INTERFERENCE DUE TO BROADBAND OVER POWER LINES

SUBMITTED IN THE PARTIAL FULFILLMENT FOR THE DEGREE OF

Master of Engineering

(CONTROL AND INSTRUMENTATION)

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CERTIFICATE

This is to certify that Major Project titled "**INTERFERENCE DUE TO BROADBAND OVER POWER LINES**", which is submitted by Ms. Pratibha Sharma is partial fulfilment for the degree of **MASTER OF ENGINEERING** (**Control and Instrumentation**) of the **Electrical Engineering Department, Delhi College of Engineering,** Bawana Road, Delhi is a bonafide record of work, she has carried under my guidance and supervision.

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ACKNOWLEDGEMENT

I would like to extend my sincere gratitude and thanks to my guide **Dr. Parmod Kumar**, Professor and Head of The Department, Electrical Engineering Department, Delhi College of Engineering, Delhi for his valuable guidance, constant encouragement and helpful discussions throughout the course of this work. Obviously the progress I had now would be uncertain without his assistance.

I would also like to thank all my friends mainly Ms. Devangli, Ms. Parul and Mr. Ravi Tiwari and respected Rachna garg madam for immense help, advice and cooperation to complete this work.

I would also like to thank all members of Bharati Vidyapeeth, College of Engineering for their help whenever I needed.

Last but not the least I am extremely grateful to my parents, my husband Pankaj, my son Shubh, my niece Dishita and my in-laws for their encouragement, support and dedication which have helped me in great way to complete this work

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ABSTRACT

The growing need for communication has fueled the need for finding cost effective methods for data and voice transfer. Researchers have been toying with the idea of finding better and ubiquitous methods of communication, which could take advantage of the existing infrastructure. One such technology is Broadband Over Power Line. This technology uses the existing electric transmission lines as a carrier channel for delivery of broadband to the consumers.

Though in some form the technology existed for quite time yet it was remotely ventured field in terms of mass scale usage. However, the technology is now looked upon to provide a seamless communication mode; to even the remotest areas, which otherwise faced a challenge in terms of having connectivity. Given its reach and penetration the technology provides a clear edge over similar technologies like wireless or wired broadband, where the cost of roll out sometimes could be commercially unviable.

However the technology faces tough issues in a real life scenario due to certain disadvantages that occur during the propagation of communication signals over power lines. One of the major burdens of BPL technology is the electromagnetic compatibility (EMC) with other wireless systems. Since electric wires might radiate electromagnetic waves at high frequencies, precautions need to be employed in order to avoid any interference to other wireless devices.

In this thesis I have used a modeling of multi-conductor wave propagation in overhead lines. The proposed model incorporates realistic ground admittance, appropriate for higher frequencies used by broadband over power line communications. By calculating the lossy ground impedance for multi-conductor lines, we derive for electric field and magnetic field radiated .In this dissertation rigorous procedure is presented for the evaluation of the rectangular components of the electromagnetic field radiated by excited carrier channels on multi-conductor overhead power lines above a lossy ground The proposed full wave approach, based on the use of Hertz potentials, allows to carry out the

high-frequency analysis of a spread spectrum transmission system. Field sources are the current traveling along the line, which are evaluated by means of an accurate line simulation model including the ground return parameters, obtained by removing the Carson quasi-static hypotheses. The frequency-spectra of the field components radiated from wire-to-ground channels on a three-conductor distribution line are computed in a frequency-range up to 10 *MHz*.

LIST OF FIGURES

LIST OF ABBREVIATIONS

1.	AM	Amplitude Modulation
2.	ASK	Amplitude Shift Keying
3.	ATR	Automatic Target Recognition
4.	BFWA	Broadband Fixed Wireless Access
5.	BPL	Broadband Over Power Line
6.	CM	Common Mode
7.	CPE	Customer Premise Equipment
8.	CSMA	Carrier Sense Multiple Access
9.	CT	Continuous Time
10.	DMT	Discrete Multi-Tone Modulation
11.	DSL	Digital Subscriber Line
12.	DSSS	Direct Sequence Spread Spectrum
13.	DT	Discreet Time
14.	EM	Electromagnetic
15.	EMC	Electromagnetic Compatibility
16.	EMI	Electromagnetic Interference
17.	FDM	Frequency Division Multiplexing
18.	FM	Frequency Modulation
19.	FSK	Frequency Shift Keying
20.	HDTV	High Definition Television
21.	HF	High Frequency
22.	HV	High Voltage
23.	ISP	Internet Service Provider
24.	LAN	Local Area Network
25.	LV	Low Voltage
26.	MDL	Multi Conductor Transmission Line
27.	MEMS	Micro Electromechanical Sensors
28.	MV	Medium Voltage
29.	MW	Medium Wave
30.	NDE	Non Destructive Evaluation
31.	OFDM	Orthogonal Frequency Division Multiplexing
32.	PCB	Printed Circuit Board
33.	PLC	Power Line Communication
34.	PLCU	Power Line Carrier Unit
35.	PN	Pseudo Noise
36.	PSK	Phase Shift Keying
37.	QAM	Quadrature Amplitude Modulation
38.	RCS	Radar Cross Section
39.	RF	Radio Frequency
40.	TE	Transverse Electric Mode
41.	TEM	Transverse Electric Magnetic Mode
42.	TL	Transmission Line
43.	TM	Transverse Magnetic Mode

44.	US	United States
45.	VHF	Very High Frequency
46.	WTG	Wire To Ground
47.	WTW	Wire To Wire
48.	SHF	Super High Frequency
49.	UHF	Ultra High Frequency
50.	ISP	Internet Service Provider
51.	QPK	Ouardature Phase Keying

CHAPTER 1

INTRODUCTION

1.1-Introduction

The increasing interest in modern multimedia applications, such as broadband Internet, HDTV, etc. and a need for a seamless and ubiquitous communication media requires new access techniques for connecting the private premises to a communication backbone. One such promising technology is Broadband over Power line (BPL). Broadband Over Power line uses electric power lines as a high-speed digital data and voice carrier channel to connect a group of private users to a very high data rate backbone, such as fiber optic. [12]

Broadband over Power Lines is use to provide broadband Internet access through ordinary power lines. BPL offers obvious benefits over regular cable or DSL connections: the extensive infrastructure already available would appear to allow more people in more locations to have access to the Internet.

BPL offers obvious benefits over regular cable or DSL connections: the extensive infrastructure already available would appear to allow more people in more locations to have access to the Internet. Also, such ubiquitous availability would make it much easier for other electronics, such as televisions or sound systems, to take advantage of the voice and data transfer .

As electricity is being supplied via a permanent connection, the data service offered over the electrical infrastructure is also permanently connected (no need to dial up the connection), making it ideal for the increasing number of online services. Power utilities will thus be able to market a basic Internet connection service at a flat-rate monthly subscription, like some cable operators. [1]

By giving electricity customers access to the Internet through their existing electrical supply system; the technology is available to virtually anyone, giving the technology potential mass-market scale, without having to invest in digging cable links to homes.

The lines used for delivery of broadband are same as those used for transmission of electricity. The lines in power delivery network can be categorized based on several criteria. Depending on line voltage, HV (high voltage), MV (medium voltage), and LV (low voltage) grids are typically defined. Most HV/MV transformers locations are equipped with a high-speed fiber connection. Therefore, MV lines can act as the first pipeline of high-speed connection from backbone to the home users. [1][3]

The development of newer, faster digital processors and sophisticated modulation schemes has allowed the creation of carrier current devices that overcome the earlier obstacles caused by the noise and impedance mismatch of power lines. BPL systems have been developed that use spread spectrum or multiple carrier techniques with adaptive algorithms to counter noise present on the lines. [2] These new unlicensed BPL systems provide high speed communications by coupling RF energy onto either the power lines inside a building ("In-House BPL") or onto the medium voltage (MV) power distribution lines ("Access BPL").

An important factor that should be considered for evaluating BPL system performance is interference with other wireless systems. Electromagnetic interference poses a challenge in penetration of this technology.

In general, emission from a single line is highly dependant on the impedance between the line and ground. In theory, emissions from differential aerial mode currents cancel one another at far field, given line symmetry (balanced loads). MV power-lines are not typically symmetrical; discontinuities might occur at different locations on different wires, causing asymmetry. Asymmetry causes broadening of near-field and far-field patterns. The recent research advancements are aimed at resolving this issue for utilizing the accrued benefits derived from using BPL. [5]

1.2-Objective Of The Study

The technology uses the power transmission lines which otherwise are used to provide electricity to the users. BPL technology operates through the use of radio frequency signals conducted along power lines in the electricity supply network. However, the electricity supply network was not designed for this purpose and so these signals will leak from the power lines. Leakage of the signal occurs as a radio frequency electromagnetic emission from the power lines and has the potential to cause interference to radio communications services, particularly where power lines are above ground.

There is a risk that undesirable amounts of the BPL radio frequency signals will radiate into the surrounds from the power lines and interfere with other uses of the radio communications spectrum.

Another major burden of BPL is the electromagnetic compatibility (EMC) of this technology to other wireless systems. Since electric wires might radiate electromagnetic waves at high frequencies, precautions need to be employed in order to avoid any interference to other wireless devices.

This particular thesis is an effort to ascertain the electromagnetic interferences that occur on delivery of broadband over power line and understanding the rectangular component of such interferences.

1.3-Problem Identification

In this particular thesis my effort is to understand the issue of electromagnetic field radiated from broadband signal transmission on a power line carrier channels over a multi conductor overhead line above a lossy ground by exciting the line of infinite length and understanding the probable interferences that might occur due to the electromagnetic radiation.[4][6]

The evaluation of the electromagnetic field radiated from overhead power lines carrier channels with wire to wire or a wire to ground coupling in a wide frequency range, up to some tens megahertz is done in my project.

The proposed analytical procedure of general validity is applied to the computation of the electromagnetic interferences from carrier channels on a medium-voltage three-conductor overhead power line above a lossy ground.

The high frequency analysis requires a full wave approach for the development of the carrier channel simulation model and the related electromagnetic filed. The rectangular components of the electric and magnetic fields radiated from the multi-conductor line are defined as functions of the hertz potentials following the procedure prepared by Wait and Olsen. [3][4]

The proposed analytical procedure of general validity is applied to the computation of the electromagnetic interference from carrier channels on a medium-voltage three-conductor overhead line above a lossy ground.

Field sources are the current travelling along the line, which are evaluated by means of an accurate line simulation model including the ground return parameters, obtained by removing the Carson quasi-static hypotheses.

The frequency-spectra of the field components radiated from wire-to-ground and wire-to-wire channels on a three-conductor distribution line are computed in a frequency-range up to 10 *MHz*.

The electric field E and the magnetic field H are defined by using the components of the electric and magnetic Hertz potentials in which the E-field operators are the following: parallel to the-direction of propagation of the guided current waves.

1.4-Dissection of Dissertation

Chapter one consists of having a general understanding of the objective and need for carrying out research on the issue of interference that occur during the transmission of communication units (data/voice packets) over a transmission line.

In chapter two we try to understand the concept and technology of broadband over power line. The issues concentrated in this particular chapter are those pertaining to history review, types of broadband over power lines, its benefits, limitations and other issues related to frequency, carrier channels, interferences and environment under which broadband over power line operates.

In chapter three basic theory of electromagnetism and radiation theory are discussed. Then the issues of electromagnetic interference over a conductor line above a lossy ground are explained.

In chapter four mathematical modelling is undertaken to ascertain the issue of electromagnetic interference over a conductor line above a lossy ground. The modelling is based on an assumed environment and tries to create a framework for understanding the rectangular components of such interferences. Simulation is carried out in an assumed environment in MATLAB 7.0 software. The code carried out to develop this simulation is given in appendix C

Chapter five gives the result of the simulated model and further scope of this particular study. The results are used to decipher the problem and find a probable solution for the same.

Future works that can be undertaken in this particular field forms the part of chapter six. This chapter provides the deductions and conclusions derived out of this study and issues of future studies.

1.5-Conclusion

Chapter one concludes our basic understanding and introduction about broadband over power line; specifically those related to problems of interference. This chapter also highlights the need for selection of this particular topic of research and the probable areas of related research. Further the chapter provides a starting point for the research topics and issues to follow.

CHAPTER 2

REVIEW WORK

2.1- Introduction

2.1.1- Signal

A signal is a codified message, ie, the sequence of states in a communications channel that encodes a message. In a communications system, a transmitter encodes a message into a signal, which is carried to a receiver by the communications channel. One of the fundamental distinctions between different types of signals is between continuous and discrete time.[3] In the mathematical abstraction, the domain of a continuous-time (CT) signal is the set of real numbers (or some interval thereof), whereas the domain of a discrete-time signal is the set of integers (or some interval).[16] What these DT signals often arise via of CT signals.[8] For instance, sensors output data continuously, but since a continuous stream is impossible to record, a discrete signal is used as an approximation.[11]

Computers and other digital devices are restricted to discrete time.integers represent depends on the nature of the signal.[9] Information theory studies both continuous signals, commonly called analog signals; and discrete signals (Shannon 2005),[34] or quantized signals, of which the most common today are digital signals.

Analog Signal

An analog or analogue signal is any variable signal continuous in both time and amplitude. It differs from a digital signal in that small fluctuations in the signal are meaningful. Analog is usually thought of in an electrical context, however mechanical, pneumatic, hydraulic, and other systems may also use analog signals.An analog signal uses some property of the medium to convey the signal's information. Electrically, the property most commonly used is voltage followed closely by frequency, current, and charge.[16]

The primary disadvantage of analog signalling is that any system has noise that is, random variation — in it. As the signal is copied and re-copied, or transmitted over long distances, these random variations become dominant. Electrically, these losses can be diminished by shielding, good connections, and several cable types such as coaxial or twisted pair.[12]

Digital Signal

A digital signal is a signal that is both discrete and quantized. Its primary counterpart is an analog signal. Digital signals usually occur in electronics, but may be found in other fields of engineering as well.Some are inherently both discrete and quantized (eg. the number of people who visit a certain establishment every day).[14]

Some describe phenomena that are actually continuous in one-way or another. The signal must be discretized, quantized, or both, in order to make it digital. This "digitization" is required if the signal is to be processed in a computer or any other electronic device.[13]

In short, the difference between them is that digital signals are discrete and quantized, as defined below, while analog signals possess neither property.

In information theory, the message is generated by a stochastic process, and the transmitted signal derives its statistical properties from the message. Conversely, usage of signal in reference to a process that generates a transmitted sequence of states in a communications channel implies that this process is stochastic.[17]

The Information in Broadband Over Power line is transmitted in the form of packets. These data packets use the carrier media and are decoded at the source end.

The two widely used methods are OFDM and DSSS

Orthogonal Frequency-Division Multiplexing (OFDM)

Also called discrete multi-one modulation (DMT), is a complex modulation technique for transmission based upon the idea of frequency-division multiplexing (FDM) where each frequency channel is modulated with a simpler modulation. In OFDM the frequencies and modulation of FDM are arranged to be orthogonal with each other, which almost eliminates the interference between channels.[15][36]

Direct Sequence Spread Spectrum (DSSS)

This is probably the most widely recognized form of spread spectrum. The DSSS process is performed by effectively multiplying an RF carrier and a pseudo-noise (PN) digital signal. First the PN code is modulated onto the information signal using one of several modulation techniques (for example BPSK, QPSK,extra)[18] Then, a doubly balanced mixer is used to multiply the RF carrier and PN modulated information signal. This process causes the RF signal to be replaced with a very wide bandwidth signal with the spectral equivalent of a noise signal.[37] The demodulation process (for the BPSK case) is then simply the mixing/multiplying of the same PN modulated carrier with the incoming RF signal. The output is a signal that is a maximum when the two signals are exactly equal to one another or are "correlated". The correlated signal is then filtered and sent to a BPSK demodulator.

The signals generated with this technique appear as noise in the frequency domain. The wide bandwidth provided by the PN code allows the signal power to drop below the noise threshold without loss of information.

Two Design Philosophies

There are two basic philosophies of reliably (that is, with acceptable error rates) transmitting data over ac lines:

- Accept the poor quality of the medium. Design a system that minimizes the most common errors. Make the system recover quickly and gracefully from dropouts, so that users never notice transmission problems.

- Look for a "magic bullet"— means of getting signals across the power line unscathed, despite the hostility of the medium. Even proponents of the second philosophy acknowledge that error correction is essential to achieving acceptable error rates.

Traditional BPL systems (both narrowband and spread-spectrum) use carrier frequencies below the medium-wave (MW) broadcast band (that is, below; 500 kHz). The oldest commercial BPL-communication system, X-10 USA's X-10 home-control system (also sold under several other brand names) uses an amplitude-modulated, 120-kHz carrier. [19]

There are certain important issues, which must be taken care of for seamless signal propagation. Keeping the packets small increases the probability of squeezing packets between noise bursts, which, if they occur during a packet, corrupt the data. (Here, noise burst refers not just to noise voltages on the line, but also to sudden drops in line impedance that attenuate signals for brief periods.)[22]

In order to solve the aforementioned problem of a multiple connection, there has been disclosed a new method named a carrier sense multiple access (CSMA), in which a signal transmission is begun after it is confirmed before the transmission that no channel is in use and no signal is present in the channels is also explored. However, this method is not helpful to avoid the collision if two nodes make transmissions at an exactly identical time. [35]

The aforementioned phenomenon happens when more than two nodes wait for the time when channels, most of which are occupied by particular nodes, become available for use after completion of communication and all the nodes start transmission at the same time.

In order to prevent a collision, it is necessary to prevent two nodes from waiting together and making a simultaneous transmission. As a method to solve the aforementioned problem, there has been a method in which two nodes waiting for the time to use channels discriminate whether the nodes become available for use and then start a transmission after respective random time delays[37]. At this time, if there is a difference in the time delays, one node firstly uses a channel and the other node starts communication after waiting for the channel to be available again.

2.1.2-Transmission Lines

A transmission line is the material medium or structure that forms all or part of a path from one place to another for directing the transmission of energy, such as electromagnetic waves or acoustic waves, as well as electric power transmission. Components of transmission lines include wires, coaxial cables, dielectric slabs, optical fibres, electric power lines, and waveguides[45]

Types Of Transmission Lines

Coaxial Cable

Coaxial lines confine the electromagnetic wave to the area inside the cable,between the center conductor and the shield. The transmission of energy in the line occurs totally through the dielectric inside the cable between the conductors. Coaxial lines can therefore be bent and twisted (subject to limits) without negative effects, and they can be strapped to conductive supports without inducing unwanted currents in them

In radio-frequency applications up to a few gigahertz, the wave propagates in the transverse electric magnetic (TEM) mode, which means that the electric and magnetic fields are both perpendicular to the direction of propagation. [49]

However, above a certain frequency called the cutoff frequency, the cable behaves as a waveguide, and propagation switches to either a transverse electric (TE) or a transverse magnetic (TM) mode or a mixture of modes[24]. This effect enables coaxial cables to be used at microwave frequencies, although they are not as efficient as the more expensive, purpose-built wave guides.

