in 2014 was, according to the World Bank, 4,645,000,000kWh, compared to 6,515,000,000kWh in Kenya and 6,715,000,000kWh in Sudan. [7]

2.2 Broadband over Power line Communication

Broadband over power line is a method for sending high-speed communications information over electric utility lines. BPL achieves this goal by coupling radio frequency energy onto existing power lines in addition to the alternating electric current (AC). This technique allows high data rate communications in both the electric distribution grid of a utility company and within the in-wall wires of a customer facility. This is accomplished by using a number of devices to place the signal onto the wire, ensure it is transported with enough strength and integrity, and finally to receive and process the signal.

The fundamental principle behind this is that electricity flows at the low-frequency (50 / 60 Hertz) portions of the power lines, leaving room in the higher frequency portions for data streams, as illustrated in Figure 2.4 [8]. Power Line Carrier was originally proposed in the early 1800's and by 1838 the first remote electricity supply metering was proposed [9]. The first patents on power line signaling were proposed in the UK in 1897 and the technology used as early as the 1920's by utilities such as the Electric Power Utility of London. Utilities early use of the power line communication technology was to remotely control some of its equipment including breakers and high voltage switches. This application of the technology only required the transfer of data at relatively low speeds of <30 kbps transfer rate and is still in use by several utilities today.

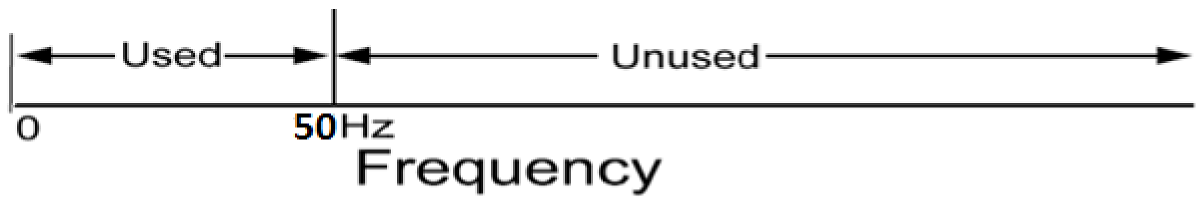


Figure 5.4 Frequency Use of Power Line [8]

Earlier attempts to transfer data at higher speeds/frequencies over power lines proved to be unattainable as the electric grid was designed for optimal operation at low frequencies (50 Hz). This resulted in severe attenuation or signal blockage of high frequency signals by voltage regulators, circuit re-closers, transformers, and shunt capacitors. The inherently noisy nature of power line channel and high reflection coefficient of the distribution network due to signal reflection at branches and unmatched terminations, also increased the challenges of BPL/BPLC [10].

2.2.1 Types of BPLC

In general, BPLC is categorized into two: Access-BPLC, In-House BPLC •

2.2.1.1 Access BPLC

When the MV and/or the LV network of the electric utility outside the customer's residence is used for the BPLC network it is called Access BPLC. In Access BPLC, the PTSN or the telecom backbone is to be coupled to the electricity network via a Fiber cable or wireless link either at the MV front end (at the HV/MV substation) or at the LV front end (at the distribution transformer.) If the coupling is made on the MV line, the distribution transformers on the lines should be bypassed using wireless or MV/LV couplers, since transformer windings act as low-pass filters and hence block high frequency signals. Very isolated communities away from city boundaries, small villages supplied by self-contained electricity sources (diesel, mini-Hydro, Wind-power) and those who get electricity via a long MV lines can be provided access to the Internet using Access BPLC. Access BPLC is the contender of xDSL, Fiber, Cable TV, WiMax.

2.2.1.2 In-House BPLC

In-House BPLC is the utilization of the electric network inside a building as a LAN network, this enables the configuration of LAN in a building without requiring or installing any additional UTP cables thereby reducing the cost and many associated inconveniencies such as chiseling of existing buildings.

In-House BPLC is the replacement and the contender to the UTP and other in building installations like Wi-Fi. Such factors as signal attenuation due to multiple presence of walls in the case of Wi-Fi get solutions by using in-House BPLC.

Currently modems up to 500 Mbps are available on the market for in-house LAN, making in-house BPLC a strong contender to the UTP cable. In case connection to the Internet is sought, it is assumed that the last-mile services are already in-place: DSL, broadband-wireless, or even Access-BPLC.

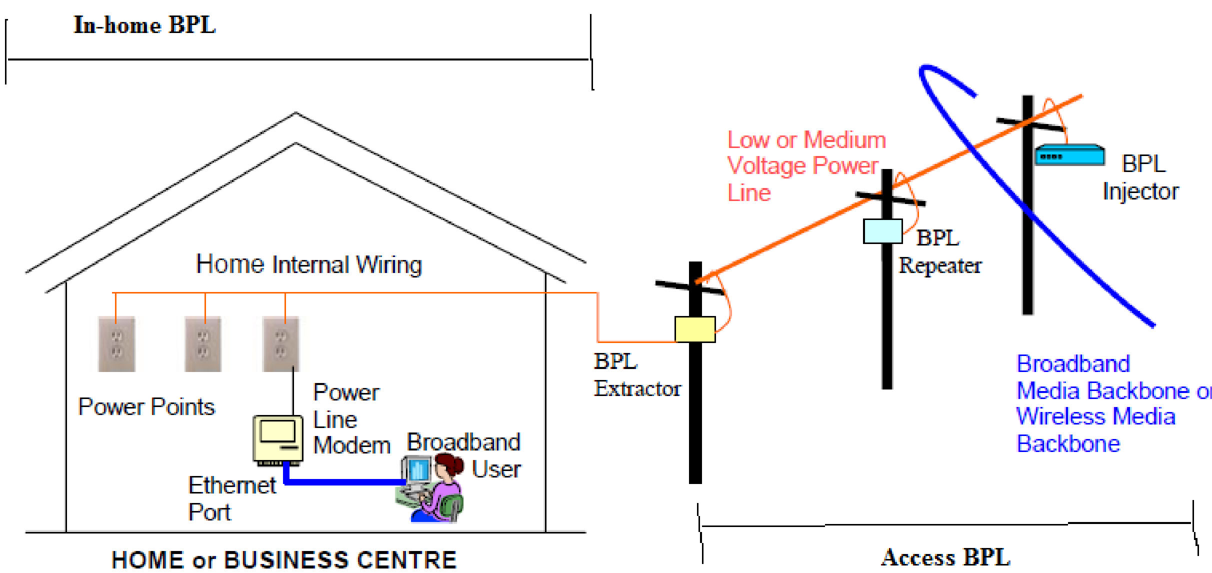


Figure 6.5 Types of broadband over power line communication technology [24]

2.2.2 Major PLC Components

To get a broad picture of how the PLC network is structured, it is very important to know the major hardware components required for the network.

2.2.2.1 Network Management System (NMS)

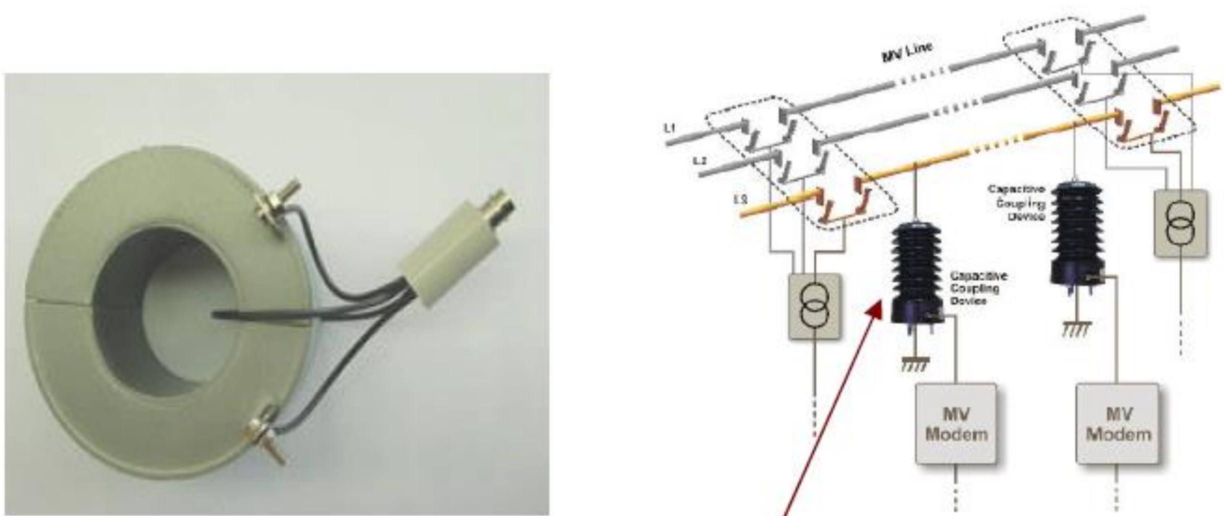
The PLC-NMS is the core of the networking structure and is composed of different hardware and software packages. Like any other WAN or MAN structures, the PLC-NMS monitors and manages the traffic on the network, and generates diagnostic information regarding the network units whenever required. Since the

Applications are TCP/IP based, this core system can also be used for configuring, controlling, monitoring and testing of the different PLC components connected on the grid.

Additionally, in the case of Automatic Meter Reading (AMR) it is the PLC-NMS where the data obtained from the different PLC-based data acquisition units (such as PLC-equipped KWHM readers) are processed, analyzed and management and billing decisions are made.

2.2.2.2 Couplers (MV and LV)

The injection of the high-frequency signal to the electric network is done either by inductive or by capacitive couplers, both to the overhead and to the underground MV or LV installations.



(a) (b)

Figure 7.6 Examples of Inductive Coupler (a) and capacitive coupler (b)[11]

Coupling Methods

Two coupling methods are used in PLC systems: capacitive and inductive coupling. When capacitive coupling is used, the modem is physically connected to the power line. In inductive coupling, ferrites are used to realize the coupling between the modem and the power line (see Figure 9).

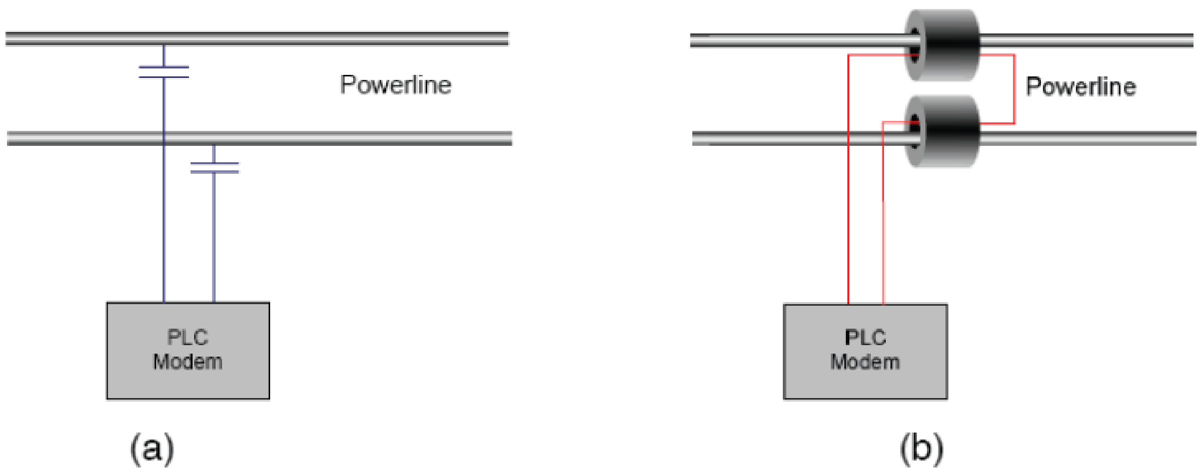


Figure 8.7 Connection in a case of (a) capacitive coupling and (b) inductive coupling [11]

Capacitive coupling introduces voltage onto the line and is the preferred method of coupling at the coupling points with relatively high impedance (>20Ω). Typically, these points are at the end of a power line (socket) and house access point with one incoming and only one outgoing cable.[11]

Capacitive coupling is also used when inductive coupling is not possible due to the geometry of the couplers (e.g., too small inner diameter of the ferrites), due to too high current ratings, etc. In the case of LV networks, capacitive coupling is always used since inductive couplers with suitable dimensions and saturation currents are not yet available [11].

Inductive coupling is used at coupling points with relatively low impedance (<20Ω), such as bus bars with many feeders or service lines and House Access Points (HAP) with more than two outgoing cables. Inductive coupling is also used wherever capacitive coupling is not possible due to safety reasons.

Since capacitive coupling requires direct connections to conductors, the electrical power is switched off whenever possible for installation. For the cases when the power cannot be switched off, the installation is dangerous. Unlike capacitive coupling, when inductive coupling is used there is no need to switch off the electrical power since no galvanic connection is involved. Inductive coupling is suitable for the coupling points with low impedance; the lower the impedance, the lower the coupling loss. It is also easy to realize multiple coupling points.

2.2.2.3 PLC Modems

For the common understanding of the terminologies, PLC modems are the NTUs that are solely used for In- House PLC applications, irrespective of whether the last-mile access is provided by Access-PLC, DSL, or any other means. During the past few years the PLC modem speeds have strongly improved from 14Mbps, 45Mbs, 85Mbps, and now the 500Mbps PLC modems are made available. The power plugs of PLC modems, which are erectly connected to the electric socket outlets, carry both the 50Hz power signal for powering the internal components of the modem, and the high-frequency broadband signals; but the UTP cable connecting the RJ-45 port (or USB port, if present) of the modem and the host computer carries only the broadband signal.

In addition to the standard PLC modems, PLC modems used as wireless extensions are also available on the market.

2.2.2.4 MV Concentrator Units (MVCU)

MVCU connects and transfers data from the telecom backbone (through Fiber, copper, or wireless) to/from the electricity grid, concentrating all the other medium voltage units into one medium-voltage cell. MVCUs are point-to-multi-point PLC units and can be installed at the HV/MV at the front end of an MV line, or anywhere along the MV line convenient for the back bone connection and are managed by the NMS.

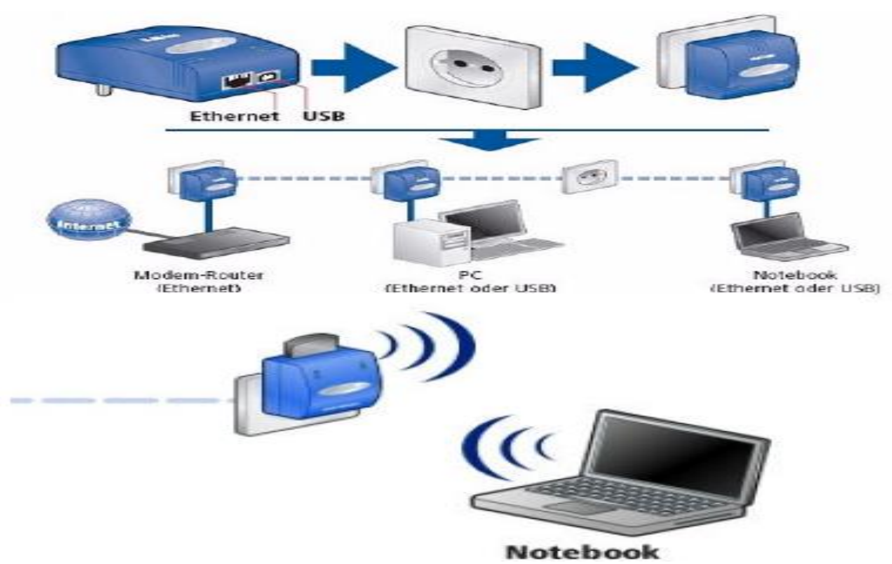


Figure 9.8 PLC Modems for In-House PLC [12]

2.2.2.5 MV Distribution Units (MVDU)

MVDU connects the MV grid to the LV grid at the distribution transformer connection points. These units can operate on both underground and overhead lines with and with both Inductive and Capacitive couplers. MVDUs also serve as repeaters on the MV line and can be enabled for other applications such as SCADA (Supervisory Control and Data Acquisition) extension and Security & Surveillance, over the grid. [12]

2.2.2.6 LV Concentrator Units (LVCU)

LVCU concentrates all low-voltage PLC units into one and transfers the data to the MVDU for connection to the backbone. In most of the installations LVCU and MVCU are placed near each other and are connected to each other using UTP (unshielded twisted pair) cables, Fiber, or wireless. LVCU can also be enabled for other broadband applications.

2.2.2.7 LV Repeater Units (LVRU)

These are repeater units for the LV line and may or may not be enabled with Ethernet ports for other broadband connections such as Surveillance Cameras or for extending the coverage of wireless by connecting Wi-Fi hot spots. Typically this are used to amplify PLC data in case of high attenuations over the Powerline.

2.2.2.8 Network Terminal Units (NTU)

In general, in the Access-PLC scenario they are commonly called Network Terminal Units (NTU), but these are the same as the PLC Modems as usually called in the In-house PLC. NTU is the customer Premises Equipment (CPE) which provides the transfer of data from the electric socket outlet to the customer's computer through its Ethernet port and enables the customer to get the required broadband services(such as Internet surfing, VoIP, and Video) from the socket outlet.

