



Addis Ababa University  
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School of Electrical and Computer Engineering

# Power line communication based real time train tracking system for Addis Ababa light rail transit

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In partial fulfillment of the requirement for the Degree of Master of  
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PLC based real time train tracking system for  
A.A LRT

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## **Abstract**

In railway traffics the low friction between wheel and rail causes long braking distances, normally much longer than the driver's sight distance, i.e. if the driver starts the braking when he discovers a problem on the track it is too late to stop the train. The conclusion will be that the railway traffic can not only rely on the driver for the traffic safety, there must also be a signaling or even an automatic surveyor system, which can supervise the positions of different trains along the track and organize the traffic. Having the traffics information on the track helps to avoid situations of conflict and those that might be potentially unsafe.

There are different train detection systems in service worldwide. Track circuit, Axle counter and GPS are the most prevailed approaches. The first two types provide the information that whether the section is occupied or not. They don't provide the information "where exactly the train is?" Beside Axle counter has huge installation cost and maintenance cost. Regarding GPS, since it is using satellites to determine the location of the train and the accuracy is dependent on the no of satellites tracked, the error spread is variable. In addition to this it doesn't operate in tunnels like we have for A.A LRT (Addis Ababa Light Rail Transit) track, from St. George church to Atikilitera. Not only these but also since the satellites are administered by third party, the operation is totally out of the control of the railway company.

With this research, Power line based real-time train tracking system is proposed for A.A LRT. It has an advantage of providing continuous distance information, low capital cost, low maintenance cost and under a full control of Railway Company. Since it uses the power line communication, the channel is secured since the train is on the track and the overhead contact system exists. Beside of the train detection software is developed to display visually the train movement according to the distance information obtained.

The system can also extend to broadcasting the information obtained via a possible communication means (GSM-R) to control center or other trains on the track. This increases the movement confidence of the trains since the driver operates with the knowledge of distance, direction and speed of trains at the back and front that helps a lot for efficient use of the track.

**Key words – Train detection, power line communication, signaling, tracking software, Axle counter**

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## **Abbreviations**

A.A LRT:	Addis Ababa light rail transit
ACB:	Axle counters board
AF:	Audio Frequency
ALU:	Arithmetic and logic unit
AMR:	Automatic meter reading
ANSI:	American national standard institute
ARIB:	Association of Radio Industries and Businesses
BBPLC:	Broad band PLC
CENELEC:	European Committee for Electro technical Standardization
CISPR:	International Special Committee on Radio Interference
CREC:	China Railway Engineering Company
CTC:	Clear time on compare match
DSM:	Demand side management
EMC:	Electromagnetic compatibility
ERC:	Ethiopian Railway Corporation
FDM:	Frequency division multiplexing
FSK:	Frequency shift keying
FCC:	Federal communications communication
GPS:	Global positioning system
GSM:	Global system for mobile communication
GPRS:	General packet radio service
HDR:	High data rates
HV:	High voltage
IGBT:	Insulated gate bi-polar transistor

ITU:	International Telecommunication union
ISO:	International standard organization
IEC:	International Electro-technical Commission
LDR:	Low data rate
LRT:	Light rail transit
LV:	Low voltage
MC:	Microcontroller
MV:	Medium voltage
MT:	Mass transit
NB-PLC:	Narrow band power line communication
OFDM:	Orthogonal frequency division Multiplex
OCS:	Overhead contact system
PLC:	Power line communication
PRIME:	Power line Related Intelligent Metering Evolution
QPSK :	Quadrature phase shift keying
RCS:	Ripple carrier signaling
SNR:	Signal to noise ratio
TDM:	Time Division Multiplex
TWACS:	Two way Automatic communication system
USART:	Universal synchronous Asynchronous receive transmit
UNB-PLC:	Ultra narrow band power line communication
VHF:	Very high frequency range
VSWR:	Voltage standing wave ratio

## **Chapter 1**

### **Introduction**

Railway transportation of people and cargo has many advantages compared with other modes of land/air transportation. Among these advantages: better control on schedule and travel time, lower exposure to risk factors such as heavy traffic and road accidents, more comfortable seating, contribution to environment and economy. Another advantage of electrified railway system is that the needed energy is delivered to the train when needed, unlike the other modes of transportation (land, air, sea) where the source of energy must be carried by the vehicle for the duration of the journey.

Recently, Ethiopia is constructing Railways throughout the country for freight and public transport. Among these projects Addis Ababa light rail transit project is at its final stage of completion and test drive is being performed. The project has more than 450 million USD budget and constructed by the Chinese contractor China Railway Engineering Corporation - CREC and a Swedish consultant. [3]

#### **1.1 A.A LRT project Overview[3]**

The LRT Project in Addis Ababa, the capital of Ethiopia, consists of the East-west Line and the South-north Line. The line is mostly based on ground line. Elevated line and underground line are adopted in some sections. The total length of the planned line in phase 1 and phase 2 is approximately 75km.

This project is implemented in the scope of the Phase I Project of these two lines and the total length of line is approximately 31km; wherein, the length of shared track section is approximately 2.662km, from Meskel square to Lideta. The full length of main line of the East-west Line is approximately 16.998km and the full length of main line of the South-north Line is 16.689km.

The East-west Line Phase I Project starts from the south side of gate of Tor Hailoch Hospital in the west. It runs through the Mexico Square, the Mesekel Square and the Megenagna and finally runs to the Ayat. The major roads which the line passes include: Chad St., Ras Mekonen St., Jomo Kenyatta St., Haile Gebre Silasie St., Equatorial Guinea St. and etc. The length of roadbed

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section in the East-west Line is approximately 12.891km, the length of elevated section is approximately 3.91km (including the 2.662km shared track section) and the full length of underground section is 0.197km. Totally 22 stations are set; wherein, 6 elevated stations (including 5 shared track stations) and 2 semi-underground stations are included and the rest stations are ground stations. The maximum distance between stations is 1.26km, the minimum distance between stations is 0.435km and the mean distance between stations is 0.798km.

The South-north Line Phase I Project starts from the east side of St. George Church in the north. After it is laid in a section along the north side of Merkato Market, it turns to the south. After it runs through the west side of this market to the Chad St. and connects the track of the East-west Line, it is laid to the east. It runs to the west side of Mesekel Square and turns to the south. It goes through the Meshalokia Bridge and the China-Ethiopia Friendship Bridge from lower side and finally it runs to the Kaliti. The major roads which the line passes include: Fitawrari Gebeyebu St., Gyorgis St., Central African Republic St., Dej. Mekonen Demisaw St., Dej. Bekele Weya St., Chad St., Ras Mekonen St., Ras Biru St., Sierra Leone

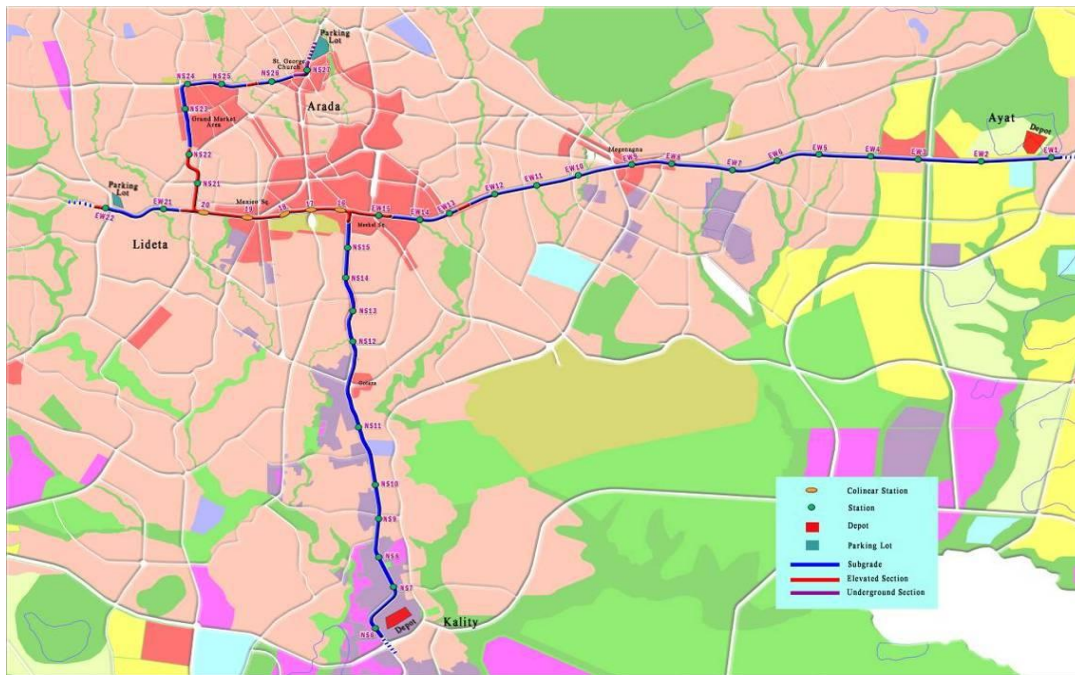


Fig 1: Track Layout Diagram of East-west Line/South-north Line Phase I [3]

St., Beyene Aba Sebsib St. and Debre Zeit Rd. The length of roadbed section in the South-north Line is approximately 10.057km, the length of elevated section is approximately 5.977km (including the 2.662km shared track section) and the full length of underground section is

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approximately 0.655km. Totally 22 stations are set; wherein, 8 elevated stations (including 5 shared track stations) and 1 underground station are included and the rest stations are ground stations. The maximum distance between stations is 1.972km, the minimum distance between stations is 0.435km and the mean distance between stations is 0.773km.

The system operates with a traction power of 750 VDC and planned to accommodate 41 operating trains, 21 trains for the East-west Line and 20 trains for the South-north Line. The Operation control center and maintenance center of this project is located inside the Kality Depot for the East-west Line and the South-north Line share the same Operation control center.

In order to provide the position information of the train, A.A LRT uses Axle counter which doesn't provide the exact position of the train but the section occupancy or vacancy information with the help of the sensors installed on the track. We shall see in later chapters briefly.

## **1.2 Statement of the Problem**

From safety perspective, signaling is the main component of Railway system. In railway traffics, the low friction between wheel and rail causes long braking distances, normally much longer than the driver's sight distance, i.e. if the driver starts the braking when he discovers a problem on the track it is too late to brake the train. The conclusions will be that the railway traffic can not only rely on the driver for the traffic safety, there must also be a signaling or even an automatic surveyor system, which can supervise the positions of different trains along the track and organize the traffic.

A need of a train detection system, which could check if the track really is free, became more and more obvious. In today's complex railway traffic in and around big cities, the train detection system is a fundamental part of the computerized supervision and interlocking system.

There are different possible detection systems for trains. These are track circuit, axle counter, GPS and etc. Among the above mentioned systems track circuit and axle counters provide the train position section wise (i.e. Provide weather a section is occupied or not). In other words we can consider that the systems give discrete position information. This is the drawback of the above mentioned detection systems. Also GPS provides the coordinate of the train position in longitude and latitude. Since it needs line of site requirment with satellites for better accuracy, some scenarios like in tunnel create difficulty for tracking more satellites. This also creates

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variable error spread for detection. Beside of accuracy issue, the GPS system operates under the control of other countries which creates system dependency. Also the cost of these infrastructure is considerable. Due to the above mentioned drawbacks from each systems in use, we need to have a system that mainly provides continuous distance information, low in cost, better accuracy and under the control of the railway system owner.

## **1.3 Motivation**

Firstly, the motivation of the research is utilizing the power line for possible technologies in addition to the intended use of transmitting power. It is obvious that the cost of the power transmission infrastructure for the traction is huge. So researching on this infrastructure creates added advantage for the country to utilize and implement new technologies for better use on the railway and for better services with low cost. Besides it serves as an initial point of start for future studies for different automation applications.

Secondly, the proposed technology will provide real-time train tracking information which makes the research to be better input for signaling system. This also improves the detection system without satellite dependency. It is independent of third party involvement on detection and other related issues of accuracy.

Also the obtained information can be broadcasted via available technologies and enables other trains to have the position information of each other. This in addition will help for the transition from fixed block to moving block operation.

## **1.4 Objectives**

### **1.4.1 General objective**

The general objective of the thesis is to design and propose Power line communication based real time train tracking system for A.A LRT project. It uses the existing power line as a medium to determine the train location from a specific reference point, then to show on a map application developed for this specific purpose.

### **1.4.2 Specific objective**

The specific objectives are:-

- To design onboard unit system components
- To design station/ground transponder unit system components
- To design a microcontroller circuit with c program for computation purpose
- To design a coupling circuit for signal injection

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- To develop a software map which helps for displaying distance information for real time tracking purpose.

## **1.5 Methodology**

In order to achieve the above mentioned objectives, the following methodologies are used.

- a. Literature review : The review has done on different books ,journals , publications and web sites on related topics and technologies
- b. Interview: this has done with ERC engineer regarding the signaling issues of the LRT.
- c. Modeling the traction system has been done. This enabled to show the visibility of PLC over traction system.
- d. Designing of subsystems has been done including microcontroller code and map application
- e. Simulation has done for the modeled power supply systems for different parameters those can determine the feasibility for data communication.
- f. Demonstration has done by integrating the developed application with a microcontroller circuit by connecting them via virtual serial port.

## **1.6 Scope of the thesis**

The scope of the research contains showing the feasibility of PLC over traction power system with the limitations by channel modeling and simulation. Then based on the simulation results it proposes the train detection system using PLC. The system architecture and the function of each subsystem are discussed in block approach. The proposed tracking system (mapping application program) also demonstrated/presented by integrating with the microcontroller circuit via a virtual serial port for simulation of the tracking system functionality.

## **1.7 Organization of the paper**

The paper is divided in to five chapters.