Microstrip

A microstrip circuit uses a thin flat conductor which is parallel to a ground plane. Microstrip can be made by having a strip of copper on one side of a printed circuit board (PCB) or ceramic substrate while the other side is a continuous ground plane. The width of the strip, the thickness of the insulating layer (PCB or ceramic) and the dielectric constant of the insulating layer determine the characteristic impedance.[29]

Stripline

A stripline circuit uses a flat strip of metal which is sandwiched between two parallel ground planes, The insulating material of the substrate forms a dielectric. The width of the strip, the thickness of the substrate and the relative permittivity of the substrate determine the characteristic impedance of the strip which is a transmission line.

Lecher Lines

Lecher lines are a form of parallel conductor that can be used at UHF for creating resonant circuits. They are used at frequencies between HF/VHF where lumped components are used, and UHF/SHF where resonant cavities are more practical.[35]

Application Of Transmission Lines

Signal Transmission

Electrical transmission lines are very widely used to transmit high frequency signals over long or short distances with minimum power loss. One familiar example is the down lead from a TV or radio aerial to the reciever.

Pulse Generation

Transmission lines are also used as pulse generators. By charging the transmission line and then discharging it into a resistive load, a rectangular pulse equal in length to twice the electrical length of the line can be obtained. These are sometimes used as the pulsed energy sources for radar transmitters and other devices.

Stub Filters

If a short-circuited or open-circuited transmission line is wired in parallel with a line used to transfer signals from point A to point B, then it will function as a filter. The method for making stubs is similar to the method for using Lecher lines for crude frequency measurement, but it is 'working backwards'.

One method is to take an open-circuited length of transmission line wired in parallel with the feeder delivering signals from an aerial. By cutting the free end of the transmission line, a minimum in the strength of the signal observed at a receiver can be found. At this stage the stub filter will reject this frequency and the odd harmonics, but if the free end of the stub is shorted then the stub will become a filter rejecting the even harmonics.

Characteristic Impedance Of A Transmission Line

The characteristic impedance of a transmission line is the ratio of the amplitude of a single voltage wave to its current wave. Since most transmission lines also have a reflected wave, the characteristic impedance is generally not the impedance that is measured on the line.[28] For a lossless transmission line, it can be shown that the impedance measured at a given position *l* from the load inpedance Z_L is

$$Z_{in}(l) = Z_0 \frac{Z_L \cos(\beta l) + Z_0 j \sin(\beta l)}{Z_0 \cos(\beta l) + Z_L j \sin(\beta l)}$$ where $\beta = \frac{2\pi}{\lambda}$ is the wave number.

This is an important concept in understanding the nature of interferances that might occur in a transmission line.

2.1.3-Frequency & Bandwidth

Most BPL products operate within the frequency range 1.7 MHz to 30 MHz, although submissions to the United States (US) BPL inquiry indicated equipment could operate in frequencies up to 80 MHz. This spectrum is used for various radio communications applications including defence purposes, short-wave broadcasting, maritime and aeronautical communications, radio astronomy, amateur radio and numerous short-range applications such as medical emergency alarms.

Distribution networks, including both medium voltage (MV) [27] and low voltage (LV) networks[43], are new candidates for providing an access to high-speed communications. Transmitting high data rates communications in the [1-30 MHz] band of the order of several Mbits/s is possible using power line communications (PLC).

BPL typically uses unshielded, 230 V/50 Hz, low-voltage distribution cables inside and outside of buildings as transmission media up to Mbits/second data rates. This requires mains-injected radio-frequency (RF) levels (e.g., total power <1 W, spectral power 40dBm/Hz, 1–30 MHz) that are EMC critical, with common-mode (CM) currents on wires (e.g., 20 dBμA at 1 MHz). Similar signals are normally injected at distribution transformers.[50]

The distribution transformer secondary windings, entrance cables, house wiring and electric loads determine residential impedance. The characterization of this impedance is important to the design of BPL systems. For them, this impedance is the driving point into which the transmitter operates and from which the receiver extracts the signal.

However there are certain issues of interferences with other devices operating in the same frequency range. The “spread spectrum” and “multiple carrier” techniques used in proposed BPL systems employ modulation that spectrally resembles noise and can employ system architectures capable of minimizing radiated interference.[54]

The multiple carriers can be controlled in amplitude, turned on and off, or “notched” to remove energy radiating at specific frequencies. Typical Access BPL frequencies start above AM radio (1.7 MHz) and end just below FM radio (up to 80 MHz). Usually the entire available range is not used—the upper frequency is typically less than 50 MHz.

2.2 – History Review

BPL as a communication mode has been used since the early 1920s, where it was first used for voice communication on the transmission system and later for protective relaying, supervisory control, and telemetry. Power companies were using power line to send control messages and had been limited to low data rates for the power company's own internal applications. It was never seriously thought of as a medium for communications due to its low speed, minimal functionality and high deployment cost. Previous BPL systems used by the power company are for the transmission of specific information concerning the state of the power network, for remote monitoring and SCADA2 applications. All this information is transmitted using relatively low frequencies, and thus having relatively low speed.

The "original" BPL was a very low frequency, narrow bandwidth signal used for control equipment in the power grid. The typical range of communication/data transfer was in the range of 100 to 180 kHz and was not intended for high speed data transfer, but for simple commands, like "turn relay on", "turn relay off". Traditionally electrical utilities used low-speed power-line carrier circuits for control of substations, voice communication, and protection of high-voltage transmission lines.

The first technique to make use of the power line for control messages was the method - Ripple Control. This is characterised by the use of low frequencies (100 Hz 900Hz) giving a low bit rate and a demand on very high transmitter power, often in the region of several 10kWs. The system provided one-way communication technology, and among the applications provided was the management of streetlights and load control. [5]

In the mid 1980s experiments on higher frequencies were carried out to analyse the characteristic properties of the electric grid as a medium for data transfer. Frequencies (in the range of 5kHz to 500kHz) were tested in which the signal to noise levels were important topics for measurements as well as the attenuation of the signal by the grid. These tests were done both in Europe and in the U.S. Scada (Supervisory Control and Data Acquisition) technology was developed at this time to carry out these studies.

Bi-directional communication was developed in the late 80?s and early 1990?s and the main difference between these systems and modern systems today is that much higher frequencies and a substantial reduction of the signal levels are used on today's power grid network. Since the 1997 experiment in a school of Manchester (United Kingdom) utility and technology companies continued to experiment with higher bandwidth data transfer across the electric grids in Europe and the U.S. Advances in PLC technology now allows for high speed, broadband communications over medium and low voltage mediums yielding extraordinary market opportunities.

More recently, high-speed data transmission has been developed using the lower voltage transmission lines used for power distribution. A short-range form of power-line carrier is used for home automation and intercoms.

The major challenge was always the fact that electric transmission and distribution organizations were trying to use the same wire that carries strong current, to also accommodate data signals.

However, new modulation techniques supported by recent technological advances have finally enabled the power line to become a means for high-speed, broadband communications over low and medium voltage lines.

Restricted bandwidth and resulting low data rates caused BPL to be used less frequently in the past. A transmission line carrier communications channel was rather simple, consisting of a transmitter, receiver, coupling capacitor, and wave trap at each end of the line. However reflections at discontinuities, such as taps or overhead/underground transitions, complicated the applications because of reflections of the travelling waves.

Recent technical achievements in the area of BPL make it possible for data to be sent at a much higher speed. This new BPL system uses a much higher frequency i.e., between 1 MHz to 30 MHz, which enables a higher transmission rate at around 1 Mbit/sec.

However, at a higher frequency than the 50 Hz electrical current, the BPL systems raise a number of issues including interference by BPL equipment to radio-based services.[62]

2.3 - Broadband Over Power Line

2.3.1-Communication Through BPL

Broadband over Power lines (BPL), uses electric power lines as a high-speed digital data channel to connect a group of private users to a very high data rate backbone, such as fiber optic.

The lines in power delivery network can be categorized based on several criteria. Depending on line voltage, HV (high voltage), MV (medium voltage), and LV (low voltage) are typically defined. Within a distribution grid, depending on the topological configuration, either overhead lines or underground cables are used. Overhead MV lines differ considerable in structure and physical properties compared to other wire-lines as twisted-pair, coaxial and fiber-optic cables.

The power utilities have been using a centralized control and monitoring of a utility's power generation and distribution network a central computer communicates with remote terminals at each generating and switching station for decades now. Such communication systems transmitted a long-wave modulated carrier signal over the three phase conductors of a power transmission line from one power substation to the next. The communication system includes a transmitter, a receiver, and associated coupling and impedance matching networks, connected at each terminal of the transmission line. [67]

The transmitters operate at a carrier frequency in the range of 30 kHz to 300 kHz. Frequencies below 30 kHz are unusable due to the difficulty of building equipment to operate below this limit. Also, there is a substantial increase in received noise power below this limit. Frequencies greater than 300 kHz suffer substantial signal attenuation on the transmission line and increased radiation of the carrier signal, thereby possibly interfering with lone-wave radio services.

The primary source of noise at the carrier receiver is high-voltage corona on the energized transmission line. Transmitted-power levels, established according to attenuation of the line and level of corona noise at the receiver, are typically in the range of 1 to 10 watts. Thermal noise, which affects telephone or radio communication systems, is much smaller than corona noise and may be disregarded when calculating the performance of a power-line carrier channel[46]

For such a transmission simple modulation schemes, i.e., on-off keying or frequency-shift keying are generally employed. Each modulated carrier signal typically occupies approximately 3 kHz of the frequency spectrum thus permitting, in theory, the multiplexing of approximately 90 individual modulated-carrier signals in the 30 kHz to 300 kHz band. Practical problems of adjacent channel interference, however, usually limit the number of signals too much fewer than 90 on any single power line.

Many power transmission lines comprise a single wire conductor for each phase; transmission lines operating at voltages above 230 kV use a bundle of spaced conductors to carry each phase current. A typical bundle consists of two or four conductors bundled together with conductive spacers to provide lower reactance and skin-effect losses than a single wire of the same total cross-sectional area. For power transmission, the bundled conductors in each phase are energized in the common mode.

In recent years the concept of using the bundled conductors of one phase in the differential mode for power-line carrier communication has evolved.

For signal communication, a moderate level of insulation is placed between the conductors of each bundle, and a differential-mode communication signal is coupled to two conductors within the bundle, while continuing to use all conductors of the bundle in the common mode for electric power transmission.

This scheme requires the use of split coupling capacitors, rated at the power-line voltage, to couple the carrier signal to and from the transmission line, and more costly insulating bundle spacers, in lieu of conducting spacers. Compared to conventional inter-phase signal propagation this intra-bundle communication technique offers the advantages of increased bandwidth in each signal link and triplication of the number of available signal links, since each phase can be used as an independent channel. [38]

Also there is a virtual elimination of interference between channels on different phases of the same transmission line and between channels on adjacent transmission lines, and between the communication signal and radio services in the same frequency band.

However, with intra-bundle communication the signal attenuation increases noticeably on long lines and during bad weather, Therefore, it may be necessary to transmit a signal with an impractically high power level or to use one or more repeaters along the transmission line.

Repeaters and regenerators are frequently used in many types of long-distance communication systems to overcome signal degradation caused by noise and signal attenuation. Repeaters are used with analog modulation schemes; regenerators can be used only with base band digital signals and pulse-code modulated signals. [73]

In analog modulation a continuously varying carrier wave is modulated by a message signal. The modulated carrier assumes a wide range of values corresponding to the message signal. When the modulated carrier is adulterated by noise, a receiver cannot discern the exact value of the message at the time the interference occurred.

To obtain adequate received signal strength, long-distance communication systems employing analog modulation, both free-space and cable, often use repeaters between terminals. These repeaters are well known in the art. With analog modulation, a repeater can do nothing more than simply amplify both the modulated carrier signal and the noise. The amplification process, causing the signal-to-noise ratio to progressively deteriorate at each repeater station, can also introduce additional noise.

With a pulse-code modulated signal or a base band digital signal, the transmitted signal can have only a limited number of discrete signal values. If the amplitude or phase separation between these signal values is large compared to the noise perturbations, the receiver can determine the signal value despite noise interruptions, and accurately demodulate (or detect for base band signals) the transmitted signal. [56]

Relying on this principle, a regenerator can therefore be utilized to demodulate (or detect), amplify, remodulate, and retransmit the signal, thereby producing a new signal free from noise (with the exception of detection errors arising during detection of the base band signal). Like repeaters, regenerators are placed at critical locations along the transmission path. Use of a regenerator obviously prevents accumulation of noise interference and improves overall system performance.

As applied to communication systems operating on power transmission lines, prior art techniques teach the insertion of a repeater or regenerator in the signal path by decoupling the signal from the power line, processing the signal, and recoup ling it to the power line for continued transmission. Such repeater or regenerator drops are expensive due to the cost of coupling capacitors rated at the power-line voltage and other power-line hardware.[68]

Use of a prior art repeater or regenerator with the intrabundle communication scheme requires that the signal entering the repeater (or regenerator) be coupled from the high-voltage power line to the repeater input, which is near ground potential. The amplified or regenerated signal must then be coupled back to the high-voltage power line.

BPL operates on the same principle where at specific points the broadband, i.e. Internet communication packets are induced in the carrier channel and transmitted through the carrier channel till the point of delivery where they are demodulated into information packet with the help of extractors.

BPL works by modulating high-frequency radio waves with the digital signals from the Internet. These radio waves synchronized and fed into the utility grid at specific points. They travel along the wires and pass through the utility transformers to subscribers' homes and businesses. Little, if any, modification is necessary to the utility grid to allow transmission of BPL.[75]

The main characteristics of BPL involves sending high frequencies using a PLC Carrier Unit (PLCU) over power lines and injecting the frequencies (or picking them up) via a coupler linked directly to the power grid.

The communication s signal is separated from the 50 Hz power supply by means of a band pass filter. The components involved in PLC are the;

Power Line Carrier Unit – provide signal transmission and reception coupler – for “clamping” around a live wire thus injecting the communication signals into the power line. In the PLCU, a Low Pass will filter the 50 Hz signal to the electricity meter at the home and a High Pass will filter the signal above 1 MHz for data communication s. Using the coupler, the communications signal is injected into the electricity supply cable.

PLCU as well as the couplers are therefore required at every node where communication s via power line is to be established. Other components of the PLC are the transformer bypass and the PLC modem, which is a Customer Premise Equipment (CPE), located at the end user/subscriber’s end. It provides Ethernet or USB connection for the end user to connect to the Internet.

On longer MV or LV lines repeaters may be required to boost the signals by amplifying weaker PLC signals along the line thus extending the distance covered.
There are two types of PLCU

Capacitative PLCU - connect and inject the signal into the cable core for delivering the signal transmission. It is physically connected to the electrical circuit.

Inductive PLCU - induce signal to cable sheath or cable core.

Typically Access BPL equipment consists of injectors (also known as concentrators), repeaters, and extractors. BPL injectors are tied to the Internet backbone via fiber or any other media lines and interface to the Medium Voltage (MV) power lines feeding the BPL service area.6 MV power lines may be overhead on utility poles or underground in buried conduit.

Overhead wiring is attached to utility poles that are typically 10 meters above the ground. Three-phase wiring generally comprises an MV distribution circuit running from a substation, and these wires may be physically oriented on the utility pole in a number of configurations (*e.g.*, horizontal, vertical, or triangular).

This physical orientation may change from one pole to the next. One or more phase lines may branch out from the three phase lines to serve a number of customers. A grounded neutral conductor is generally located below the phase conductors and runs between distribution transformers that provide Low Voltage (LV) electric power for customer use. In theory, BPL signals may be injected onto MV power lines between two-phase conductors, between a phase conductor and the neutral conductor, or onto a single phase or neutral conductor.

Extractors provide the interface between the MV power lines carrying BPL signals and the households within the service area. BPL extractors are usually located at each LV distribution transformer feeding a group of homes. Some extractors boost BPL signal strength sufficiently to allow transmission through LV transformers and others relay the BPL signal around the transformers via couplers on the proximate MV and LV power lines.

Other kinds of extractors interface with non-BPL devices (*e.g.*, WiFi™) that extend the BPL network to the customers' premises.

There are certain important processes that one must understand in order to understand the methodology of communication through BPL;

Source and Destination: The source can be any digital source of information. If the source is analog such as speech, then an analog to digital converter must precede the transmitter. At the receiving end, the decoded information is delivered to the destination.

The source may also compress redundant data, which minimizes the number of bits transmitted over the channel, but can also create a loss of source information. The data is unpacked at the destination to either an exact replica of the source information (lossless data compression) or a distorted version (lossy data compression) [1].

Channel Encoder and Channel Decoder: Channel coding reduces the bit error probability by adding redundancy (extra check bits) to the bit sequence. The check bits are computed over a k-symbol input sequence to create an n-symbol output code sequence. This determines the code rate Rc where $Rc = k/n$ and $Rc \leq 1$. This is the ratio of the number of actual data bits to the total number of bits transmitted T.

The channel decoder uses the extra bits to detect and possibly correct errors, which occurred during transmission. The number of extra bits added depends on how much error detection and correction is needed. Channel coding (also known as error control coding) is a heavily studied area. It is used to improve performance over noisy channels (such as the power line). [68]

Two major classes of codes exist: block codes and convolution codes. Block codes are implemented by combinational logic circuits. Reed-Solomon (RS) codes are a popular block code. Convolution codes (also known as tree codes or trellis codes) are implemented by sequential logic circuits [4].

Channel Modulator and Channel Demodulator: The purpose of the modulator is to take the encoded data and produce an analog signal suitable to propagate over the channel. The data is converted from a stream of bits into an analog signal. An M-ary modulator takes a block of Y binary digits from the channel encoder to select and transmit one of M analog waveforms at its disposal where M = 2Y and Y ≥ 1. At the receiver, the demodulator tries to detect which waveform was transmitted, and convert the analog information back to the sequence of bits. Varying the amplitude, the phase, or the frequency of a high-frequency carrier signal typically performs modulation.

For example, if the input signal of the modulator is used to vary the amplitude of the carrier signal, the modulation is called Amplitude Shift Keying (ASK). There are several other modulation techniques including FSK (Frequency Shift Keying), PSK (Phase Shift Keying) and QAM (Quadrature Amplitude Modulation).

Channel: The channel can be any physical transmission medium including coaxial cable, twisted pair, optical fiber, air, water, or for this work - the power line. It is important to know the characteristics of the channel, such as the attenuation and noise level because these parameters directly affect the performance of the communication system.

Inductive couplers are used to connect BPL modems to the medium voltage power lines. An inductive coupler transfers the communications signal onto the power line by wrapping around the line, without directly connecting to the line. A major challenge is how to deliver the signal from the medium voltage line to the low voltage line that enters your house, because the transformer that lowers the electric power from several thousands volts down to 220/110 is a potential barrier to the broadband signal.

The power flowing down high-voltage lines is between 155,000 to 765,000 volts. That amount of power is unsuitable for data transmission. It's too "noisy." Both electricity and the RF used to transmit data vibrate at certain frequencies. In order for data to transmit cleanly from point to point, it must have a dedicated band of the radio spectrum at which to vibrate without interference from other sources.