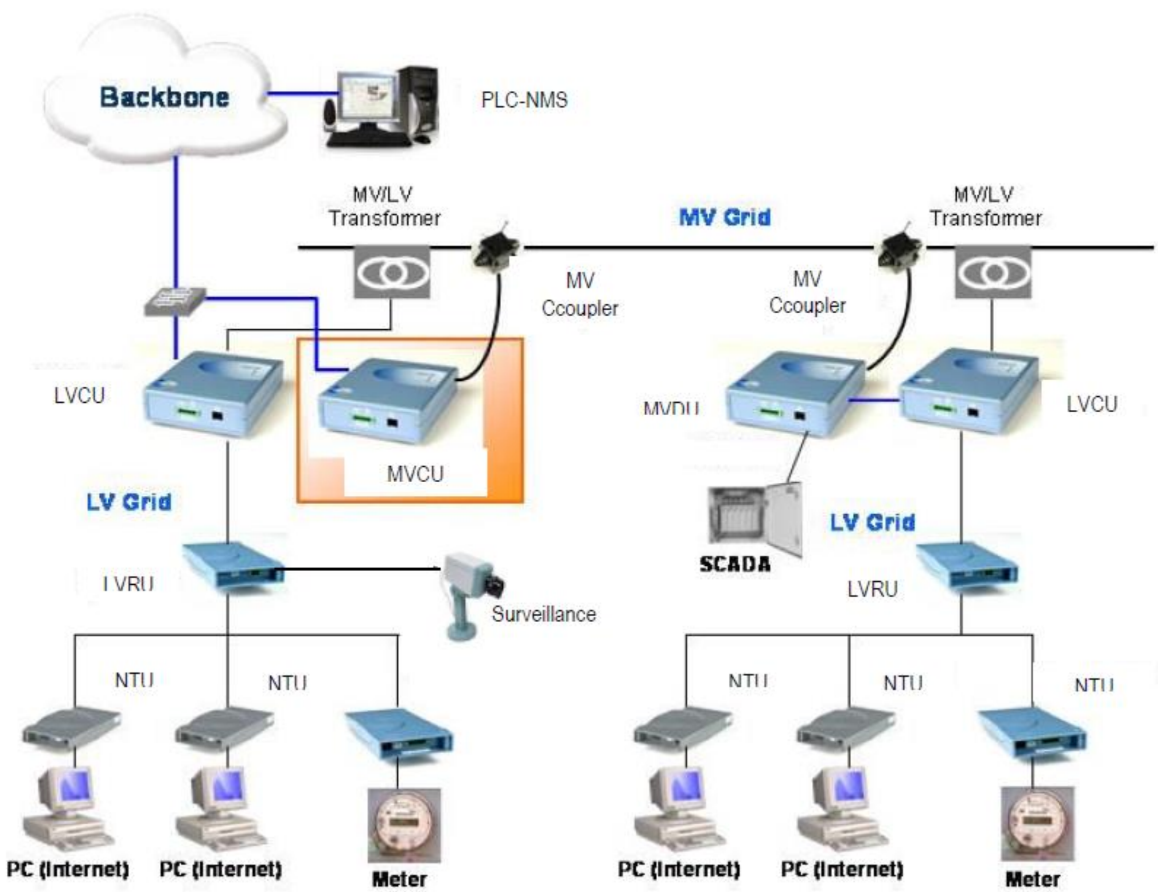


Figure 10.9 Placement of different Access-PLC components [12]

CHAPTER THREE

LITERATURE REVIEW

3.1 Electromagnetic Compatibility of BPL Systems

PLC technology uses the power grid for the transmission of information signals. From the electromagnetic point of view, the injection of the electrical PLC signal in the power cables results in the radiation of an electromagnetic field in the environment, where the power cables begin acting like antennas. This field is seen as a disturbance for the environment and for this reason its level must not exceed a certain limit, in order to realize the electromagnetic compatibility. Electromagnetic compatibility refers to emissions and immunity of different systems that use the same frequency band. For any piece of equipment to be widely deployed, it is necessary to ensure that the emissions produced by it do not significantly disturb other services and systems using the same frequency band, and that it can function properly in the presence of a given measure of electromagnetic pollution. The levels of immunity and emissions are regulated by EMC standards. As shown in Figure 3.1, emissions and immunity can be either conducted or radiated.

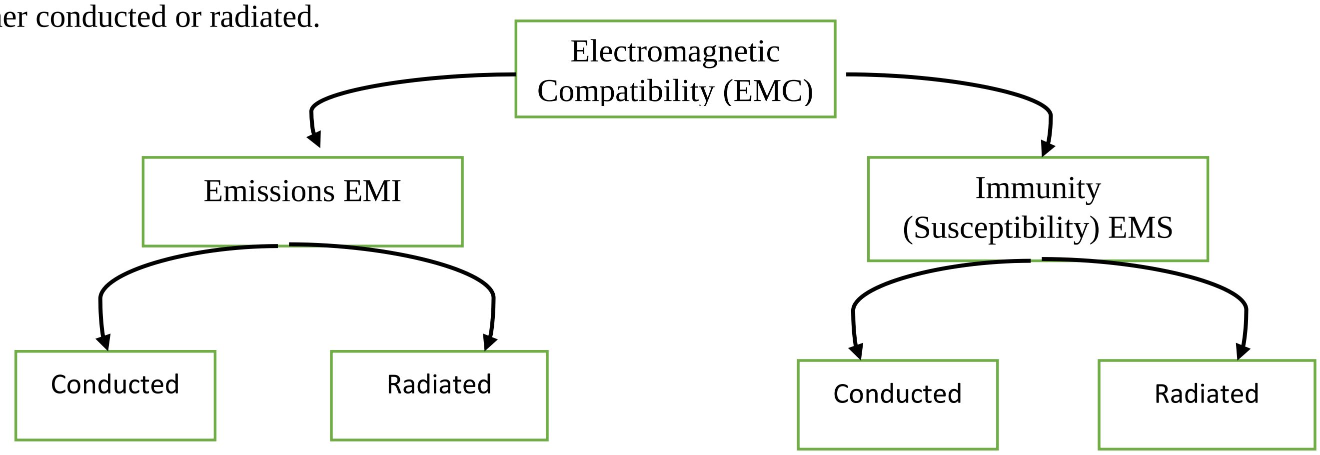


Figure 11 Different areas of Electromagnetic Compatibility. [11]

Several forms of electromagnetic coupling between a transmitter and a receiver are possible as illustrated in Figure 3.2 [17]. Depending on the frequency of the electromagnetic interference (EMI), various models describing the field coupling are used, ranging from low-frequency capacitive and inductive coupling to the higher frequency radiative coupling.

Field coupling

Field coupling (also known as Radiated coupling) between transmitter and receiver takes place by the transfer of electromagnetic energy through a radiation path, usually the air. Very often there is an element that behaves as an undesired transmitter or receiver antenna. At low frequencies, radiated coupling can be classified in terms of:

- Capacitive coupling, due to parasitic capacitances between nearby conductors. Its origin is the existence of an electric field.
- Inductive coupling, due to currents induced by time-varying magnetic field. All conductors generate a magnetic field and its variations can have an effect on nearby conductors.

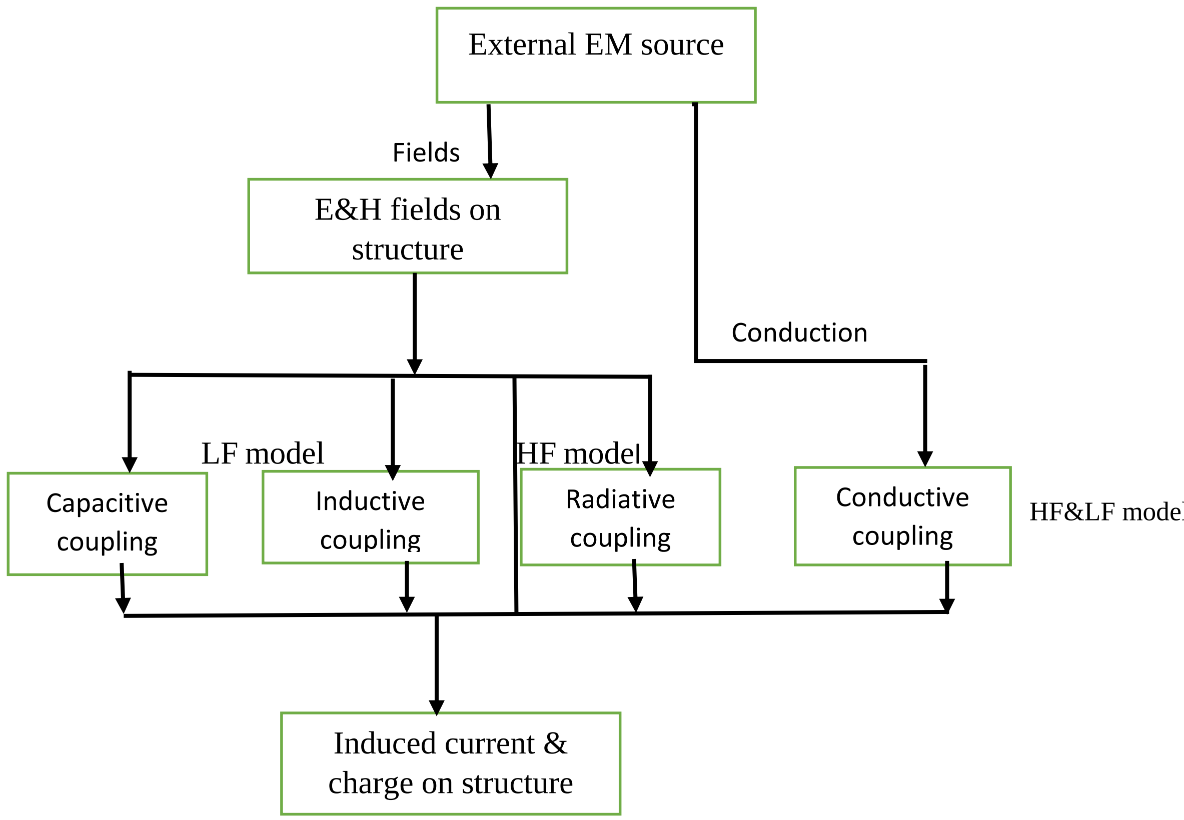


Figure 122 EM coupling process [11]

Conducted coupling

Conducted coupling between a source and a victim takes place via a direct path between transmitter and receiver, this path being different from the air. This coupling can take place because of the existence of direct conduction or common impedance:

- Direct conduction takes place when there is a physical connection between transmitter and receiver through the power supply cables, signal cables or control cables. The interference propagates among the different devices via these connections.
- Common impedance exists when there is a common wire among the various devices, typically power supply and ground wires. The interference propagates over these common lines to all and among all devices.

3.2 BPL Deployment Options

BPL deployment options are classified as access BPL deployment and in-house BPL deployment. The MV and LV line portions of the BPL are usually referred to as the access BPL, while the portion inside a home or office using the inside wiring is called the in-house BPL.

Deploying access BPL in Ethiopia either as end-to-end BPL or as hybrid BPL for access BPL portion, using one of the three options illustrated in Figure 3.3 [16]. 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 using option one bypass the MV/LV transformer or second deployment option 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 access BPL deployment option is hybrid BPL. In this option, typically only the MV/LV lines are used, and a fixed wireless network replaces the LV lines that feeds the customers from LV poles to the customers' lines

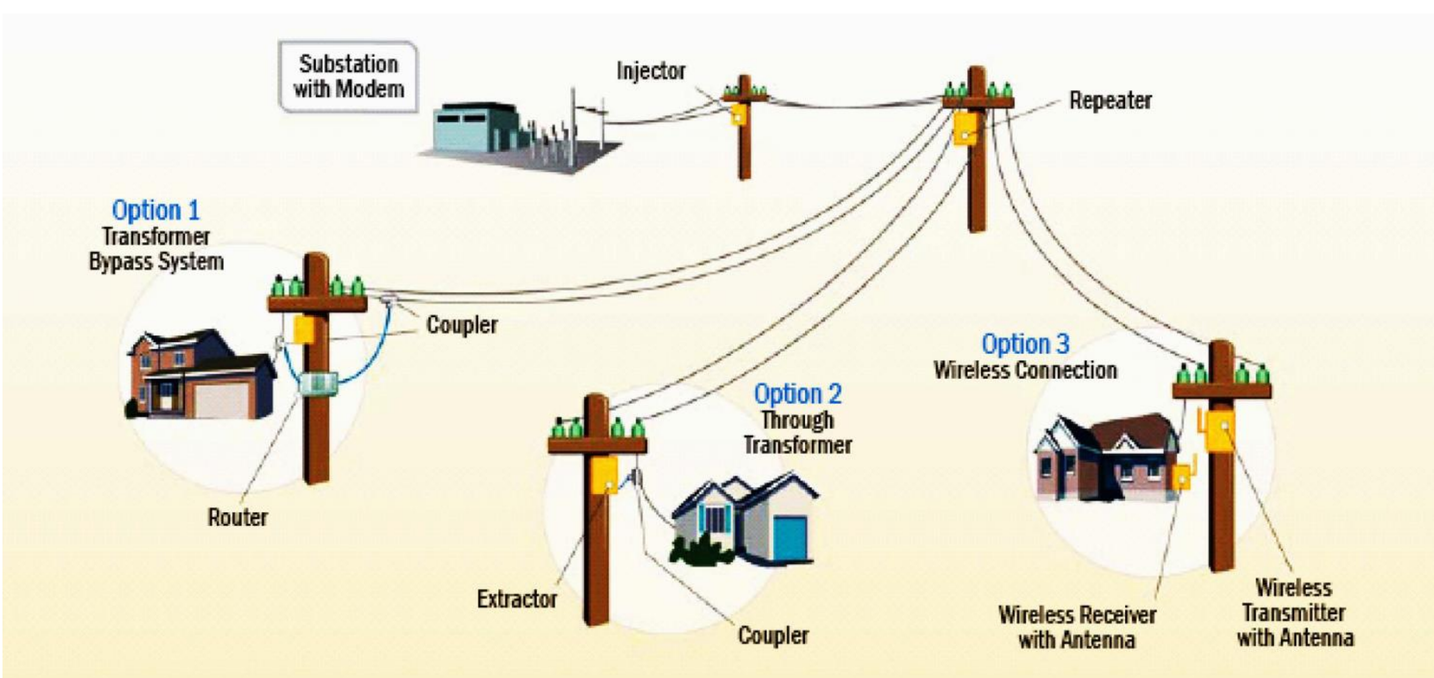


Figure 133 BPL deployment options [23]

and in-house BPL. In hybrid BPL, 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.

In –house BPL deployment options are direct i.e. using RJ 45 Ethernet cable directly plug into the power outlet using BPL modem and connect it directly to the computer/pc and the other option is wireless connection i.e. using BPL wireless modem connected to the power outlet and then connect all devices that have wireless (Wi-Fi) capability wirelessly.

3.4 BPL Speeds and Standards

Just as wireless technology has grown in speed over the years, Power line communications has experienced a similar growth path. The following standards are currently dominated BPL communication than others.

HomePlug 1.0

First available in 2002 with max physical layer rate 14Mbps it delivered 5 - 8 Mbps speeds and certified by the HomePlug Powerline Alliance. Interoperable with 85Mbps rated devices (Atheros/Intellon Turbo) and 28Mbps devices (Arkados 1Plus). Standardized by the ANSI-accredited Telecommunications Industry Association in May 2008 as TIA-1113.

HomePlug AV

First available in 2006 with max physical layer speed 200Mbps it delivered 70 - 100 Mbps speeds and certified by the HomePlug Powerline Alliance. Interoperable with IEEE 1901; Some HomePlug AV semiconductors are interoperable with HomePlug 1 devices. Some HomePlug AV devices incorporate semiconductors that use proprietary extensions to HomePlug AV technologies and claim 500Mbps and Gigabit speeds.

IEEE 1901

First available in 2010 with 545 Mbps max physical layer speed it delivers XXX Mbps (depending on mode) speeds.IEEE 1901 technology includes PHYs interoperable with both HomePlug AV and HD-PLC and provides smart coexistence through an Inter-system Protocol. Products and semiconductors are certified by the HomePlug Powerline Alliance. Devices are interoperable with HomePlug AV. Some semiconductors are interoperable with both HomePlug 1 and HomePlug AV.

HomePlug GP ("Green PHY")

First available: Certified chips expected in early 2011, though HomePlug GP implementations can be deployed now using HomePlug AV chips. HomePlug GP uses 75% less power, and is a cost-optimized, lower data rate version of HomePlug AV, IEEE 1901, and HomePlug AV2.

Targeted at Smart Grid applications such as HVAC, smart meters, home appliances, plug-in electric hybrid vehicles, lighting control, security, supports IP networking.

Market-leading HomePlug-certified devices are carried online and in brick-and-mortar retail stores throughout the world, but some powerline devices incorporate non-HomePlug technologies, and are not interoperable.

3.5 COMPARISON BETWEEN BPL AND OTHER ACCESS TECHNOLOGIES

3.5.1 ADSL

Uplink speed of ADSL is 256 Kbps – 2 Mbps. Downlink speed of ADSL is 144 Kbps– 9Mbps.Approximate monthly cost per user in Ethiopia is 546.25 – 3536.25 birr [Ethio-telecom website]. It uses the same pair of copper wires as POTs. ADSL is distance sensitive. Maximum distance it can cover is 500 m. This is a major drawback of ADSL. ADSL is the main broadband access technology deployed in Ethiopia. Fixed Wired Broadband Internet is an internet service provided by Ethio-telecome with unlimited usage. The service is available for residential customers with speeds options starting from 256 Kbps up to 2Mbps.

Tariff

Table 2 ADSL tariff in birr. Source from Ethio-telecome website

Speed	Monthly usage fee in Birr	Subscription Fee In Birr
256 Kbps	**546.25**	**280**
512 Kbps	**1092.50**	
1 Mbps	**1955.00**	
2 Mbps	**3536.25**	

Terms and conditions

- Monthly usage fee doesn't include cost of Modem. One modem with one-off payment it cost 300 Birr for copper and 500 Birr for fiber.
- No installation fee will be requested within 500 Meter from the connection point to the customer premises. Beyond 500 Meter additional payment will be requested.

3.5.2 CABLE MODEM

Uplink speed of Cable Modem is128- 500 Kbps. Downlink speed of Cable Modem is 1–3 Mbps. Approximate monthly cost per user is $30 - $40. It uses coaxial cables which are used for cable television transmission. Cable Modem is not distance sensitive. Limitation of this access technology is that the speed is affected because of shared bandwidth. Now a days Cable Modem is not deployed in Ethiopia but EBC (Ethiopian Broadcasting Corporation) is in the way to deploy Cable television service at that time may be Cable Modem access technology will deploy in most cities.