**First chapter** is introduction for the research and presents about project overview for A.A. LRT project, Motivation for doing this research, scope, objective and methodology of the research.

**Chapter two** provides a background about topics related to the research area like traction power supply system, Power line communication (concepts, standards, and regulations), train

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Signaling (train detection system), digital communication and modulation. In addition to this, literature review on railway PLC topic and channel modeling are discussed.

**Chapter three** briefly presents the existing train detection system (Axle counter) and proceeds to the proposed system design and architecture.

The next chapter (**Chapter four**) is about simulation and result discussions by grouping the simulation as MATLAB simulation, proteus simulation and map application simulation.

The last chapter (**Chapter five**) finalizes the research report by recommendation, future works and conclusion regarding the proposed train tracking system using power line communication.

## **Chapter 2**

### **Background and literature review**

The chapter presents and discusses points which are related to power line communication theory and signaling/detection concepts of railway systems in order to provide basic understanding on the general proposed system. It is achieved by literature review of journals books and other resources.

#### **2.1 Railway electrification systems[1]**

A railway electrification system supplies electrical energy to railway locomotives and multiple units so that they can operate without having an on-board prime mover. There are several different electrification systems in use throughout the world. Railway electrification has many advantages but requires significant capital expenditure for installation.

The main advantage of electric traction is a higher power-to-weight ratio than forms of traction such as diesel or steam that generate power on board. Electricity enables faster acceleration and higher tractive effort on steep gradients. On locomotives equipped with regenerative brakes, descending gradients require very little use of air brakes as the locomotive's traction motors become generators sending current back into the supply system and/or on-board resistors, which convert the excess energy to heat. Other advantages include the lack of exhaust fumes at point of use, less noise and lower maintenance requirements of the traction units. Given sufficient traffic density, electric trains produce fewer carbon emissions than diesel trains, especially in countries where electricity comes primarily from non-fossil sources.

Electrification system can be categorized by three main parameters. These are:-

- i. Voltage
- ii. Current
- iii. Contact system

#### **i. Voltage**

Six of the most commonly used voltages have been selected for European and international standardization. These are independent of the contact system used, so that, for example, 750V DC may be used with either third rail or overhead lines (the later normally by trams). There are many other voltage systems used for railway electrification systems around the world, and the list of current systems for electric rail traction covers both standard voltage

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and non-standard voltage systems. The following table shows the most standard voltage levels across the world.

Electrification System	Lowest Non-permanent voltage	Lowest permanent voltage	Nominal voltage	Highest permanent voltage	Highest nonpermanent voltage
600 V DC	400 V	400 V	600 V	720 V	800 V
750 V DC	500 V	500 V	750 V	900 V	1 kV
1,500 V DC	1,000 V	1,000 V	1,500 V	1,800 V	1,950 V
3 kV DC	2 kV	2 kV	3 kV	3 kV	3 kV
15 kV AC, 16.7 Hz	11 kV	12 kV	15 kV	17.25 kV	18 kV
25 kV AC, 50 Hz	17.5 kV	19 kV	25 kV	27.5 kV	29 kV

Table 1: Standard voltage levels

According to the European and international standards (BS EN 50163 and IEC 60850) , these different permissible voltage ranges allowed for standardized voltages. These ranges consider number of trains drawing current and their distance from the substation.

## ii. Current

Basically we can have two types of current types. These are:-

A. **Direct current:** Early electric systems used low-voltage DC. Electric motors were fed directly from the traction supply and were controlled using a combination of resistors and relays that connected the motors in parallel or series.

During the mid-20th century, rotary converters or mercury arc rectifiers were used to convert utility (mains) AC power to the required DC voltage at feeder stations. Today, this is usually done by semiconductor rectifiers after stepping down the voltage from the utility supply. The DC system is quite simple but it requires thick cables and short distances

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between feeder stations because of the high currents required. There are also significant resistive losses. The feeder stations require constant monitoring and, on many systems, only one train or locomotive is allowed per section.

The most common DC voltages are 600 V, 750 V and 1,500 V for trams and metros.

**B. Alternating current:** These are overhead electrification systems. Alternating current can be transformed to lower voltages inside the locomotive. This allows much higher voltages and therefore smaller currents along the line, which means smaller energy losses along long railways.

An early advantage of AC is that the power-wasting resistors used in DC locomotives for speed control were not needed in an AC locomotive: multiple taps on the transformer can supply a range of voltages. Separate low-voltage transformer windings supply lighting and the motors driving auxiliary machinery. More recently, the development of very high power semiconductors has caused the classic "universal" AC/DC motor to be largely replaced with the three-phase induction motor fed by a variable frequency drive, a special inverter that varies both frequency and voltage to control motor speed. These drives can run equally well on DC or AC of any frequency, and many modern electric locomotives are designed to handle different supply voltages and frequencies to simplify cross-border operation.

The alternating current system can be sub divided into three operating frequency ranges.

- a. **Low-frequency alternating current:** due to the standard frequency (50 Hz) difficulties with inductive reactance and eddy current loss particularly in non-laminated pole pieces,  $16 \frac{2}{3}$  Hz or 16.7 Hz is proposed. This solved overheating problems with the rotary converters used to generate some of this power from the grid supply.
- b. **Polyphone alternating current systems:** such system uses three phase AC power. The system provides regenerative braking with the power fed back to the system, so it is particularly suitable for mountain railways provided the supply grid or another locomotive on the line can accept the power.
- c. **Standard frequency alternating current:** Uses single phase 25 KV /50 Hz supply. Today, some locomotives in this system use a transformer and rectifier to provide low voltage pulsating direct current to motors. Speed is controlled by switching

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winding taps on the transformer. More sophisticated locomotives use thyristor or IGBT circuitry to generate chopped or even variable-frequency alternating current (AC) that is then supplied to the AC induction traction motors.

This system is quite economical but it has its drawbacks, the phases of the external power system are loaded unequally and there is significant electromagnetic interference generated as well as significant acoustic noise.

### **iii. Contact system**

Regarding the contact system, Railway power supply can have two types of Contact systems namely:-

#### **a. Overhead contact**

**Overhead lines** or **overhead wires** are used to transmit electrical energy to trams, trolleybuses or trains at a distance from the energy supply point. These overhead lines are known variously as:

<b>Naming</b>	<b>Countries</b>
<b>Overhead contact system (OCS)</b>	Europe, except UK and Spain
<b>Overhead line equipment (OLE or OHLE)</b>	UK
<b>Overhead equipment (OHE)</b>	UK, India, Pakistan and Malaysia
<b>Overhead wiring (OHW)</b>	Australia
<b>Catenary</b>	United States, India, UK, Singapore, Canada and Spain.

Table 2: Naming of overhead line in different countries [1]

Here, the generic term *overhead line* is used.

Overhead line or catenary wire suspended from poles or towers along the track or from structure or tunnel ceilings. Locomotives or multiple units pick up power from the contact wire with pantographs on their roofs that press a conductive strip against it with a spring or air pressure. It is designed on the principle of one or more overhead wires or rails (particularly in tunnels) situated over rail tracks, raised to a high electrical potential by connection to feeder stations at regular intervals. The feeder stations are usually fed from a high-voltage electrical grid.

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Electric trains that collect their current from an overhead line system use a device such as a pantograph, bow collector, or trolley pole. The device presses against the underside of the lowest wire of an overhead line system, the contact wire. The current collectors are electrically conductive and allow current to flow through to the train or tram and back to the feeder station through the steel wheels on one or both running rails.

## **b. Third rail**

A third rail is a method of providing electric power to a railway train, through a continuous rigid conductor placed alongside or between the rails of a railway track. It is used typically in a mass transit or rapid transit system, which has alignments in its own corridors, fully or almost fully segregated from the outside environment. In most cases, third rail systems supply direct current electricity.

Third rail systems are a means of providing electric traction power to railway trains, and they use an additional rail (called a "conductor rail") for the purpose. On most systems, the conductor rail is placed on the sleeper ends outside the running rails, but in some cases a central conductor rail is used. The conductor rail is supported on ceramic insulators or insulated brackets, typically at intervals of 10 feet (3 meters) or so.

The trains have metal contact blocks called "shoes" which make contact with the conductor rail. The traction current is returned to the generating station through the running rails. The conductor rail is usually made of high conductivity steel, and the running rails have to be electrically connected using wire bonds or other devices, to minimize resistance in the electric circuit.

There is considerable diversity about the contact position between the train and the rail; some of the earliest systems used top contact, but developments used side or bottom contact, which enabled the conductor rail to be covered, protecting track workers from accidental contact and protecting the conductor rail from snow and leaf fall.

## **2.2 Power line communication(PLC)**

A communication channel is defined as the path between two communication nodes on which the communication signal is propagated. There are different communication channel technologies like wireless, fiber optics, cables and etc. Power line communication is among these different types. It is a technology that utilizes power transmission line for communication purpose based on electrical signals, carrying information, propagating over the power transmission line.

## **2.2.1 PLC Historical Overview [2]**

Communications over power lines is not a new technology but an old idea which can be historically traced back to the 1900s, when power line communication recorded its first patent in this area. Subsequently, electric power utilities worldwide have been utilizing this technology for load control and remote metering using single carrier narrowband solutions. Historically, HV power lines apart from being used for power transmission have alternatively been used as medium of voice communications since as early as the 1920s.

Moreover, the historical motivation behind the use of power lines as a data transmission medium was primarily done to protect power distributions systems in the emergence of faults. The use of HV power lines for PLC purposes by power utilities engineers in those early years was an alternative means of communication due to the poor coverage of telephones. Low data rates (few hundreds of bits per seconds) were later achievable for support of telemetry and tele-control applications with the emergence of digital communication techniques.

Narrowband PLC emerged as a result of wide-spread of electrical power supply network. In the early 1920s, the first carrier frequency system became operational utilizing high-tension lines (15-500 kHz frequency range) for telemetry application, which is still in existence presently. Consumer products such as baby alarms were introduced since the 1940s.

Historically, the usage of PLC for load control management was another essential driver for the use of PLC by power utilities. This enabled power utilities to remotely switch ON/OFF high energy consuming electrical appliances and equipment such as water heaters, air conditioner etc. Its application can be found in the control of peak event at the demand side using the Ripple Control System or Ripple Carrier Signaling (RCS), with the power utilities sending control signals to end users to switch off heavy duty appliances to achieve Demand Side Management (DSM) by saving energy. The deployment of RCS was quite successful in the European context, finding its application in street light control, equipment control on power grid, and day/night tariff switching. Another important motivation for the use of PLC has been its usage for meter reading. From study meter reading utilizes an average information rate of about 1 bits/sec, with field trials of meter reading reported in.

The current increasing interest on PLC is as a result of combinational effects of some technological changes and events which includes the explosive internet growth that occurred in the 1990s, extremely large leaps in also the deregulation of the telecommunication market

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which first took place in the US, and followed by Europe and Asia. All these technological changes and events awakened the increasing interest in PLC technology thus making this technology a feasible technology for numerous applications. Such applications include: Home Automation, Home Networking and Internet Access (Broadband over Power Lines, BPL), Narrowband PLC-Radio Broadcasting, Automotive, and other specific applications by end-users such as: quality of power measurement using PLC, and a solution to remotely detect illegal electricity usage in. Beside of the above mentioned applications currently researches are conducting on utilizing the technology for marine, Automobile, broadcast (TV/Radio) and railway areas.

### **2.2.2 PLC technology overview [2]**

PLC technology describes a concept that utilizes the existing power line network infrastructure and cabling for the purpose of data communication. As a result of this, a cost effective and reliable communication can be built. Data is transmitted and travels over the same power line network used to supply electricity, which thus allows the existing power line infrastructure present in homes to serve the purpose of transporting data without the need for adding new wires. Therefore, power line communication technology allows the development and realization of an in-house network or providing “last mile” for telecommunication services to the end subscribers, which is achieved in a very cost effective way.

Due to increasing research interest in this field, PLC technology is experiencing rapid growth and is been utilized in multiple commercialized applications and different market segments; this includes lighting control, smart grid, in-home automation, solar panel monitoring, electric cars and energy metering to mention but few. PLC provides a no-new-infrastructure approach that can enable rapid deployment of in-home automation and smart or intelligent energy management technology available around the world. Power line communication is not faced with the problem of line-of-sight and short transmission range limitations like its wireless counterpart and it is cost-effective and easy-to-install for so many applications. The three main classes of Power line technologies are discussed as follows.

***Ultra-Narrowband PLC Technology (UNB-PLC):*** The UNB-PLC technologies is operational in the ultra-low frequency range between (0.3-3 kHz), achieving a very low data rate at approximately 100 bps and has a very large operational range/coverage of ( $\geq 150$  km). In this

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class of PLC technology the data rate per link is low but various forms of effective addressing and parallelization possessing dependable scalability is utilized by deployed systems. The UNB solutions have been deployed by power utilities and have been in the market for over two decades making it a mature technology despite been proprietary. A historic use can be found in its utilization in the following application: RCS (Ripple Control System), which is a one way communication link for load control support application, extremely low speed (0.001 bit/sec) Automatic Meter Reading (AMR) Turtle System, and TWACS (a Two-Way Automatic Communication System) .

***Narrowband PLC Technology (NB-PLC):*** The NB-PLC technologies operate at Very Low Frequency (VLF), Low Frequency (LF) and the Medium Frequency band (MF), which all falls between the (3-500 kHz) frequency range. The narrow band frequency includes the CENELEC band (3-148.5 kHz) defined by the European Standard, the United States Federal Communications Commission (FCC) band which ranges from (10-490 kHz) and the Japanese Association of Radio Industries and Businesses (ARIB) band falling in the frequency range between (10-450 kHz). The NB-PLC is further categorized into two as follows:

**Low Data Rate (LDR):** These are Single carrier technologies with achievable data rates of few kb/sec. Devices that operates at Low data rates conforms to various standards and recommendations such as X10, LonWorks, CEBus, BacNet and other protocols recommended are typical examples of LDR NB-PLC technologies.