Hundreds of thousands of volts of electricity don't vibrate at a consistent frequency. That amount of power jumps all over the spectrum. As it spikes and hums along, it creates all kinds of interference. If it spikes at a frequency that is the same as the RF used to transmit data, then it will cancel out that signal and the data transmission will be dropped or damaged en route.

BPL bypasses this problem by avoiding high-voltage power lines all together. The system drops the data off of traditional fibre-optic lines downstream, onto the much more manageable 7,200 volts of medium-voltage power lines.

Once dropped onto the medium-voltage lines, the data can only travel so far before it degrades.

To counter this, special devices are installed on the lines to act as repeaters. The repeaters take in the data and repeat it in a new transmission, amplifying it for the next leg of the journey.

In one model of BPL, two other devices ride power poles to distribute Internet traffic. The Coupler allows the data on the line to bypass transformers, and the Bridge**,** a device that facilitates carrying the signal into the homes.

The transformer's job is to reduce the 7,200 volts down to the 240-volt standard that makes up normal household electrical service. There is no way for low-power data signals to pass through a transformer, so you need a coupler to provide a data path around the transformer. With the coupler, data can move easily from the 7,200-volt line to the 240-volt line and into the house without any degradation.

The last mile is the final step that carries Internet into the subscriber's home or office.

In the various approaches to last-mile solutions for BPL, some companies carry the signal in with the electricity on the power line, while others put wireless links on the poles and send the data wirelessly into homes. The Bridge facilitates both.

The signal is received by a power line modem that plugs into the wall. The modem sends the signal to your computer.

BPL modems use silicon chipsets specially designed to handle the workload of pulling data out of an electric current. Using specially developed modulation techniques and adaptive algorithms, BPL modems are capable of handling power line noise on a wide spectrum.

2.3.2-Types Of BPL System

Depending the access at the point of last mile connectivity BPL is classified into three different types. It is important here to understand that the definition of types solely takes into consideration the mode of last mile connectivity, though the process of transmission of communication and traversing of broadband is in no way different for any of these three types of BPL;

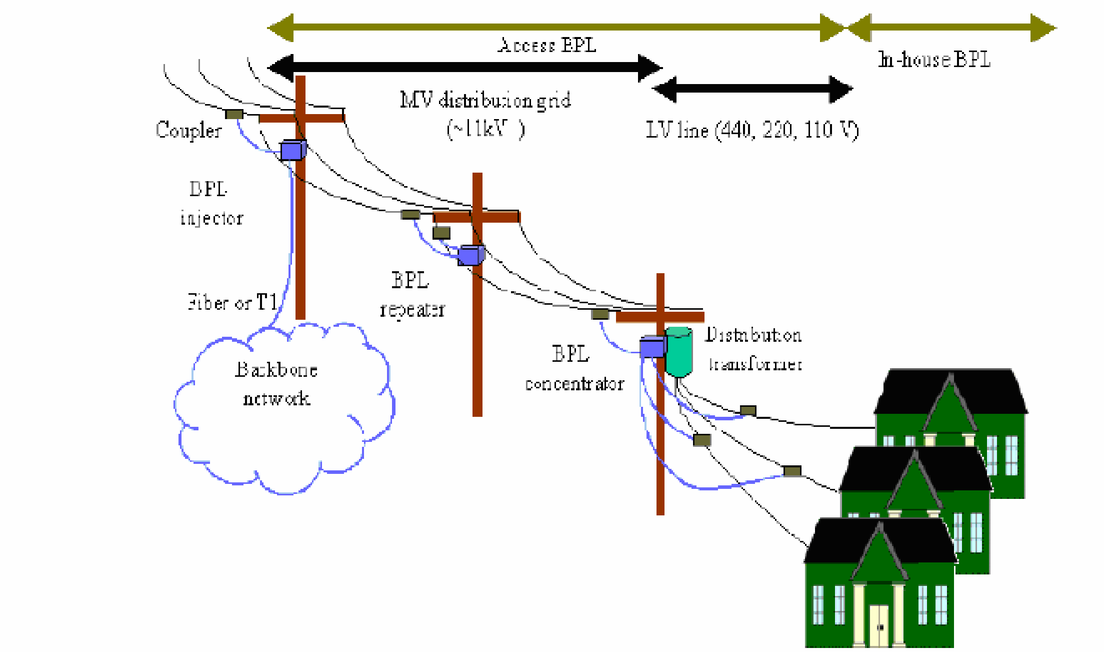


Figure 2-1: A typical power line access network architecture

Access (Outside) BPL

It provides communications between homes and equipment outside the home. It uses either the overhead or underground electrical distribution lines. The house wiring will radiate Radio Frequency (RF) unless suitable RF filters are fitted at numerous applicable locations. Since the electricity grid is vast and extends across entire neighbourhood, access BPL systems pose a significant interference potential to over-the-air radio services.

However, there could be several possible applications for Access BPL, among others;

- As a final link for connecting the end users with the communications service providers or Internet service providers (ISPs).
- As an alternative platform for broadband communications capability which is comparable to digital subscriber line (DSL) technology.
- As an easy access for providing communications services to underserved rural and remote areas with minimal additional capital outlay.

Access BPL systems carry high-speed data signals to neighborhoods from the point of generation through a connection on a telecommunications network. The point of network connection may be at a power substation or at an intermediate point between a substation and users. Some systems complete the connection between the medium voltage lines and their subscribers by using WiFi wireless links, while other implementations employ an extractor at the distribution transformer to transfer the Access BPL signals across them

In-House BPL

In-house or In-building BPL systems provide communication s between equipment within the home. The RF signal is injected into the house wiring and uses the electrical wiring within a building to network computers. In-house BPL operations may provide for Internet sharing or other external service connections independently of Access BPL service.

For example, an in-house local area network (LAN) could interface with an Internet connection that may be provided from a variety of sources such as cable, DSL, or dial-up analog line, not necessarily just from an Access BPL service. In other words, the operation and external networking functions of In -house BPL do not depend on the subscriber having Access BPL service.

Thus, the In-house BPL system will allow the 3-pin electrical outlets to provide internal links in a home or office network allowing easy integration of all devices in the building.

Control BPL

These are BPL systems that operate below 500 kHz, and used by electric power companies to control their equipment using the power-lines as transmission lines. This type of BPL does not pose any significant interference risk to high frequency (HF) operations.

2.3.3-Benefits and Limitation of BPL

- **Benefits**

BPL offers obvious benefits over regular cable or DSL connections: the extensive infrastructure already available would appear to allow more people in more locations to have access to the Internet. Also, such ubiquitous availability would make it much easier for other electronics, such as televisions or sound systems, to take advantage of the voice and data transfer.

However, variations in the physical characteristics of the electricity network and the current lack of IEEE standards mean that provisioning of the service is far from being a standard, repeatable process and the amount of bandwidth a BPL system can provide compared to cable and wireless is in question.

Nevertheless despite all the issues mentioned above BPL have certain inherent advantages. There are numerous benefits to BPL and one of them is the provision of the end connectivity to the final subscriber that will increase the availability of broadband thus improving the competitiveness of the broadband service market.

Where broadband access has lagged notably in rural areas, BPL opens up a new communications infrastructure, as electricity is more prevalent in homes than telephone lines. Along with telephones (via DSL) and broadband fixed wireless access (BFWA) type of technologies, BPL offers an alternative for the last link for the delivery of broadband services. Communities that are serviced by the power grid but not by broadband providers can now gain access to the Internet.[67]

The technology has improvised since its inception infact a much higher speed transmissions using microwave frequencies transmitted via a newly discovered surface wave propagation mechanism have been demonstrated using only a single power line conductor. These systems have shown the potential for symmetric and full duplex communication in excess of 1 GBit/s in each direction. Multiple WiFi channels as well as simultaneous analog television in the 2.4 and 5.3 GHz unlicensed bands have been demonstrated operating over medium voltage lines.

Furthermore, because it can operate anywhere in the 100 MHz - 10 GHz region, this technology can completely avoid the interference issues associated with utilizing spectrum shared with other bands .

Advantages of BPL technology could be summarized as

- As BPL is being positioned as an IP-type service it will use packet routers rather than the circuit switching typical of traditional telecoms providers, thus keeping IT equipment costs down.
- As electricity is being supplied via a permanent connection, the data service offered over the electrical infrastructure is also permanently connected (no need to dial up the connection), making it ideal for the increasing number of online services. Power utilities will thus be able to market a basic Internet connection service at a flat-rate monthly subscription, like some cable operators. Paying a standard fee, irrespective of usage levels, will be a key attraction to customers.
- By giving electricity customers access to the Internet through their existing electrical supply system, the technology is available to virtually anyone, giving the technology potential mass market scale, without having to invest in digging cable links to homes.
- A number of technologies already exist for turning existing electrical cables into LAN wiring. What make BPL different is the high data rate achievable and the fact that it is also designed to work outside the home or building. Thus sophisticated domestic-automation systems could be implemented, allowing remote access and control of household appliances, burglar alarms, etc.

- BPL could also enable utilities to offer added-value sector-oriented services such as energy management (by linking up 'smart' meters, programmable controllers and 'Intelligent' demand/supply management devices so the utility could implement innovative tariffs to reward the sensible use of energy), remote monitoring (the permanent connection offered by BPL could be optimized to provide real-time information or status indicators in support of certain security applications for alarm/monitoring systems), and distribution automation (automatic remote meter reading would improve monitoring and assist utilities in the control of power distribution peaks). Some utilities have recently started some of these applications.

❖ *Limitation*

Being a ubiquitous technology BPL poses some distinct problems, which has resulted in its slow proliferation. In spite of its promising features, BPL still has a number of inherent limitations to overcome, such as its susceptibility to electromagnetic interference (which particularly affects aerial cables), resulting in unacceptably high levels of high frequency (HF) interference.

Also, its topology has similarities to that of cable networks in the sense that, as a shared medium, the advertised optimal bandwidth could be reduced as the number of users simultaneously connected to the same electrical substation increases.

The medium of BPL (the power line cable), unlike any other broadband medium (copper twisted pair, fiber, coaxial cable), is inherently unsuited for carrying the frequencies BPL uses. Power lines, copper twisted pair, and coaxial cable all act like natural low pass filters, meaning higher frequencies are attenuated more than lower frequencies when attempting to transmit them through the medium. The exact slope of the graph of attenuation depends on the specific construction of the material, but in general, twisted pair is suitable up to 100 MHz and coaxial cable can go up to about 3 GHz.

Again, these are very general figures and determining the suitability for any application depends on other factors. Power lines would be suitable for up to perhaps 20 KHz, maybe 350 kHz at a stretch, with caveats. These are essentially audio frequencies, and equate to a data rate in the neighborhood of ISDN.

Further power lines are designed to carry electrical power. They were not designed to carry radio signals. Though they can be used to carry small amount of data, yet in when subjected to carry large amount of data they end up loosing much of the signal to losses and, more importantly, radiating them as radio signals that can and do affect nearby receivers using those frequencies.
Amateur radio operators, CB operators and short-wave listeners are all found commonly in the residential neighborhoods where BPL will be installed causing a great amount of interference to such users.

They will all suffer strong interference if BPL uses their frequencies at the permitted levels. Other uses of HF spectrum include business, government, military and aeronautical. Many of these users and their organizations have expressed strong concern about BPL and its interference potential. [1]

The main problem associated with BPL is spark discharge generated due to radio frequency interference covering 0.5–800 MHz, so understanding the propagation and radiation characteristics of power line noise is instructive for what may happen with BPL.[5] Location of noise sources is difficult because once a radio frequency signal is coupled on a power line:

- Some is radiated from the location of the source.
- Some is propagated down the line to be radiated and received at a distance from the source.
- Some is coupled to other nearby lines and propagated down those lines to be radiated and received at additional distant locations.

The degree of potential interference is related to the strength of the radiated emissions from BPL systems and the signal levels being used by radio services in use near BPL systems. The strength of these emissions depends on a number of factors, such as:[9]

- The frequencies being used
- The BPL power level into the lines
- The radiation pattern and efficiency of the power line
- The path attenuation between the power line and the radio-receiving antenna
- The sensitivity and other characteristics of the radio receiving system.

The above-mentioned characteristics pose a serious challenge in delivering Broadband Over Power line. There may indeed be “variability” in the ability of power lines to radiate, but at the high end of that variability, the radiation can be quite strong.

Another major issue with BPL is the electromagnetic compatibility (EMC) of this technology to other wireless systems. Since electric wires might radiate electromagnetic waves at high frequencies, precautions need to be employed in order to avoid any interference to other wireless devices.

Coupling of the BPL signal into nearby conductors, and subsequent re-radiation from those conductors, is outside the control of the electrical utility.

There is, likewise, no scientific foundation for the belief that such signals would “cancel each other out.” Power line noise signals certainly do not cancel each other out, and, as stated above, there is no rational argument for BPL signals behaving differently.

In some measurements carried out in Japan clearly demonstrated that interference from a broadband power line (BPL) system generates spurious RF emissions beyond 300 MHz. BPL injects RF energy along power lines to provide broadband Internet services into homes and businesses, but it also leaks radiation as modulated carriers at intervals of about 1 kHz. The frequencies used are commonly between 2 MHz and 30 MHz and some proposed systems will extend this to 80 MHz.

Regarding electromagnetic compatibility (EMC), one has to be careful, when choosing an appropriate modulation scheme. Selection of a modulation scheme for BPL must account for three major factors:

- Presence of noise and impulse disturbances causing a relatively low SNR
- Time-varying frequency-selective nature of channel.
- Regulatory constraints with regards to electromagnetic compatibility that limits the transmitted power.
- Reduction of power spectral density of BPL signals in order to minimize radiation.

2.4-Powerline

Electric power transmission is one process in the delivery of electricity to consumers. The term refers to the bulk transfer of electrical power from place to place. Typically, power transmission is between the power plant and a substation near a populated area. This is distinct from electricity distribution, which is concerned with the delivery from the substation to the consumers. Power Transmission Line is a carrier link needed to transfer electrical power from the point of generation to the load center. This transfer of power is closely related to the electrical properties of the transmission line. Due to the large amount of power involved, transmission normally takes place at high voltage (110 kV or above). Electricity is usually sent over long distance through overhead power transmission lines. Underground power transmission is used only in densely populated areas (such as large cities) because of the high capacitive and resistive losses incurred

An overhead power line is an electric power transmission line suspended by towers or poles. Since most of the insulation is provided by air, overhead power lines are generally the lowest-cost method of transmission for large quantities of electric power. The wire conductors on the line are generally made of aluminum (either plain or reinforced with steel or sometimes composite materials), though some copper wires are used in medium-voltage distribution and low-voltage connections to customer premises.

Operators of long transmission lines require reliable communications for control of the power grid and, often, associated generation and distribution facilities. Fault-sensing protection relays at each end of the line must communicate to monitor the flow of power into and out of the protected line section. Protection of the transmission line from short circuits and other faults is usually so critical that common carrier telecommunications is insufficiently reliable. In remote areas a common carrier may not be available at all. Communication systems associated with a transmission project may use Microwaves,BPL or Optical Fiber.
Transmission lines are also be used to carry data and now with new modulation technology even voice and broadband.

Typically the design of a power line could either be in an analog mode or it could be in the digital mode. Prior to the recent developments data communication over transmission lines posed a serious challenge . Data transmission over long distance and at high speeds were unreliable and uneconomical, however with recent advancements in digital transmission technologies has resulted in reducing and controlling problems associated with noise and leakages of the signal in course of transmission of data over the transmission lines.

The information carried by a signal may be measured either on a per second basis, or per transmitted symbol; that is, either in continuous or discrete time. Digital circuits are now available that can help manage noise and attenuation. There are now ways whereby a digital model of transmission line can be interfaced with digital filters which could provide a better filtering of noise.

There are certain other benefits of a digital model like;Data transmission, digital protection scheme, further still it is now possible to better study digital speech transmission and their relative performance under various circumstances.

The digital design of the powerline to a large extend have been successful in resolving the issues of probable interferances that occur during the transmission of data and voice over carrier channels.

2.5 – Conclusion

This chapter consist of working , advantages and didadvantages of broadband over power line technology . This chapter majorily dealt with operation, communication, a small theory about various signal propogation techniques like DSSS and OFDM. Further, various kinds of BPL modes like in house, access, etc were also covered in this chapter.we also understood about the roles equipments like repeaters, switches and various carrier units.

CHAPTER 3

ELECTROMAGNETIC INTERFERENCE

3.1-Electromagnetic Field Theory

The term "electromagnetism" comes from the individual component electrical and magnetic forces involved. A changing magnetic field produces an electric field (this is the phenomenon of electromagnetic induction, which underlies the operation of electrical generators, induction motors, and transformers). Similarly, a changing electric field generates a magnetic field.

It is often convenient to understand the electromagnetic field in terms of two separate fields: the electric field and the magnetic field. A non-zero electric field is produced by the presence of electrically charged particles, and gives rise to the electric force; this is the force that causes static electricity and drives the flow of electric charge (electric current) in electrical conductors. [7]

The motion of electric charges, or electric current, on the other hand, can produce the magnetic field, and gives rise to the magnetic force associated with magnets.

Electromagnetic waves of much lower frequency than visible light were predicted by Maxwell's equations and subsequently discovered by Heinrich Hertz. Maxwell derived a waveform of the electric and magnetic equations, which made explicit the wave nature of the electric and magnetic fields. These equations displayed the symmetry of the fields.[9]

According to the theory, a time-varying electric field generates a magnetic field and vice versa. Thus, an oscillating electric field creates an oscillating magnetic field, which in turn creates an oscillating electric field, and so on. By this means an EM wave is produced which propagates through space.

Electromagnetism has persisted as a vibrant field despite it being over a hundred year old is because many electrical engineering technologies depend on it. To name a few, these are: physics based signal processing and imaging, computer chip design and circuits, lasers and opto-electronics, MEMS (micro-electromechanical sensors) and microwave engineering, remote sensing and subsurface sensing and NDE (non-destructive evaluation), EMC/EMI (electromagnetic compatibility/electromagnetic interference) analysis, antenna analysis and design, RCS (radar cross section) analysis and design, ATR (automatic target recognition) and stealth technology, wireless communication and propagation, and biomedical engineering and biotech.[21]

Electric and magnetic fields exhibit the property of superposition. This means that the field due to a particular particle or time-varying electric or magnetic field adds to the fields due to other causes. (As magnetic and electric fields are vector fields, this is the vector addition of all the individual electric and magnetic field vectors.) As a result, EM radiation is influenced by various phenomena such as refraction and diffraction. For example, a travelling EM wave incident on a particular arrangement of atoms induces oscillation in the atoms and thus causes them to emit their own EM waves.

These emissions interfere with the impinging wave and alter its form.