3.5.3 BPL

Uplink speed of BPL is 500 Kbps – 200 Mbps. Downlink speed of BPL is 500 Kbps– 200Mbps.Approximate monthly cost per user is $28 - $40. It uses the power lines to provide Internet service. Interference problem is one of the major drawback of this system. Also it needs repeaters at every 2500 feet. Like Cable Modem speed is affected due to shared bandwidth.

BPL gives Wide, spread and extensive infrastructure that is already available in Ethiopia urban , sub urban and remote areas in terms of electrical cables allow easy access to internet with relatively very little equipment investment, particularly in areas where limitations in terms of having a ADSL connections are experienced by Ethio-telecome. Maintenance costs of BPL are also extremely low. Cost effectiveness and large scale broadband penetration are two distinct and unique advantages of BPL. In addition, installation time is less than 45 in average minutes and rural penetration is relatively easy.

BPL is a good solution for Home Networking than other available solutions as no other infrastructures is required. Access BPL systems have the potential in increasing the availability of broadband services to homes and businesses.

BPL systems have been increasing the competitiveness of the broadband services market. BPL systems have also been identified as a means of improving the quality and reliability of electric power delivery and creating a more intelligent power grid. BPL technology could allow utilities to more effectively manage power, perform automated metering and monitor the existing power grid for potential failures because of this Ethiopian Electric Utility is installing automated metering and monitoring technology in Addis Ababa.

3.5.4 BPL compare with wireless broadband

According to companies who sell the equipment, BPL is a great way to distribute a computer network through your home that's at least as convenient as wireless Internet (Wi-Fi):

- It can send signals up to 200m or 650ft (further than a typical Wi-Fi router, which offers only 35m or 115ft).
- It offers data rates from 200Mbps (million bits per second) to over 1 Gbps (gigabits per second = thousand megabits per second), comparable with or better than a typical Wi-Fi router.
- It will work with other networking products based on Ethernet, such as Net-linked computer games machines.

- It uses encryption to protect signals traveling around your home and is (theoretically at least) much more secure from eavesdropping than wireless networks. However, as with any network, there are still security loopholes.
- You don't need any additional wiring. All you need is two plug units, one for each socket you want to use.

3.6 ADVANTAGES

- BPL systems have also been identified as a means of improving the quality and reliability of electric power delivery and creating a more intelligent power grid. BPL technology could allow utilities to more effectively manage power, perform automated metering and monitor the existing power grid for potential failures.
- BPL technology does not require new infrastructure to be installed as it provides internet over already installed power lines hence it can be used to provide broadband services in rural areas
- Maintenance costs of BPL are also extremely low. In nutshell, cost effectiveness and large scale broadband penetration are two distinct and unique advantages of BPL. In addition, installation time is less than other technology and rural penetration is relatively easy.
- BPL can provide wide coverage, since the power lines are already installed almost everywhere. This is advantageous especially for substations in rural areas where there is usually no communication infrastructure.
- The communication network can be established quickly and cost-effectively because it utilizes the existing wires to carry the communication signals. Thus, PLC can offer substations new cost-saving methods for remotely monitoring power uses and outages.

3.7 DISADVANTAGES

- BPL uses power lines for providing broadband services in the range 1-30 MHz or in some case 80 MHz when these broadband signals which are high frequency alternating current signals are guided through powers lines these lines act as antennas radiating electromagnetic waves which can possibly hinder other radio communications falling in the same frequency range. This problem can be solved by standardizing frequencies to be used by BPL service providers.
- The power lines are noised environments for data communications due to several noise sources such as electrical motors, power supplies, fluorescent lights and radio signal interferences .These noise sources over the power lines can result in high bit error rates during communication which severely reduces the performance of BPL

- Power line is a shared medium and therefore, the average data rate per end user will be lower than the total capacity depending on coincident utilization, i.e., the number of users on the network at the same time and the applications they are using. Thus, possible technical problems should be comprehensively addressed with various field tests before the BPL technology is widely deployed
- Communication over the power lines is lost with devices on the side of an open circuit. This fact severely restricts the usefulness of PLC for applications especially involving switches.
- In power lines, the attenuation and distortion of signals are immense due to the reasons such as physical topology of the power network and load impedance fluctuation over the power lines. In addition, there is significant signal attenuation at specific frequency bands due to wave reflection at the terminal points. Therefore, there is loss in signal due to high signal attenuation and distortion.

Table 3 Comparison of broadband access technologies.

Access Technology	**Speed**	**Typical *Cost per Month**	**Reach**	**Availability in Ethiopia**	**Remarks**
BPL—broadband over Powerline, defined as long distance, high speed transmission of data over the power delivery system.	Commercial - up to 3 Mbps Residences - 5 Mbps or higher	522Birr 725 Birr Depending on speed and features.	BPL can be applied to the ubiquitous electric distribution network.	Not available	Speeds same for upload and download; Number of users affects the speed.
Cable—use of cable TV provider's coaxial or fiber-coaxial systems to transmit broadband signals.	1 Mbps to 3 Mbps	880 Birr to 1028 Birr	Available where cable has been installed so some rural and suburban locations may not have access.	Not available	The speed of the signal varies by the number of users on the neighborhood network loop; it degrades with high numbers of users.
ADSL—use of existing copper telephone wires and fiber to transmit broadband signal.	256Kbps to 2 Mbps	546.25 **Birr to** 3536.25 Birr	In general, a residence must be within about 500 m of the ADSL central equipment office.	Available	Not capable of transmitting TV signals.
Fiber (FTTx)—use of optical fiber lines to home (FTTH) or business (FTTB) to deliver broadband services.	1 Mbps to 1 Gbps	For 1 Mbps link: 2935Birr For 1 Gbps link: Instalment: 30,300Birr Maintenance: 2150-3500Birr	Fiber to the premises is available in some locations, but its deployment has been limited by high costs.	Available/but its only for special customers	Cost reductions enabled by passive optical networks (PON) and advances in component technology are expected to bring costs down. Some telecom companies are already installing Fiber.
Satellite	500Kbps	1054 Birr to 2,537Birr	Requires a clear view to the satellite	Available	Trees and even heavy rain may affect reception on Internet data.

WiMax_worldwide interoperability for microwave access, based on a January 2003 IEEE standard (802.16), supports development.	Up to 75 - 100 Mbps	Modem: 4000 Birr For 512 Kbps: 2250 Birr For 1 Mbps: 5250 Birr For 256 Kbps: 1250 Birr	Has a range of about 10 - 12 kilo meters of a single base station. This technology has a predicted point-to point range of 25 miles or more	Not available	WiMax has recently entered the market. It is expected to reduce its service charge as it could catch a large number of customers.

* This cost is an approximate value based on International market and changed to Birr based on Ethiopian currency exchange market.

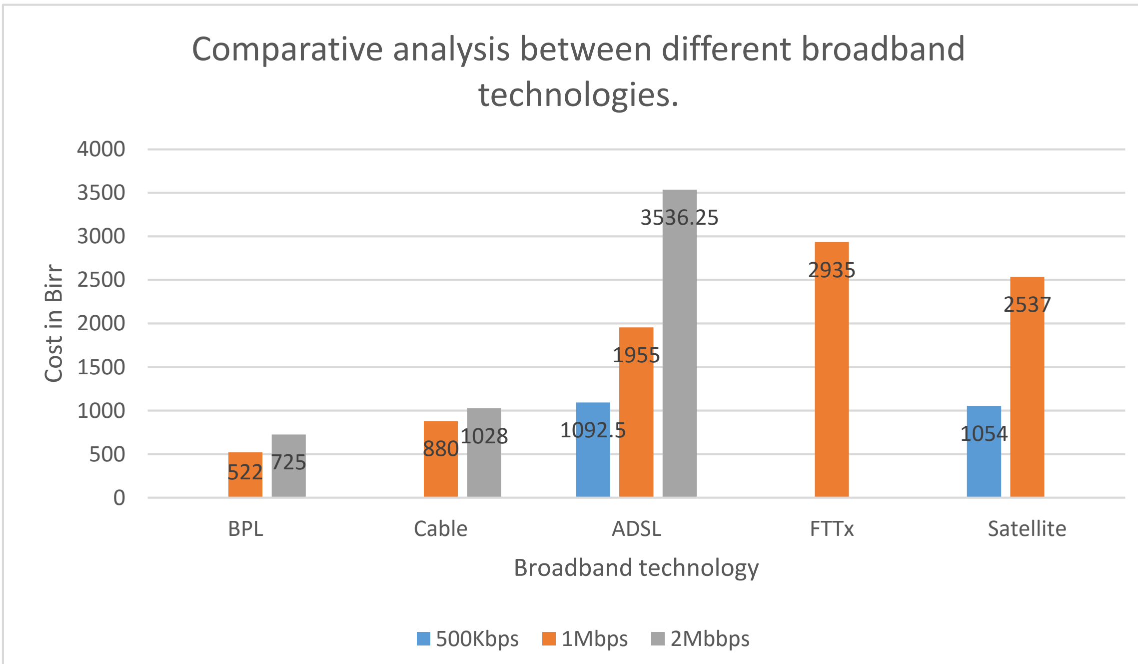


Figure 144 Comparative analysis between different broadband technologies.

3.8 Final Analysis

Broadband over power lines presents a unique opportunity to provide broadband access all over the country using the existing power distribution grid. A country should start the issue by arranging good policy and regulation in the regulatory area. BPL has been able to largely overcome the issue of harmful interference. Although the optimal price setting methodology a regulated utility should employ when entering the competitive broadband services market remains uncertain, the utilities (i.e. Ethiopian Electric Utility EEU) should have to establish incentives for the deployment of BPL in the efficiency improvements for the coming BPL communication technology deploying in the power distribution grid. Although BPL may have a difficult time competing with cable and ADSL in the established broadband services market on price alone, the performance enhancements provided by intelligent network capabilities will make tremendous headway towards defraying the cost of the infrastructure.

Even though the importance and direct socioeconomic impact of access to broadband services are well understood, presently solely less than seventeen percent of the Ethiopian's total population has access to some kind of internet services, typically via ADSL and Mobile internet. BPL providing high-speed net services, VoIP, and alternative broadband services to homes and businesses by exploitation existing MV and LV power lines. As a result of roughly 31 % of Ethiopian population have access to power lines, BPL may play a major role in bridging the prevailing digital divide. The Broad Band over Power Line communication network technologies will have potential for Ethiopian telecom network and will grow extensively in near future for higher capacity applications e.g. Triple Play services (telephony, data and TV etc.). Ethiopian Broadcasting Corporation is on the way to install cable TV services for some Ethiopian cities like Addis Ababa, and regional cities so BPL will give another choice to do so. Also BPL is a better option with less cost for network operators. BPL is already on the scene with commercial products readily available. Green Energy technologies like Solar, Wind etc. may be used as Power Line solutions. Combination of BPL with AADSL, 3G, 4G, etc. may be economical solution for access networks in future.

3.9 Review of Related Works

Several techniques have been introduced to model the transfer characteristics of power lines. Basically, there are two essential factors in these models; the model parameters and the modeling algorithms. These two factors determine the reliability and accuracy of the model. The wide literature on PLC channel modeling essentially follows two approaches; a top-down or a bottom-up approach. While the top-down approach considers the PLC channel as a black box, and describes the multipath propagation via an echo model in the time domain, or in the frequency domain using a parametric model whose parameters can be obtained with fitting the results from measurements [13], [14] and [15]. This is a phenomenological approach, and we can say that in this case the transfer function is computed with *a posteriori* methodology, i.e. an empirical approach. An empirical model determines the modeling parameters from measurements, is easy to implement and computationally efficient, but is prone to measurement errors. Such models are not capable to describe the physics of propagation, the topology, and the effect of the loads.

Several channel models from multipath propagation principles have been suggested [Philipps, (1999), Philipps, (1998)]. The work presented in Philipps, (1998) and Matov, (2004) is in fact very close to the approach introduced herein. The Philipps model was based on evolutionary strategy to get lumped circuit parameters of the SRC load, however, the model did not take the length of cable into consideration. The model proposed here is based on scattering matrix approach to get the transmission line parameters to do so cable length taken into consideration.

In the bottom-up approach or analytical approach, the transfer function is computed with a priori methodology, i.e. a deterministic approach. A deterministic model derives the modeling parameters from a theoretical basis, is computationally more intensive in comparison to the empirical approach, but allows predicting the change in the transfer function due to any change in the network, since all parameters are properly formulated. The transfer function can be obtained by either using the network matrix approach, or with the theory of transmission lines that considers the effects of multiple transmissions and reflections. It also describes clearly the relationship between the network behavior and the model parameters. Moreover, this modeling approach is more versatile and flexible since all the parameters are formulated, making it easy to predict the changes in the transfer function, should there be any change in the system configuration [13], [14] and [15]. Depending on the modeling approach for the transfer function used, either time domain or frequency domain analysis can be done.

Channel models based on transmission matrix theory offer the advantage of low computational complexity that is almost independent of the power line link topology [29]. However, full and detailed knowledge of the transmission link must be available *a priori*. The model requires details about the topology, properties of the cables used and impedance values at the end of every branch involved. The accuracy of the model can be significantly affected if perfect knowledge of such parameters is not available. In a practical scenario, such knowledge of the power line network is nearly impossible, which makes modelling the power line channel models based on TL theory unrealistic.

The focus of this work is to achieve the transfer function characterization of most common electrical wiring installation topology indoor PL network in Ethiopia using a bottom-up approach based on the frequency-domain modeling and using scattering matrix. The computation of the voltage ratio between the receiver and transmitter ports gives the transfer function. Unlike multipath modeling this approach does not require finding of all possible signal propagation paths. The motivation and the reason why a bottom-up approach is chosen by the goal of obtaining an accurate model starting from the knowledge of the topology and cables characteristics.

In this work, instead of the transmission matrix method as the transmission matrix gives the relationship of the voltage (V) and current (I) at the two terminals while the scattering matrix [S-matrix] gives the relationship of the incident waves (a) and reflected waves (b) the scattering matrix method is chosen. The transfer function derived from the transmission matrix is basically V2/V1, which is the transfer ratio of the standing waves (including both incident and reflected waves).
However, for PLC, the transfer function in the forward direction, which is the ratio of the incident power into the receiver over the power injected by the transmitter, is of interest. This can readily be expressed by S21 or b2/a1 in the scattering matrix.

This thesis focused on broadband over power line technology for Ethiopia broadband services, so the gap showed in the reviewed paper has been fulfill as Ethiopian context and add other contribution to this field of study for specially Ethiopia broadband services.

CHAPTER FOUR

SYSTEM MODEL DESCRIPTION AND ANALYSIS

4.1 Introduction

In this chapter transmission line channel transfer function model and Ethiopian low voltage distribution line are modeled and described. Channel transfer function modeled using Matlab and low voltage distribution line was modeled using 4nec2 software. Different cases are used to analyze each models in different conditions.

Those models was modeled to study broadband over power line to be an additional alternatives for broadband service coverage shortage and expensiveness in Ethiopia. In order to do so comprehensive understanding about BPL with in its implementation prospects in Ethiopia was first task that this thesis does. To do this the existing theory, standards, technologies, implementation, advantages and disadvantages of BPL were investigated and analyzed based on Ethiopia context. Data collection taken place from international journals, and research papers.

4.2 Power line channel transfer model

For many years Power Line Communication (PLC) has been used for low bandwidth services. Recently, PLC technology has been improved in term of high speed data transmission, video, voice applications [4]. It is observed that power line network and its communication channel has good chance for Broadband PLC technology. However, power line network was basically built for power transmission at 50Hz. means that, unlike to other communication channels. Therefore, to understand Broadband PLC, up to 30MHz frequency of the signal is used. The first thing that must be in standard is power line channel model, since broadband PLC QoS is highly affected by its channel characteristics [5].

The focus of this portion of work is to achieve the transfer function characterization of most common electrical wiring installation topology indoor PL network in Ethiopia as shown in figure 16 using a bottom-up approach based on the frequency-domain modeling and using scattering matrix. A two-wire line model with no effect of third conductor i.e. as used in electrical wiring installation in Ethiopia is used since the conductors of concern are the ones on which the signal propagates i.e. the ‘Hot’ and ‘Return’ wires respectively. An indoor power line network model was modeled for a high radio frequency up to 30 MHz.

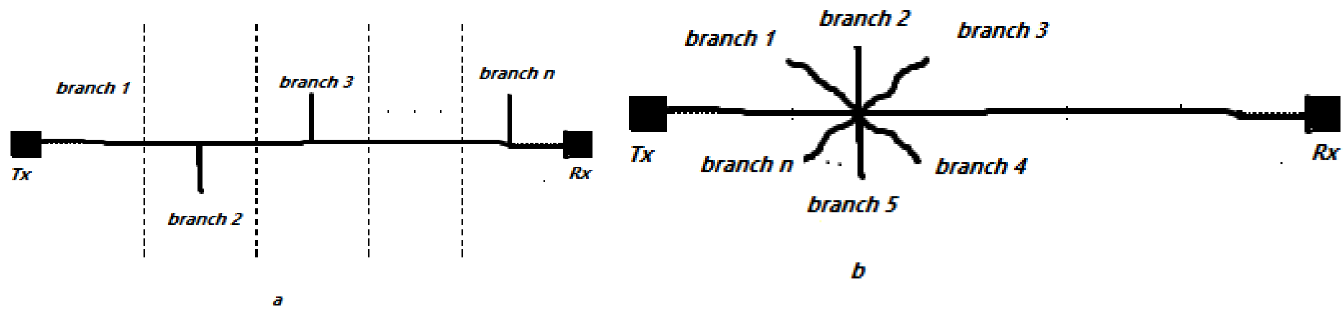
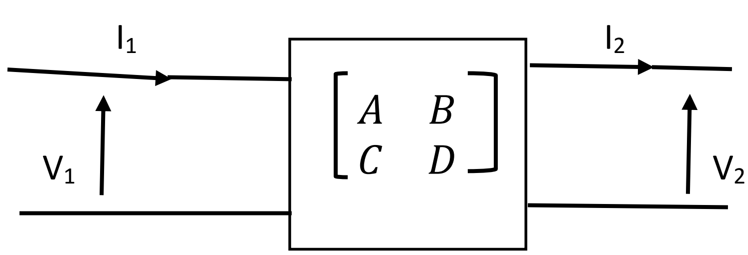


Figure 151 electric wire topology [11]

The computation of the voltage ratio between the receiver and transmitter ports gives the transfer function. Unlike multipath modeling this approach does not require finding of all possible signal propagation paths. The motivation and the reason why a bottom-up approach is chosen by the goal of obtaining an accurate model starting from the knowledge of the topology and cables characteristics. This work also proposed simplification techniques for complex topologies for easy and efficient computation without loss of accuracy. And this technique is dividing the total network into simpler sections where the evaluation of the voltage ratio is simplified. Compared with the two-port network matrix approach presented by [4], this method greatly saves calculation time when the BPL network becomes more complex.