**High Data Rate (HDR):** These are multicarrier technologies with achievable data rates ranging between tens of kb/sec to 500 kb/sec. Devices that operates at High data rates conforms to various ongoing standards such as ITU-T G.hnem, PRIME, G3-PLC and IEEE 1901.2 are typical examples of HDR NB-PLC technologies .

***Broadband (BB) PLC Technology (BB-PLC):*** The BB-PLC technologies are PLC technologies that operate at both High Frequency (HF) and Very High Frequency (VHF) and these frequency band ranges between (1.8-250 MHz) with achievable data rates also referred to as PHY rate ranging from Mb/sec to several hundreds of Mb/sec. Devices that operates and conforms to HomePlug 1.0, IEEE 1901, Gige MediaXtreme are typical examples of BB-PLC technologies.

## 2.2.3 PLC Standardization and Regulations [2]

This section discusses and addresses the subject of standardizations and regulations in the PLC landscape. It gives a brief overview of the PLC standards, and goes ahead to discuss some of the current Narrowband PLC standards available and concludes with CENELEC Standard and Band Classification.

### 2.2.3.1 Overview of PLC Standardizations and Regulations :

There are different working frequency ranges specifically for PLC purpose. The overview of these standards is presented as follows.

#### European Committee for Electrotechnical Standardization (CENELEC) [2][20]

CENELEC (French: Comité Européen de Normalisation Électrotechnique) is responsible for European Standardization in the area of electrical engineering. Together with ETSI (telecommunication) and CEN (other technical areas) CENELEC form the European system for technical standardization.

The regulations concerning Low Bit Rate PLC are described in CENELEC standard EN 50065 entitled “**Signaling on low-voltage electrical installations in the frequency range 3 kHz to 148.5 kHz**”. The frequency range which is allowed for communication ranges from 3 to 148.5 kHz and is subdivided into Five sub-bands which are shown in Table.

<b>CENELEC Band</b>	<b>Frequency Range</b>	<b>Use /Application</b>
*	3 – 9 KHz	Limited to electrical network operators for their specific needs, like remote meter reading
<b>A</b>	9 -95 KHz	Limited to electrical network operators
<b>B</b>	95 – 125 KHz	Home automation use (baby phones, and so forth)
<b>C</b>	125 – 140 KHz	Home automation use (X10, and so forth)
<b>D</b>	140 – 148.5 Kz	Home automation use

\* No letter description exists, due to the fact that this band was defined at a later stage.

Table 3: CENELEC band classification [20]

According to European Standard CENELEC bands application and operation can also be considered as follows. “A-Band” is limited to energy providers and their concession-providers.

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The other bands are for the energy provider's customers. The "C-Band" requires a CSMA access-protocol whereas the other two bands have no access-protocols. That leaves the "B-Band" and the "D-Band" with no access protocol, regulated to the energy provider's customers and hence appropriate for in house communication system trials. The "B-band" offers a wider bandwidth, and moreover a center frequency of 110 KHz (or 100 KHz) that can be defined as standard and allow a number of communication devices to work with this center frequency. CENELEC norm makes possible data rates up to several thousand bits per second, which are sufficient only for some metering functions, data transmission with very low bit rates and the realization of few numbers of transmission channel for voice connections. [21]

### **Federal Communications Commission (FCC) [2]**

The regulatory body for radio communications and telecommunications in the USA is the Federal Communications Commission (FCC). The FCC enforces mandatory requirements for telecommunications and radio communications systems.

The frequency band allowed here ranges from 0 to 530 kHz (allocated at 100 - 490 kHz) which is considerably larger than Europe. Part 15 of the FCC rules allows power line communication outside the AM frequency band (outside 535 to 1705 kHz).

### **Association of Radio Industries and Business (ARIB)**

In Japan, the Association of Radio Industries and Business (ARIB) regulates the frequency spectrum. For power line communication, the allowed frequency goes from 10 kHz to 450 kHz.

### **Electric Power Research Institute (EPRI)**

In China, the Electric Power Research Institute (EPRI) had not regulated the frequency domain devoted to power line communication. On the other hand, there are some practical practices that the frequency is 3-90 KHz and 3-500 KHz is used.

The need for these regulatory bodies in power line communications field is prompted and motivated by the fact that the PLC devices that transmit over the power line networks are electrical equipment which is then used for communication purposes. Therefore, Power line Communication is categorized under both telecommunication and the electrical. Hence, to prevent interference from and to other communication systems, the power line channel, PLC products and services must adhere to and work under certain operational regulations such as, electromagnetic compatibilities, electric safety and nets and communication services. The

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various standard regulations under these three operational regulations are discussed briefly accordingly.

***Electromagnetic capability:*** The standard regulation described in the CENELEC EN50065 standard addresses the subject of electromagnetic capability for narrowband application (low frequency, low data rates application like a typical in-home or in-building automation). Part 1 of this standard regulation also specifies the allowable limit for conducted disturbances at the main port in the frequency range (3-148.5 kHz).[2]

***Electric safety:*** According to the European standards 73/23/EEC, 93/68/EEC and EN 60950 governing the European community, it is specified that all equipment and appliances which are connected across the power line networks should be in total adherence to the low voltage directives. This is to ensure the safety of power line devices and information technology equipment using the power line network as a communication medium.[2]

***Nets and communication services:*** The 2002/19/EC (Access Directive), 2002/20/EC (Authorization Directive), 2002/21/EC (Framework Directive) and 2002/21/EC (Universal Service Directive) are European directives that deal with regulations implied by their name under the Net and communication services. The access directive addresses issues on access to, and the interconnection of electronic communication networks and other associated facilities. Moreover, the authorization directive deals with issues relating to services and electronic communications network authorization, while, the framework directive specify a common regulatory framework for the use of electronic communications networks and services. Finally, the universal service directive takes care of issues relating to universal services and users' right to electronic communication networks and services.

The major international standard bodies saddled with the responsibilities of regulating and approving standards in different existing areas by producing international standards for electronic and telecommunications equipment, are highlighted and briefly discussed as follows.

***The International Electro-technical Commission (IEC)*** came into existence in 1906 and was responsible for the preparation and publishing of international standards for all electrical, electronics and related technologies [2].

***The International Special Committee on Radio Interference (CISPR)*** is responsible for promotion of international agreement that pertains to the subject of radio interference therefore encouraging international trade. The CISPR standard body produces standards that protect

radio reception from various interferences sources which includes but are not limited to electricity supply system, electrical appliances, and broadcast receivers. They also address issues on the methods and equipment used in the measurement of interference emanating from both electric and electronic equipment operating above the 9 kHz frequency band [2].

***The International Organization for Standardization (ISO)*** came into existence in 1947 and is constituted of 140 national standard bodies from 140 different countries in the world. They are responsible for promoting worldwide development of standardization and other related activities [2].

***The International Telecommunication Union (ITU)*** is saddled with the responsibility of creating telecommunication standards, as it also adopts international regulations and agreements. The ITU became a specialized agency of the United Nations in 1947 but was originally founded in 1865. Furthermore, ITU allows global telecommunications networks and services to be coordinated by both the private sector and government [2].

**Other relevant standard bodies include:** *American National Standards Institute (ANSI) , Electronic Industries Alliance (EIA) , Institute of Electrical and Electronics Engineers (IEEE) , European Telecommunications Standards Institute (ETSI) , Information and Communications Technologies Standards Board (ICTSB) .* The first three aforementioned are American bodies while the latter two are European bodies. The next section focuses on latest standards that are developed for narrowband applications.[2]

### **2.2.3.2 Narrowband PLC Standards [2]**

This section describes briefly some of the standardization developments that are taking place in the narrowband PLC landscape.

***Lon Works:*** The ANSI/EIA 709.1 standard, also referred to as LonWorks was one of the first low data rate narrowband PLC standards to be sanctioned. This standard was issued in 1999 by ANSI before it metamorphosed into an international standard in 2008 (ISO/IEC 14908-1). It is a seven-layered OSI protocol that provides services that enables the application program embedded in a device to transmit and receive messages from other devices present in the network without prior knowledge of the network topology and/or the functions of this other devices. The LonWorks technology is now an open standard which is used worldwide because of its interoperability. It can be configured for use in electric utility

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applications making use of the CENELEC A-band. On the other hand, industrial, commercial and in-home application uses the C-band. Other multi-applications include but are not limited to: Smart Buildings (HVAC controls, elevators/escalator controls, irrigation, lighting and security); Smart Cities (Street lighting, buses and subway systems, theater and stage lighting); Smart Grid (Advanced metering, demand response, and distribution automation).

***Power line Related Intelligent Metering Evolution (PRIME)***: This standard came into being as a result of the growing interest in exploiting high data rate narrowband PLC solutions that operates in the FCC, CENELEC, and ARIB frequency bands. This standard is fast becoming popular and gaining the support of European industries. PRIME has established and specified an Orthogonal Frequency Division Multiplexing (OFDM) based high data rate narrowband-PLC solution that operates and makes use of the CENELEC A-band frequency. PRIME initiative has capacity of PHY data rates up to 125 kb/s and it is an open standard. Another high data rate narrowband PLC initiative similar to the PRIME initiative is the G3-PLC discussed below.

***G3-PLC***: Just like PRIME, G3-PLC is an open standard. It is an OFDM based high data rate narrowband-PLC that promotes interoperability as it can coexist with IEC 61334 and IEEE P1901.2. It operates in the 10-490 kHz frequency range thereby complying with CENELEC, FCC and ARIB. It has also got built in robustness as it possess two layers of forward error correction and a robust mode that overcomes noisy channel conditions. Other key feature of the G3-PLC is cyber security as its 6LoWPAN adaptation layer supports IPv6 packets. The G3-PLC standard is useful in Distribution Automation and Smart Electricity Meters.

Other recent standards for narrowband application are the ITU-T G.hnem and IEEE 1901.2 which came into being in 2010.

### **2.2.4 PLC Channel Characteristics [2][19]**

The power communication channel is a notoriously bad channel that has been developed without regard for any communications considerations. However, it is so widely distributed that considerable cost savings can be achieved if use is made of its cable infrastructure.

Electrical power lines are usually classified into high (>100 KV) , medium ( 1 KV to 100 KV) and low (<1 KV) voltage networks , with respectively increasing communications difficulties.( Note that the Aforementioned voltages represent rather loose bounds on the effective voltage values, measured between phases in a three phase network.) Much of the past research has

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focused on low voltage electrical distribution networks, which are also geographically the widest spread and which usually have the most convenient access with in various buildings.[19]

Power line channel when compared with other conventional media such as coaxial cables, twisted pair cables and fiber-optic cables considerably differs in structure, physical properties and topology. It exhibits a rather hostile characteristic, as it was originally designed for power distribution at very low frequency of 50/60 Hz or DC power with no prior thought of its eventual use for high frequency data transmission.

Power line communication using this network as a medium of communication inherits the intrinsic properties and characteristics of the power line network. Hence, PLC inherits a hostile medium for its eventual use as a medium of data transmission at high frequency. PLC does not only inherit the nasty and hostile behavior of the power line network but in addition combines that of a communication channel. Variation in impedance, high attenuation as a result of impedance mismatch, noise and disturbances present on the network or coupled onto the network are some of the main challenges PLC has to overcome to achieve its full potential and development as a reliable medium of data transmission when compared to other data transmission technology. In view of this, PLC transmission environment can be seen to be worse when compared to its mobile communication counterpart.

The channel characteristics could both be frequency and time-dependent, and there possibility of its dependence on where both the transmitter and receiver are located in the power line infrastructure. Thus, the channel is described generally as a random time varying with a frequency-dependent SNR (Signal to Noise Ratio) over the communication bandwidth.

The design of good power line communications systems demands a detailed knowledge of the channel characteristics such as impedance, noise scenario, interference and the channel capacity, which helps to design and/or choose suitable methods of data transmission. These channel characteristics are discussed briefly in the following section and literatures are referenced for a detailed and comprehensive knowledge of these channel characteristics.

### **2.2.4.1 Impedance [19]**

Impedance is one of the channel characteristics important in the design of PLC systems as impedance variation has a great effect on the PLC systems performance. Power line as a medium of communication has reflections and signal attenuation that is induced by its impedance properties.

Varying impedance on the PLC channel is one of the challenges PLC technology has to combat as it affects the performance and reliability of data transmission on the channel. The power line channel comprises of interconnection of wires or cables having different sizes and varying impedance value forming a branch in the power line topology. This variation in impedance of the wires and cables could lead to a phenomenon referred to as impedance mismatch resulting from unbalanced impedance. Consequently this phenomenon leads to reflection, attenuation and multipath fading of signal transmitted on the PLC channel. Moreover, impedance mismatch is not only caused by the varying wires and cable impedance alone but also the impedances of several electrical loads connected onto the PLC channel have a great effect on signal attenuation . The varying impedance encountered on the PLC channel is dependent upon frequency and time the electrical loads are active on the network. Hence, the impedance that the transmitted signal encounters on the PLC channel has a great effect on the signal power the transmitter can couple onto the PLC channel.

### **2.2.4.2 Attenuation[19]**

The injection of high frequency signals unto the power line network can be achieved through a suitable high pass filter known as coupling circuit. The signal received at the receiver will be maximized if and only if the power line, transmitter and the receiver impedance are matched. Otherwise an impedance mismatch leads to a phenomenon called attenuation.