In refraction, a wave moving from one medium to another of a different density changes its speed and direction when it enters the new medium. The ratio of the refractive indices of the media determines the extent of refraction. Refraction is the mechanism by which light disperses into a spectrum when it is shone through a prism.
For long runs of MV power lines, signal attenuation or distortion through the power line may lead BPL service providers to employ repeaters to maintain the required BPL signal strength and fidelity. [56]

For WTW injections, differential modes are mostly excited. For a WTG injection, in a case of coupling to the middle phase, the common mode and the differential mode 2 are excited. Generally, these modes are not orthogonal unless the wavelength of electromagnetic wave inside the conductors is a small fraction of the height of wires and the spacing between the wires is a small fraction of wavelength ' satisfied for practical

MV power-line systems up to 100 MHz. Beyond this frequency, the discrete modes lose their orthogonality and continuous modes start to appear.[18]
EM radiation exhibits both wave properties and particle properties at the same time characteristics are mutually exclusive and appear separately in different circumstances: the wave characteristics appear when EM radiation is measured over relatively large timescales and over large distances, and the particle characteristics are evident when measuring small distances and timescales. These characteristics have been confirmed by a large number of experiments.

The electromagnetic field equations have an intimate link with special relativity: the magnetic field equations can be derived from consideration of the transformation of the electric field equations under relativistic transformations at low velocities. (In relativity, the equations are written in an even more compact, "manifestly covariant" form, in terms of the rank-2 anti-symmetric field-strength 4-tensor that unifies the electric and magnetic fields into a single object.)[76]

Generally, EM radiation is classified by wavelength into electrical energy, radio, microwave, infrared, the visible region we perceive as light, ultraviolet, X-rays and gamma rays.

The behavior of EM radiation depends on its wavelength. Higher frequencies have shorter wavelengths, and lower frequencies have longer wavelengths. When EM radiation interacts with single atoms and molecules, its behavior depends on the amount of energy per quantum it carries.[59]

Radio waves carry information by varying amplitude and by varying frequency within a frequency band. When EM radiation impinges upon a conductor, it couples to the conductor, travels along it, and induces an electric current on the surface of that conductor by exciting the electrons of the conducting material. This effect (the skin effect) is used in antennas. EM radiation may also cause certain molecules to absorb energy and thus to heat up and radiate.

3.2 Electromagnetic Interference

Characterization of electromagnetic emissions associated with BPL systems is a complex problem due essentially to:

- Complicated and huge variety of possible configurations of MV network in power transmission system;
- Variation of load for different networks at different time;
- The definition of an adequate measurement method for emission;
- The definition of adequate limits in order to achieve a reasonable compromise between avoiding interference with other equipment and not forbidding the use of this new technique.

Recently, NTIA, in their extensive reports [45], made recommendations to FCC to devise regulatory methods for measurements, deployment and simulation of BPL systems. According to this report, there are some frequency intervals that are dedicated to emergency services and all BPL systems have to avoid occupying these frequency

3.3-Electromagnetic Field Radiated From A Multi-Conductor Line

The electromagnetic radiation pattern of a single wire over ground is studied under the context of receiving (wave) antennas by H. Beverage in early 1920 [44].

Afterward, several research attempts are conducted to find a mathematical expression for radiation pattern of this kind of antennas. Wait in [3] and [42] provides a comprehensive mathematical insight. In [42], Wait introduces two functions as Hertz Potential Functions to describe the radiated electric and magnetic fields. As, it is mentioned earlier, lines in power line networks are composed of three or more wires.

Therefore, by using MTL theory of [7] and Wait's method, we can develop mathematical expressions for radiated fields.

The rectangular components of the electric and magnetic fields radiated from the multi conductor line are defined as functions of the Hertz potentials following the procedure proposed by Wait [2] and Olsen with reference to the single-conductor configuration.

The multi-conductor overhead line above a lossy ground is represented in the below mentioned figure. The line of infinite length is excited by a wire-to-ground or a wire-to-wire voltage source at x = 0.

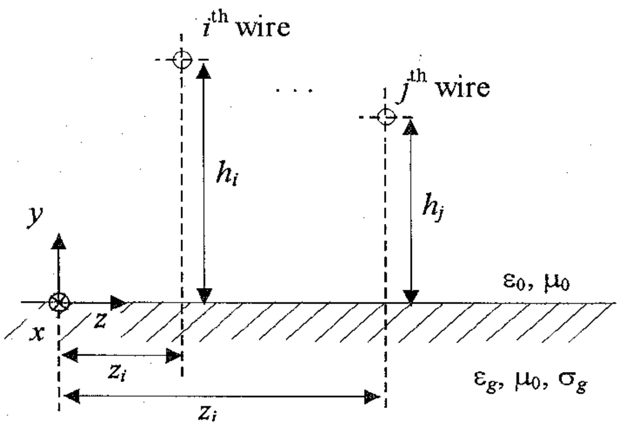


Figure 3.1- Sketch of the multi conductor line section

An accurate simulation model in the frequency-domain represents the n-conductor line. The per-unit-length (p.u.1.) series impedance matrix Z takes account of the skin effect in the conductors and ground, internal reactance are expressed in terms of Bessel functions, the ground impedances are calculated using a new formulation which removes the Carson quasi-static hypotheses and is valid in a wide frequency-range [5]. The p.u.1. shunt admittance matrix **Y** includes not only the contribution of the capacitive coupling but also the ground admittance, which is neglected in the Carson approach [5]. The calculation for the same is given in Appendix B

The line propagation matrix of order *n* x *n* is defined by:

$$\mathbf{P} = \mathbf{Z} * \mathbf{Y} \quad \textbf{(3.1)}$$

The vector of the line current I(x) at generic abscissa **.IC** is expressed as function of the vector of the modal currents Io(x)

$$I(x)=NI^{o}(x) \quad \textbf{(3.2)}$$

in which the transformation matrix **N** makes diagonal

$$\mathbf{Pt} = \mathbf{Y^*Z} \qquad \mathbf{(3.3)}$$

conforming to the following expression:

$$N^{-1}\, YZN=\mathrm{diag}\{\lambda_\kappa) \qquad k=1,n \qquad \mathbf{(3.4)}$$

Matrix **N** is then constituted by the *n* column-eigenvectors related to the *n* eigen values λ_κ of the propagation matrix P**.**

The line current vector I(x) is expressed as a function of the impressed voltage source V(0). In the hypothesis of unidirectional propagation, it results:

$$I(x)= \phi_1(x)YcV(0) \qquad \mathbf{(3.5)}$$

Broadband power line wires are transmission lines (TL) for the electromagnetic waves similar to any electromagnetic TL. Frequency response, H (f), of a matched transmission line can be expressed by means of a propagation constant, γ. The voltage along wire at a distance *l* from the source, *V (l)*, is obtained by

$$V(l)=H(f)V(o) \qquad \mathbf{(3.6)}$$

$$H(f)= e^{-\gamma (f)l} = e^{-\alpha (f)l}\, e^{-j\beta (f)l} \qquad \mathbf{(3.7)}$$

Where *V(0)* is the voltage at the source. α is the real part of propagation constant and is called attenuation constant, β is the imaginary part of propagation constant and is called phase constant.

By having the propagation constant, one may easily find the transfer function for TL at a desired point on the line. Therefore, the major attention in channel modeling of Transmission Lines is focused on finding the respective propagation constant for that specific line.

3.3.1- THE EXCITING SOURCE

Besides the amplitude and phase distortion, noise is the crucial factor influencing higher data rates achieving over power lines. The design of appropriate coding and modulation techniques, by means of computer simulation, requires detailed discrete model of power line noise. Noise spectral density level is also important parameter for evaluating network performance and capacity.

Moreover, Electromagnetic Compatibility (EMC) problem is an issue that should be considered in deployment of BPL systems. The main EMC problem is the emission of electromagnetic noise, which can interfere with public radio.

A suitable model for the power line channel that incorporates signal degradation through the line and interference sources, determining the appropriate frequency allocation scheme and acceptable transmission power levels to minimize interference into existing services, and finally selecting suitable modulation, coding and detection schemes and measures to minimize the effect of external interference on the proposed system.

Analysis of transmission lines consisting of two parallel conductors has been a well-understood topic. This understanding can be further extended to matrix notations to cover multi-conductor transmission lines (MTL), involving more than 2 conductors. [7]

For a two-conductor line, we have forward- and reverse- traveling waves. For an MTL with (n+1) conductors placed parallel to the x-axis, there are n forward- and n reverse traveling waves with respective velocities. These waves can be described by a coupled set of 2n, first-order, matrix partial differential equations which relate the line voltage Vi(x,t),

i=1, 2,…n, and line current Ii(z,t), i=1, 2,…n.

Each pair of forward- and reverse-traveling waves is referred to as a mode. For example, in the case involving 3 conductors and a ground return, we can define 3 modes. Using these independent modes, we can decompose currents I1 through I3 as a linear combination of 3 modal currents. [11]

Common mode (also called ground mode) is characterized by the highest attenuation among the modes, and is propagation through 3 phases and a return via the earth. Involving signal propagation and return only through wires, differential mode (also called aerial mode) While the common mode current Ic is the same in magnitude and in direction for 3 lines, the differential mode currents ID1 and ID2 are the same in magnitude but differ in direction for 3 lines.

Common mode currents are much smaller in magnitude than differential mode currents, but are significant since while the radiated E-field from the differential mode currents subtract, those from common mode currents tend to add. This is an important issue in terms of Electromagnetic Compatibility (EMC) of BPL systems and potential interference into existing local communications systems in the shared bands.

The electromagnetic radiation pattern of a single wire over ground is studied under the context of receiving (wave) antennas by H. Beverage in early 1920 [43].

The mentioned mathematical method is applied to the calculation of the high frequency electromagnetic field radiated from carrier channels on the MV power line having the geometrical configurations shown in figure below,

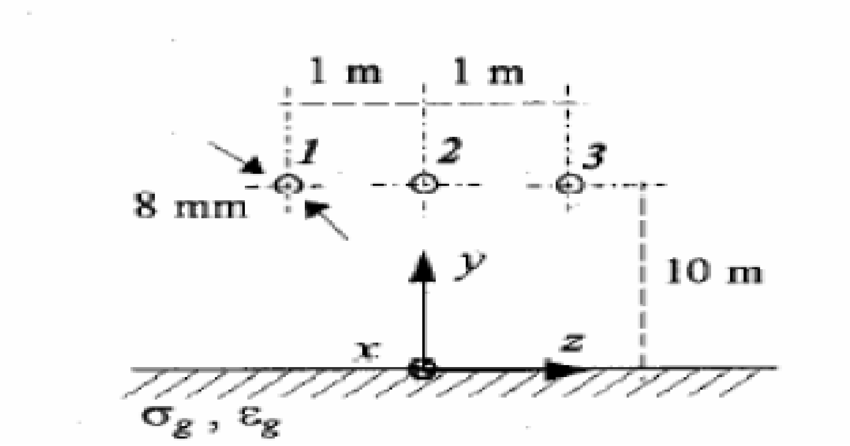


Figure 3.2-Geometrical configuration of the medium voltage 3 conductor line

Afterward, several research attempts are conducted to find a mathematical expression for radiation pattern of this kind of antennas. Wait in [3] and [42] provides a comprehensive mathematical insight. In [42], Wait introduces two functions as Hertz Potential Functions to describe the radiated electric and magnetic fields. As, it is mentioned earlier, lines in power line networks are composed of three or more wires. Therefore, by using MTL theory of [7] and Wait's method, we can develop mathematical expressions for radiated fields.

The current of the ith-wire at distance *x* from the source can be written as a function of modal currents in the following form:[82]

$$I_i(x)=N_{i1} I_1^m (x) +\ldots N_{in} I^m_n (x) \tag{3.8}$$

Assuming the matched condition, the kth modal currents is described by:

$$I^k_m (x)= I^k_m (0) \exp (-\gamma_k x) \tag{3.9}$$

where $I^k_m(0)$ is the value at $x=0$.

Following the steps mentioned in [7], the Hertz Potential Functions generated by the kth mode current from the ith wire are the following:[82][83]

$$\Pi_{Eik}(x,y,z) = \frac{1}{j\omega\varepsilon_0 2\pi}\left[\Lambda_{ik}^{(1)} + \frac{2k_0^2}{k_0^2+\gamma_k^2}\left(S_{ik}^{(1)} + \frac{\gamma_k^2}{k_0^2} S_{ik}^{(2)}\right)\right]N_{ik} I_k^m(x) \tag{3.10}$$

$$\Pi_{Hik}(x,y,z) = \frac{\gamma_k}{j\pi(k_0^2 + \gamma_k^2)}(S_{ik}^{(3)} - S_{ik}^{(4)})N_{ik}I_k^m(x) \qquad \textbf{(3.11)}$$

The definitions of $S_{ik}^{(j)}$ and $\Lambda_{ik}^{(j)}$ are given in [49]. IN [49] the field components are given as the functions of hertz Potential Functions. By taking the derivatives and mathematical procedures the radiated filed components of Kth modal current over the ith wire are expressed as

$$\begin{aligned} E_{xik}(x,y,z) &= (k_0^2 + \gamma_k^2)\Pi_{Eik} \\ &= -\frac{j}{\omega\pi\varepsilon_0}(\Lambda_{ik}^{(2)} + k_0^2 S_{ik}^{(1)} + \gamma_k^2 S_{ik}^{(2)})N_{ik}I_k^m(x) \end{aligned} \qquad \textbf{(3.12)}$$

$$\begin{aligned} E_{yik}(x,y,z) &= \left(\frac{\partial^2 \Pi_{Eik}}{\partial y \partial x} - j\omega\mu_0 \frac{\partial \Pi_{Hik}}{\partial z}\right) \\ &= -\frac{\gamma_k}{\omega\pi\varepsilon_0}[\Lambda_{ik}^{(3)} - j(k_0^2 S_{ik}^{(5)} + \gamma_k^2 S_{ik}^{(6)} - S_{ik}^{(8)})]N_{ik}I_k^m(x) \end{aligned} \qquad \textbf{(3.13)}$$

$$\begin{aligned} E_{zik}(x,y,z) &= \left(\frac{\partial^2 \Pi_{Eik}}{\partial z \partial x} + j\omega\mu_0 \frac{\partial \Pi_{Hik}}{\partial y}\right) \\ &= -\frac{\gamma_k}{\omega\pi\varepsilon_0}[\Lambda_{ik}^{(4)} - S_{ik}^{(10)})]N_{ik}I_k^m(x) \end{aligned} \qquad \textbf{(3.14)}$$

$$\begin{aligned} H_{xik}(x,y,z) &= (k_0^2 + \gamma_k^2)\Pi_{Hik} \\ &= -\frac{j\gamma_k}{\pi}(S_{ik}^{(3)} - S_{ik}^{(4)})N_{ik}I_k^m(x) \end{aligned} \qquad \textbf{(3.15)}$$

$$\begin{aligned} H_{yik}(x,y,z) &= \left(\frac{\partial^2 \Pi_{Hik}}{\partial y \partial x} + j\omega\varepsilon_0 \frac{\partial \Pi_{Eik}}{\partial z}\right) \\ &= \frac{j}{\pi}[\Lambda_{ik}^{(3)} - S_{ik}^{(9)})]N_{ik}I_k^m(x) \end{aligned} \qquad \textbf{(3.16)}$$

$$H_{zik}(x,y,z) = \left(\frac{\partial^2 \Pi_{Hik}}{\partial z \partial x} - j\omega\varepsilon_0 \frac{\partial \Pi_{Eik}}{\partial y}\right) \quad \textbf{(3.17)}$$

$$= -\frac{j}{\pi}[\Lambda_{ik}^{(4)} + j(k_0^2 S_{ik}^{(5)} + \gamma_k^2 S_{ik}^{(6)} - S_{ik}^{(7)})] N_{ik} I_k^m(x)$$

All the aforesaid equations are based on the assumption that the wavelength of electromagnetic wave inside the conductors is a small fraction of the height of wires and the spacing between the wires is a small fraction of wavelength.

The x- component of the electric field due to ith wire current is obtained as a sum of n contributions in 3.18 related to n propagation modes. The total x component of the electric filed radiated by n-conductor system is the following

$$E_x(x,y,z) = \sum_{i=1}^{n} \sum_{k=1}^{n} E_{xik}(x,y,z) \quad \textbf{(3.18)}$$

The x-, *y*- and z-derivatives of the Hertz potentials are developed and the following new expressions are obtained:

$$E_{xik} = \Gamma_{xik} N_{ik} I_k^0 \quad , \quad E_{yik} = \Gamma_{yik} N_{ik} I_k^0 \quad , \quad E_{zik} = \Gamma_{zik} N_{ik} I_k^0 \quad \textbf{(3.18)}$$

$$H_{xik} = \Theta_{xik} N_{ik} I_k^0 \quad , \quad H_{yik} = \Theta_{yik} N_{ik} I_k^0 \quad , \quad H_{zik} = \Theta_{zik} N_{ik} I_k^0 \quad \textbf{(3.19)}$$

in which the E-field operators are the following:

$$\Gamma_{xik} = -\frac{j}{\omega\pi\varepsilon_0}\left(\Lambda_{ik}^{(2)} + k_0^2 S_{ik}^{(1)} + m_k^2 S_{ik}^{(2)}\right) \quad \textbf{(3.20)}$$

$$\Gamma_{yik} = -\frac{m_k}{\omega\pi\varepsilon_0}\left[\Lambda_{ik}^{(3)} - j\left(k_0^2 S_{ik}^{(5)} + m_k^2 S_{ik}^{(6)} - S_{ik}^{(8)}\right)\right] \quad \textbf{(3.21)}$$

$$\Gamma_{zik} = -\frac{m_k}{\omega\pi\varepsilon_0}\left(\Lambda_{ik}^{(4)} - S_{ik}^{(10)}\right) \quad \textbf{(3.22)}$$

whereas the H-field operators read:

$$\Theta_{xik} = -\frac{j m_k}{\pi}\left(S_{ik}^{(3)} - S_{ik}^{(4)}\right) \quad \textbf{(3.22)}$$

$$\Theta_{yik} = \frac{j}{\pi}\left(\Lambda_{ik}^{(3)} - S_{ik}^{(9)}\right) \quad \textbf{(3.23)}$$

(3.24)

$$\Theta_{zik} = -\frac{j}{\pi}\left[\Lambda_{ik}^{(4)} + j\left(k_0^2 S_{ik}^{(5)} + m_k^2 S_{ik}^{(6)} - S_{ik}^{(7)}\right)\right]$$

The expressions of $\Lambda_{ik}^{(j)}$**,** for ***j*** = 2,4, and S $_{ik}^{(j)}$, for *J'* = l, 10, including modified Bessel functions and Sommerfeld integrals, are described in Appendix A .[84] [11]

The x-component of the electric field due to the ***ith*** wire-current is obtained as sum of the ***n*** contributions in (1 la) **related to** the ***n*** propagation modes:

$$E_{xi}(x,y,z) = \sum_{k=1}^{n} E_{xik}(x,y,z) = \sum_{k=1}^{n} \Gamma_{xik} N_{ik} I_k^0(x) \tag{3.25}$$

Therefore, the total x-component of the electric field radiated by the n-conductor system is the following:

$$E_x(x,y,z) = \sum_{i=1}^{n} E_{xi}(x,y,z) = \sum_{i=1}^{n}\sum_{k=1}^{n} \Gamma_{xik} N_{ik} I_k^0(x) \tag{3.26}$$

Similar expressions are defined for all the components of the *E*- H conclusion, the resulting fields are given by:

$$\vec{\mathbf{E}}(x,y,z) = E_x\,\hat{\mathbf{x}} + E_y\,\hat{\mathbf{y}} + E_z\,\hat{\mathbf{z}} \tag{3.27}$$

$$\vec{\mathbf{H}}(x,y,z) = H_x\,\hat{\mathbf{x}} + H_y\,\hat{\mathbf{y}} + H_z\,\hat{\mathbf{z}} \tag{3.29}$$

The proposed model is applied to the calculation of the high- frequency electromagnetic field radiated from carrier channels on the medium-voltage power line having the geometrical configuration shown above.