In this work, instead of the transmission matrix method as the transmission matrix gives the relationship of the voltage (V) and current (I) at the two terminals while the scattering matrix [S-matrix] gives the relationship of the incident waves (a) and reflected waves (b) the scattering matrix method was used[4.2] . The transfer function derived from the transmission matrix is basically V2/V1, which is the transfer ratio of the standing waves (including both incident and reflected waves).

However, for BPL, the transfer function in the forward direction, which is the ratio of the incident power into the receiver over the power injected by the transmitter, is of interest. This can readily be expressed by S21 or b2/a1 in the scattering matrix. Also, at higher frequencies, input and output variables in terms of wave variables are easily measured than currents and voltages. The frequency-domain modeling based on the scattering matrices is applied to account for the many branches in the power line.



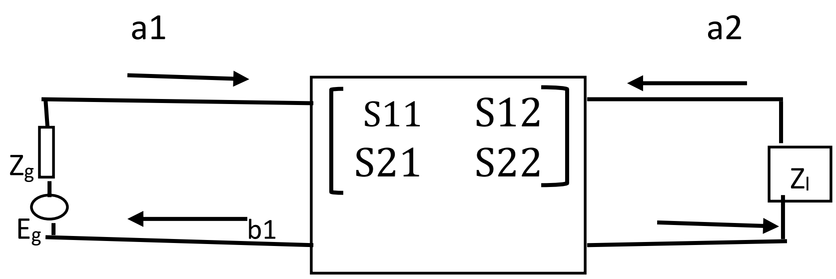


Figure 4.216 Comparison of Transmission Matrix and Scattering Matrix of 2-port Network.

In Matrix Representation, the travelling waves are related to S-parameters according to equation 1.

$$\begin{bmatrix} b1 \\ b2 \end{bmatrix} = \begin{bmatrix} S11 & S12 \\ S21 & S22 \end{bmatrix} \begin{bmatrix} a1 \\ a2 \end{bmatrix} \quad \ldots\ldots\ldots\ldots\ldots 1$$

Where a1 and a2 represent the incident waves at ports 1 and 2 respectively and b1 and b2 represent the reflected waves at ports 1 and 2 respectively.

4.2.1 Mathematical Modeling of Two Wire Transmission Line

The electromagnetic theory states that to achieve efficient point-to-point transmission of power and information, the source energy must be guided. When power lines are used to transmit high frequency communication signals, they can be regarded as transmission lines, which guide the transverse electromagnetic (TEM) waves along them. According to this theory, the two-wire transmission line must be a pair of parallel conducting wires separated by a uniform distance. In the actual installation, the power cables are simply pulled through the conduit and the separation between them is not uniform at all. However, the conduit normally has small cross-sectional area and this limits the variation of the separation between the cables. Based on the above consideration, the paired power cables are regarded as a distributed parameter network, where voltages and currents can vary in magnitude and phase over its length. Fig.4.3 describes such a circuit where circuit parameters are distributed over its length.

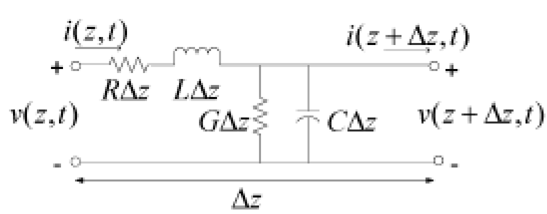


Figure 173 Equivalent Circuit of Two-Wire Transmission Line [25]

The quantities v (z, t) and i (z, t) denote the instantaneous voltage and current at location z respectively and v (z + Δ z, t) and i (z + Δ z, t) denote the instantaneous voltage and current at location z + Δ z, respectively. R defines the resistance per unit length for both conductors (in Ω/m), L defines the inductance per unit length for both conductors (in H/m), G is the conductance per unit length (in S/m), and C is the capacitance per unit length (F/m). Based on the lumped-element circuit, the two intrinsic line parameters for the transmission line, i.e., the propagation constant γ and the characteristic impedance Z_0, can be written as [26]

$$\gamma = \alpha + j\beta = \sqrt{(\mathrm{R} + \mathrm{j\omega L})(\mathrm{G} + \mathrm{j\omega C})} \dots\dots\dots\dots\dots 2$$

$$\mathrm{Z}_0 = \sqrt{(R + j\omega L)/(G + j\omega C)} \dots\dots\dots\dots\dots 3$$

Where ϖ is the angular frequency. The real part and the imaginary part β of the propagation constant are the attenuation constant (in/*Npm*) and phase constant (in/*radm*) respectively. Note that both γ and Z_0 are characteristic properties of a transmission line even if the line is infinitely long. In other words, they depend on *R*, *L*, *G*, *C*, and ϖ.

With the power line being modeled as a transmission line, its γ and Z_0 will dominate the wave behavior along the line. In the model proposed in this thesis, they serve as the parameters to model the transfer function of the channel. In the next section, these two parameters are derived for the typical house power cables.

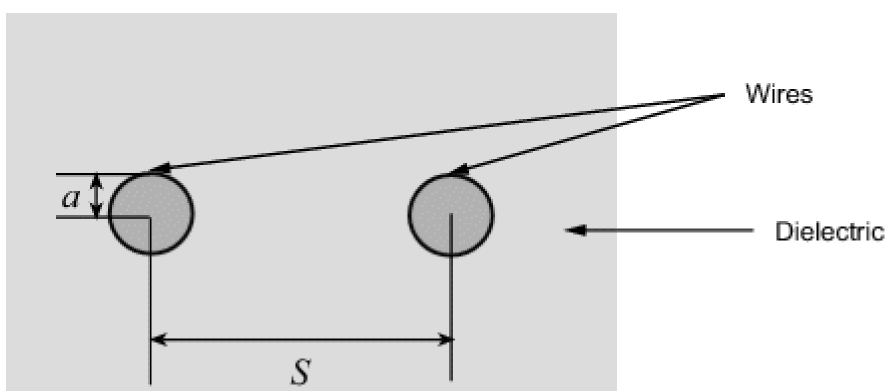


Figure 184 19 Cross Sectional View of Two Wire Transmission Line.[25]

Fig.4.4 shows a two-wire transmission line. Its physical characteristics include the radius of the wires a, the separation or physical distance between the wire centers S, and the relative permittivity and permeability of the wires. Proposed model assumed the relative permittivity and permeability are uniform. The resistance (R), inductance (L), conductance (G), and capacitance (C) per unit length (meters).

The line can be described by primary parameters of power Line using R´, L´, C´, G´ parameters. These parameters denote a resistance, inductance, capacity and leakage relative to the length of the line. For the purpose of modeling, consider the three-wire line as the two conductors and one transmission conductor, which they are a conductive coper wire and they are surrounded by the same dielectric material which is conduit. Then it is possible to determine the primary parameters with the equations [26]:

$$R = \sqrt{\left(\frac{\mu r\ \mu 0\ f}{\pi\sigma a2}\right)}\left[\left(\frac{d}{2}\right)/\sqrt{\left(\frac{d}{2}\right)^2 - 1}\right] \ldots\ldots\ldots\ldots\ldots 4$$

$$L = (\mu_r\ \mu_0\ /\pi)\ \cosh^{-1}(d/2a) \ldots\ldots\ldots\ldots 5$$

$$C = \pi\ \epsilon_r\ \epsilon_0\ /\ \cosh^{-1}(d/2a) \ldots\ldots\ldots\ldots 6$$

$$G = 2\pi\ f_c \tan\delta \ldots\ldots\ldots\ldots 7$$

Where *d* is a distance between the center of conductors, *a* is a radius of conductor, σ is a copper conductivity, ε_r indicates a relative permittivity of insulation, ε_0 is a permittivity of vacuum, tan δ is a factor variance a μ_r is a relative magnetic permittivity of the copper.

With γ and Z_0, the transfer function of the BPL channel can be determined. A frequency-domain modeling approach is suggested because it is very hard to use the time-domain modeling approach to account for all reflected and delayed paths in the power network. The BPL channel can be regarded as a branch network as shown in Fig. 4.5 below. Obtaining the scattering matrix of such a network is quite complex and, the channel is divided into a group of cascaded single-branch networks. The scattering matrix for each single-branch network is derived in the following section and the scattering matrix of the whole channel can then be determined by using the chain-scattering matrix method.

To analyze the S-parameters of a single-branch network, the following diagram shown in Fig. 4.5 is used. In this derivation, the power line on the direct signal path (excluding the branches) is defined as the path line. Let l_1 be the cable length from left end of the path line to the tap point, l_2 the cable length of the cable branched off from the tap point and the cable length from the tap point to the right end of the path line. Using transmission line theory, Zin_1, Zin_2, Z_{IN}, Γ_1, and Γ_1 can be determined

$$Z_{in1} = Z_0 * \frac{ZL + Z0 * \tan(\gamma l3)}{Z0 + Zl * \tan(\gamma l3)} \text{ in } \Omega \ldots\ldots\ldots\ldots 8$$

$$Z_{in2} = Z_0 * \frac{Zb + Z0 * \tan(\gamma l2)}{Z0 + Zb * \tan(\gamma l2)} \text{ in } \Omega \ldots\ldots\ldots\ldots 9$$

$$Z_{in} = Z_0 * \frac{(Zin1\ //\ Zin2) + Z0 * \tanh(\gamma l1)}{(Z0 + (Zin1\ //\ Zin2) * \tanh(\gamma l1)} \text{ in } \Omega \ldots\ldots\ldots\ldots 10$$

$$\Gamma_1 = \frac{Z_L - Z_0}{Z_L - Z_0} \ldots\ldots\ldots\ldots 11$$

$$\Gamma_2 = \frac{(Zin1\ //\ Zin2) - Z0}{(Zin1\ //\ Zin2) + Z0} \ldots\ldots\ldots\ldots 12$$

Where:

Z_s: source impedance (50 Ω)

Z_{in}: input impedance of the single branch network

Z_{in2}: input impedance of the branch network

Z_{in1}: input impedance of the network on the right of the tap

Z_L: load impedance at the end

Z_b: load impedance at branch end

Γ_1: reflection coefficient from path end

Γ_2: reflection coefficient from the tap point

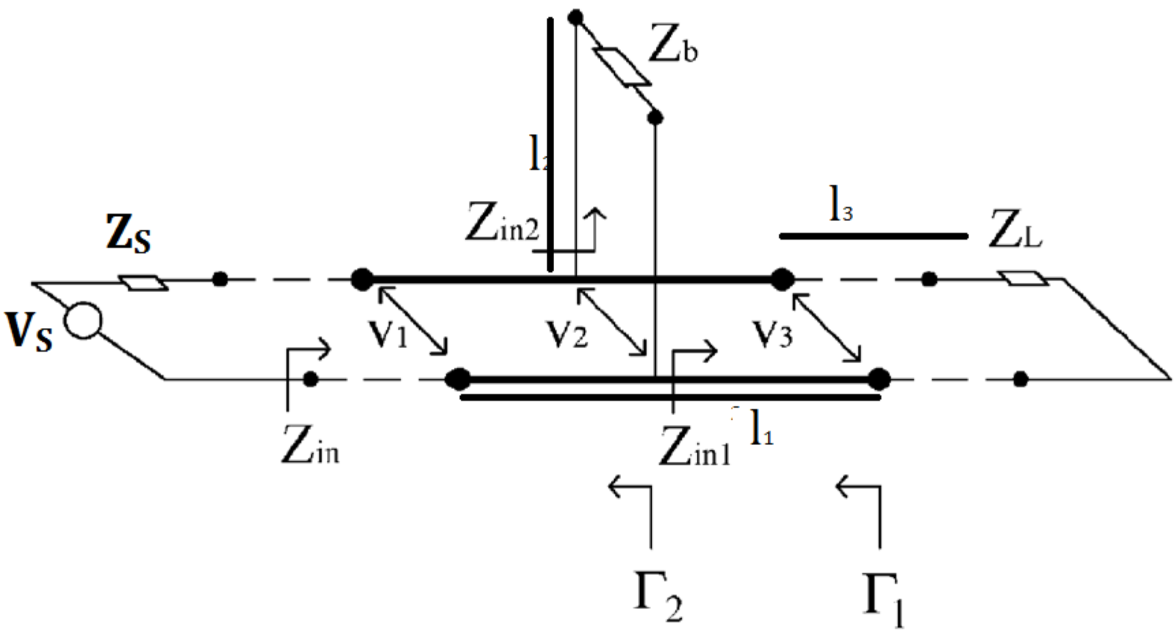


Figure 205 *Diagram for single-branch network.*

Based on [12], the S_{11} and S_{22} of the network scattering matrix is given by

$$S_{11} = \frac{Z_{in}-50}{Z_{in}+50} \quad \ldots\ldots\ldots\ldots\ldots\ldots 13$$

$$S_{21} = 2 * \frac{V_3}{V_S} \quad \ldots\ldots\ldots\ldots\ldots\ldots 14$$

Since it is not easy to obtain the ratio of V_s and V_3, S_{21} can be computed indirectly by

$$S_{21} = 2 * \frac{V_3}{V_2} * \frac{V_2}{V_1} * \frac{V_1}{V_S} \quad \ldots\ldots\ldots\ldots\ldots\ldots 15$$

Where

$$\frac{V_1}{V_S} = \frac{Z_{in}}{Z_{in}+Z_S} \ldots\ldots\ldots\ldots\ldots\ldots 16$$

By applying shifting in the reference planes [12], i.e.

$$\frac{V_3}{V_2} = \frac{(1+\ \Gamma_1) * e^{-\gamma l_3}}{1+\ \Gamma_1 *\ e^{-\gamma l_3}} \ldots\ldots\ldots\ldots\ldots\ldots 17$$

$$\frac{V_2}{V_1} = \frac{(1+\ \Gamma_2) * e^{-\gamma l_1}}{1+\ \Gamma_2 *\ e^{-\gamma l_1}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots 18$$

and then substitute (16), (17), and (18) into (15), S_{21} can be obtained. Similar method can be used to determine S_{12} and S_{22}.

$$\mathrm{S21}\ = 2 * \frac{(1+\ \Gamma_1) * e^{-\gamma l_3}}{1+\ \Gamma_1 *\ e^{-\gamma l_3}} * \frac{(1+\ \Gamma_2) * e^{-\gamma l_1}}{1+\ \Gamma_2 *\ e^{-\gamma l_1}} * \frac{Z_{in}}{Z_{in}+Z_S} \ldots\ldots\ldots\ldots\ldots\ldots 19$$

After analyzing the single-branch network, the remaining task is the determination of the scattering matrix for a cascade of several single-branch networks. Using the microwave theory, there are generally two methods that can be used. The first method is to use the chain scattering matrix (or T-matrix), and the second is to use signal flow graph [26]. For the sake of easier computation, the first method is used in this thesis.

The T-matrix for the whole network can be obtained by the product of all the T-matrices of the cascaded portions. The relation between the S -matrix and T-matrix is shown as follows [27, 28]:

$$[\mathrm{T}] = \begin{bmatrix} \mathrm{T}_{11} & \mathrm{T}_{12} \\ \mathrm{T}_{21} & \mathrm{T}_{22} \end{bmatrix} = \begin{bmatrix} \dfrac{1}{\mathrm{S}_{12}} & \dfrac{-\mathrm{S}_{22}}{\mathrm{S}_{21}} \\ \dfrac{\mathrm{S}_{11}}{\mathrm{S}_{21}} & \mathrm{S}_{12} - \dfrac{\mathrm{S}_{11}\mathrm{S}_{22}}{\mathrm{S}_{21}} \end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots\ldots 20$$

Then T-matrix for the N-branch network will be

$$[\mathrm{T}] = \prod_{\mathrm{k}=1}^{\mathrm{N}} [\mathrm{T_k}] \ldots\ldots\ldots\ldots\ldots\ldots\ldots 21$$

Where T_k is the T-matrix for the k^{th} cascaded portion in the network. Finally, the S-matrix for the whole network can be obtained by using the following conversion equation:

$$[S] = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} = \begin{bmatrix} \dfrac{T_{21}}{T_{11}} & T_{22} - \dfrac{T_{21}T_{12}}{T_{11}} \\ \dfrac{1}{T_{11}} & \dfrac{-T_{12}}{T_{11}} \end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots\ldots 22$$

The S_{21} term in (22) gives the network transfer function.

Table 4 Line parameters for simulation

Characteristic Value selected(Cu)	Characteristic Value selected
ε_r	0.8
Line Length	5m,7m,10m,15m,
A	$2.5x10^{-3}$ m
S	$5.1x10^{-3}$,$6.0x10^{-3,}$, $6.5x10^{-3}$, $7.5x10^{-3}$
σ_{cond}	$5.80.x10^{7}$
σ_d	$1.0x10^{-5}$

Analytical results of the BPL system are carried out by MATLAB. The performance of the indoor power line communication channel at high frequency was analyzed for different cases as effect of varying wire separation, effect of varying the cable lengths, effect of number of branches on the network, and effect of varying branches line length.

The cables used in this model are considered to have cross section 2.5 mm^2. The line parameters as per the cross section and separation the values of R L and C are calculated using equation (2).