Often, low impedances of the LV power line channel results in high signal attenuation. The impedance mismatch that occurs between the transmitter, PLC channel and the receiver are often triggered by the time-variant loading activities that occur on the channel. Consequently, this contributes vastly to high attenuation of signals often experienced, hence rendering the attenuation to be time-variant. High attenuation experienced on LV PLC channel most times necessitates positioning of repeaters at distance of less than 1 km. On the contrary, HV PLC channels do not experience high signal attenuation as their LV counterpart does, as data communications at long distances in the range of hundreds of kilometers without repeaters have been achieved [2].

Below is an overview of some factors that influence signal attenuation on PLC channels.

***Signal Attenuation Dependency on Time:*** Time of the day is one of the factors that influence the severity of signal attenuation on PLC channel. In reality, signal attenuation and

network impedance have a very close relationship. Hence, based on the fact that network impedance is time-dependent, such a dependency on time must be taken into consideration for signal attenuation investigation. The fact that several electrical appliances are active on the PLC channel during the peak period (daytime) results in firm day and night sensitivity. Hence, high attenuation will often occur during the day due to numerous active appliances during this time [19].

***Signal Attenuation's Dependency on Frequency:*** Based on measurement reported on the Canadian LV power line network, it was observed that signal attenuation is independent of frequency for frequencies below 100 kHz while on the other hand, signal attenuation increase of 0.25 dB/kHz were observed for frequencies above 100 kHz. Signal attenuation is capable of rising extremely high at certain frequencies of cable length greater than 400 m as a result of transmission line effects [19].

***Signal Attenuation's Dependency on Distance:*** Based on principle, signal attenuation is presumed to be linearly dependent on distance, and so far no loads exist between the data communication transmitter and the receiver. On the contrary in practical situations, several loads are often connected between the transmitting and receiving device with worst-case occurrence of signal attenuation of around 100 dB/km frequently recorded [19].

***Signal Attenuation over Differing Network Phases:*** The impedance between two power line phases strongly defines the signal attenuation experienced between the two phases. According to [2], the signal attenuation experienced between two points that are connected unto the same phase is oftentimes smaller than that experienced between two points at the same distance but connected unto differing phases [19].

### 2.2.4.3 Noise

There are different sources of noise and disturbances on electrical power networks. Due to the different source and nature of noise on any given channel, predicting noise is hard. The source of noise in the above mentioned different voltage levels differ.

On **high voltage networks**, channel noise may be due to, among other causes, atmospheric or static discharges, low level corona discharge, lightning, circuit breaker operations, and transients produced with in a power station.

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On **medium voltage networks**, the on and off switching of capacitor banks used for power factor is infamous for causing high noise peaks.

On the notoriously **low voltage network**, some of the forgoing may also contribute noise (although the medium/low voltage transformers are effective filters), but the worst offenders are the various house hold devices and office equipment connected to the network. [19]

In addition to the above sources, other sources of noise that affects the power line network are noise coupled unto the network from various broadcast station and spurious disturbances from other unknown sources which impair certain frequency bands on the power line network. Generally, the characteristic of this channel noise varies strongly with frequency, load, time of the day, and source and geographical location [2].

Noise on PLC can be categorized under three major noise types as Background noise , Impulse noise and narrow band noise as shown below.

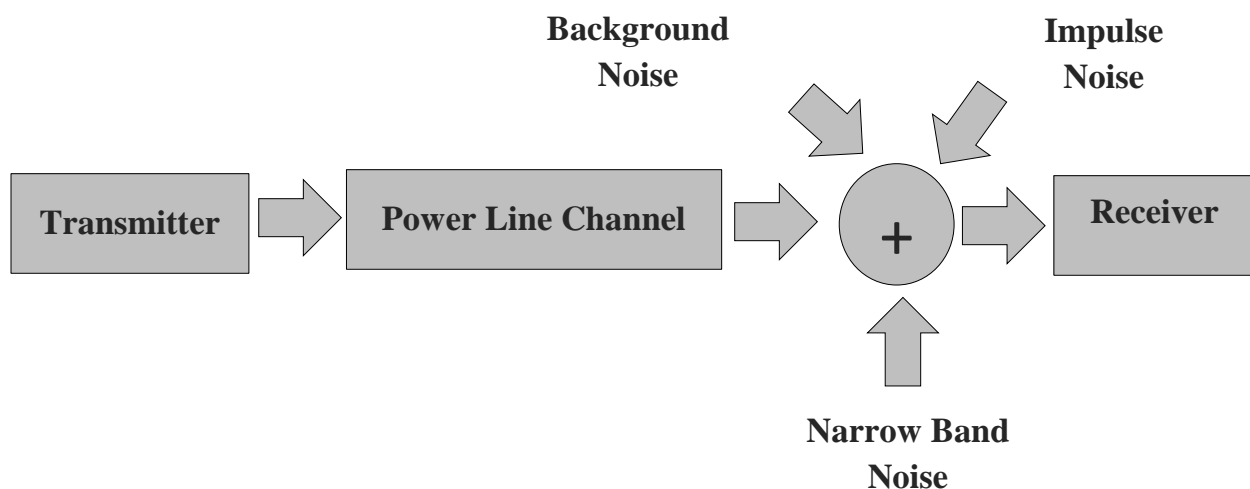


Fig 2: PLC System model

### **Background Noise [2]**

This type of noise is frequently characterized by constant envelope for a long duration (For AC supply case, at least more than a few cycles of mains AC voltage) . Background noise frequently includes flicker noise, thermal noise resulting from front-end amplifiers of receivers, and noise from universal motors often found in household electrical loads. Background noise (BN) is assumed to be cyclo-stationary in nature, possessing relatively low PSD emanating from a combination of numerous low power sources. By definition, background noise is quantifiable in the absence of other dominant noise sources and varies with frequency. Background noise often

exists permanently on the PLC channel and non-whiteness is its most vital attribute, which implies that the PSD is frequency-dependent.

### **Narrowband Noise [2]**

This noise type normally occupies narrow portion of the frequency band of the spectrum under consideration. Narrowband noise originates from sinusoidal signals that are coupled onto the PLC channel via radiation from amateur radios or broadcast stations sharing the same frequency spectrum with the narrowband PLC channels and system. Other narrowband noise sources are spurious disturbances that emanate from the various electrical loads having inbuilt transmitter and receiver. The severity of narrowband disturbances often varies depending on time of day.

### **Impulse Noise [2]**

Despite the fact that this type of noise is transient in nature, it has been reported to be the major source of long bursty errors observed on the PLC channel. Unlike the narrowband noise which is confined to a narrow portion of the frequency band of interest, impulse noise occupies and spreads randomly over a larger part of the frequency band of interest as a result of its high PSD. Impulse noise is often characterized by its duration, magnitude, and inter-arrival time. Impulse noise is further classified into two categories as described below.

- a. ***Periodic impulsive noise synchronous with the mains:*** This category of impulse noise is mainly regarded as a cyclo-stationary noise. The noise waveforms possess a train of impulses synchronous with the 50/60 Hz AC mains frequency or twice this frequency. Sources of this category of impulse noise include power supplies with silicon controlled rectifier and light dimmers with thyristors. In the case of the light dimmer, noise impulse synchronous to the AC mains voltage is been switched onto the PLC channel while the light dimmer is controlling the brightness of a light (it switches the AC current based on its phase). This noise type also originates from the commutating effect that occurs in a brush motor. [2][19].
- b. ***Periodic impulsive noise asynchronous with the mains:*** This noise type is also cyclo-stationary because it exhibits underlying period which is same as that of the mains. It has been conventionally considered to occur as a result of periodic impulse with repetition rates between 50-200 kHz and is typically caused by transient switching that occurs in power supplies. Consequently, because of this high repetition rate, a spectrum

constituting discrete lines results with the frequency spacing based on the repetition rate [2][19].

### **2.3 PLC for Railway**

The rapid progress in Power line Communication (PLC) accomplished through the application of different modulation techniques also generated interest in using PLC-technology on special power grids such as **750 V** DC networks.

Currently, researches are conducting to utilize traction power supply system for communication purpose and new achievements are observed on applications like communicating wayside equipment with moving train via power line, passenger information system and the like. These achievements show that the PLC technology has potential to address different communication demands in Railway and other special power systems. The followings are researches conducted on DC power systems and Traction systems.

**Gerd Griepentrog** in [6] describes the characteristics of DC-networks (750 V DC network installed in an underground traction power system of Nuremberg, Germany) which need to be considered with regard to the implementation of PLC. Advice also given as to which peculiarities have to be taken into account when adapting OFDM modulation to DC-networks.

#### **Characteristics of the DC-voltage**

##### **DC network**

The DC-voltage, provided alternately by each of the two six-pulse rectifiers is shown in figure 3. In this way each rectifier is conducting for  $30^\circ$  or 1.67 ms (at 50 Hz) before the current commutates to the other rectifier. Because of the inevitable inductivity of the wiring between the rectifiers each commutation process causes a voltage peak on the DC network.

##### **Typical Disturbances and Harmonics**

For economic reasons the power rectifiers in underground systems do not contain elements for smoothing DC voltage or suppressing harmonics introduced.

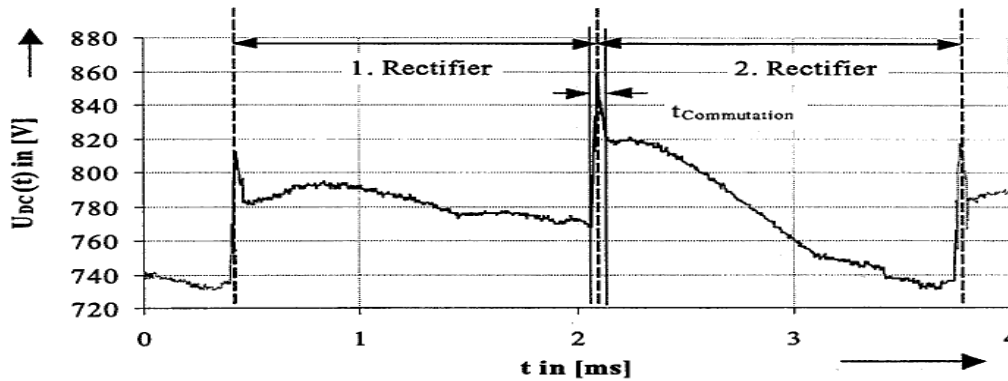


Fig 3: Periodic noise caused by Rectifier circuit

Thus, the DC voltage is subjected to voltage rises up to 80 V within 50  $\mu$ s (= 1600 kV/s) during the commutation process as shown in the Figure 3.

Spectral noise measurements have shown that superimposed upon strong harmonics caused by the rectifier between 300 Hz and 6 kHz there is also a band of noise which decreases up to 50 KHz and then remains nearly constant at -47 dBm/Hz (= 80 dB $\mu$ V @ 100 Hz BW). Consequently it is highly recommended to use frequencies above 50 kHz for data transmission.

### Access Impedance and Signal Attenuation

The access impedance has been determined by utilizing a spectrum analyzer at the underground railway system of Nuremberg – Germany by **Gerd Griepentrog**, the reference and test input of which were connected to current and voltage probes respectively and Oscillations in the frequency range up to 40 kHz result observed.

Signals transmitted between two substations over a distance of 2.5 km are attenuated by 25-35 dB in the frequency range from 60 to 150 KHz. Obviously the signal attenuation is highly dependent on changing conditions; e. g. moving traction units change their position along the section between substations.

After the above measurement has been taken a test of transmitting data via the channel conducted and the following conclusion is given.

“A 750 V DC network which is used in local transportation systems has been described with regard to the transmission of high frequency signals. Measurements to ascertain attenuation, access impedance, Disturbances and noise level have shown that PLC on this special network is fundamentally feasible. By means of an OFDM (Orthogonal frequency division multiplex)

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transmitter sending with a rate of 40 Kbit/s a data transfer between two substations over a distance of 2.5 Km in an underground system has been performed.

In order to reduce the transmission power or to improve SNR periodic disturbances caused by commutating processes in the rectifier need to be faded out. Hence, an adapted OFDM modulation technique is proposed which limits OFDM-frames in length and places them between two consecutive disturbances.”

**Pavels Karols Klaus et al. in [5]** proposes traction power supply networks as a communication link between wayside equipment and the moving trains. The work reported in this paper focuses on MT channel investigation and modeling, in order to develop novel adapted solutions. The outcome is a stochastic MT channel model, which besides multipath and time-variance also includes peculiar properties such as the behavior of ring structures and the impact of the Doppler effect invoked by moving trains. In addition, a very special interference scenario is treated, caused by the rectifiers in these DC-powered environments.

Among different measurements conducted, the paper summarizes the noises observed on the power line grouped as follows,

**1) Colored background noise:** It has a relatively low-power spectral density (PSD), varying with frequency and is caused by summation of numerous noise sources with low power.

**2) Narrowband noise:** It emerges in form of discrete lines in the spectrum. This type of noise is mainly caused by spectral repetitions of high-power low-frequency disturbances introduced by nonlinearities of power supply components. A further reason for narrowband noise in the frequency range above 148.5 kHz is interference from long wave broadcast stations.

**3) Non-periodic impulsive noise:** Its casual nature is caused by switching transients within the network.

**4) Periodic impulsive noise:** This periodic impulses have repetition rates of 150, 300, or 600 Hz. Periodic impulsive noise is caused by switching transients in rectifiers at traction substations. The PSD can reach values of more than 40 dB above the background noise.

As per the research conclusion, the signal injection mode is proposed as follows.

**Transmission mode:** the reseach also describes how to inject the signal (data) to the power line by proposing two possibilities (i.e. synchronized/unsynchronized).