The ground return path is characterized by conductivity **og=** 5 mS/m and relative permittivity ***srg*** = 5.

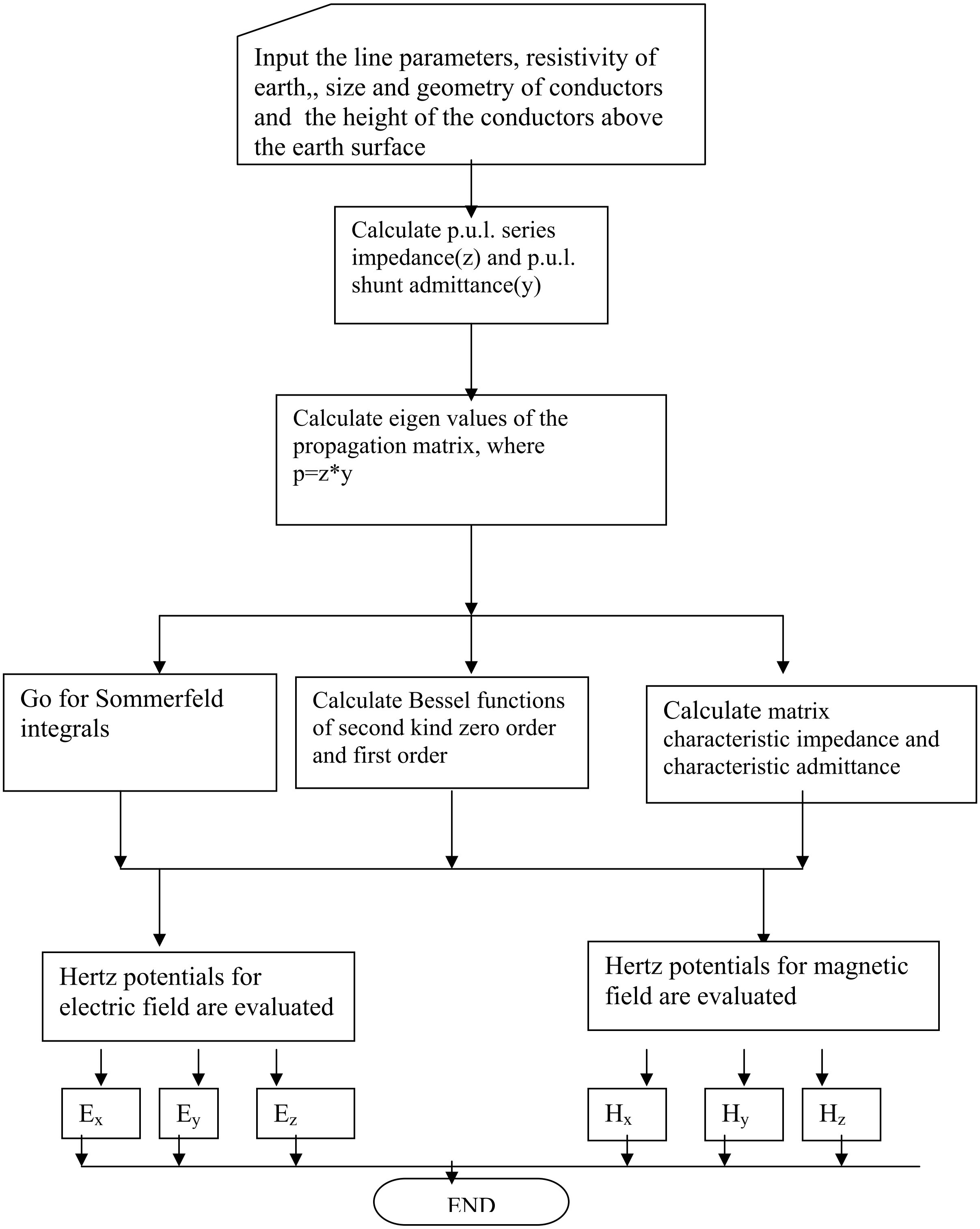
3.4-Conclusion

In this chapter we have tried to resolve the issue of electromagnetic interference problem faced by BPL. The issue is dealt through usage of Bessel functions and Sommerfeld's integrals. The rectangular components of electrical field and magnetic field were calculated the electromagnetic field in a BPL scenario.

CHAPTER 4

MATHEMATICAL MODELLING

4.1- Flowchart



4.2- Algorothim To Work With Matlab 7.0

1. Click desktop->MATLAB 7.0.
2. Click File->New M-File.
3. Write all the parameters of power lines.
4. Radius (r) of each sub conductor.
5. Height (h) of each sub conductor above the ground.
6. Input the number of conductors in outermost layer (ns).
7. Enter the resistivity of earth (rhoe).
8. Enter the value of geometric means radius (gmr).
9. a=((gmr^9)/(4*r^3))^(1/6) (4.1)

   Where a is the horiz spacing between conductors.
10. x1=sqrt(a^2+h^2) (4.2)

    x2=sqrt((2*a)^2+h^2) (4.3)

    Where x1, x2 are intermediate variables.
11. Calculate

    Rc2 = (k*sqrt(mu*rho/2)*sqrt(w*i)/(r*(ns+2)*pi)) (4.4)
12. Xc=Rc=(abs(Rc2))*I (4.5)

    Where Rc is resistance of conductor and Xc is inductance due to properties of conductor material.
13. Calculate P and Q matrix using Carson rigorous formulae.
14. Calculate Re= (2*P*w*mu)/(2*pi); (4.6)

    Where Re is the resistance of the earth.
15. Calculate the potential coefficient matrix

    F= (4.7)

$$\begin{vmatrix} \text{Log(2*h/r)} & \text{log(x1/a)} & \text{log(x2/(2*a)} \\ \text{Log(x1/a)} & \text{log(2*h/r)} & \text{log(x1/a)} \\ \text{Log(x2/(2*a)} & \text{log(x1/a)} & \text{log(2*h/r)} \end{vmatrix}$$

    B=inv(F);

16. Calculate

Xg=w*mu*B/(2*pi) (4.8)

Xe= (2*Q*mu)/(2*pi) (4.9)

Where Xe and Xg are the inductances of earth return path and the geometry of the conductor respectively.

17. Calculate

Z=Rc+Re+(Xe+Xg+Xc)*I (4.10)

Where Z is the p.u.l.series impedance matrix

18. Calculate

y=w*i*2*pi*E0*B (4.11)

where y is the value of per unit length shunt admittance matrix .

19. P=Z*Y (4.12)

Where P is Line propagation matrix.

20. Calculate variable d where d is eigen values of Line propagation matrix.
21. Calculate variable t where t is eigen vectors of Line propagation matrix.
22. Calculate Propagation constant of the Kth mode

Where $mk=(d)^{1/2}$ (4.13)

23. Calculate $yc=t(mk)^{-1}(t)^{-1}y$ (4.14)

Where yc is characteristic admittance matrix

24. Calculate Zc=Inv(yc) (4.15)

Where Zc is characteristic impedance matrix.

25. q_o =exp(-mkx) (4.16)

Where q_o is modal transition matrix.

26. Enter the values of u_o,e_o,e_g,s_g,w,za,zi,ya and hi.

where u_o is the value of permeability at free space ,

e_o is the value of permittivity at free space,

e_g is the value of permeability at ground,

s_g is the value of sigma at ground, and

za , zi ,ya and hi are distances in meters

27. Calculate

ko=w*(u_o*e_o)^1\2 (4.17)

kg=ko*(e_g\e_o-j*s_g\w*e_o) (4.18)

where ko and kg are variables.

28. Calculate Sommerfelds integrals sik$^{(j)}$

for c=1:1:3,

Sik$^{(1)}$=int(exp((-(u^2-m(c,:)... (4.19)

^2-ko^2)^1\2)*(ya+hi))\((u^2-m(c,:)^2-ko^2)^1\2)...

+((u^2-m(c,:)^2-kg^2)^1\2)*exp(-j*u*(za-zi)),0,inf);

end

for c=1:1:3,

sik$^{(3)}$=int((u)*(exp((-(u^2-m(c,:)... (4.20)

^2-ko^2)^1\2)*(ya+hi))\(((u^2-m(c,:)^2-ko^2)^1\2)^2)...

+((u^2-m(c,:)^2-kg^2)^1\2)*((u^2-m(c,:)^2-ko^2)^1\2)*exp(-j*u*(za-zi))),0,inf);

end

where int is integral and so on till j=10.

29. Referring the steps 26,27 ,calculate

rho1=[(ya-hi) ^{2}+(za-zi) ^{2}]$^{1/2}$ (4.21)

rho2=[(ya+hi) ^{2}+(za-zi) ^{2}] ^{½} (4.22)

30. Using the modified Bessel functions of second type , zero order and first order , calculate the expressions of lik$^{(j)}$,for j=1,4

as shown below:-

for c=1:1:3,

lik$^{(1)}$=besselk(0,(12)',1)[(j*rho1*(ko^2+m(c,:) ^{2}) ^{½}]... (4.23)

… -besselk(0,(12)',1)*[j*rho2*(ko^2+m(c,:) ^{2}) ^{½}]

end

for c=1:1:3,

lik$^{(2)}$=((ko^2+m(c,:) ^{2}) $^{1/2}$)*lik$^{(1)}$/2; (4.24)

end

for c=1:1:a,

lik$^{(3)}$=(((ko^{2}+m(c,:) ^{2}) $^{1/2}$)/2)*{((ya+hi)/rho2)*... (4.25)

…besselk(1,(12)',1)[(j*rho2*(ko^{2}+m(c,:)^{2})$^{1/2}$)...

+((ya+hi)/rho1)*besselk(1,(12)',1)[(j*rho1*(ko^{2}+m(c,:)^{2})^$^{1/2}$] }

end

for c=1:1:a,

lik$^{(4)}$=(((ko^{2}+m(c,:) ^{2}) $^{1/2}$)/2){(((za+zi)/rho2)... (4.26)

*besselk(1,(12)',1)[(j*rho2*(ko^{2}+m(c,:)^{2})$^{1/2}$)]+...

((za+zi)/rho1)*besselk(1,(12)',1)[(j*rho1*(ko^{2}+m(c,:) $_{2}$) $^{1/2}$]}

end

31. calculate the Current transition matrix of the reflection free transition line, is given by q1

    q1=t*q0*t^{-1} (4.27)

    where q0 is modal transition matrix and t is eigen vector of propagation matrix.

32. Calculate the line current vector

    Ix=q1*yc*v (4.28)

    where yc is the characteristic admittance and v is the impressed voltage

32. Assuming the one way propagation of current the modal current is given by the formulae

    Io=inv(t)*Ix (4.29)

34. The line current vector

    Iox=Io*exp(-mk*x); (4.30)

    Where mk is the propagation constant of kth mode

35. using the values of sommerfeld integrals specified in algorithm c and the values of lambda (lik) specified in algorithm c , calculate the Hertz potential of Electric field and magnetic field.

    Eik=(1/(i*w*eo*2*pi))*(lik1+((2*ko^2)/(ko^2+m(c,:)^2))*…

    ...((sik1)+((m(c,:)^2)/ko^2))*sik2)*t*Iox; (4.31)

    Hik= (m(c,:)/j*pi*((ko^2)+(m(c,:)^2)))*(sik3-sik4)*t*Iox; (4.32)

36. Calculate the rectangular component of electric field

$$E_{xik}(x,y,z)=\left(k_0^2+m_k^2\right)\Pi_{Eik} \tag{4.33}$$

$$E_{yik}(x,y,z)=\left(\frac{\partial^2\Pi_{Eik}}{\partial y\,\partial x}-j\omega\mu_0\frac{\partial\Pi_{Hik}}{\partial z}\right) \tag{4.34}$$

$$E_{zik}(x,y,z)=\left(\frac{\partial^2\Pi_{Eik}}{\partial z\,\partial x}+j\omega\mu_0\frac{\partial\Pi_{Hik}}{\partial y}\right) \tag{4.35}$$

36. Calculate the rectangular component of magnetic field

$$H_{xik}(x,y,z)=\left(k_0^2+m_k^2\right)\Pi_{Hik} \tag{4.36}$$

$$H_{yik}(x,y,z)=\left(\frac{\partial^2\Pi_{Hik}}{\partial y\,\partial x}+j\omega\varepsilon_0\frac{\partial\Pi_{Eik}}{\partial z}\right) \tag{4.37}$$

$$H_{zik}(x,y,z)=\left(\frac{\partial^2\Pi_{Hik}}{\partial z\,\partial x}-j\omega\varepsilon_0\frac{\partial\Pi_{Eik}}{\partial y}\right) \tag{4.38}$$

4.3-Conclusion

In this chapter algorithm to work with MATLAB 7.0 , i.e. the mathematical modelling of electromagnetic interference over a 3 conductor line above a lossy ground is undertaken. The modelling is based on an assumed environment and tries to create framework for understanding the rectangular component of such interferences.

CHAPTER 5

RESULTS AND DISCUSSIONS

The value of per unit length shunt admittance matrix is:-

```
y =

  1.0e-008 *

      0 + 0.6076i        0 - 0.0496i        0 - 0.0175i
      0 - 0.0496i        0 + 0.6111i        0 - 0.0496i
      0 - 0.0175i        0 - 0.0496i        0 + 0.6076i
```

The value of per unit length series impedance matrix is:-

```
  1.0e-003 *

   0.8698 + 0.4694i   0.4197 - 0.0010i   0.4189 + 0.0001i
   0.4197 - 0.0010i   0.8698 + 0.4696i   0.4197 - 0.0010i
   0.4189 + 0.0001i   0.4197 - 0.0010i   0.8698 + 0.4694i
```

LINE PROPAGATION MATRIX = P

```
  1.0e-011 *

  -0.2853 + 0.5004i   0.0239 + 0.1926i   0.0081 + 0.2186i
   0.0239 + 0.2046i  -0.2871 + 0.4899i   0.0239 + 0.2046i
   0.0081 + 0.2186i   0.0239 + 0.1926i  -0.2853 + 0.5004i
```

Eigen values of propagation matrix is λ =

```
  1.0e-011 *

  -0.2489 + 0.9075i        0                  0
        0            -0.2934 + 0.2818i        0
        0                  0            -0.3153 + 0.3014i
```

Eigen vectors of propagation matrix is γ =

```
   0.5807 - 0.0000i   0.7071             -0.3871 + 0.0126i
   0.5703 - 0.0144i  -0.0000 + 0.0000i   0.8367
   0.5807            -0.7071 - 0.0000i  -0.3871 + 0.0126i
```

The value of impressed voltage source,v =

```
   110
```

Propagation constant of the kth mode ,mk =

```
  1.0e-005 *
```

```
   0.1860 + 0.2439i        0                 0
        0             0.0753 + 0.1871i       0
        0                  0            0.0777 + 0.1938i

Diagonal matrix of propagation matrix ,m =
  1.0e-005 *

   0.1860 + 0.2439i
   0.0753 + 0.1871i
   0.0777 + 0.1938i

Charactereristic admittance matrix ,yc =
   0.0024 + 0.0011i  -0.0005 - 0.0001i  -0.0005 - 0.0000i
  -0.0006 - 0.0001i   0.0024 + 0.0011i  -0.0006 - 0.0001i
  -0.0005 - 0.0000i  -0.0005 - 0.0001i   0.0024 + 0.0011i

Charactereristic impedance matrix ,zc=
  1.0e+002 *

   3.4922 - 1.9555i   0.5554 - 0.7524i   0.4988 - 0.7507i
   0.5963 - 0.8200i   3.4961 - 1.9579i   0.5963 - 0.8200i
   0.4988 - 0.7507i   0.5554 - 0.7524i   3.4922 - 1.9555i

Diagonal matrix of madal traition matrix, q=
   0.9985 - 0.0019i
   0.9994 - 0.0015i
   0.9994 - 0.0015i

Modal transition matrix is q0=
   0.9985 - 0.0019i   1.0000             1.0000
   1.0000             0.9994 - 0.0015i   1.0000
   1.0000             1.0000             0.9994 - 0.0015i

Current transition matrix of the reflection free transition line is given by q1 =
   0.8054 + 0.0218i   1.2335 + 0.0233i  -0.4678 + 0.0055i
   1.2597 + 0.0061i   1.9265 - 0.0116i  -0.7301 + 0.0264i
  -0.4602 + 0.0041i  -0.7037 + 0.0135i   0.2653 - 0.0151i

The line current vector ,the hypotesis of unidirectional propagation is given by I=
   0.1585 + 0.0987i   0.3072 + 0.1566i  -0.2421 - 0.0685i
   0.2512 + 0.1491i   0.4856 + 0.2323i  -0.3806 - 0.0977i
  -0.0925 - 0.0531i  -0.1784 - 0.0824i   0.1394 + 0.0332i
```

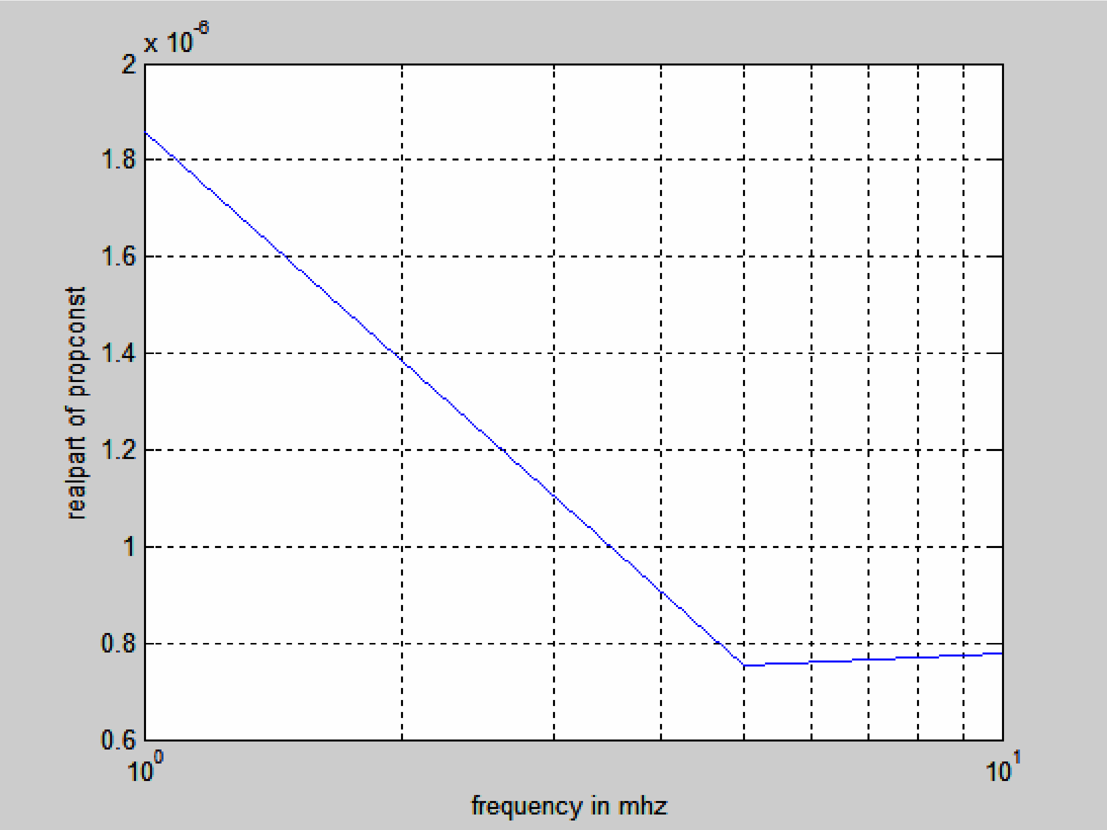


Figure 5.1 Real part of the propagation Constant of an overhead wire.