4.2.2 Analysis cases of Transfer Function of Indoor Power-line Installation Topology in Ethiopia

4.2.2.1 Case 1: Effect of Varying Wire Separation on Transfer function

As found by survey most of home and office electric wire installation are installed without the consideration of keeping wire separation. This is happened because of type of wire used to install are separate wire for both phase and neutral line without physical dielectric material between them. As the result the separation distance is varying throughout the network.

To analyze the effect of varying line separation of indoor power line network on transfer function four different separation distances are considered which are chosen based on the measured data in sampled Ethiopian residents and offices as 5.02mm, 6mm, 6.5mm and 7.5mm. Table 4 depicts the parameters of the line selected for Simulation work.

4.2.2.2 Case 2: Effect of Varying Line Length on Transfer function

To analyze the effect of varying line length of indoor power line network on transfer function four different lengths are considered which are chosen based on the real installation length in most Ethiopian residents and offices as 5m, 7m, 10m, and 15m. Table 4 depicts the parameters of the line selected for Simulation work.

4.2.2.3 Case 3: Effect of Number of Branches on Transfer function

To analyze the effect of number of branches, keeping each branch line length as constant and equal to 5m. First simulate the network as un-branched network. Second as a two branch cascaded network with each section having line length of 5m and finally as a three branches cascaded network with each branch having line length of 5m. The other line parameters remain the same as selected in Table 4.

4.2.2.4 Case 4: Effect of varying Branched line lengths on Transfer function

To analyze the effect of branched line lengths, keeping the line length as constant and equal to 15m, first simulate the network as un-branched network then as a two section cascaded network with each section having line length of 7.5m and finally as a three section cascaded network with each section having line length of 5m.The other line parameters remain the same as selected in Table 4.

4.2.2.5 Case 5: Effect of number of branches at a single point as tap on transfer function

To analyze the effect of number of branches at a single point as a taps, number of branches at a single node are changed as first three tap branches and then as six number of tap branches.

4.3 Modeling of Distribution Power Line Electromagnetic Radiation

4.3.1 Power Systems in Ethiopia

In Ethiopia, Ethiopian Electric Power, EEP generate electricity and it is distributed throughout the country via high voltage line at 161kV. EEP transmit power to Ethiopian electric utility, EEU via the 430kV high voltage power lines. EEU then distributes electricity to low power consumers such as households, companies, factories and etc. At the EEU substations transformers are used to step down this high voltage in to a much lower 33 and15kV medium voltage which is then distributed to consumers in areas where power needs to be. Before entering the customer’s house, another transformer is used to drop the voltage down from 33 and 15kV to more manageable levels of 220V.

4.3.2 Numerical Electromagnetic Code (NEC)

The Numerical Electromagnetics Code, NEC is a user-oriented computer code for the analysis of the electromagnetic response of antennas and other metal structures. It is built around the numerical solution of integral equations for the currents induced on the structure by sources or incident fields. This approach avoids many of the simplifying assumptions required by other solution methods and provides a highly accurate and versatile tool for electromagnetic analysis.

The code combines an integral equation for smooth surfaces with one specialized to wires to provide for convenient and accurate modeling of a wide range of structures. A model may include non-radiating networks and transmission lines connecting parts of the structure, perfect or imperfect conductors, and lumped-element loading. A structure may also be modeled over a ground plane that may be either a perfect or imperfect conductor. The excitation may be either voltage sources on the structure or an incident plane wave of linear or elliptic polarization. The output may include induced currents and charges, near electric or magnetic fields, and radiated fields. Hence, the program is suited to either antenna analysis or scattering studies. 4NEC2 has been used successfully to model a wide range of antennas including complex environments such as ships.

The integral-equation approach is best suited to structures with dimensions up to several wavelengths. Although there is no theoretical size limit, the numerical solution requires a matrix equation of increasing order as the structure size is increased relative to wavelength. Hence, modeling very large structures may require more computer time and file storage than is practical on a particular machine. In such cases standard high-frequency approximations such as geometrical or physical optics or geometric theory of diffraction may be more suitable than the integral equation approach used in 4NEC2.

The NEC program uses both an electric-field integral equation, EFIE and a magnetic-field integral equation, MFIE to model the electromagnetic response of general structures. Each equation has advantages for particular structure types. The EFIE is well suited for thin-wire structures of small or vanishing conductor volume while the MFIE, which fails for the thin-wire case, is more attractive for voluminous structures, especially those having large smooth surfaces The EFIE can also be used to model surfaces and is preferred for thin structures where there is little separation between a front and back surface. Although the EFIE is specialized to thin wires in this program, it has been used to represent surfaces by wire grids with reasonable success for far-field quantities but with variable accuracy for surface fields. For a structure containing both wires and surfaces the EFIE and MFIE are coupled. This form of simulation breaks the structure of interest down into moments or line segments (for solid structures, a wire mesh is used). The current in each segment is calculated and the resulting electromagnetic fields are derived. To solve radiation and scattering problems, it is often useful to formulate the problem in terms of an equivalent one that may be easier or more convenient to solve in the region of interest. These equivalents are often written in terms of surface currents that mathematically modify or eliminate the presence of obstacles present in the original problem. Scattering problems can be considered as radiation problems where the locally radiating currents are generated by other currents or fields [18].

Antenna analysis is consequently a scattering problem, where antenna currents are excited via an externally applied voltage source. The Electric Field Integral Equation, EFIE describes a radiated field **E** given a set of sources **J**, and as such it is the fundamental equation used in antenna analysis and design. It is a very general relationship that can be used to compute the radiated field of any sort of antenna once the current distribution on it is known. The most important aspect of the EFIE is that it allows us to solve the radiation/scattering problem in an unbounded region, or one whose boundary is located at infinity. For closed surfaces it is possible to use the Magnetic Field Integral Equation, MFIE or the Combined Field Integral Equation, both of which result in a set of equations with improved condition number compared to the EFIE [18].

4.3.3 Model Ethiopian Power Distribution Line

BPL use the existing power grid as the medium to deliver broadband services. So the existing Ethiopian power grid infrastructure and system discussed elaborately. To do so data were collected from Ethiopian Electric Power (EEP) and the Ethiopian Electric Utility (EEU). Field observation was taken place in selected substations and residential homes in selected urban, sub-urban, and rural areas and observed power line length from the distribution line to their home and cheeked topology of inside home installation. Simulation of transmission line characteristics were carried out by using Numerical Electromagnetic Code (NEC) used to model Ethiopian distribution line and to investigate EMIF radiation of distribution power line.

This thesis was conducted in order to determine potential signal leakage of a BPL system. BPL has a target spectrum from 1MHz (just above the AM broadcast band) to 30MHz (just below the FM broadcast band) for delivery of wideband data signals to residential neighborhoods using overhead power line as radio frequency transmission line. Unfortunately, overhead power distribution lines can act rather as efficient antennas at high frequencies which can disturb other services operating in the same frequency range. The following factors and their effects on BPL signal radiation were also simulated using 4NEC2.

- Power lines' wire spacing and BPL signal frequency.
- The method of BPL signals injection on power lines

The 4NEC2 software was used to create a number of power line models to gain a greater understanding of the effects various physical power line topologies might have on the BPL signal leakage. In Ethiopia, a typical arrangement of medium voltage, MV power line consist of three horizontal parallel Aluminum Conductor Steel Reinforced (or ACSR) wires which are about 12mm in diameter and 10m above the ground. The conductors have a minimum line spacing of about 400mm. And that of a three phase low voltage, LV power line consist of four vertical parallel ACSR wires which are about 10 mm in diameter and 7 m above the ground. Figure 20 depicts the orientation of power line conductors topologies found in Ethiopia. Several ways can be imagined to configure the overhead power lines for conducting radio frequency signals. These include driving a single live wire against an adjacent grounded wire or driving two live wires against each other in a balanced mode. In the 4NEC2 models, two-wire transmission lines representing simplified versions of the power line were used.

All models assumed the power lines were configured for balanced two-wire operation to achieve the maximum amount of radiation suppression possible. The 4NEC2 model used for the simulation is a two-wire transmission line 100m long in free space composed of 12.7-mm diameter conductors as shown in Figure 21. The transmission lines were vertically parallel just like the LV power lines here in Ethiopia. The resistance of the conductors is assumed to be zero and the spacing between them is 1m. A power source is connected at one end of the line and a terminating load of 500 Ω is connected at the other end. The values of the electric field radiation are obtained as a function of frequency and load impedance using 4NEC2.

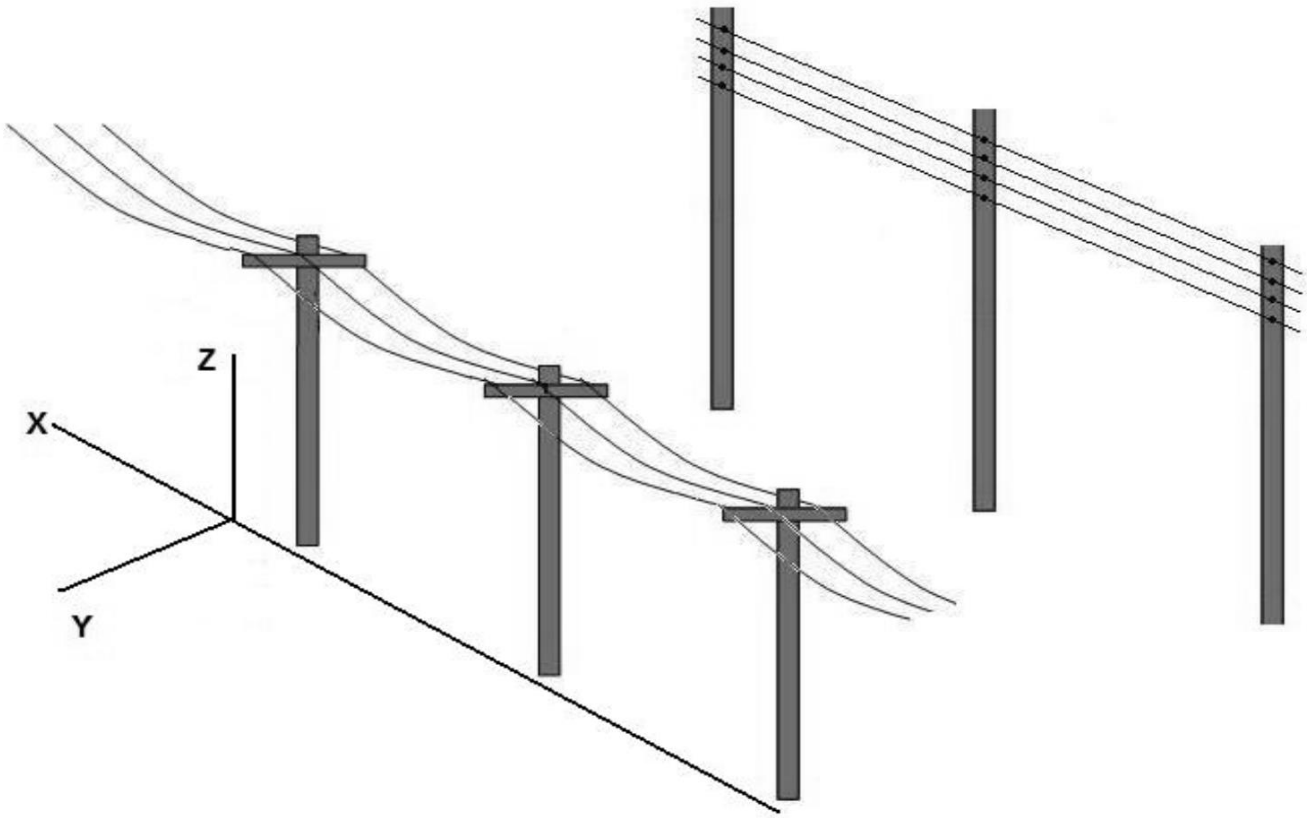


Figure 216 Common Power line topologies in Ethiopia (medium voltage and low voltage) and the coordinates used in NEC [20]

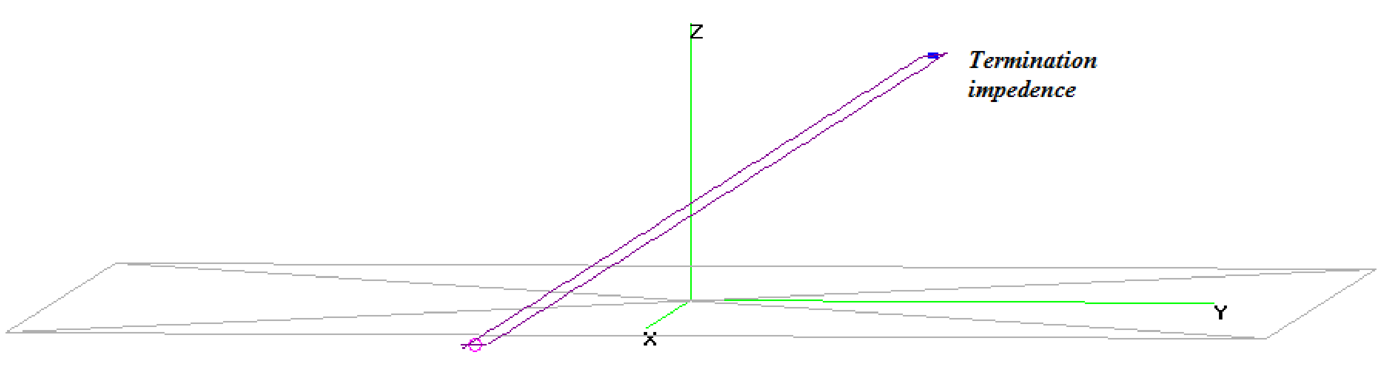


Figure 4.722 NEC Model of a two-wire transmission line

4.3.4 Case 1: Effect of power line's wire spacing on PLC signal radiation leakage

To examine the effect of increasing power line wire spacing on radiation leakage, the 4NEC2 model described above was used. The resistance of the conductors is assumed to be zero. 0.55m, 1m, 1.5m and 2m separation between two wires were used. This work considered only the balanced mode configuration described above, as this is the only mode recognized as being capable of significant external field cancellation. The values of the source and load powers are obtained as a function of frequency and load impedance using 4NEC2 [19]. Because the line is located in free space and has no resistance, the only loss mechanism for the line is through radiation.

4.3.5 Case 2: Effect of signal injection method on PLC signal radiation leakage

A PLC access network produces electromagnetic emission by acting as an antenna which disturbs other communications services operating in the same frequency range. A number of possible means for the prevention and reduction of BPLC interference to other services have been proposed. The researcher looked at BPLC signal injection mode as a means of prevention and reduction of BPLC interference to other services. The method of feeding overhead electrical power distribution lines with PLC signals and the relationship between these methods and the BPLC signal radiation were studied. Three different ways of feeding BPLC signal onto power lines were modeled. They are

- Differential feed (also known as balanced feed) between two phases for vertical and horizontal power lines as shown in Figure 4.8 and Figure 4.9 respectively.
- Differential feed between one phase and the neutral line for the vertical power lines as shown in Figure 4.10 and
- Feeding BPLC signal onto only one phase (unbalanced or common mode feed) similar to the way a dipole antenna is fed as shown in Figure 4.11.

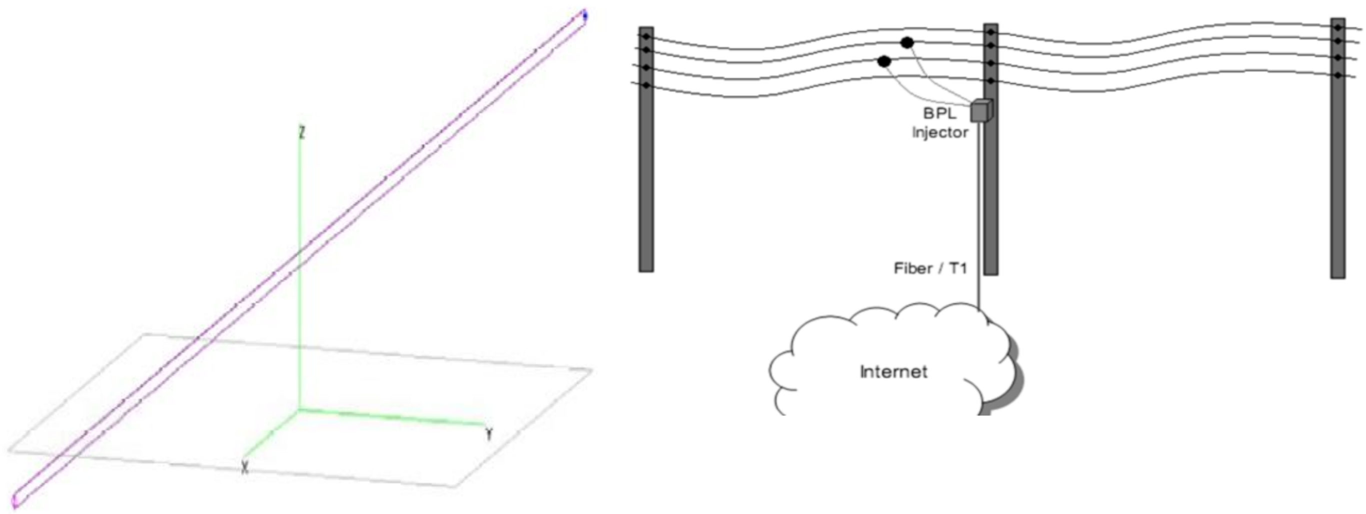


Figure 4.823 Pictorial view of differential feed between two phases on a vertical power line and its model used in 4NEC2

The power-line radiator antenna model was configured with two 12.7mm aluminum conductors, 100m in length. One line was placed 7m and other line was 7.3m above ground except for the horizontal line were both conductors were placed 10m above the ground. The ground was modeled with average conductivity and dielectric constant. The two conductors were parallel, spaced 300mm for LV power line and 500mm for the MV power line. For the differential feed between a phase wire and the neutral wire of the vertical power line, the neutral wire was grounded to simulate typical imbalance in the line. The ground connection consists of four 10- meter radials, 5cm above ground. This is a relatively poor RF ground, to simulate the typically poor RF characteristics of power-line grounds. This also allows NEC-2 calculation engine, which cannot handle direct ground connection, to simulate the model correctly. The simulations use the “average” ground characteristics with a conductance of 0.005 S/m and a dielectric constant of 13 to model the ground under the power lines.