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- a. *Synchronization Based on Noise Impulses:* Investigating the noise scenario revealed that background noise and periodic impulsive noise have substantial influence on channel characteristics with respect to communications. While the background noise is continuously present, the impulsive disturbances occur only as long as traction current flows through the rectifier. In the time interval between impulsive bursts and between individual impulses no significant disturbances are present, except the background noise. Hence, the synchronization of information signals with noise impulses appears advantageous, so that communication takes only place between such noise impulses. In this way, the necessary injected signal power could be significantly reduced.
- b. *Unsynchroisation base on Noise impulse:* this type allows injecting signal power without waiting for the timing between impulsive noises. When the SNR exceeds 50 dB, the unsynchronized version is more favorable. It should also be noted, that the implementation of an MT-PLC system without synchronization on noise impulses is less complicated.

Currently, however, there are no regulations for the use of PLC in railway applications, which have their special norms. Hence, it can be expected, that the applicable limits for the intended application will be below the limits of the railway EMC regulation specified in EN 50121. This means, that the allowable transmission power will in any case be so severely limited, that a synchronized version will exhibit superior performance.

### **2.4 Signaling System [14]**

In railway traffics, the low friction between wheel and rail causes long braking distances, normally much longer than the driver's sight distance, i.e. if the driver starts the braking when he discovers a problem on the track it is too late to brake the train. The conclusions will be that the railway traffic can not only rely on the driver for the traffic safety, there must also be a signaling or even an automatic surveyor system, which can supervise the positions of different trains along the track and organize the traffic.[14]

In the early days of railway traffic supervision was done by means of token. Each section of the track, normally the part between two stations, had its own, and only one, token, .i.e. a physical object used as evidence. A train was only allowed to run on a certain track section, when the train driver possessed the token. The token was given to him at the departure station and he left it at the arrival station, where he received a new token for the next track section. The token-based

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system works well when every second train runs in opposite direction. However when two trains after each other run in the same direction, the token must be brought back from the arrival station to the departure station by some other means.

When electricity was introduced in the society the problem was solved in an electrical way. In the station at each end of a track section a limited number of tokens were stored in a token instrument, one in each station. Both token instruments were connected electrically. When a token was taken from either of the two instruments, both became locked by electric means and it was not possible to take another token until the first token was returned to any of the instruments. In this way a number of trains can run in the same direction without any need for trains running in opposite direction.

When telephones and telegraphs were introduced, and today even radio, the "token" could be brought as a message, but to do this the token had to be converted from a physical to a logical thing. Instead the risk of duplication of the token arose. To avoid that two trains simultaneously got a token for the same track part, the rules and regulations of token handling became very rigorous.

However, even with rigorous rules, there was always an uncertainty if the track section really was not occupied when a train was given permission to run.

A need of a train detection system, that could check if the track really was free, became more and more obvious. In today's complex railway traffic in and around big cities, the train detection system is a fundamental part of the computerised supervision and interlocking system.

The aim of all railway signaling systems is to prevent head-on and end-on collisions, prevent derailments and to allow trains to travel at maximum speed allowed for the line and for the vehicle. To achieve this, information about restrictions etc. is given to the driver by visual means, track side colored lights or semaphore arms. Information can also be presented to the driver's cab by a display, often in combination with an audible signal and recently also as ATC (Automatic train control). The information from the train detection system is transferred to the supervising traffic control, where the track interlocking is done.

A signaling system has the following key elements:

- A train detection system based on track circuits or axle counters or GPS
- Control of points and crossings (a point is where a track is split in two tracks or two tracks are merged into one single track)

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- Interlocking of points and signals
- Indication to the driver by line side signals or cab signaling
- Enforcement of signal controls on the train with train stops or ATP (automatic train Protection)
- Braking characteristics of the trains on the line

As mentioned above, signaling system in Railway is very important and critical issue from safety point of view. As much as possible the movement in the area should be under control and synchronized manner in order to avoid accidents. From the overall signaling system components, detection of train is a main component of the signaling system.

## **2.4.1 Train detection system**[4]

It is important to detect the presence of trains for several reasons. Maintaining trains headway, locking points (also called “switches”) and selecting a route, announcing the arrival of trains at stations, coordinating the information appearing on displays and given by loudspeakers, ensuring the use of free tracks, thus avoiding situations of conflict and those that might be potentially unsafe. Some of them require that the operations are fail-safe at all times, and signaling devices dedicated to such operations are often referred to as “vital”. A more detailed definition of train detection leads to a classification of devices depending on the required function. Detecting the presence of a train on a specified track or detecting the passing by of a train at a specified point creates functional opportunities for scheduling and train automation. There are different technologies, with their own advantages, around the world on service. Among these different types track circuit, Axle counter and GPS are commonly implementing ones.

### **2.4.1.1 Track Circuit** [14]

The track circuit was invented in the USA at the end of the last century, when all traffic was based on steam locomotives. The main purpose for the track circuit is to prove that there are no other rail vehicles in a track section. When this is done, points may be operated and signals may be cleared for a train to move safely into the section. The second purpose for the track circuit is to detect the presence of a train within a certain section of the track. When this is being done the route ahead of the train will be locked in order to ensure the safe transit of the train.

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The track circuit makes it possible to indicate on the train traffic surveyor's control panel the detailed position of a train along the track in order to keep the surveyor knowing where different trains are. Also it is used to detect the track/Rail status.

It consists of a transmitter, a receiver and the two rails. The transmitter sends a signal to the receiver at the other end of the track section and the running rails are used as conductor to connect the transmitter to the receiver. If there is a train in the track section the signal will be short circuited by the wheel sets in the train and no signal reaches the receiver. The track circuit is isolated from adjacent track circuits by means of insulated rail joints, which prevents the signal from interfering other track circuits.

The insulated rail joints must not prevent the traction current (the power current) from returning to the substation. There are three ways to achieve this:

In **single rail system** one rail, "the traction rail", is used for traction current. This rail has no insulated rail joints. The other rail, "the signal rail", is divided into insulated sections. A track circuit is formed of one of these sections and the corresponding part of the traction rail. Single rails system is used on tracks with such traffic, where the traction current has a small magnitude, i.e. traffic with low weight vehicles, the number of vehicles is low or where high voltage supply is used. The voltage drop in the running rail is therefore low, despite that only one rail is used as the traction current return. Single rail track circuits are normally not allowed at crossings, due to the current shunt in the surrounding earth.

In **double rail system** the traction current has high magnitude and is equally distributed between the two rails, the traction current is a common mode current. The signal current has different directions in the two rails and is therefore a differential mode current. Both running rails have insulated rail joints. Between adjacent track circuits an impedance bond is connected, which has low impedance for common mode traction current and high impedance for the differential mode signal current. The impedance bond allows the traction current to pass on to the feeding supply substation, but prevents the signal from reaching adjacent track circuits and from shunting the receiver. This system is used on the tracks with heavy traffic, where both running rail must be used as traction current return, in order to keep the voltage drop low.

### 2.4.1.2 Axle counter [9][14]

Axle counters were first used in Germany in the 1960s and are now extensively used in most parts of Europe, Asia, Africa and Australia.

The term “axle counters” refers to subsystems which are utilized for track vacancy detection on fixed-guide way transport systems such as railways. Axle counters function by detecting the presence and traveling direction of wheels at various points along the right of way. The right of way is broken into “blocks” with wheels (axles) being counted into and out of the block. If the same amount of axles is detected departing the block as were previously detected entering it, the block is considered vacant.

Axle counters primarily consist of two types of components, the axle counting head, and the axle counting computer (sometimes referred to as an evaluation computer). The axle counting heads are mounted alongside the rail profile and actually detect the presence of wheels. They typically use LC oscillators to detect when the flange of a railroad wheel has modified the magnetic field created around the axle counter. The evaluation computer typically resides in a signal control enclosure alongside the wayside. The evaluation computer generates data based on the axle counting heads and generates either a vacant or occupied declaration of one or more blocks (track sections). The axle counting heads and the computer are physically connected, typically by copper wire to sense the condition of the fields created within the head about the rail. Some recent products also offer alternative transmission media such as fiber optic cable.

Evaluation computers typically interface to interlocking controllers, grade crossing controllers, etc via a dry contact relay interface. In some systems, these connections can be made through serial communications such as a LAN. In any case, the interface is easily made compatible with conventional signal technology to allow axle counting vacancy detection with virtually any train control system.

Traditional axle counters are of the mechanical type, with a pedal moved by the edge of the passing wheel. It is well known that these devices suffer extreme environmental conditions, in particular snow and ice, and may be subject to various kinds of mechanical breaks. They may still be found in very old transportation systems and in some low performance applications, such as in a depot, loading or marshaling yards.

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The modern axle counters are all of the magnetic type, with the passing wheel that modifies the magnetic reluctance of a tuned magnetic circuit, through which a transmitting and a receiving coil are coupled: the transmitter sends a sinusoidal signal in the form of a magnetic field that is coupled to the receiver; the signal toggles normally between two frequencies so that the detection of reluctance change due to the passing wheel is accomplished as the detection of a relative change of amplitude between the two.

### **Axle counters Vs. track circuits [9]**

Axle counters and track circuits are both used for monitoring track occupancy automatically. In contrast to track circuits, axle counters have some features that make them particularly well suited to some specific urban and long-distance rail applications. The highlights of these advantages and disadvantages are explained below.

### **Advantages**

1. Track circuits are sensitive to ballast resistance, power fluctuations, and other track conditions while Axle Counters are not. In wet conditions, when the ballast resistance generally drops, track circuit operation is less reliable. Similarly with rusted rails, rails covered with leaves or flying dust/flakes, or a large amount of salt or conductive minerals impairing its surface conduction properties, track circuit operation is often unreliable. Axle counter applications are independent of track bedding and ballast, which means they can be used with steel structures (bridges), concrete or wood ties, and embedded rails.
2. Track circuits are, by design, reliant on a very specific shunting characteristic of train axles (often 0.06 or 0.25 Ohms). If a train axle actually differs from this resistance (perhaps due to environmental influences such as those mentioned above), track circuits can “overlook” trains and incorrectly determine track vacancy.
3. Track circuits consume a significant amount of electrical power and involve elaborate power supply equipment and cabling which can lead to frequent maintenance. Axle counters consume very low electrical power, simple cabling, and are virtually maintenance free.
4. High traction currents do not influence the detection method used in axle counters, and their installation and maintenance is faster and simpler than the installation of track circuits and related hardware.

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5. No insulated joints are required with axle counters.
6. Less traction power bonding is required with axle counters than with track circuits. This has the additional benefit of minimizing the risk of DC stray current leakage into the ground which causes corrosion of nearby utility services.
7. No impedance bonds are required with axle counters.
8. Axle counters are essentially unlimited in block length. Track circuits vary greatly depending on type (AF, AC, DC), but are all very limited in track circuit length.
9. Experience with axle counters in Europe demonstrates an improvement of up to five times the reliability of track circuits carrying out the same function. This has an immediate improvement in service reliability as track circuit failure is often the most significant cause of train delay. It also has safety benefits as it reduces the use of degraded modes of operation outside of the control of the signaling system due to failure.

### **Disadvantages:**

1. Reset Requirements – If for any reason there is a failure (possibly a loss of power during a train movement), axle counters must be manually reset (the default startup mode is to create an occupied block). This can be done remotely, but requires a pro-active, manual manipulation.
2. No “shunt” – track circuits can be easily physically shunted by maintenance personnel (hard wired shunt applied to the rails), axle counters do not provide this function. A manual occupancy can also be accomplished with axle counters by hand manipulation of a metal object in front of the sensor. However, there is no visualization of the state (as is the case with a physical shunt), and the system must be reset.
3. Axle counters, unlike closed loop track circuits, do not provide broken rail protection. Although there is a great deal of controversy in the industry as to the percentage of broken rails actually detected by track circuits before they are traversed by a train, axle counters will not detect any break whatsoever.
4. By very small wheel profiles (less than 12 inches in diameter), axle counters can suffer from degraded reliability.

### 2.4.1.3 Global Positioning system (GPS) [16]

GPS is the third possible technology that serves for location detection of a train. The Global Positioning System was conceived in 1960 under the auspices of the U.S. Air Force, but in 1974 the other branches of the U.S. military joined the effort. The first satellites were launched into space in 1978. The System was declared fully operational in April 1995. The Global Positioning System consists of 24 satellites, that circle the globe once every 12 hours, to provide worldwide position, time and velocity information.

GPS has three segments. These are:

**The Space segment:** The space segment consists of 24 satellites circling the earth at 12,000 miles in altitude. This high altitude allows the signals to cover a greater area. The satellites are arranged in their orbits so a GPS receiver on earth can always receive a signal from at least four satellites at any given time. Each satellite transmits low radio signals with a unique code on different frequencies, allowing the GPS receiver to identify the signals. The main purpose of these coded signals is to allow for calculating travel time from the satellite to the GPS receiver. The travel time multiplied by the speed of light equals the distance from the satellite to the GPS receiver. Since these are low power signals and won't travel through solid objects, it is important to have a clear view of the sky.

**The Control segment:** The control segment tracks the satellites and then provides them with corrected orbital and time information. The control segment consists of four unmanned control stations and one master control station. The four unmanned stations receive data from the satellites and then send that information to the master control station where it is corrected and sent back to the GPS satellites.

**The User segment:** The user segment consists of the users and their GPS receivers.

The accuracy of the location information is dependent on the number of satellites among the above mentioned 24 satellites. Once both satellite and position are known/tracked for at least 4 satellites, the receiver can determine a position by triangulation (Algorithm to manipulate the location data based on the time difference of arrival between signals from each satellites).

GPS integrated with other wireless technologies like GSM or GPRS, in order to provide the required location information of a train for central control facility.