This graph shows the real part of propagation constant m_k with respect to frequency ranges between 1MHz to 10 MHz. Real part of propagation constant is also called as attenuation constant of the overhead wire. This graph shows that propagation constant first decreases from 1MHz to 5 MHz approximately and then become almost constant in the range 6-10 MHz.

Propagation constant is m_k which is derived from n eigen values λ_k of the propagation matrix P

Where P =Z*Y

And Z= per-unit-length impedance matrix

Y=per-unit-length admittance matrix

For this graph ,command used in MATLAB 7.0 is

```
Semilogx (w,real(diag(mk)));
xlabel ('frequency in MHz')
ylabel('real part of propconst')
```

Grid;

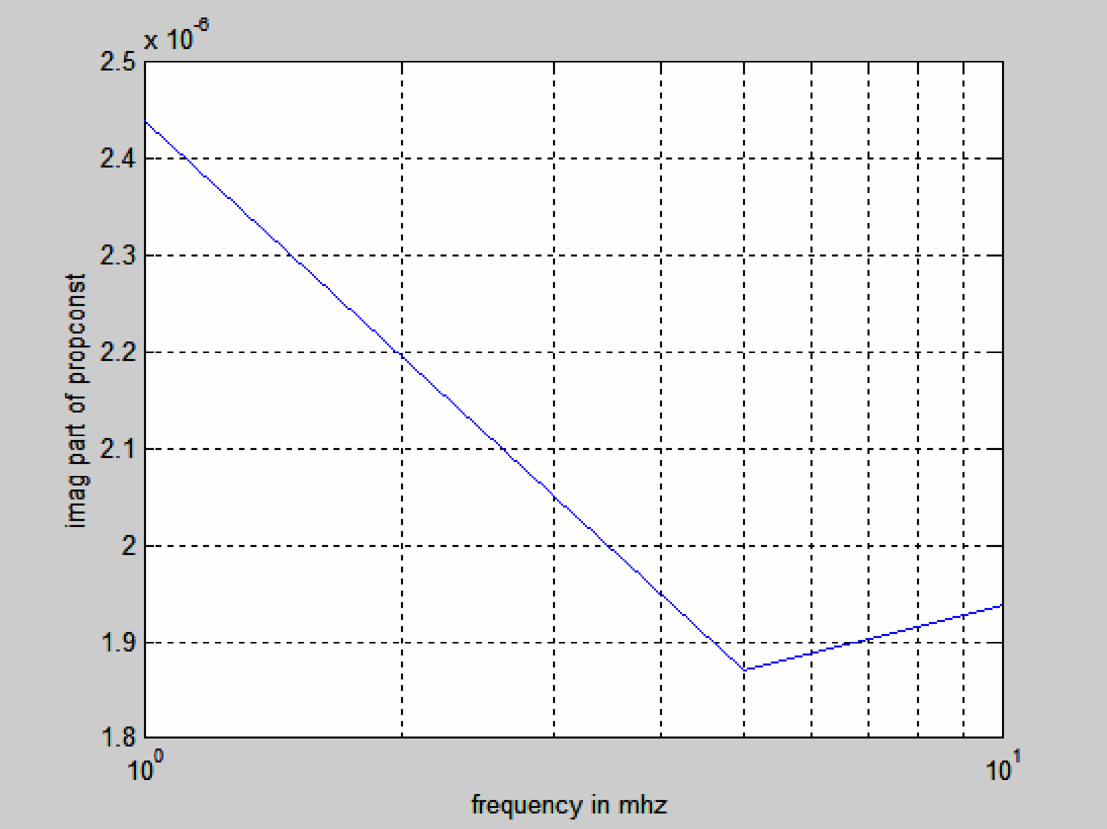


Figure 5.2 Imaginary part of the propagation Constant of an overhead wire.

This graph shows the real part of propagation constant m_k with respect to frequency ranges between 1MHz to 10 MHz. This graph shows that propagation constant first decreases from 1MHz to 5 MHz approximately and then become almost constant in the range 6-10 MHz.

$$m_k = (\lambda_k)^{1/2}$$

Propagation constant is m_k which is derived from n eigen values λ_k of the propagation matrix P

Where P =Z*Y

And Z= per-unit-length impedance matrix

Y=per-unit-length admittance matrix

For this graph ,command used in MATLAB 7.0 is

```
semilogx (w,imag(diag(mk)));
```

```
xlabel('frequency in mhz')
ylabel('imag part of propconst')
grid;
pause
```

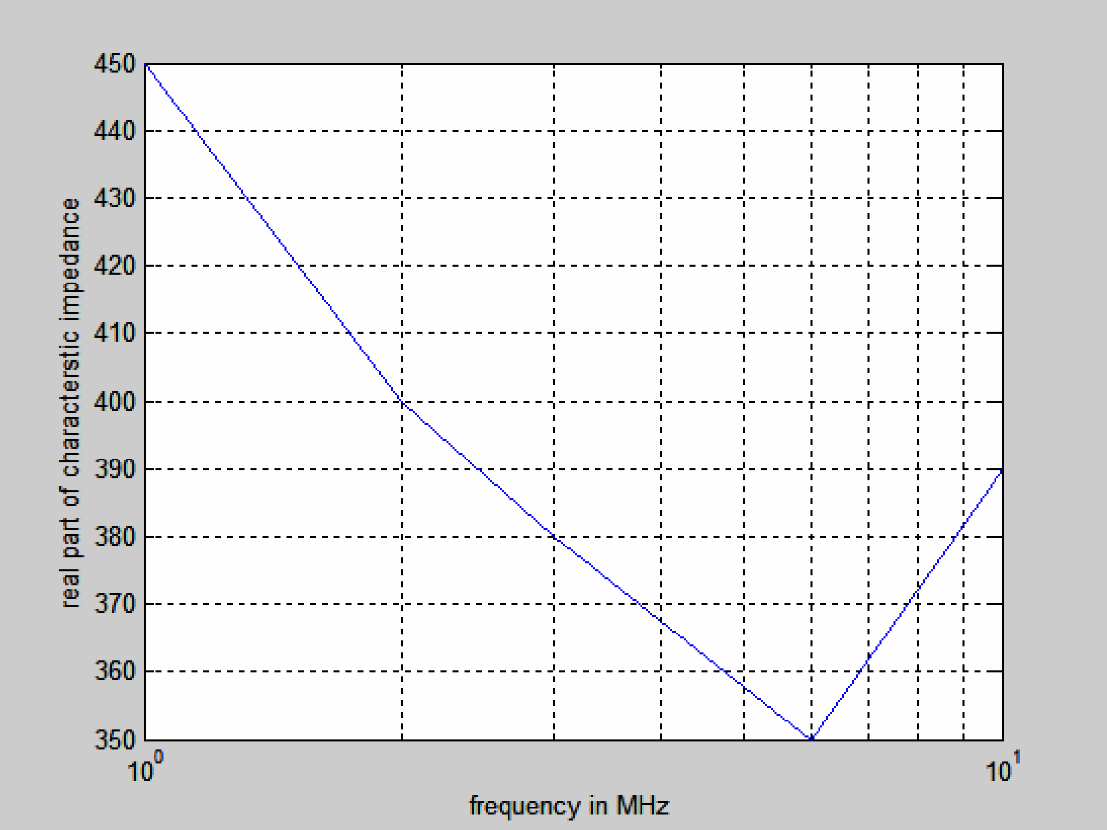


Figure 5.3 Real part of Characteristic impedance

This graph is plotted between the real parts of characteristic impedance and the frequency, the plot shows that its value varies from 350 ohms to 450 ohms in the frequency range 1MHz to 10MHz. As we further increase the frequency the characteristic impedance will increase and maximum value it can have is till 550 ohms.

Characteristic impedance is inverse of characteristic admittance Yc.

Yc=N*m-1*N-1*Y

Where

m is the diagonal matrix of propagation matrix.

Y is the per unit length of shunt admittance

And N is the transformation matrix which is constituted by the n column Eigenvectors related to the n eigenvalues λ_k of the propagation matrix P.

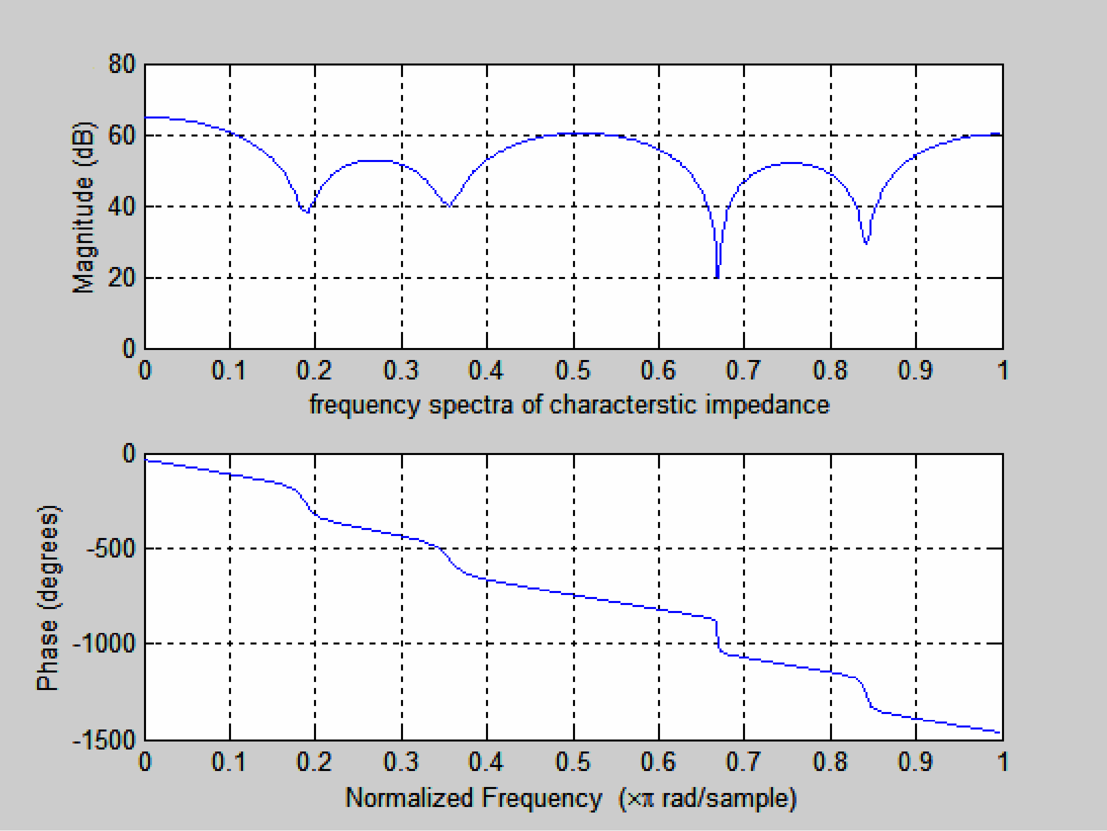


Figure 5.4 a)Magnitude ,b)Phase part of the characteristic impedance

This graph shows the frequency spectra of characteristic impedance.

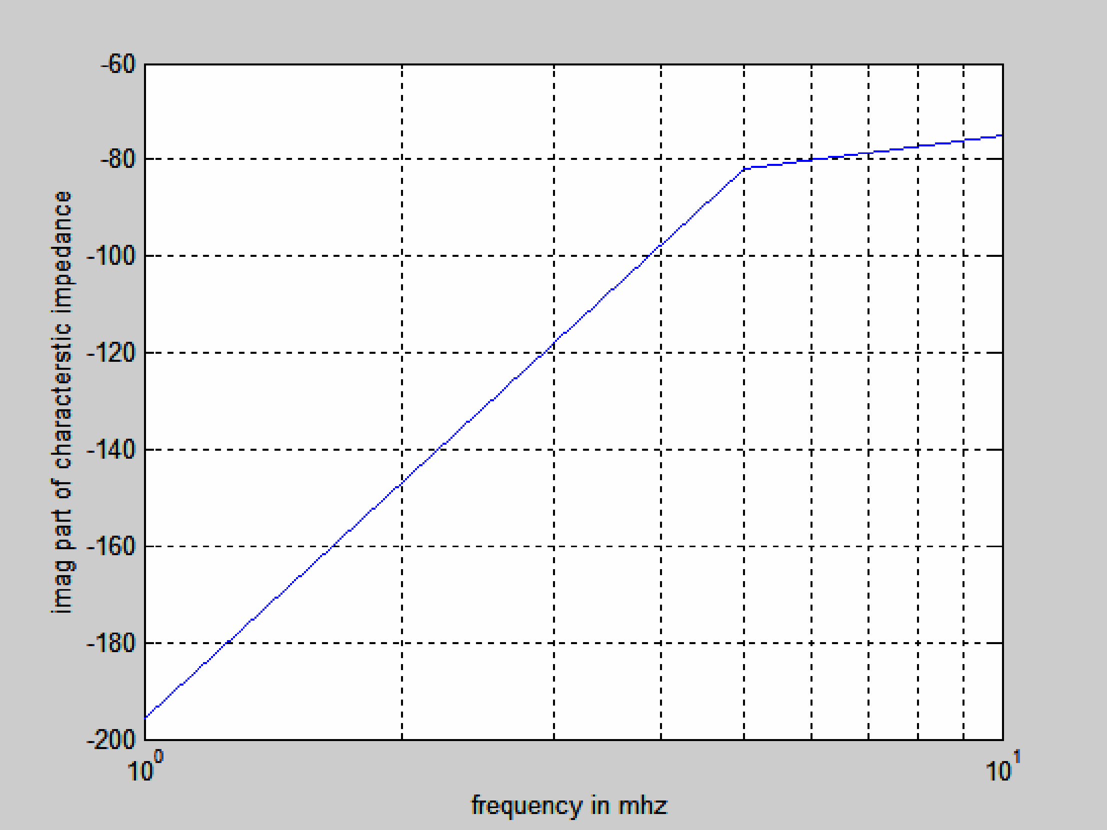


Figure 5.5 Imaginary part of characteristic impedance

Graph 5.5 is plotted between the Imaginary parts of characteristic impedance and the frequency, the plot shows that its value varies from -75 ohms to -196 ohms in the frequency range 1MHz to 10MHz.

Characteristic impedance is inverse of characteristic admittance Yc.

Yc=N*m-1*N-1*Y

Where

m is the diagonal matrix of propagation matrix.

Y is the per unit length of shunt admittance

And N is the transformation matrix which is constituted by the n column Eigenvectors related to the n eigenvalues λ_k of the propagation matrix P.

Therefore,

Zc=Inverse(Yc).

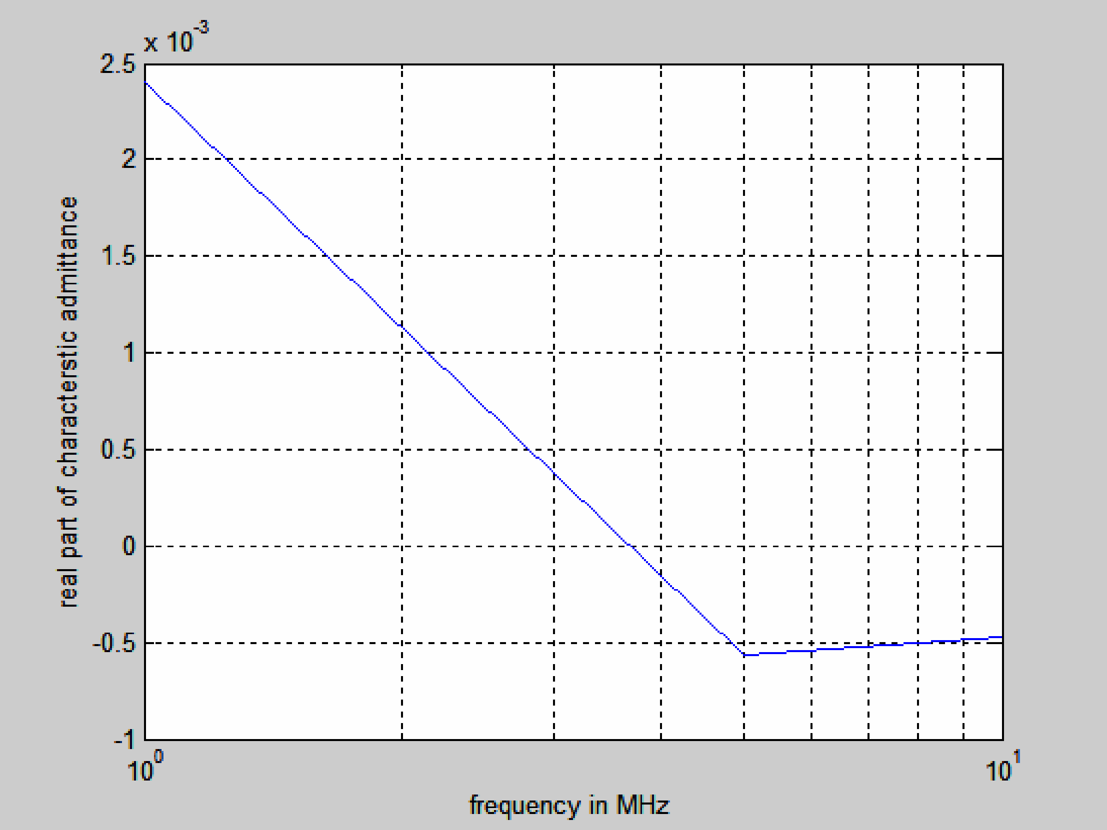


Figure 5.6 Real part of Characteristic Admittance

Graph 5.6 is plotted between the real parts of characteristic Admittance and the frequency, the plot shows that its value varies from -5*10^{-3} mhos to 2.5 *10^{-3}mhos in the frequency range 1MHz to 10MHz.Firstly it decreases from 1 MHz to 7MHz and then it become constant on further increasing the value of frequency.