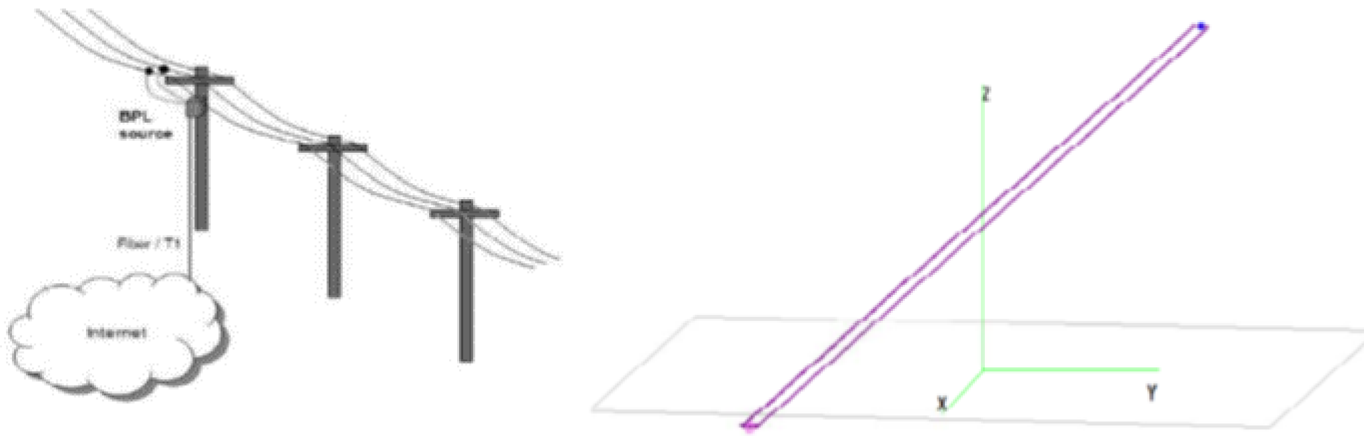


Figure 4.924 Pictorial view of differential feed between two phases on a horizontal power line and its model used in 4NEC2

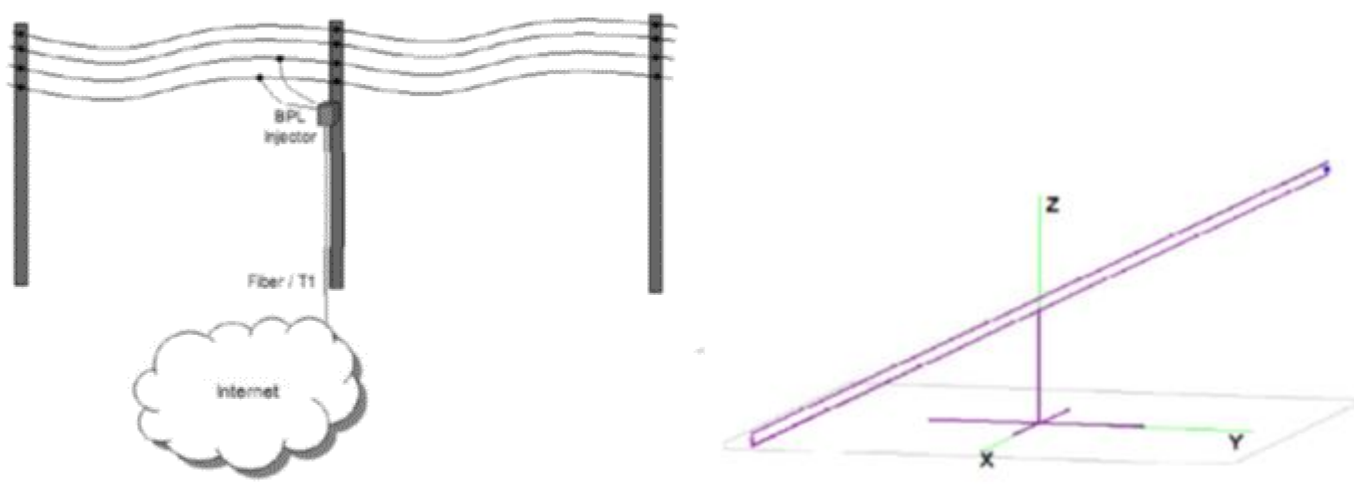


Figure 4.1025 Pictorial view of differential feed between one phase and the neutral line and its model used in 4NEC2

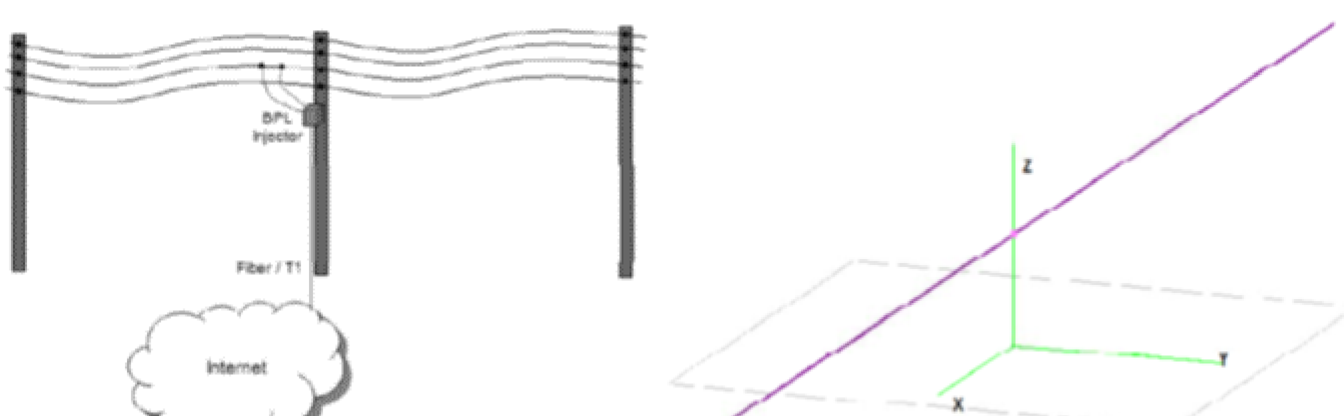


Figure 4.1126 Pictorial view of feeding one phase (unbalanced or common mode feed), similar to the way dipoles are fed and its model used in 4NEC2

The field strength (dBμV/m), in the near field was plotted in a plane 2m above the ground at frequency 20 MHz. With source impedance of 150Ω and load impedance of 500Ω, each method of feeding PLC signal to power line was modeled in the Near-field at a distance of 0 – 60 m perpendicular to the PLC source. The source power used was 1000W.

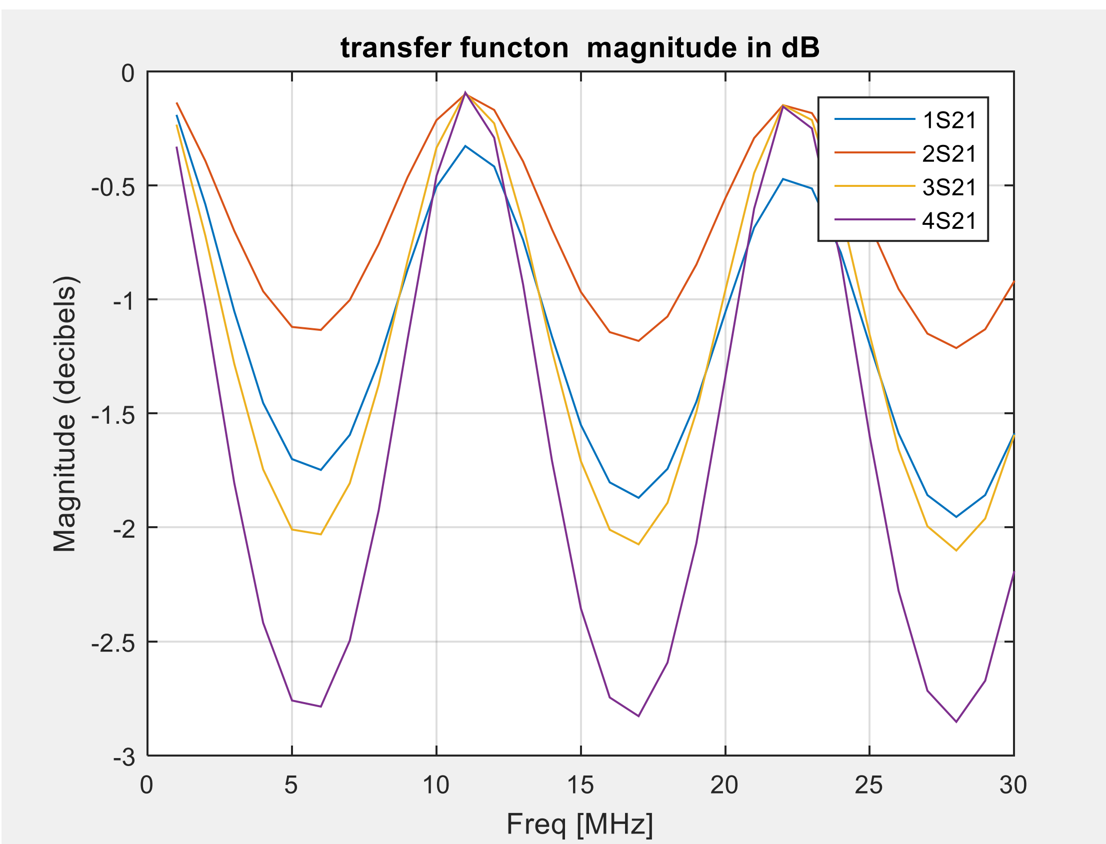
CHAPTER FIVE

RESULTS AND DISCUSSION

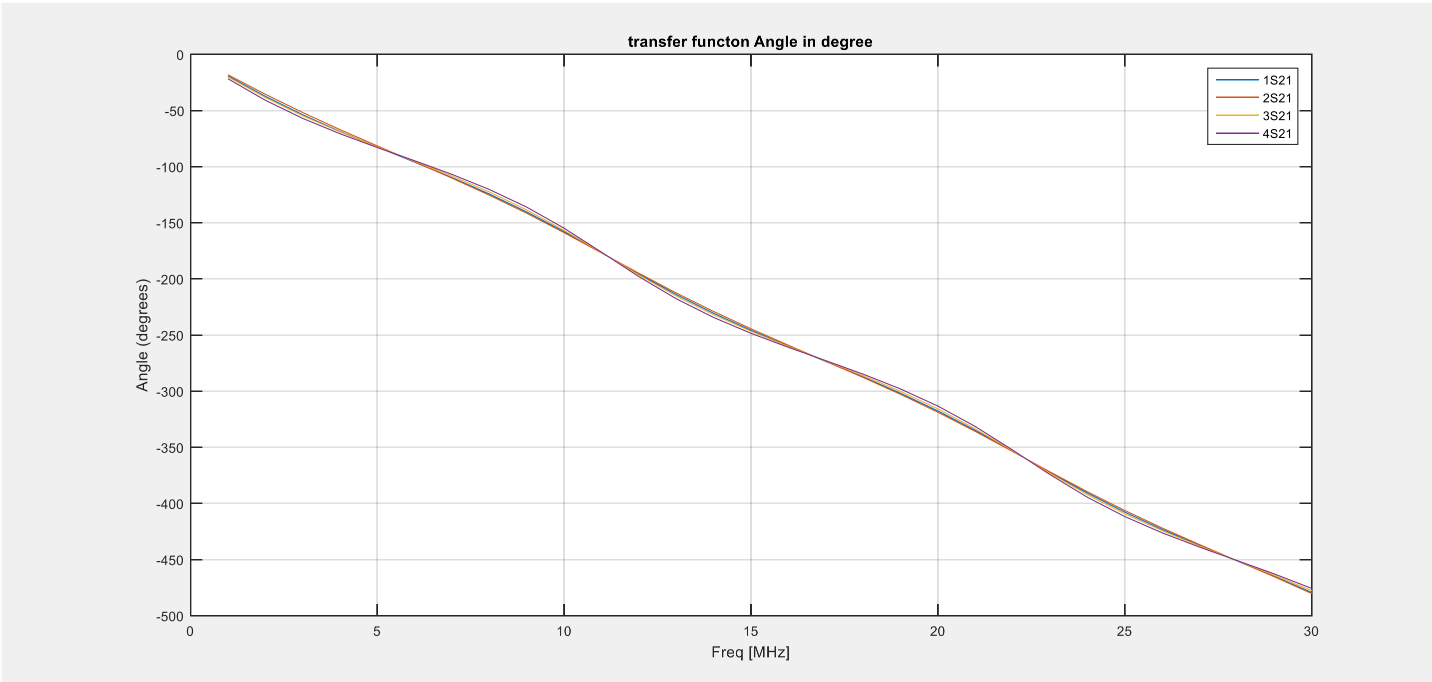
5.1 MATLAB RESULTS

5.1.1 Case 1: Effect of Varying Wire Separation on Transfer function

Software simulation using MATLAB was carried out to obtain the transfer function whose magnitude (dB) versus frequency plot gives the attenuation in the signal strength and angle (degree) versus frequency plot gives the phase distortion or delay as shown in Figure 5.1 (a) and Figure 5.1 (b) respectively for a typical separation of 5.02mm. 6.0mm 6.5mm and 7.5mm separation distance respectively.



a



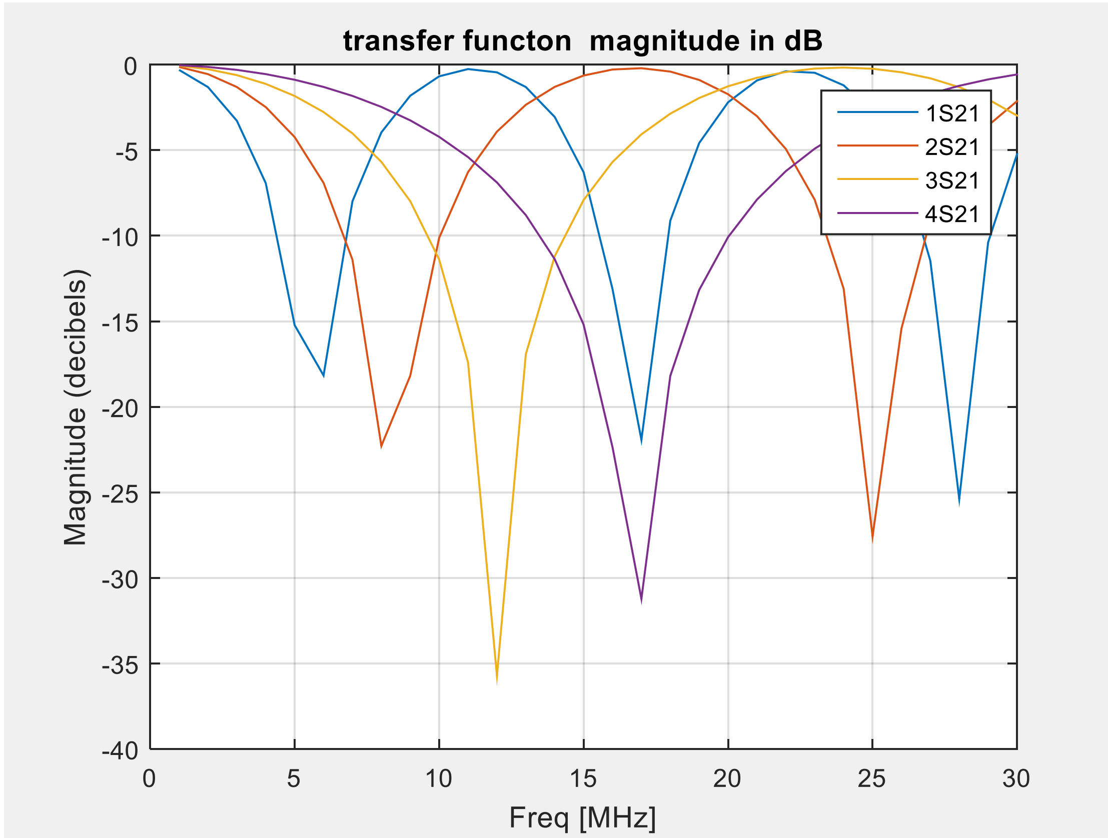
b

Figure 5.127 a-d shows the frequency response and phase response (a and c) simulated values

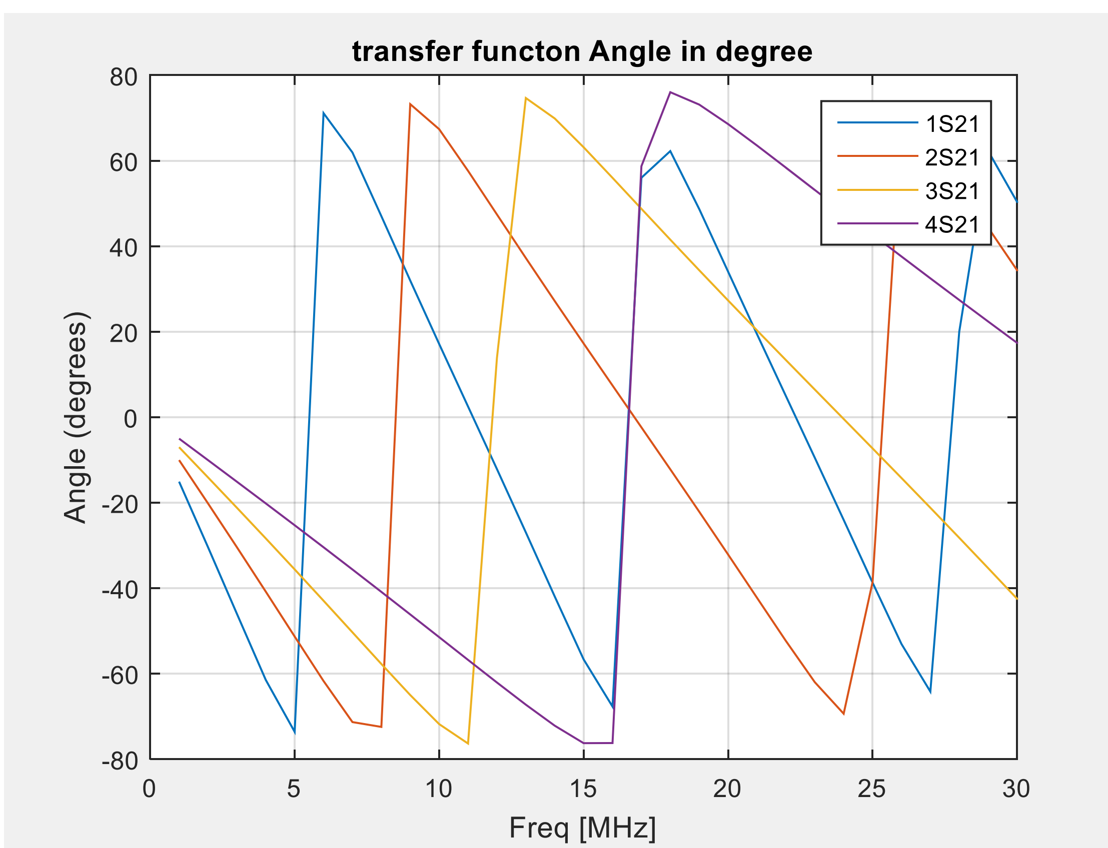
Figure 5.1a & b shows the frequency response and phase response of the different separation distance between two wires. It is observed that as the separation distance increases, the values of transfer function gradually decreases. The position of the notches and peaks with respect to frequency does not depend upon the separation distance of the wires. In Fig. 5.1 a & b, it is observed that phase responses also slightly loses its linearity significantly because of increase in separation distance of two wires and due to this the signal distorted..