## **2.5 Coupling Circuit [2]**

In the power line communication concept, the application of coupling circuit with modem circuit has great portion. The coupling circuit is not just a piece of circuit but a vital part of the PLC system. It is the interface circuit that is used to couple signals in the PLC channel. Hence proper care must be taken when designing this circuit as it must adhere to operating standards set by PLCs international regulatory bodies. A coupling circuit is designed as a peculiar filter (band-pass filter), with the primary aim of coupling the signal unto the network, while it also blocks and filters the AC mains power waveform (for AC operation) but allows PLCs high frequency communication signals to pass. A careful consideration of its constituent components must be made so as to overcome the challenging characteristic the PLC channel possesses. The coupling circuit must also be designed to provide galvanic isolation and on the other hand prevent excess voltage from entering the sensitive measuring equipment used in noise data capture. Most importantly this circuit must be able to withstand and adapt to the varying impedance experienced on the PLC channel hence preventing insertion and coupling losses.

Coupling circuit circuits can be realized in one of the two types. These are:-

### **a. Differential Mode Coupling [2]**

This coupling mode requires the live terminal to constitute a terminal while the neutral terminal is utilized as the second terminal. This coupling mode is realizable and implementable with the existence of neutral terminal as we have in LV power line networks. On the contrary, differential coupling mode is not realizable and implementable on MV and HV power line networks due to the unavailability of a separate neutral line. Alternatively, though not recommended most often the ground (earth terminal) constitutes the second terminal in such cases.

### **b. Common mode coupling [2]**

The common mode coupling involves the interconnection of both the line (live) and neutral terminal to constitute one terminal while the ground (earth terminal) becomes the second terminal. This mode is unachievable theoretically, based on the fact that the ground and neutral wires are always connected at the transformer point. On the contrary, it is practically achievable because the inductance which exists between the coupling points and the short circuit point is big enough to outsmart this problem. This mode of coupling is preferred over its

differential mode counterpart because of the 30 dB better coupling that it yields. In some countries, common mode coupling is highly prohibited on the LV power line network as a result of the danger it poses to end users. A solution to this danger is designing the input current not to exceed the sensitivity of the earth leakage protection device (30 mA for LV applications) present at the location where the coupling circuit is to be used. For the physical implementation of coupling circuit, there exist two possible ways of realizing this. These are:-

### ***Capacitive Coupling***

In capacitive coupling mode a capacitor is basically used to impress or couple the communication signal into the network. This is achieved by modulating the communication signal unto the network's voltage waveform. A capacitive coupling interface is connected in parallel to the power line network. It is an affordable and compact interface commonly used in LV applications such as AMR and other in-home applications.

### ***Inductive Coupling***

In this case the use of an inductor is utilized to impress and couple the communication signal unto the network. It is achieved by impressing the communication signal unto the network's current waveform. Inductive coupling circuit is connected in series with the loads in the power line network. This inductive coupling has been reported to be rather lossy. Nevertheless, since no physical connection is made with the power line network, this coupling mode is safer to implement than its capacitive coupling counterpart.

Capacitive coupling is mainly utilized on LV power line network due to power restriction (there is a maximum allowable power) on the LV network. Both inductive and capacitive coupling modes are allowable on MV power line networks.

## **2.6 Digital Communication [22]**

Figure 4 shows a simplified model of a digital communication system. The data to be transmitted could origin at any source of information. In case, the information is an analog signal, such as speech, then an A/D converter must precede the transmitter.

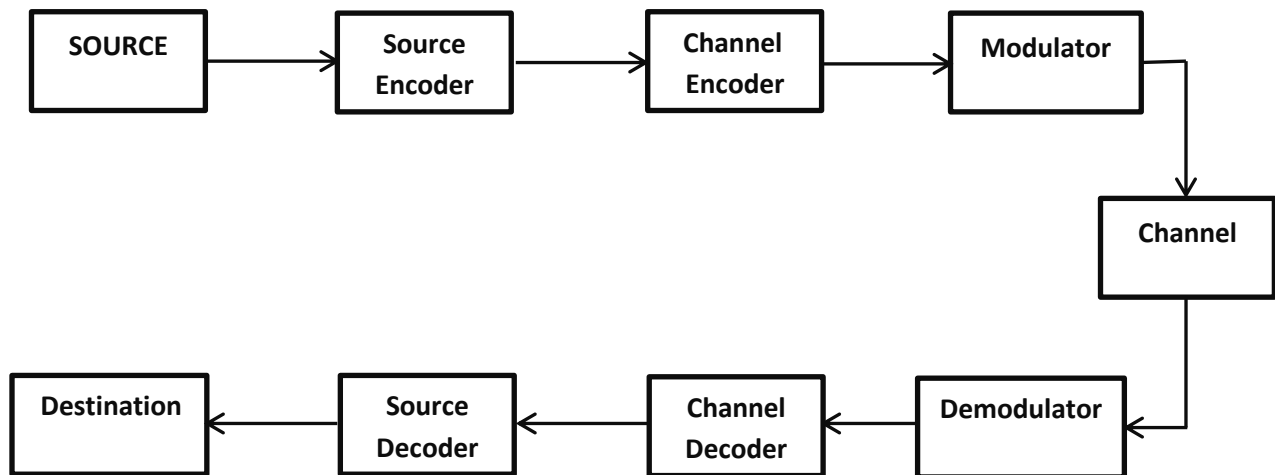


Fig 4: digital communication System model

## **Source Coding**

Most data contains redundancy, which makes it possible to compress the data. This is done by the source encoder and minimizes the amount of bits transmitted over the channel. At the receiver the source decoder unloads the data to either an precise replica of the source (lossless data compression) or a distorted version (lossy data compression). If the received sequence does not have to be an exact copy of the transmitted stream then the degree of compression can be increased.

## **Channel coding**

In order to reduce the bit error probability the channel encoder adds redundancy (extra control bits) to the bit sequence in a controlled way. When an error appears in the bit stream the extra information may be used by the channel decoder, to detect, and possibly correct, the error. The redundancy added is depending on the amount of correction needed but is also tuned to the characteristics of the channel.

## **Modulator**

The modulator produces an information-carrying signal, propagating over the channel. At this stage the data is converted from a stream of bits into an analog signal that the channel can handle. The modulator has a set of analog waveforms at its disposal and maps a certain waveform to a binary digit or a sequence of digits. At the receiver, the demodulator attempts to detect which waveform was transmitted, and convert the analog information back to an order of bits. Numerous modulation techniques exists, e.g., spread-spectrum, OFDM (Orthogonal

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Frequency Division Multiplex), GMSK (Gaussian Minimum Shift Keying), QAM (Quadrature Amplitude Modulation), FSK (Frequency Shift Keying) and PSK (Phase Shift Keying).

### Channel

The channel might be any physical medium, such as coaxial cable, air, water or telephone wires. It is important to know the characteristics of the channel, such as the attenuation and the noise level, because these parameters directly affect the performance of the communication system.

### **2.7 OFDM (orthogonal frequency division multiplex) [18][10]**

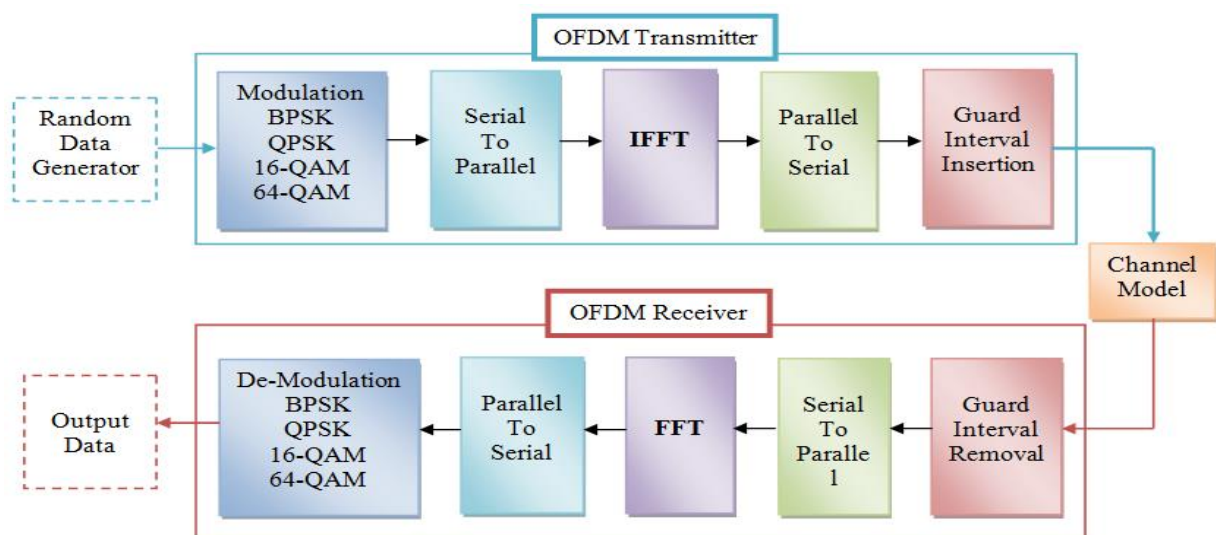


Fig 5: OFDM Tx/Rx block diagram

Multicarrier modulation has long been known as an efficient modulation scheme for band-limited channels. OFDM is considered as one of the most promising modulation methods for power line communications. Despite wide use of the OFDM in conjunction with (or without) other techniques, there is a great potential for this technique to be employed in PLCs.

The basic idea of OFDM is to divide the available spectrum into several sub channels (subcarriers). By making all sub channels narrowband; they experience almost flat fading, which makes equalization very simple. To obtain a high spectral efficiency the frequency response of the sub channels are overlapping and orthogonal, hence the name OFDM. The orthogonality can be completely maintained, even though the signal passed through a time dispersive channel, by introducing a cyclic prefix. There are several versions of OFDM, but we focus on systems using such a cyclic prefix. A cyclic prefix is a copy of the last part of the OFDM symbol which is

prepending to the transmitted symbol. This makes the transmitted signal periodic, which plays a decisive role in avoiding inter symbol and inters carrier interference. Although cyclic prefix introduces a loss in signal-to-noise ratio (SNR), it is usually a small price to pay to mitigate interference.

The following figure shows a schematic picture of the frequency response of the individual sub channels in an OFDM symbol. In this figure the individual sub channels of the system are separated. The rectangular windowing of the transmitted pulses results in a sinc-shaped frequency response of each channel. [10]

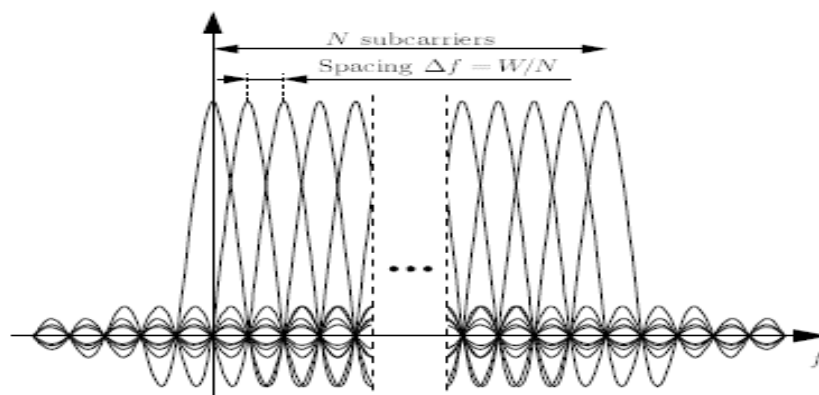


Fig 6 : A symbolic picture of the individual sub channels for an OFDM system with N tones over a Bandwidth of W [10]

### **2.8 Powerline communication channel modeling [7][15]**

Railway overhead lines use copper, copper alloys and aluminum based catenary cables. For the sake of understanding and studying the transmission line characteristics as a communication channel, modeling the system is mandatory. As with any other power transmission systems, the railway traction power system overhead line model can be modeled by the multiconductor transmission line theoretical approach.

This is a bottom-down approach and the lines are viewed as a two-port network. The two-port network is specified by the ABCD matrix, which is also called the transmission matrix. A two-port network is a linear electrical circuit with two pairs of terminals, such that the voltages and currents at one port (pair of terminals) may be expressed as linear combinations of the voltages



Fig 7: Simple Two-wire Transmission Line

and currents at the other terminal. The simple representation of two line transmission line is shown above in figure 7.

Using the distributed parameter line theory, the transmission line configuration shown above can be modeled as shown in Figure 8 below. In the distributed parameter model, the unit line constants (resistance ( $R$ ), inductance ( $L$ ), Conductance ( $G$ ) and capacitance ( $C$ )) are considered to be uniformly distributed along the transmission line and are the per unit values. Where,

$$Z = R + j\omega L \quad (1)$$

$$Y = G + j\omega C \quad (2)$$

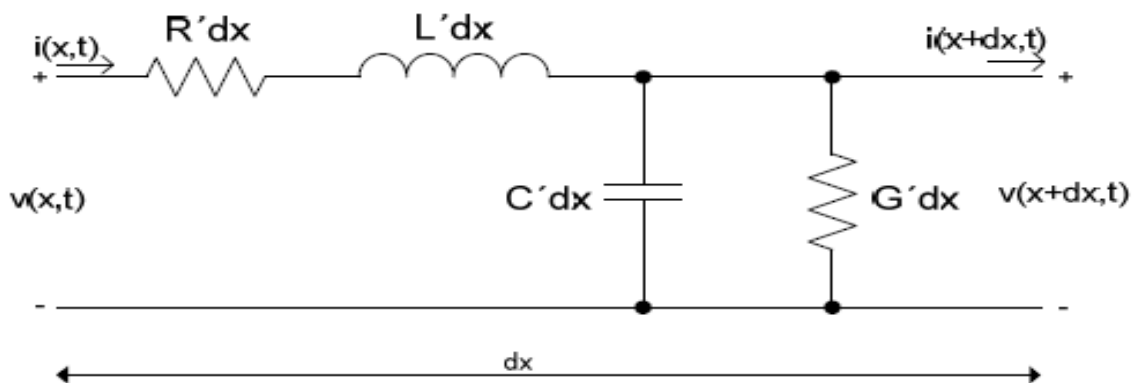


Fig 8: Distributed parameter transmission line [23]

The electrical characteristics between the lines are characterized by the transmission matrix. The ABCD coefficients are derived from the primary line equations for characteristics impedance and propagation constant,  $Z_c$  and  $\gamma$  respectively.

$$Z_c = \sqrt{\frac{Z}{Y}} = \sqrt{\frac{(R+j\omega L)}{(G+j\omega C)}} \quad (3)$$

$$\gamma = \sqrt{ZY} = \sqrt{(R+j\omega L)(G+j\omega C)} \quad (4)$$

In the above equations R,L,C and G can be found using standard formulae. These parameters depend on radius of the cable, distance between cables, wave frequency, permeability and conductivity of conducting material. Below the two ports model is shown.