Characteristic admittance is represented by Yc,

$$Yc=N*m-1*N-1*Y$$

Where

m is the diagonal matrix of propagation matrix.

Y is the per unit length of shunt admittance

And N is the transformation matrix which is constituted by the n column

Eigenvectors related to the n eigenvalues λ_k of the propagation matrix P.

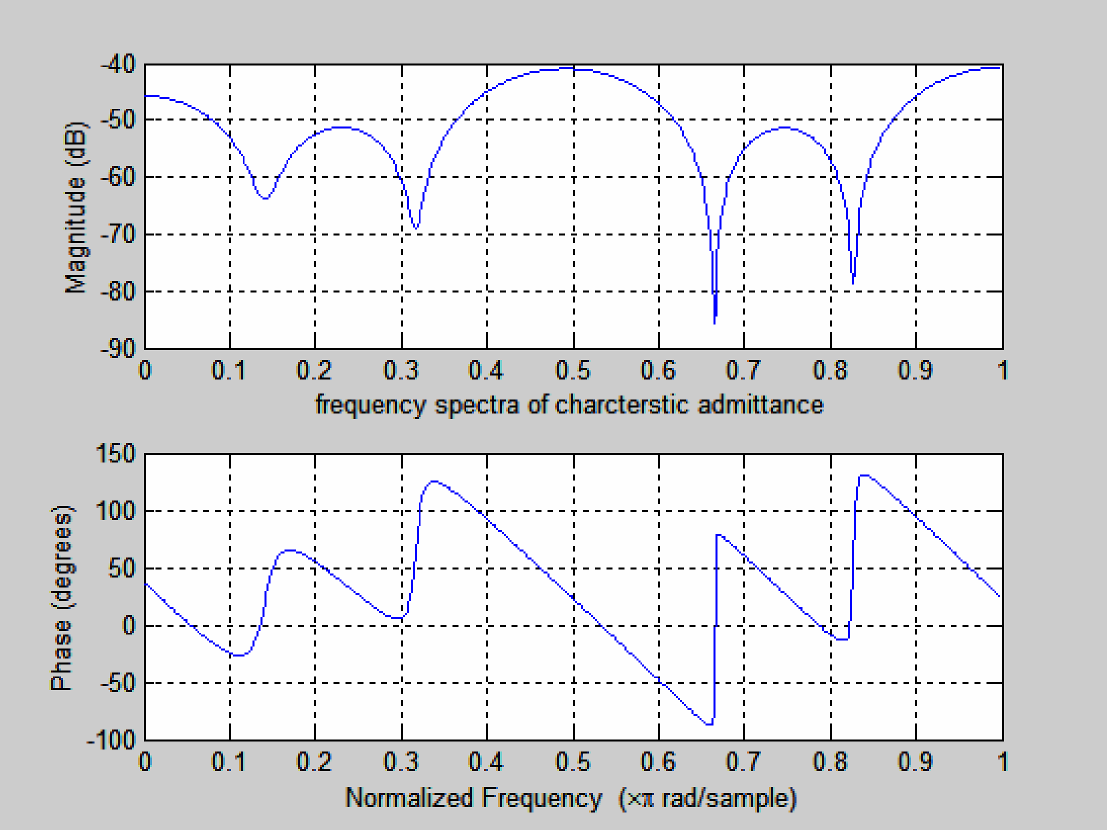


Figure 5.7 Frequency spectra of characteristic admittance

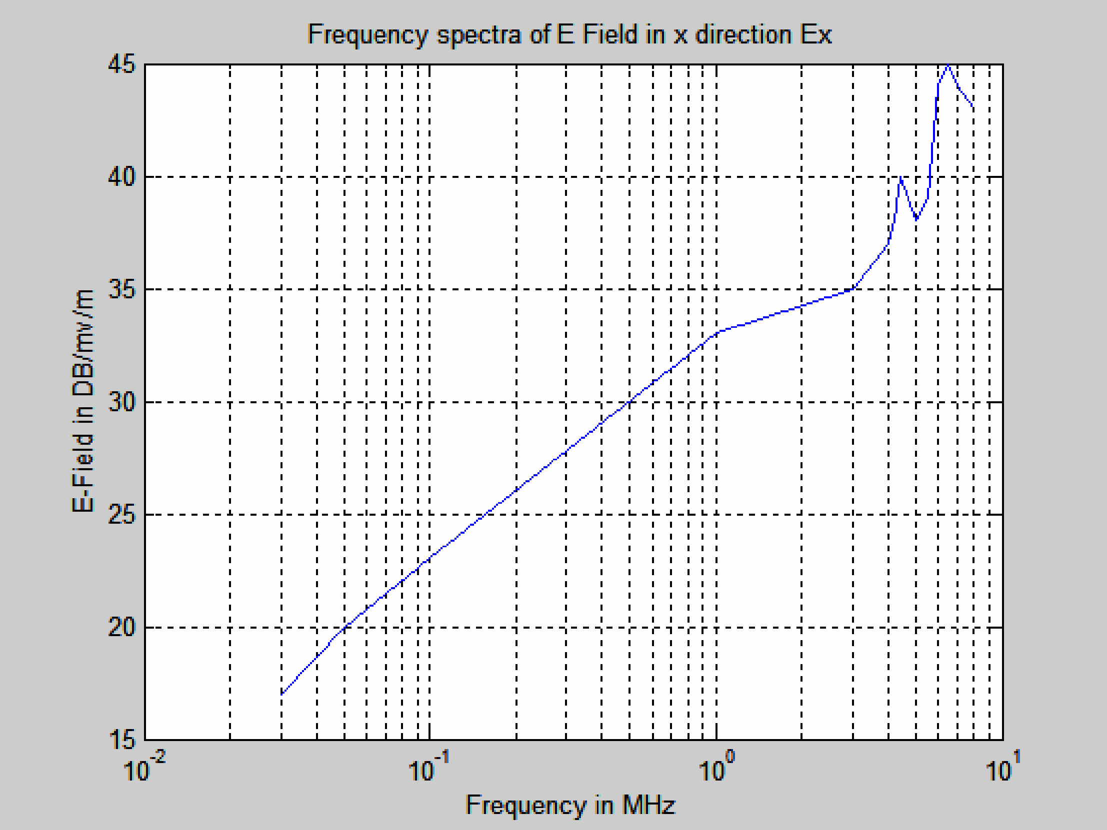


Figure 5.8 Amplitude frequency spectra of the electric field Ex (radiated field) at point

X=800m,y=1m and z=11m.

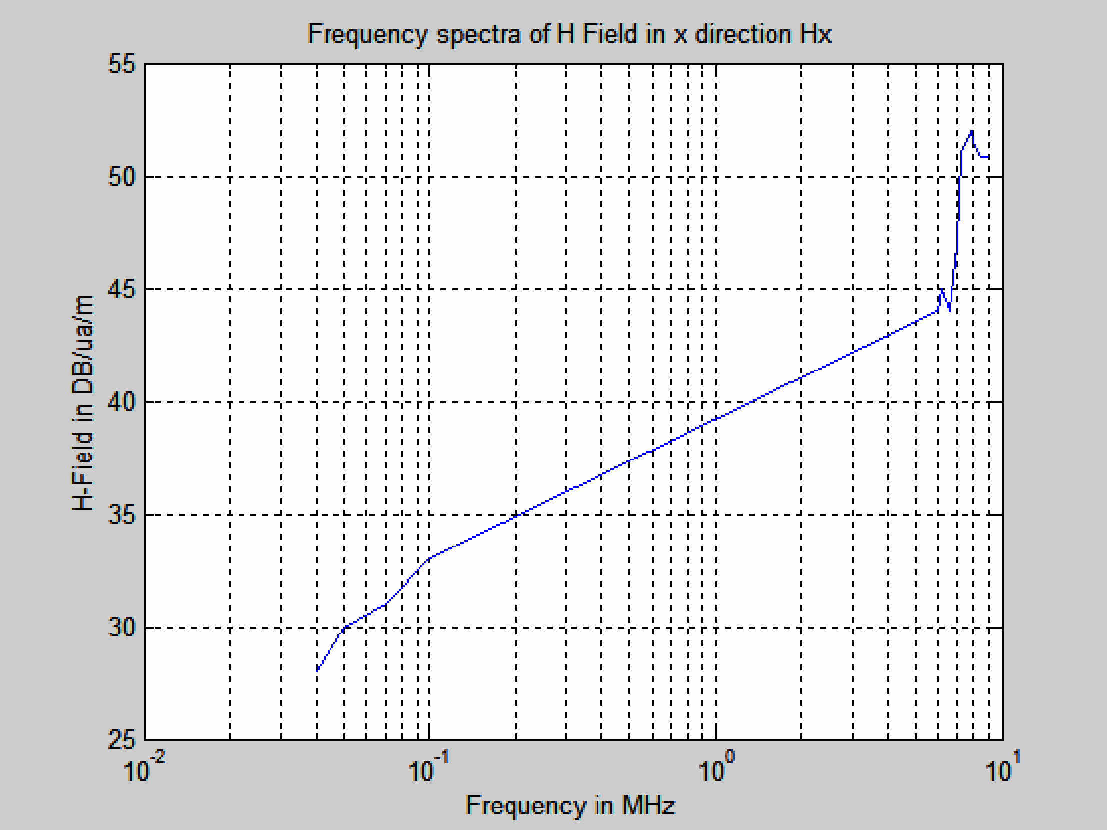


Figure 5.9 Amplitude frequency spectra of the Magnetic field Hx (radiated field) at point

X=800m,y=1m and z=11m.

The proposed model is applied to the calculation of the high- frequency electromagnetic field radiated from carrier channels on the medium-voltage power line having the geometrical configuration shown in third chapter. The ground return path is characterized by conductivity og= 5 mS/m and relative permittivity srg = 5.

The amplitude frequency-spectra of the electric and magnetic field components are computed at a point distant x = 800 m along the line from the exciting source, 10 m outside the lateral conductor 3, and 1 m above the ground plane.

The conductor 2-to-ground coupling is considered. The carrier channel is excited by a voltage source V(0) having the constant rms value of 100 V in the frequency range between 20 kHz and 20 MHz. The obtained results are shown in above figures. It should be noted that in first part of frequency they are increasing linearly and then with large value. The peak that the waveforms show between 3 MHz and 5MHz is due to the resonance phenomenon occurring in the ground medium, which is initially inductive and then capacitive for increasing values of the frequency.

CHAPTER 6

CONCLUSION AND FUTURE WORK

6.1 Conclusion

The analysis of the results obtained from the proposed model in a frequency-range up to 10 *MHz,* are as under;

- Real part of propagation constant also referred as attenuation constant of the overhead wire first decreases from 1MHz to 5 MHz approximately and then became almost constant in the range 6-10 MHz.
- The graph is plotted between the real parts of characteristic impedance whose value ranges from 350 ohms to 450 ohms in the frequency range of 1MHz to 10MHz.

The proposed model is applied for the calculation of the high- frequency electromagnetic field radiated from carrier channels on the medium-voltage power line having the geometrical configuration is discussed in third chapter. The ground return path is characterized by conductivity of σg= 5 mS/m and relative permittivity εrg = 5. The amplitude frequency-spectra of the electric and magnetic field components were computed. It was found that in the lower part of frequency the frequency spectra increased in a linear manner and after reaching higher frequency it increased steeply. The peak that the waveforms show between 3 MHz and 5MHz is due to the resonance phenomenon occurring in the ground medium, which is initially inductive and then capacitive for increasing values of the frequency.

6.2 Future Work

Electromagnetic interference is an issue of concern in delivery of broadband over power line. This based on the contributions and tools developed in this thesis, future research in is aimed at development of Broadband over Power line Communications and potential Electromagnetic Interference while transmission. There is major gap at the moment in understanding the resultant impact of electromagnetic interference and resolution of the same. Broadband communications should focus more on practical aspect of these fields. For example, the various communication channels and their behavior found during the transmission in this research for BPL systems should be verified more, experimentally.

- The EMC characterization of power lines and the impedance matching of lines are also vital issues for this technology to improve. There is no practical technology available to provide load matching for power line networks, as yet. Furthermore, the effect of coupling on the radiation pattern should be explored. Also, high bandwidth coupling techniques are not easy procedures and several research groups are working on this subject.
- The coding schemes specially using of Fountain codes as the outer code need to be more investigated as this scheme shows a promising performance.

- Moreover, EMC issue and its resolution is still in its infancy and commercially difficult to achieve. There is also debate about the uplink communication scheme for these systems. Either 170 Time Division Multiplexing (TDM) or Wavelength Division Multiplexing (WDM) can be used for this matter. The feasibility of any of these techniques and their performance need to be investigated further.

- In the present thesis EMC component were analyzed over a three phase lossy carrier channel however of future developments, the electromagnetic field radiated from carrier channels on finite length power lines, in any terminal load condition, will be analyzed.

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Appendix-A

The expressions of $\Lambda^{(j)}_{ik}$ for j = 1,4 are the following

$$\Lambda_{ik}^{(1)} = \mathrm{K}_0\left[j\rho_i^-\left(k_0^2+m_k^2\right)^{1/2}\right] - \mathrm{K}_0\left[j\rho_i^+\left(k_0^2+m_k^2\right)^{1/2}\right] \qquad \text{(A.1a)}$$

$$\Lambda_{ik}^{(2)} = \left(k_0^2+m_k^2\right)^{1/2} \frac{\Lambda_{ik}^{(1)}}{2} \qquad \text{(A.1b)}$$

$$\begin{aligned}\Lambda_{ik}^{(3)} = \frac{\left(k_0^2+m_k^2\right)^{1/2}}{2}\Bigg\{ & \frac{y+h_i}{\rho_i^+}\mathrm{K}_1\left[j\rho_i^+\left(k_0^2+m_k^2\right)^{1/2}\right] + \\ & -\frac{y-h_i}{\rho_i^-}\mathrm{K}_1\left[j\rho_i^-\left(k_0^2+m_k^2\right)^{1/2}\right]\Bigg\}\end{aligned} \qquad \text{(A.1c)}$$

$$\begin{aligned}\Lambda_{ik}^{(4)} = \frac{\left(k_0^2+m_k^2\right)^{1/2}}{2}\Bigg\{ & \frac{z-z_i}{\rho_i^+}\mathrm{K}_1\left[j\rho_i^+\left(k_0^2+m_k^2\right)^{1/2}\right] + \\ & -\frac{z-z_i}{\rho_i^-}\mathrm{K}_1\left[j\rho_i^-\left(k_0^2+m_k^2\right)^{1/2}\right]\Bigg\}\end{aligned} \qquad \text{(A.1d)}$$

in which K_0, K_1 are the modified Bessel functions of second type, zero order and first order respectively, and:

$$\rho_i^- = \left[\left(y-h_i\right)^2+\left(z-z_i\right)^2\right]^{1/2} \;,\; \rho_i^+ = \left[\left(y+h_i\right)^2+\left(z-z_i\right)^2\right]^{1/2} \qquad \text{(A.2)}$$

where the geometrical parameters are shown in Fig. 3.2.
The Sommerfeld integrals $S^{(j)}_{ik}$, for j =1,10 are given by:

$$S_{ik}^{(1)} = \int_0^\infty f_{1ik}(\zeta)\,\mathrm{d}\zeta \quad , \quad S_{ik}^{(2)} = \int_0^\infty f_{2ik}(\zeta)\,\mathrm{d}\zeta \qquad \text{(A.3a)}$$

$$S_{ik}^{(3)} = \int_0^\infty \frac{\zeta}{u_{0k}} f_{1ik}(\zeta)\,\mathrm{d}\zeta \quad , \quad S_{ik}^{(4)} = \int_0^\infty \frac{\zeta}{u_{0k}} f_{2ik}(\zeta)\,\mathrm{d}\zeta \qquad \text{(A.3b)}$$

$$S_{ik}^{(5)} = \int_0^\infty \frac{1}{u_{0k}} f_{1ik}(\zeta)\,\mathrm{d}\zeta \quad , \quad S_{ik}^{(6)} = \int_0^\infty \frac{1}{u_{0k}} f_{2ik}(\zeta)\,\mathrm{d}\zeta \qquad \text{(A.3c)}$$

$$S_{ik}^{(7)} = \int_0^\infty \frac{\zeta^2}{u_{0k}} f_{1ik}(\zeta)\,\mathrm{d}\zeta \quad , \quad S_{ik}^{(8)} = \int_0^\infty \frac{\zeta^2}{u_{0k}} f_{2ik}(\zeta)\,\mathrm{d}\zeta \qquad \text{(A.3d)}$$

$$S_{ik}^{(9)} = \int_0^\infty \zeta f_{1ik}(\zeta)\,\mathrm{d}\zeta \quad , \quad S_{ik}^{(10)} = \int_0^\infty \zeta f_{2ik}(\zeta)\,\mathrm{d}\zeta \qquad \text{(A.3e)}$$

where:

$$f_{1ik}(\zeta) = \frac{\exp\left[-u_{0k}\left(y+h_i\right)\right]}{u_{0k}+u_{gk}} \exp\left[-j\zeta\left(z-z_i\right)\right] \qquad \text{(A.4a)}$$

$$f_{2ik}(\zeta) = \frac{\exp\left[-u_{0k}\left(y+h_i\right)\right]}{k_g^2 k_0^{-2} u_{0k}+u_{gk}} \exp\left[-j\zeta\left(z-z_i\right)\right] \qquad \text{(A.4b)}$$

$$u_{0k} = \left(\zeta^2 - m_k^2 - k_0^2\right)^{1/2} \quad , \quad u_{gk} = \left(\zeta^2 - m_k^2 - k_g^2\right)^{1/2} \qquad \text{(A.4c)}$$

$$k_0 = \omega\left(\mu_0 \varepsilon_0\right)^{1/2} \quad , \quad k_g = k_0\left(\frac{\varepsilon_g}{\varepsilon_0} + \frac{\sigma_g}{j\omega\varepsilon_0}\right)^{1/2} \qquad \text{(A.4d)}$$

Appendix B

A transmission line can be analyzed by determining the series impedance matrix and shunt admittance matrix per unit length of line.

Series impedance matrix is given as:-

$Z=R_c+R_e+j(X_g+X_e+X_c)$ (B.1)

Where suffixes g,e,c, represent contributions due to geometry of the conductor ,earth return path, physical properties of the conductor material, respectively X_g is given as:-

$X_g=j*\omega*\mu_o/2*\pi$ (B.2)

When earth wires are present, there effect can be considered as per conventional conductor present while forming the potential coefficient matrix, [F]. However, considering zero potential on these conductors eliminates them and accordingly the rows and column related to earth are discarded

Where the elements of matrix F can be given as

$F_{ii}=\ln 2h_i/r_i$ (B.3)

$F_{ij}=\ln U_{ij}/u_{ij}$ (B.4)

Where h is the height of the conductor above the earth plane, r is the radius of the conductor, Uij is the distance between the ith conductor and the image of the jth conductor, uij is the distance between the ith conductor and jth conductor.