5.1.2 Case 2: Effect of Varying Line Length on Transfer function

Software simulation using MATLAB was carried out to obtain the transfer function whose magnitude (dB) versus frequency plot gives the attenuation in the signal strength and angle (degree) versus frequency plot gives the phase distortion or delay as shown in Figure 5.2 a & Figure 5.2 b for a typical line length of 5m, 7m, 10m, and 15m show the simulations performed on different line length respectively.


transfer functon magnitude in dB
Magnitude (decibels)
Freq [MHz]
1S21
2S21
3S21
4S21
0
-5
-10
-15
-20
-25
-30
-35
-40
0
5
10
15
20
25
30

a


transfer functon Angle in degree
Angle (degrees)
Freq [MHz]
1S21
2S21
3S21
4S21
80
60
40
20
0
-20
-40
-60
-80
0
5
10
15
20
25
30

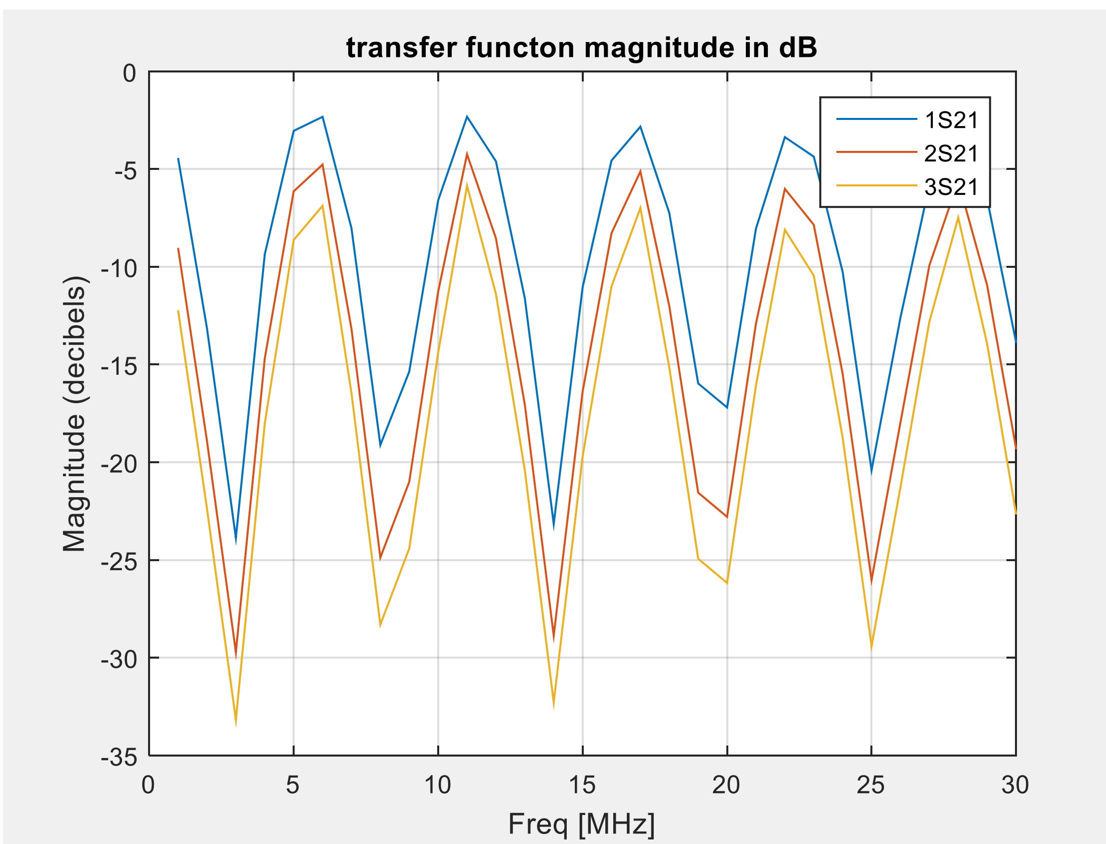
b

Figure 282 a-d shows the frequency response and phase response (a and c) simulated values

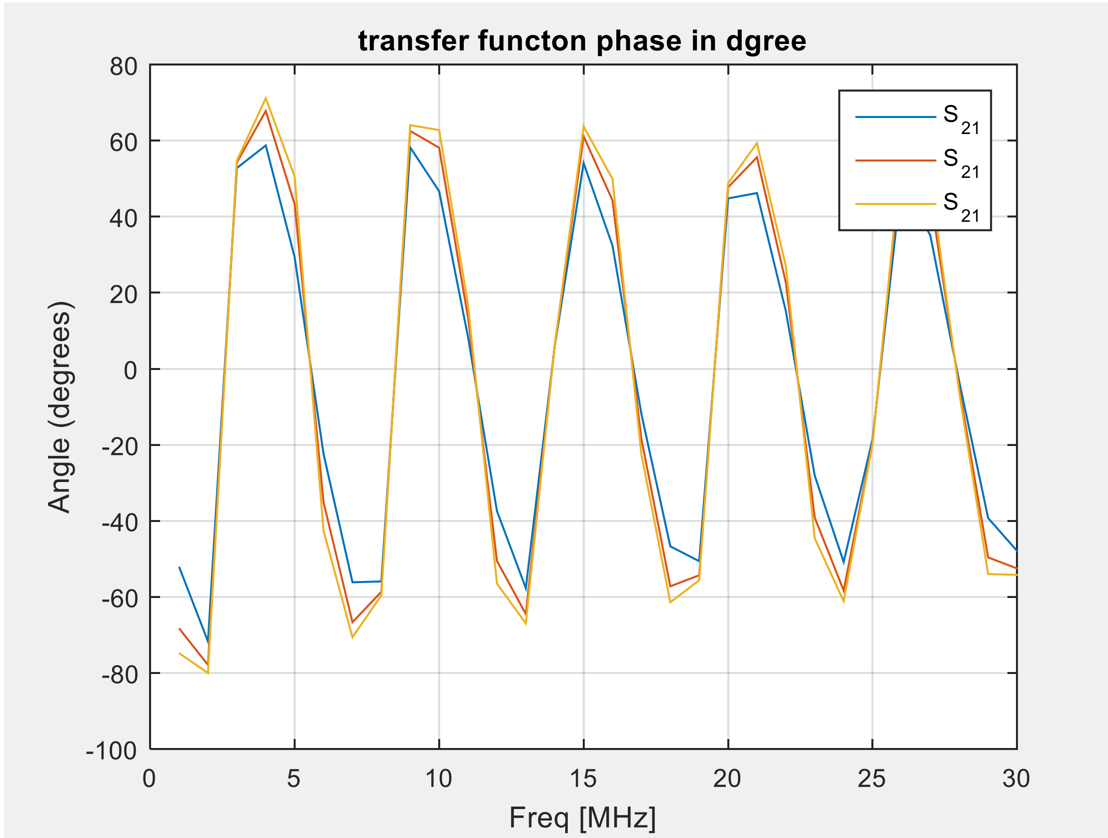
Figure 5.2 a. and d shows the frequency response and phase response of the power line network un- branch and with different lengths of the line. From the Fig.5.2, it has been observed that the position of notches and peaks are depend on line lengths and the phase is also shifted to the right as the line length is increased. As is obvious that as the line length is increased, notches is also increased proportionally, as expected. Also, Fig 5.2 a & b show that there is deep notch at certain frequencies in the transfer function when the line length is increased i.e. there is a non-linearity in the phase characteristics leading to phase distortion or delay.

5.1.3 Case 3: Effect of Number of Branches on Transfer function

Figure 5.3 (a)&(b) shows the frequency response and phase response of the power line network transfer function with one branch, with two branch lines, and with three branch lines.



a



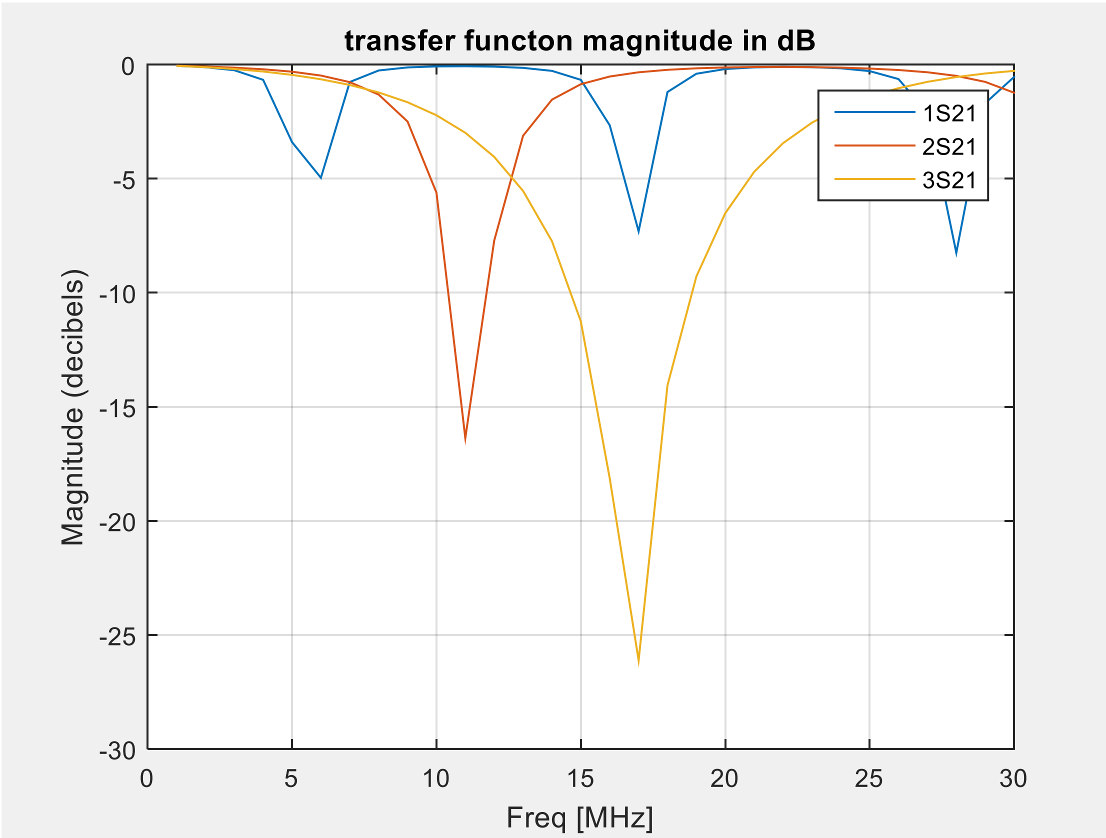
b

Figure 5.29 a-d shows the frequency response and phase response (a and b) are simulated values

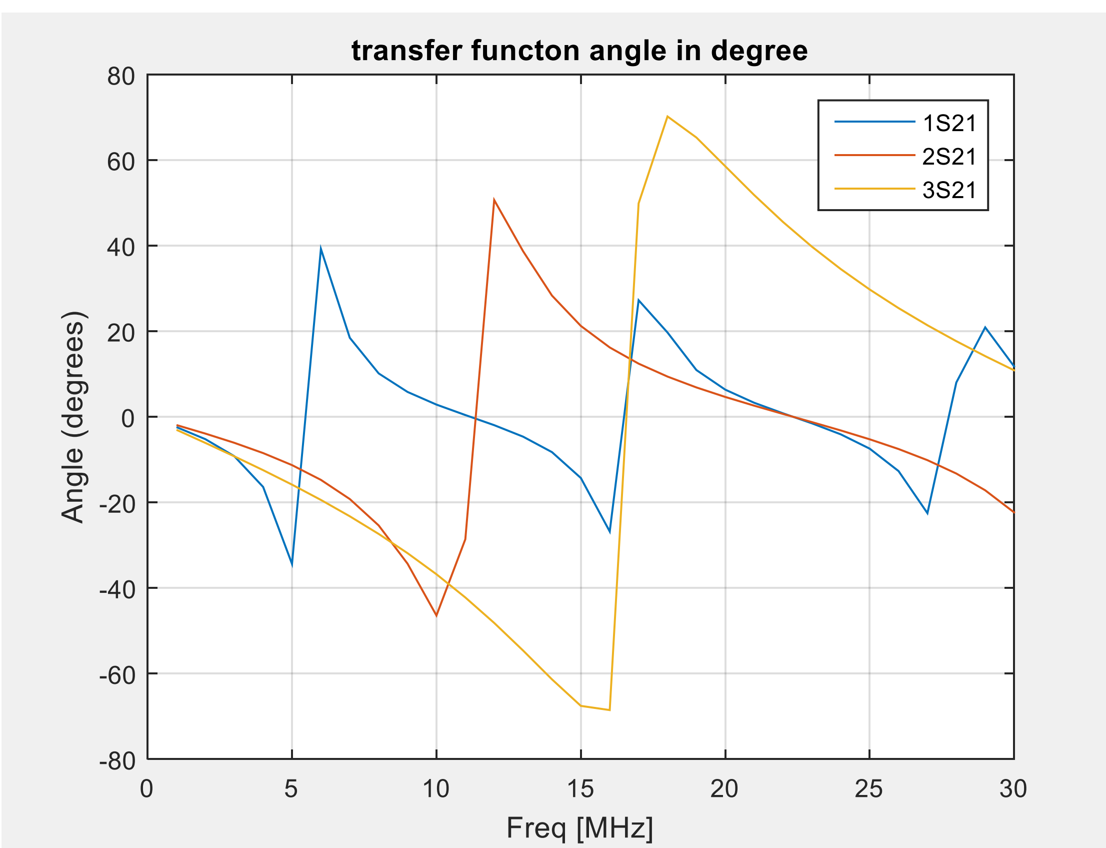
Figure 5.3 a &b shows the frequency response and phase response of the different number of bridge taps. It has been observed that as the number of branches increases, the values of magnitude of transfer function gradually decreases and the values of notches are also increased. The position of the notches and peaks with respect to frequency does not depend upon the number of branches. It has been also observed that as the number of branches increases signal attenuation value also increases gradually. In Figure 5.3a&b, it is observed that phase responses also loses its linearity because of increase in number of branches and due to this the signal will get distorted. From the Fig.5.3 a &b, it is observed that as the number of branches increases the signal will get attenuated.