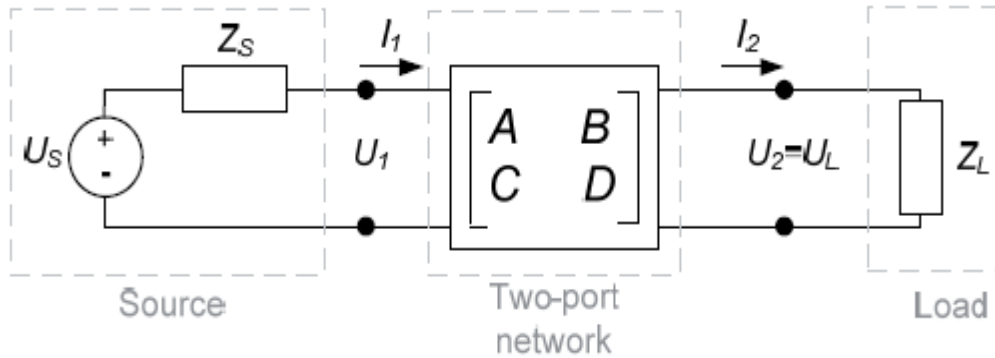


Fig 9: two port model representation [23]

From the above representation, the matrix elements can be found as the following mathematical forms.

$$A = D = \cosh(\gamma l) \quad (5)$$

$$B = Z_c \sinh(\gamma l) \quad (6)$$

$$C = \frac{1}{Z_c} \sinh(\gamma l) \quad (7)$$

Where  $l$  is the length of the conductor.

The transmission matrix is calculated for each section of the transmission line and cascaded in order to find the overall matrix.

$$T = \begin{bmatrix} A & B \\ C & D \end{bmatrix}$$

Then the transfer function is computed, that is used for simulating the parameters for the possibilities of data transmission. The transfer function for the transmission line is obtained as follows.

$$H(f) = \frac{V_R}{V_S} = \frac{Z_L}{AZ_L + B + CZ_S Z_L + DZ_S} \quad (8)$$

### **Pantograph impedance, $Z_p$** [8]

Beside of the transmission line characteristics and modeling, the pantograph impedance determines the channel characteristics seen from the pantograph in frequency variation and distance from the substation. In order to find or model the pantograph impedance, it considers the per unit impedance and transmission matrix obtained above. The following assumptions help for system model.

### **Assumptions**

It is considered a catenary section fed by a substation (in one of the terminals) which has an equivalent impedance  $Z_{sub}$ , a traction unit at position  $x$ . The catenary has a length  $l$ , and it's terminated by impedance  $Z_{ter}$  in the substation opposite end. The following figure illustrates this configuration and in which is the pantograph voltage  $V_p$  in the traction unit.  $Z_{ter}$  is considered to be very high, in other words, the right terminal is open.

As it is seen from the pantograph side to the line it can be considered as a parallel impedance and can be describe the pantograph impedance as

$$Z_p = (Z_L * Z_R) / (Z_L + Z_R) \quad (9)$$

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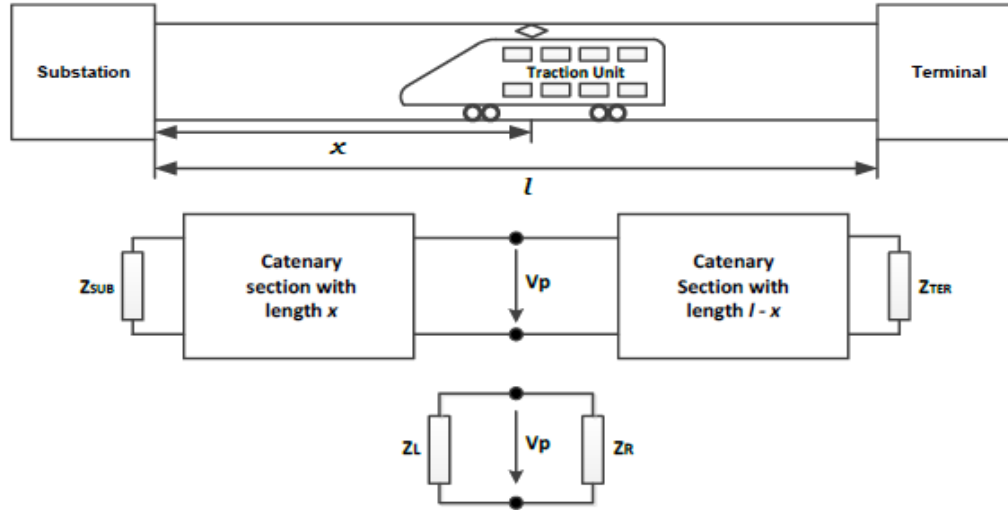


Fig 10: Configuration of the railway section in study; equivalent model; equivalent simplified model [8]

Where  $Z_L$  left side impedance and  $Z_R$  right side impedance ,expressed as

$$Z_L = Z_c \frac{(Z_s \cosh(\gamma x) + Z_c \sinh(\gamma x))}{(Z_c \cosh(\gamma x) + Z_s \sinh(\gamma x))} , \quad (10)$$

Where  $x$  is a train distance from substation, and

$$Z_R = Z_c \frac{\cosh \gamma(l-x)}{\sinh \gamma(l-x)} \quad (11)$$

Finally it is possible to find the pantograph impedance by substituting (10) and (11) in (9) and we get;

$$Z_p = \frac{Z_c \cosh \gamma(l-x) \cdot [Z_s \cosh \gamma x + Z_c \sinh \gamma x]}{Z_s \sinh \gamma l + Z_c \cosh \gamma l}$$

## **Chapter 3**

### **Real Time Train Tracking System**

As discussed in preceding chapters above, the aim of the research is to propose a system that is capable to provide continuous distance information which has an advantage over the existing one. The system is composed of different subsystems which are loaded on the vehicle(train) , installed on the line (ground) and the display unit which is used to display the real time movement of the train or in other words the “where” information visually on maps. Before we proceed to discuss about the components and operation of the proposed system we will discuss the existing detection system installed for A.A LRT project for signaling purpose.

#### **3.1 Existing System for train detection for A.A LRT – Axle counter [3]**

The axle counter, installed for A.A LRT project model ACS2000 imported by Chengdu Railway Communication Equipment Co.Ltd (Austrian Frauscher Company), is arranged at the main track and depot for inspection of position of the train.

ACS2000 axle counter is divided into the indoor and outdoor equipment, a wheel sensor is arranged respectively at the starting point and ending point of the track section, and used together with the evaluation board for detecting of information of wheel set of the train. Each wheel sensor includes 2 groups of systems, which are used for distinguishing the driving direction of the train. Each wheel sensor is connected with the evaluation board by four-core signal cable, which supplies the power for the wheel sensor and transfers the data of axle to the evaluation board.

The axle counting board ACB of the axle counting system processes the data of axle of all connected counting probes, and outputs the results of vacancy and occupation of the detected section into the relevant system (e.g. interlocking system) in manner of interface conditions of relay (output of vacant section is  $DC \geq 21.6V$ ; output of occupied section is  $DC \leq 2V$ ).

The block diagram of the system composition is shown as follows:

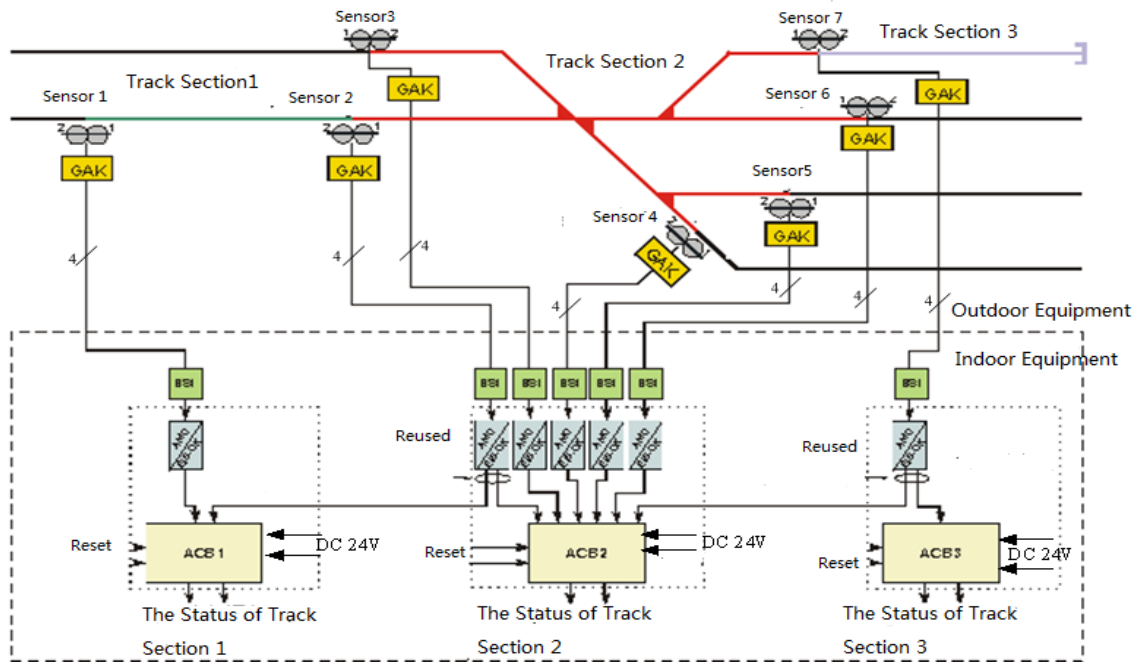


Fig 11 : Block diagram of axle counting system

## Outdoor Unit

The outdoor unit is composed of wheel sensor, Jig and protecting tube of wheel sensor and Cable coupling box of wheel sensor.



Fig 12: (a) Wheel sensor RSR180



(b) Protecting device of wheel sensor

## **Indoor UNIT**

The indoor system(single-board) has different components as shown below.

- Over-voltage protection board BSI;
- Axle counting floor board ABP;
- Evaluation board IMC;
- Axle counting board ACB;
- Fuse board SIC.



Fig : Composition of the component of host axle counting device

## **Train detecting function**

The function of axle counting system is to check and distinguish the state of vacancy and occupation by train on the track section under monitoring. Meanwhile, the distinguishing results are outputted in the form of relay conditions.

- When the train enters into the track section under monitoring, the condition of loss of excitation representing the occupation of track section is outputted;
- When the train enters into the track section under monitoring, the condition of loss of excitation representing the occupation of track section is outputted;

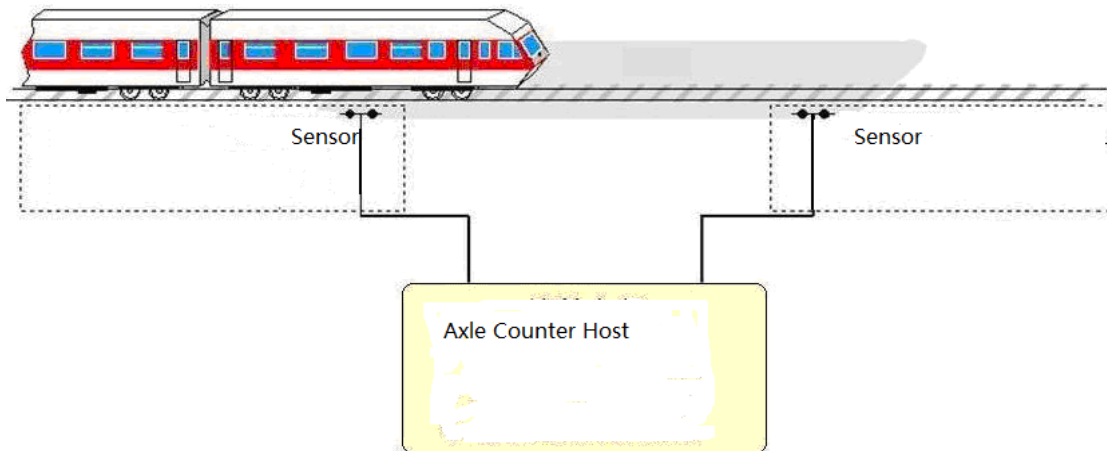


Fig 13: set up diagram of ACS2000 axle counting system

- In case of equipment failure, the condition of loss of excitation for occupation of track section is outputted until the equipment is repaired.

### **3.2 Proposed System overview**

The proposed system is power line based real time train tracking system for A.A LRT system.