The resistance and reactance due to conductor can be given as

$R_c=X_c= (k*sqrt(\mu_o*\rho_c/2)*sqrt(\omega*i)/(r_s*(n_s+2)*\pi))$ (B.5)

Where k is a factor due to conductor stranding, rs is the radius of each outer strand,

n_s are the number of strands in the outermost layer ρ_c is the resistivity of conductor material.

Resistance and reactance due to earth return path can be given as

R_e=2Pωμ$_o$/2*π (B.6)

X_e=2Qωμ$_o$/2*π (B.7)

Where P and Q are correction component matrices and can be calculated in terms of two parameters C_{ij} and Θ_{ij},

$C_{ij=}$ sqrt((μ$_o$*ω/ρ$_c$)* U_{ij}) (B.8)

Θ_{ij} is the angle subtended at the ith conductor by the images of ith and jth conductor.
And

Shunt admittance matrix the shunt admittance matrix can be given as

Y=jω2πε$_o$B (B.9)

Where matrix B is obtained by inverting the potential coefficient matrix,F.

Appendix C

```
%   THE ELECTROMAGNETIC FIELD RADIATED FROM A MULTICONDUCTOR LINE
%   THE EXCITING SOURCE
% Z= Rc + Re + i(Xg+Xe+Xc) where Rc is the resistance of conductor ,Re is the reistance of earth
% and Xe,Xc and Xg are the inductances of earth return path, properties of the conductor material
% and the geometry of the conductor respectively.
Rc2 = (k*sqrt(mu*rho/2)*sqrt(w*i)/(r*(ns+2)*pi)); %Resistance
Rabs=abs(Rc2);
Rc=Rabs*I;
Xc=Rc;



%Finding out F (the potential coeff matrix)
%a=((gmr^9)/(4*r^3))^(1/6); % a is the horiz spacing between conductors.
x1=sqrt(a^2+h^2);
x2=sqrt((2*a)^2+h^2);
F=[log(2*h/r) log(x1/a) log(x2/(2*a)); log(x1/a) log(2*h/r) log(x1/a); log(x2/(2*a)) log(x1/a) log(2*h/r)];
%Finding out B
B=inv(F);
Xg=w*mu*B/(2*pi);
%Finding out Xe and Re hence P and Q matrix
U=[2*h x1 x2; x1 2*h x1; x2 x1 2*h];
c=sqrt(w)*sqrt(mu/rhoe)*U;
theta=[0 asin(a/x1) asin(2*a/x2); asin(a/x1) 0 asin(a/x1); asin(2*a/x2) asin(a/x1) 0];
gam=1.7811; %gamma
P=zeros(3,3);
```

```
Q=zeros(3,3);
for col=1:3
    for row=1:3
        a0(row,col)=c(row,col)^2/8;
        c0(row,col)=c(row,col)^4/192;
        e0(row,col)=c(row,col)/3;
        f0(row,col)=c(row,col)^3/45;
    end
end

%an
for col=1:3
    for row=1:3
    a1(row,col)=(-a0(row,col)/(2*1*(2*1+1)^2*(2*1+2)))*((c(row,col)/2)^4);
    a2(row,col)=(-a1(row,col)/(2*2*(2*2+1)^2*(2*2+2)))*((c(row,col)/2)^4);
    a3(row,col)=(-a2(row,col)/(2*3*(2*3+1)^2*(2*3+2)))*((c(row,col)/2)^4);
    a4(row,col)=(-a3(row,col)/(2*4*(2*4+1)^2*(2*4+2)))*((c(row,col)/2)^4);
    a5(row,col)=(-a4(row,col)/(2*5*(2*5+1)^2*(2*5+2)))*((c(row,col)/2)^4);
    a6(row,col)=(-a5(row,col)/(2*6*(2*6+1)^2*(2*6+2)))*((c(row,col)/2)^4);
    end
end

%cn
for col=1:3
    for row=1:3
    c1(row,col)=(-c0(row,col)/(2*1*(2*1+2)^2*(2*1+3)))*((c(row,col)/2)^4);
    c2(row,col)=(-c1(row,col)/(2*2*(2*2+2)^2*(2*2+3)))*((c(row,col)/2)^4);
    c3(row,col)=(-c2(row,col)/(2*3*(2*3+2)^2*(2*3+3)))*((c(row,col)/2)^4);
    c4(row,col)=(-c3(row,col)/(2*4*(2*4+2)^2*(2*4+3)))*((c(row,col)/2)^4);
    end
end
```

```
%en
for col=1:3
   for row=1:3
   e1(row,col)=(-e0(row,col)/((4*1-1)*(4*1+1)^2*(4*1+3)))*(c(row,col)^4);
   e2(row,col)=(-e1(row,col)/((4*2-1)*(4*2+1)^2*(4*2+3)))*(c(row,col)^4);
   e3(row,col)=(-e2(row,col)/((4*3-1)*(4*3+1)^2*(4*3+3)))*(c(row,col)^4);
   e4(row,col)=(-e3(row,col)/((4*4-1)*(4*4+1)^2*(4*4+3)))*(c(row,col)^4);
   end
end

%fn
for col=1:3
   for row=1:3
      f1(row,col)=(-f0(row,col)/((4*1+1)*(4*1+3)^2*(4*1+5)))*(c(row,col)^4);
      f2(row,col)=(-f1(row,col)/((4*2+1)*(4*2+3)^2*(4*2+5)))*(c(row,col)^4);
      f3(row,col)=(-f2(row,col)/((4*3+1)*(4*3+3)^2*(4*3+5)))*(c(row,col)^4);
      f4(row,col)=(-f3(row,col)/((4*4+1)*(4*4+3)^2*(4*4+5)))*(c(row,col)^4);
   end
end

%gn
g0=5/4;
g1=g0+(1/(4*1))+(1/(2*1+1))+(1/(2*1+2))-(1/(4*1+4));
g2=g1+(1/(4*2))+(1/(2*2+1))+(1/(2*2+2))-(1/(4*2+4));
g3=g2+(1/(4*3))+(1/(2*3+1))+(1/(2*3+2))-(1/(4*3+4));
g4=g3+(1/(4*4))+(1/(2*4+1))+(1/(2*4+2))-(1/(4*4+4));

%hn
h0=5/3;
h1=h0+(1/(4*1+2))+(1/(2*1+2))+(1/(2*1+3))-(1/(4*1+6));
```

```
h2=h1+(1/(4*2+2))+(1/(2*2+2))+(1/(2*2+3))-(1/(4*2+6));
h3=h2+(1/(4*3+2))+(1/(2*3+2))+(1/(2*3+3))-(1/(4*3+6));
h4=h3+(1/(4*4+2))+(1/(2*4+2))+(1/(2*4+3))-(1/(4*4+6));

%s2
for col=1:3
   for row=1:3

s2(row,col)=a0(row,col)*cos(2*theta(row,col))+a1(row,col)*cos(6*theta(row,col))+a2(row,col)*cos(10*theta(row,col))+a3(row,col)*cos(14*theta(row,col))+a4(row,col)*cos(18*theta(row,col));

t2(row,col)=a0(row,col)*sin(2*theta(row,col))+a1(row,col)*sin(6*theta(row,col))+a2(row,col)*sin(10*theta(row,col))+a3(row,col)*sin(14*theta(row,col))+a4(row,col)*sin(18*theta(row,col));

s4(row,col)=a0(row,col)*cos(4*theta(row,col))+a1(row,col)*cos(8*theta(row,col))+a2(row,col)*cos(12*theta(row,col))+a3(row,col)*cos(16*theta(row,col))+a4(row,col)*cos(20*theta(row,col));

t4(row,col)=a0(row,col)*sin(4*theta(row,col))+a1(row,col)*sin(8*theta(row,col))+a2(row,col)*sin(12*theta(row,col))+a3(row,col)*sin(16*theta(row,col))+a4(row,col)*sin(20*theta(row,col));

w1(row,col)=a0(row,col)*cos(theta(row,col))+a1(row,col)*cos(5*theta(row,col))+a2(row,col)*cos(9*theta(row,col))+a3(row,col)*cos(13*theta(row,col))+a4(row,col)*cos(17*theta(row,col));

w3(row,col)=f0(row,col)*cos(3*theta(row,col))+f1(row,col)*cos(7*theta(row,col))+f2(row,col)*cos(11*theta(row,col))+f3(row,col)*cos(15*theta(row,col))+f4(row,col)*cos(19*theta(row,col));
```

```
   end
end

%w2
for col=1:3
   for row=1:3
      w2(row,col)=s2(row,col)*(1*g1+2*g2+3*g3+4*g4);
      w4(row,col)=s4(row,col)*(1*h1+2*h2+3*h3+4*h4);
   end
end



for col=1:3
   for row=1:3
P(row,col)=pi/3*(1-
s4(row,col))+1/2*log(2/(gam*c(row,col)))*s2(row,col)+1/2*theta(row,col)*t2(row,col)-
w1(row,col)/sqrt(2)+w2(row,col)/2+w3(row,col)/sqrt(2);
Q(row,col)=1/4+log(2/(gam*c(row,col)))*(1-s4(row,col))/2-
theta(row,col)*t4(row,col)/2+w1(row,col)/sqrt(2)-pi*s2(row,col)/8+w3(row,col)/sqrt(2)-
w4(row,col)/2;
   end
end
Re= (2*P*w*mu)/(2*pi);
Xe= (2*Q*mu)/(2*pi);

%Finding out Z now
Z=Rc+Re+(Xe+Xg+Xc)*i;%
disp('The value of per unit length shunt admittance matrix is:-')
y=w*i*2*pi*E0*B
disp('The value of per unit length series impedance matrix is:-')
disp(Z)
```

```
disp('LINE PROPAGATION MATRIX = P');
Pr=Z*y;
disp(Pr);

pt=y*Z
%disp('TRANSFORMATION MATRIX = t');
%N=diag(pt);
%disp(N);
[t,d]=eig(Pr);
disp('eigen values of propagation matrix is d =');
disp(d);
disp('eigen vectors of propagation matrix is t =');
disp(t);
v=input('enter the value of impressed voltage source,v =');
disp('propagation constant of the kth mode ,mk =');
mk=d^0.5;
disp(mk);
disp('diagonal matrix of propagation matrix ,m =');
m=diag(mk);
disp(m);
yc=t*mk^-1*t^-1*y;
disp('Charactereristic admittance matrix ,yc =');
disp(yc);
zc=inv(yc)
disp('Charactereristic impedance matrix ,yc =');
disp(yc);
q=diag(exp(-mk*x));
disp('diagonal matrix of madal traition matrix, q=');
disp(q);
q0=exp(-mk*x);
```

```
disp('modal transition matrix is q0=')
disp(q0);
q1=t*q0*t^-1;
disp('current transition matrix of the reflection free transition line is given by q1 =')
disp(q1);
Ix=q1*yc*v;
disp('The line current vector ,the hypotesis of unidirectional propagation is given by I=')
%disp(I)

%    THE FIELD RESPONSE
%    THE EXPRESSION OF LAMBDA,IK(J) FOR J=1,4 ARE THE FOLLOWING
%    THE SOMMERFELDS INTEGRALS S,IK(J) FOR J=1,10 ARE GIVEN BELOW
syms u unreal;
u = sym('u','unreal');
for c=1:1:a,

sik1=int(exp((-(u^2-m(c,:)...
    ^2-ko^2)^1\2)*(ya+hi))\((u^2-m(c,:)^2-ko^2)^1\2)...
    +((u^2-m(c,:)^2-kg^2)^1\2)*exp(-j*u*(za-zi)),0,inf);

disp('sik1')
 disp(sik1)
end

syms u unreal;
u = sym('u','unreal');

% for c=1:1:a,
%
%     sik3=int((u\(u^2-m(c,:)^2-ko^2)^1\2)*exp((-(u^2-m(c,:)...
%     ^2-ko^2)^1\2)*(ya+hi))\((u^2-m(c,:)^2-ko^2)^1\2)...
```

```
%    +((u^2-m(c,:)^2-kg^2)^1\2)*exp(-j*u*(za-zi)),0,inf);
%
% %sik3=int((u\(u^2-m(c,:)^2-ko^2)^1\2)*(exp((-(u^2-m(c,:)...
%    % ^2-ko^2)^1\2)*(ya+hi)))\((u^2-m(c,:)^2-ko^2)^1\2)...
%    % +((u^2-m(c,:)^2-kg^2)^1\2)*exp(-j*u*(za-zi)),0,inf);
%
% disp('sik3');
% disp(sik3);
% end
for c=1:1:a,

sik5=int((1\(u^2-m(c,:)^2-ko^2)^1\2)*(exp((-(u^2-m(c,:)...
   ^2-ko^2)^1\2)*(ya+hi)))\((u^2-m(c,:)^2-ko^2)^1\2)+...
   ((u^2-m(c,:)^2-kg^2)^1\2)*exp(-j*u*(za-zi)),0,inf);

disp('sik5');
disp(sik5);
end
for c=1:1:a,

sik7=int(((u^2)\(u^2-m(c,:)^2-ko^2)^1\2)*(exp((-(u^2-m(c,:)...
   ^2-ko^2)^1\2)*(ya+hi)))\((u^2-m(c,:)^2-ko^2)^1\2)+(...
   (u^2-m(c,:)^2-kg^2)^1\2)*exp(-j*u*(za-zi)),0,inf);

disp('sik7');
disp(sik7);
end
for c=1:1:a,

sik9=int(((u)*(exp((-(u^2-m(c,:)^2-ko^2)^1\2)*(ya+hi)))\...
   ((u^2-m(c,:)^2-ko^2)^1\2)+((u^2-m(c,:)^2-kg^2)^1\2))*exp(-j*u*(za-zi)),0,inf);
```

```
disp('sik9');
disp(sik9);
end
for c=1:1:a,

sik2=int(exp((-(u^2-m(c,:)^2-ko^2)^1\2)*(ya+hi))\kg^2*ko^-2*...
   (((u^2-m(c,:)^2-ko^2)^1\2))+((u^2-m(c,:)^2-kg^2)^1\2)*exp(-j*u*(za-zi)),0,inf);

disp('sik2');
disp(sik2);
end
% for c=1:1:a,
%                              sik4=int((u\(u^2-m(c,:)^2-ko^2)^1\2)*exp((-(u^2-m(c,:)^2-
ko^2)^1\2)*(ya+hi))\kg^2*ko^-2*...
%    (((u^2-m(c,:)^2-ko^2)^1\2))+((u^2-m(c,:)^2-kg^2)^1\2)*exp(-j*u*(za-zi)),0,inf);
%
% % sik4=int((u\(u^2-m(c,:)^2-ko^2)^1\2)*(exp((-(u^2-m(c,:)^2-ko^2)...
%  %          ^1\2)*(ya+hi))\((u^2-m(c,:)^2-ko^2)^1\2)+((u^2-m(c,:)^2-kg^2)^1\2))*exp(-
j*u*(za-zi)),0,inf);
%
% disp('sik4');
% disp(sik4);
% end
for c=1:1:a,
 sik6=int((1\(u^2-m(c,:)^2-ko^2)^1\2)*exp((-(u^2-m(c,:)^2-
ko^2)^1\2)*(ya+hi))\kg^2*ko^-2*...
   (((u^2-m(c,:)^2-ko^2)^1\2))+((u^2-m(c,:)^2-kg^2)^1\2)*exp(-j*u*(za-zi)),0,inf);

% sik6=int((1\(u^2-m(c,:)^2-ko^2)^1\2)*(exp((-(u^2-m(c,:)^2-ko^2)^1\2)...
```

```
%           *(ya+hi))\((u^2-m(c,:)^2-ko^2)^1\2)+((u^2-m(c,:)^2-kg^2)^1\2))*exp(-j*u*(za-
zi)),0,inf);

disp('sik6');
disp(sik6);
end
for c=1:1:a,
 sik8=int((u^2\(u^2-m(c,:)^2-ko^2)^1\2)*exp((-(u^2-m(c,:)^2-
ko^2)^1\2)*(ya+hi))\kg^2*ko^-2*...
   (((u^2-m(c,:)^2-ko^2)^1\2))+((u^2-m(c,:)^2-kg^2)^1\2)*exp(-j*u*(za-zi)),0,inf);

% sik8=int((u^2\(u^2-m(c,:)^2-ko^2)^1\2)*(exp((-(u^2-m(c,:)^2-ko^2)...
%              ^1\2)*(ya+hi))\((u^2-m(c,:)^2-ko^2)^1\2)+((u^2-m(c,:)^2-kg^2)^1\2))*exp(-
j*u*(za-zi)),0,inf);

disp('sik8');
disp(sik8);
end
for c=1:1:a,
sik10=int((u)*exp((-(u^2-m(c,:)^2-ko^2)^1\2)*(ya+hi))\kg^2*ko^-2*...
   (((u^2-m(c,:)^2-ko^2)^1\2))+((u^2-m(c,:)^2-kg^2)^1\2)*exp(-j*u*(za-zi)),0,inf);

% sik10=int(u*(exp((-(u^2-m(c,:)^2-ko^2)^1\2)*(ya+hi))\((...
%    u^2-m(c,:)^2-ko^2)^1\2)+((u^2-m(c,:)^2-kg^2)^1\2))*exp(-j*u*(za-zi)),0,inf);

disp('sik10');
disp(sik10);
end
```

THE EXPRESSION OF LAMBDA,IK(J) FOR J=1,4 ARE THE FOLLOWING

```
rho1=((ya-hi)^2+(za-zi)^2)^1/2
rho2=((ya+hi)^2+(za-zi)^2)^1/2
syms  z unreal
for c=1:1:a,

lik1=besselk(0,(12)',1)*(j*rho1*(ko^2+m(c,:)^2)^1/2)-
besselk(0,(12)',1)*(j*rho2*(ko^2+m(c,:)^2)^1/2)

disp('lik1');
disp(lik1);
lik2=((ko^2+m(c,:)^2)^1/2)*lik1/2

lik3=(((ko^2+m(c,:)^2)^1/2)/2)*(((ya+hi)/rho2)*besselk(1,(12)',1)*(j*rho2*(ko^2+m(c,:)
^2)^1/2)...
    +((ya+hi)/rho1)*besselk(1,(12)',1)*(j*rho1*(ko^2+m(c,:)^2)^1/2))

lik4=(((ko^2+m(c,:)^2)^1/2)/2)*(((za+zi)/rho2)*besselk(1,(12)',1)*(j*rho2*(ko^2+m(c,:)
^2)^1/2)...
    +((za+zi)/rho1)*besselk(1,(12)',1)*(j*rho1*(ko^2+m(c,:)^2)^1/2))
end
%
%
%%%%THE CURRENT TO FIELD TRANSFERRING FUNCTIONS
%THE CURRENT OF ITH WIRE IS A FUNCTION OF MODAL CURRENTS
% THE MODAL CURRENT IS GIVEN BY Io AS

Io=inv(t)*Ix;
```