5.1.4 Case 4: Effect of varying Branched line lengths on Transfer function

Fig. 5.4 (a)&(b) shows the simulated frequency response and phase response of the power line network transfer function as un-branched network i.e. 15m , as a two section cascaded network with each section having line length of 7.5m and finally as a three section cascaded network with each section having line length of 5m respectively.


transfer functon magnitude in dB
Magnitude (decibels)
Freq [MHz]
1S21
2S21
3S21
0
-5
-10
-15
-20
-25
-30
0
5
10
15
20
25
30

a

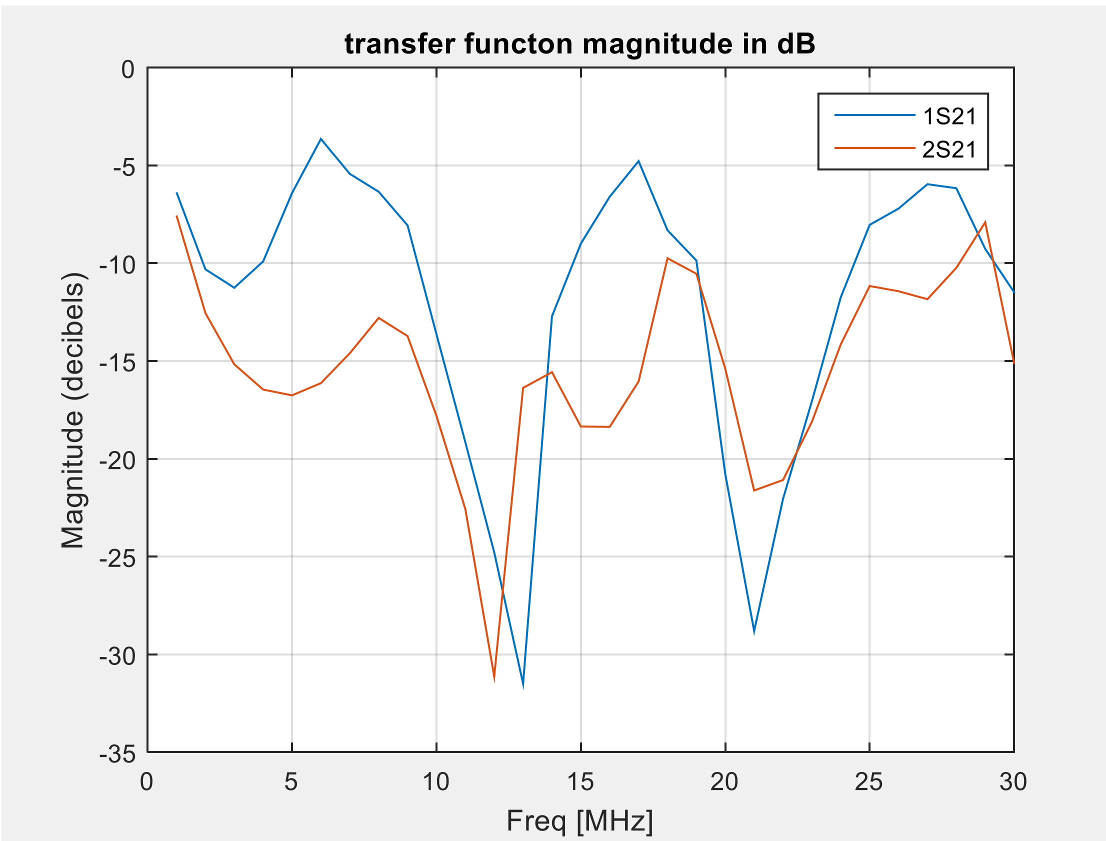

transfer functon angle in degree
Angle (degrees)
Freq [MHz]
1S21
2S21
3S21
80
60
40
20
0
-20
-40
-60
-80
0
5
10
15
20
25
30

b

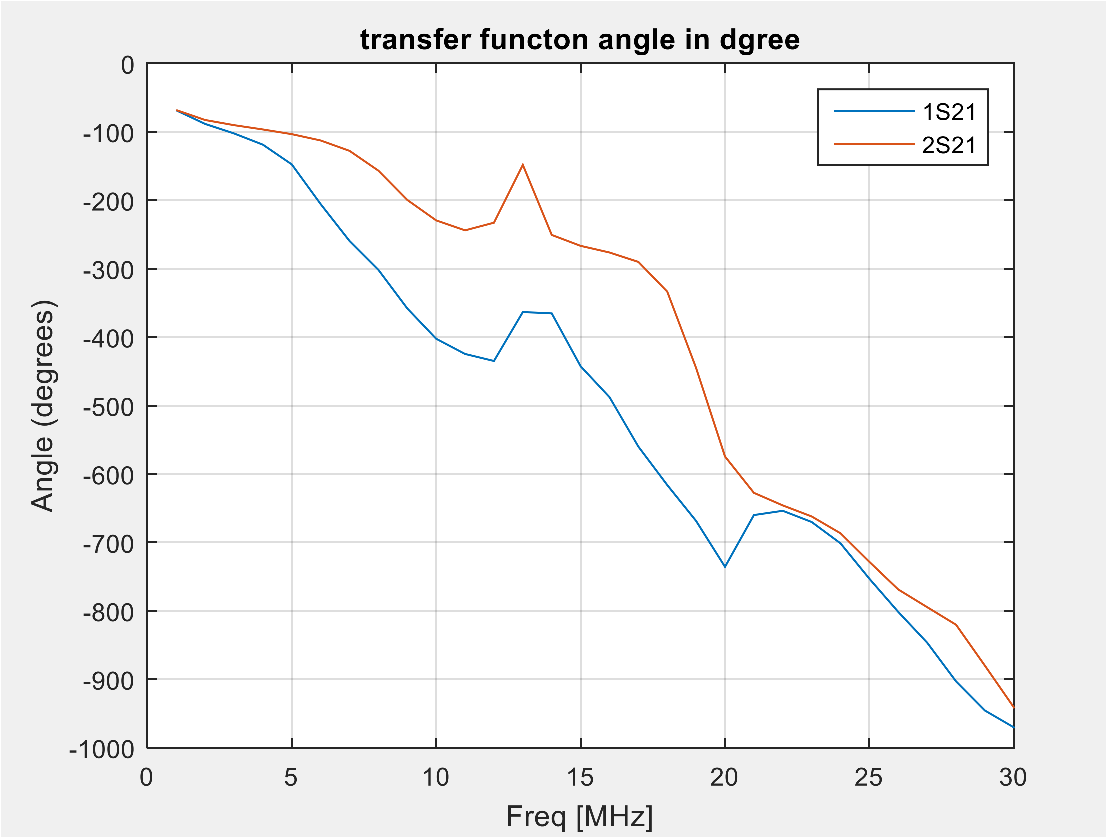
Figure 304 shows the simulated frequency response and phase response (a and b) are simulated values

From the Fig. 5.4 a &d, it has been observed that the position of notches and peaks, and number and value of notches are highly dependent of branch line lengths and the phase is also dependent. The position of notches are shifted to the right and values of notches are deeper result but number of notches looks like independent.

5.1.5 Case 5: Effect of number of branches at a single point as tap on transfer function



a



b

Figure 315 shows the simulated frequency response and phase response (a and b) are simulated values

In Fig. 5.5 a, & b. It has been observed that position of notches and peaks are remaining unchanged with respect to the frequencies but notches and peaks values are increased as the number of branches at a single point is increased. As the number of branches increases at a single node, the attenuation was not significantly affected .The behavior of the phase with respect to the changes of branches at a single node was not significantly affected.

5.2 NEC RESULTS

5.2.1 Case 1: Effect of power line wire spacing on PLC signal radiation

Table 6 shows how the radiated power, *P*rad varies on a line spacing of 0.55m, 1m, 1.5m and 2m. The radiated power increases significantly with increasing frequency because the spacing between the line conductors is larger relative to the wavelength as the frequency and line spacing increase. The maximum value shown is 24.21% of source power, which is 1000w (i.e. source power used during simulation) for the case of 30 MHz on 2m spacing line. This is not too surprising considering that 2m is 20% of a wavelength at 30 MHz. Things improve quickly as frequency lowers and the line spacing is reduced. A 1m spacing line at 20 MHz still radiates about 7.25% of the source power. That is, the difference between the source power P_{src} and the load power P_{load} must be completely due to radiation. Therefore, the percentage power radiated by the line P_{rad} is calculated using

$$P_{rad} = 100\ (1- P_{load}/\ P_{src})$$

Table 5 Simulation results of radiated power leakage of power lines with wire spacing 0.5 m, 1 m, 1.5 m and 2 m.

Frequancy MHz	**Percentage og radiated power**			
	0.55m	**1m**	**1.5m**	**2m**
5	0.137	0.347	0.711	1.192
10	0.636	1.798	3.612	5.733
15	1.408	4.067	7.988	12.18
20	3.11	7.25	14	20.13
25	3.14	7.974	14.73	22.05
30	4.209	9.803	17.11	24.21

5.2.2 Case 2: Effect of signal injection method on PLC signal radiation

The result is shown in Figure 5.6. In the balanced feed, the PLC signals traveling side by side down the wire generate fields that tend to cancel one another. The electric field near and along the PLC tends to decay with distance from the power line. The “horizontal balance” decay rapidly with distance compared to the “vertical balance”. This could be due to the difference in height of the conductors, in the “vertical balance”, which affect the electric field near the PLC power line.

The differential feed between a phase and a neutral (vertical with ground) is implemented by feeding PLC signal on a phase and the neutral line that typically runs at the lower boundary of the “power space” on the utility poles. The near fields at 20 MHz associated with this configuration are shown as “vertical with ground” in Figure 35.

The field suppression compared to the unbalanced case “single wire feed or common mode injection” is apparent, but not as good as with the (vertical and horizontal) balanced configurations. The effectiveness of the “vertical with ground” configuration may be seriously compromised by the grounding wires that are typically connected to the neutral wire. For the “vertical with ground” configuration in Figure 5.6, the electric field radiation does not measurably decay with distance from the device (along the power line). At point y= 2.5 and 4.5 in Figure 5.6 b and a respectively, the electric field actually increased with increasing distance from the BPLC devices. This is thought to be due to BPLC signal reflection by one or more impedance discontinuities and the generation of standing waves. In general the location variability in the field is thought to be due to the presence of standing waves in the current distribution along the power line.

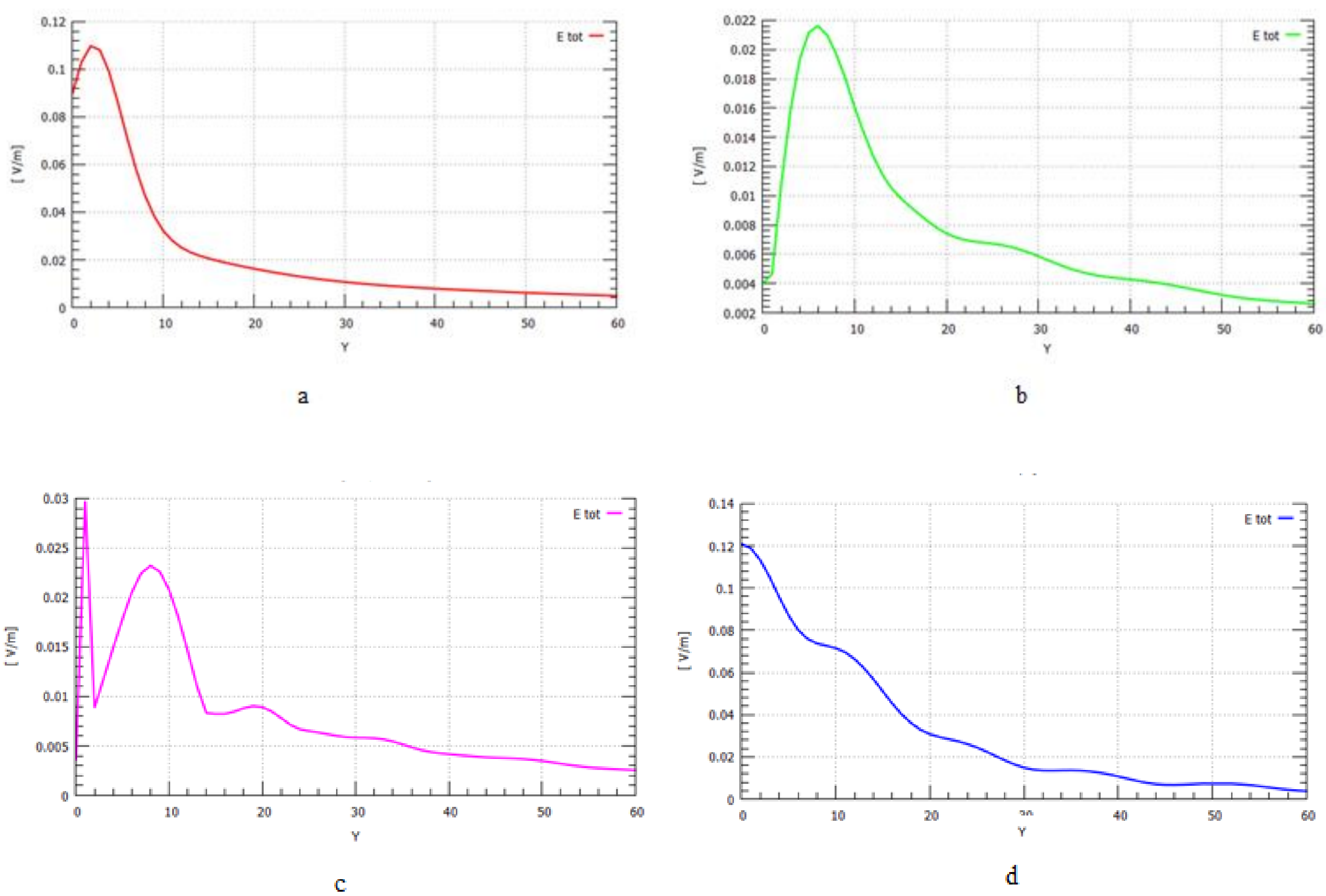


Figure 32.6 simulation results of electric field radiations of power lines with various methods of feeding PLC signals on them at 20MHz. the various methods are (a) Vertical feed, (b) Horizontal feed, (c) Vertical with ground feed and (d) single wire feed.

As we see the result of simulation, the spacing between the wires on the power lines has effect on the radiation leakage. As wire spacing increases and external cancellation degrades, radiation escapes similar to those of long wire antennas. External cancellation of equal and opposite fields relies on the signals on the two wires being of opposite sign, equal in amplitude, and physically close together in terms of wavelength. High levels of radiation suppression can be achieved only if the wires are very close together in terms of wavelength and carry carefully balanced signals. As a guide to what kind of line spacing is suitable for transmission line use, consider the open wire lines in common use in the radio and TV industries. Open wire line normally used at HF frequencies (less than 30 MHz) is typically 450-ohm "ladder line" with 2 cm spacing. The open wire line used at VHF (300 ohm TV "twin lead") has about 6.5 mm spacing. At worst case, the line spacing is less than 1% of a wavelength [20]. To minimize line radiation, the distance between the conductors should be a very small fraction of a wavelength [17]. For the usual conductor spacing used in overhead distribution lines, this requirement is clearly not satisfied at PLC frequencies.

In Ethiopia, several residence are served from a single phase low-voltage (LV) cable operating at 220 V. Key challenges at the physical layer include dealing with the high losses of the cable (several tens of decibels in a few hundred meters) and multiple, possibly time-varying, reflections associated with taps to individual residences. Neglecting all these factors, radiated interference from LV cables is relatively very low compared to medium-voltage (MV) and high voltage (HV) cables. This is because the conductors in the LV cable are closely spaced, so their radiation fields decay rapidly with distance from the cable [21].

In differential mode injection, reverse and forward paths are two currents flowing with the same amplitude in opposite directions. These currents travel in two parallel identical conductors with relatively small separation distance. Due to their opposite direction and small separation distance, their radiated electric fields tend to cancel out one another. On the other hand, in common mode injection, forward path is a current flow in one phase conductor and the return path is ground surface, which is a dielectric with losses [22]. Also, in common mode injection, forward current travels in a near-perfectly conducting material, whereas return current has to go through a material with loss. Because of all these facts, it is expected that the cancellation of electric fields, emitted from forward and return paths, in common mode injection, is much less than those in differential mode injection.

CHAPTER SIX

CONCLUSION

From the simulation work carried out, the following findings were made:

6.1 From Matlab Results

It is observed that as the separation distance increases, the values of transfer function gradually increases. The position of the notches and peaks with respect to frequency does not depend upon the separation distance of the wires. It is also observed that signal attenuation value is not much affect by separation distance increment.

The position and number of notches and peaks are depend on line lengths and the phase is also losses its linearity as the line length is increased. As is obvious that as the line length is increased, the number of such notches is also increased proportionally, as expected.

As the number of branches increases, the values of transfer function gradually decreases and the number of notches are also increased. The position of the notches and peaks with respect to frequency does not depend upon the number of branches. It is also observed that as the number of branches increases signal attenuation value also increases gradually. It is observed that phase responses also loses its linearity because of increase in number of branches and due to this the signal will get distorted. It is observed that as the number of branches increases the signal will get both distortion as well as attenuation.

Position of notches and peaks are remaining unchanged with respect to the frequencies but notches and peaks values are decreased as the number of branches at a single point is increased. As the number of branches increases at a single node, the attenuation also increases .The behavior of the phase with respect to the changes of branches at a single node is significantly affected

6.2 From NEC Results

As wire spacing of power lines increases, the external field cancellation degrades resulting in higher radiation leakages.

Horizontal power lines such as the medium voltage power network radiates less PLC signals compared to the low voltage vertical power lines. The vertical power lines configuration may be seriously compromised by the grounding wires that are typically connected to the neutral wire. These grounds unbalance the system and degrade the cancellation associated with differential drive.

Differential mode PLC signal injection onto power lines significantly reduces radiation leakage than Common mode PLC signal injection. In differential mode injection radiation leakage from currents flowing opposite directions with the same amplitude tends to cancel out one another. On the other hand, in common mode injection, current flow in one phase conductor and the return path is ground surface, which is a dielectric with losses.

Broadband over power lines presents a unique opportunity to provide broadband access all over the country using the existing power distribution grid. A country should start the issue by arranging good policy and regulation in the regulatory area. BPL has been able to largely overcome the issue of harmful interference. Although the optimal price setting methodology a regulated utility should employ when entering the competitive broadband services market remains uncertain, the utilities (i.e. Ethiopian Electric Utility EEU) should have to establish incentives for the deployment of BPL in the efficiency improvements for the coming BPL communication technology deploying in the power distribution grid. Although BPL may have a difficult time competing with cable and ADSL in the established broadband services market on price alone, the performance enhancements provided by intelligent network capabilities will make tremendous headway towards defraying the cost of the infrastructure.

Even though the importance and direct socioeconomic impact of access to broadband services are well understood, presently solely less than seventeen percent of the Ethiopian's total population has access to some kind of internet services, typically via ADSL and Mobile internet. BPL offers a brand new, probably powerful different suggests that of providing high-speed net services, VoIP, and alternative broadband services to homes and businesses by exploitation existing MV and LV power lines. As a result of roughly 41 % of Ethiopian population have access to power lines, BPL may play a major role in bridging the prevailing digital divide. The Broad Band over Power Line communication network technologies will have potential for Ethiopian telecom network and will grow extensively in near future for higher capacity applications e.g. Triple Play services (telephony, data and TV etc.). Ethiopian Broadcasting Corporation is on the way to install cable TV services for some Ethiopian cities like Addis Ababa, and regional cities so BPL will give another choice to do so. Also BPL is a better option with less cost for network operators. BPL is already on the scene with commercial products readily available. Green Energy technologies like Solar, Wind etc. may be used as Power Line solutions. Combination of BPL with AADSL, 3G, 4G, etc. may be economical solution for access networks in future.

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