The system basically will have two subsystems, namely;

- a. Onboard unit
- b. Fixed/station unit

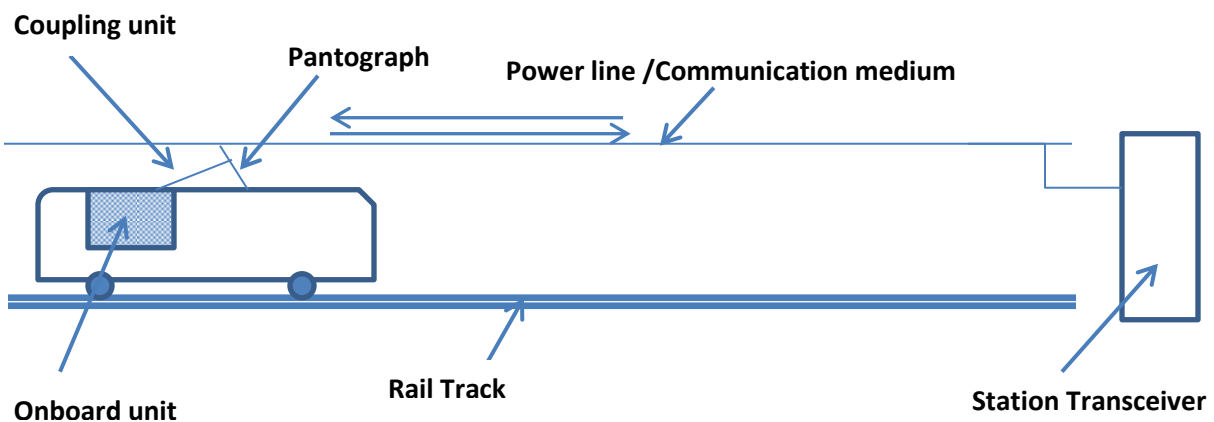


Fig 14: Block diagram of the system

## 3.2.1 Onboard sub-system

The onboard system is a transceiver which is capable to transmit and receive the required modulated signal to the power line. It is loaded on the train and plays a role as an **interrogator**. This sub system is responsible for duties like generation, transmission, reception, manipulation and displaying the result visually.

## 3.2.2 Ground/stationary sub-system

The Transponder (RX/TX) system is installed at stations or any convenient place along the traction power line and uses as reference for distance measurement (i.e. 0 references). It replies as an interrogation signal is received. At this sub-system reception, accuracy check, pattern generation, and transmission are performed. It is almost the same but reverse actions done regarding data communication.

## 3.2.3 System Architecture

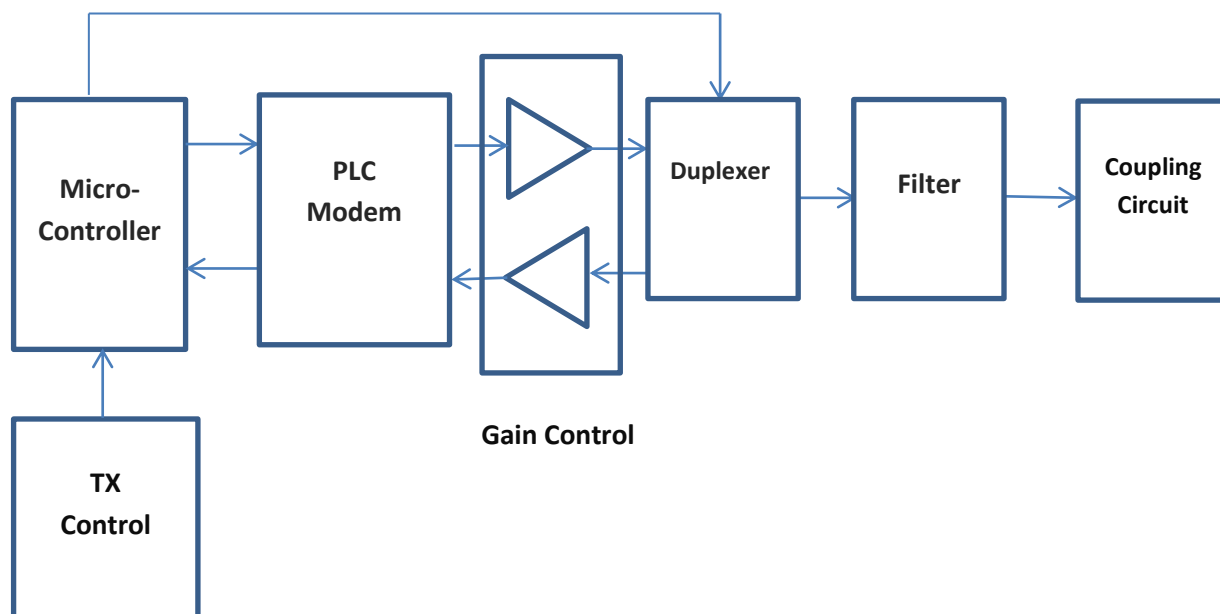


Fig 15: PLC module Block diagram

As shown on the figure the module is basically composed of the above shown sub units. The function of each sub unit is discussed below.

## PLC based real time train tracking system for A.A LRT

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Both subsystems are composed of same units except the operational difference. For instance both uses microcontroller but the onboard unit used the MC for manipulation and data communication via USART in addition to the function of MC in ground subsystem. The units which are common are discussed below.

a. **Microcontroller(MC) (ATMEGA 32)** [24]

The ATmega32 is a low-power CMOS 8-bit microcontroller based on the AVR(trade mark) enhanced RISC architecture. By executing powerful instructions in a single clock cycle, the ATmega32 achieves throughputs approaching 1 MIPS (million instructions per second) per MHz allowing the system designed to optimize power consumption versus processing speed.

The AVR core combines a rich instruction set with 32 general purpose working registers. All the 32 registers are directly connected to the Arithmetic Logic Unit (ALU), allowing two independent registers to be accessed in one single instruction executed in one clock cycle. The resulting architecture is more code efficient while achieving throughputs up to ten times faster than conventional CISC microcontrollers. It has inbuilt timer1 (1x 8 bit and 2 x 16 bit timer) , Analogue to digital converter and serial communication port(USART) in addition of the basic MC functionalities. Timer and USART discussed below.

**TIMER** [17]

An AVR timer in simplest term is a register. Timers generally have a resolution of 8 or 16 bits. So an 8 bit timer is 8 bits wide, and is capable of holding value within 0-255. It's rate value increases/decreases automatically at a predefined proportion of CPU (supplied by user). This is the timer clock. And this operation does not need CPU's intervention.

The AVR timers are very useful as they run asynchronous to the main AVR core. This is a fancy way of saying that the timers are separate circuits on the AVR chip which can run independent of the main program, interacting via the control and count registers, and something called timer interrupts.

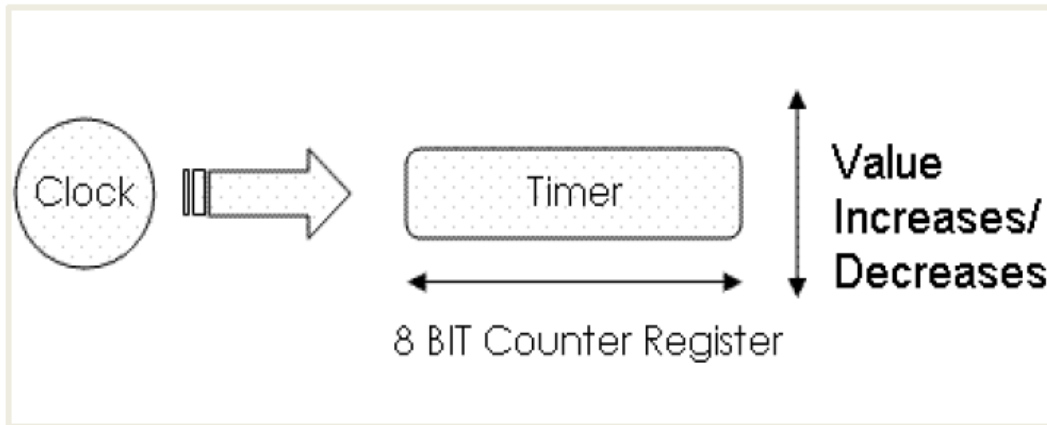


Fig 16: 8 bit AVR Timer

Since Timer works independently of CPU it can be used to measure time accurately. Timer upon certain conditions takes some action automatically or informs CPU. As we know a timer is an 8 bit register that keeps on increasing its value, so one of the basic conditions is the situation when timer register OVERFLOWS i.e. it has counted up to its maximum value (255 for 8 BIT timers) and rolled back to 0. In this situation timer can issue an interrupt and you must write an Interrupt Service Routine (ISR) to handle the event. There are three different timers available in Atmega16 and all the timers work in almost same way. They are TIMER0, TIMER1 and TIMER2.

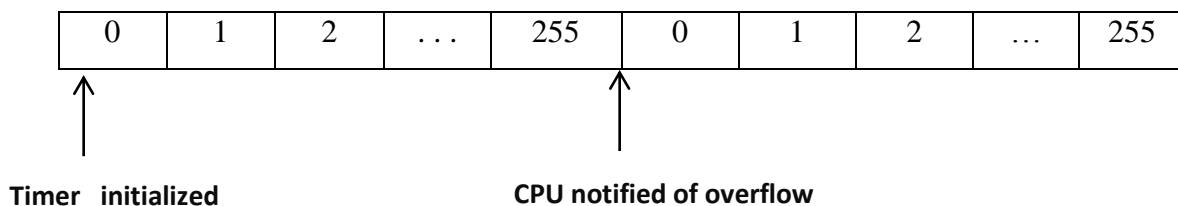


Fig 17 : Overflow diagram

The Prescaler is a mechanism for generating clock for timer by CPU clock. Every CPU has a clock source and the frequency of this source decides the rate at which instructions are executed by the processor. Atmega has clocks of several frequencies such as 1 MHz, 8 MHz, 12 MHz, 16 MHz (max). The Prescaler is used to divide this clock frequency and produce a clock for TIMER. The Prescaler can be set to produce the following types of clocks:

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# PLC based real time train tracking system for A.A LRT

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- ❖ No Clock(Timer stop)
- ❖ No prescaling (clock frequency = CPU frequency)
- ❖ FCPU/8
- ❖ FCPU/64
- ❖ FCPU/256
- ❖ FCPU/1024
- ❖ External clock, however, it will rarely be used.

## **TIMER MODES**

There are four modes that a timer operates. These are:

### 1. Normal Mode

A timer running in normal mode will count up to its maximum value (255 for 8 bit counter and 65535 for 16 bit timer). When it reaches this maximum value, it issues an Overflow interrupt and resets the value of the timer to its original value.

### 2. CTC - Clear Timer on Compare Match

Compare mode makes use of a register known as the Output Compare Register which stores a value of our choice. The timer continuously compares its current value with the value on the register and when the two values match;

- a pin can be set high or low ,
- PWM signals can be generated or
- can generate, interrupt and call a handler.

### 3. Fast Pulse Width Modulation(Fast PWM) mode

When the TIMER0 is configured for fast PWM mode, then, while the timer is counting up, whenever the value of TIMER0 counter matches the value in the OCR0 register, an output PIN is pulled low (0) and when counting sequence begin again from 0 it is SET again (pulled high=VCC). This continues throughout the operation. This PIN is named OC0 and you can find it in the PIN configuration of ATmega32.

### 4. Phase Correct PWM MODE

This mode is very similar to the Fast PWM mode except that whenever the value of the timer reaches its maximum value then instead of clearing the value of the timer it simply starts counting down. The value of the pin toggles only when the value of the OCR0 matches with the TIMER0 counter.

## PLC based real time train tracking system for A.A LRT

For this specific paper, the MC is set up with operating with normal mode , a pre-scalar of 256, internal clock of 8Mhz microcontroller oscillator and from the available timers timer 1 ,which is a 16 bit timer , is used to count the delay between transmission and reception.

### **USART (Universal synchronous Asynchronous serial Receiver and Transmitter) [24]**

USART is a highly flexible serial communication device. The main features are Full Duplex Operation (Independent Serial Receive and Transmit Registers), Asynchronous or Synchronous Operation, Master or Slave Clocked Synchronous Operation , High Resolution Baud Rate Generator , Supports Serial Frames with 5, 6, 7, 8, or 9 Data Bits and 1 or 2 Stop Bits, Odd or Even Parity Generation and Parity Check Supported by Hardware , Data OverRun Detection, Framing Error Detection, Noise Filtering Includes False Start Bit Detection and Digital Low Pass Filter , three Separate Interrupts on TX Complete, TX Data Register Empty, and RX Complete , Multi-processor Communication Mode, Double Speed Asynchronous Communication.

For this project it is programmed to operate at 9600 baud rate, 8 data bit, no parity and 1 stop bit.

### **PLC modem**

This unit is responsible to modulate the pattern from MC and transfer it to the next stage or demodulates the received analogue signal from the line to Digital format to the MC. This module assumed to contain the Recommended OFDM with appropriate modulation type. Then it routes modulated signal to the gain control. The gain control amplifies while transmission and plays as an automatic gain control module for signal conditioning while reception. The signal passes after the gain control to filter section in order to cut out unwanted frequency contents and finally routed to coupling section for filtering, impedance matching and signal injection purpose. The same is done while reception to cut out unwanted frequency ranges which could inject from different noise sources.

### **Coupling circuit**

In order to inject and to receive the signal which carries the pattern, we need to have a reliable coupling circuit with high pass filters in order to pass high frequency contents. Since the system is designed for LV purposes, capacitive couplers are preferred. Basically, capacitive couplers

# PLC based real time train tracking system for A.A LRT

consist of a radio frequency (RF) transformer (to provide galvanic insulation from the power grid and impedance adaptation) and a capacitor (to filter the DC or AC power supply signal).

## **Tx Controller**

This unit is required to control the transmitter when to transmit. According to suggestions from researches (refer [5]) that among the two different possible signal injection possibilities if we prefer the synchronous one we need a controller to activate the microcontroller when to start transmitting in order to inject in to the relative noise free time gap. Also it is shown on the block diagram that there is a duplexer (single path for the signal) that should be controlled by a controller when to access the path regarding the operation (i.e. Tx or Rx).

## **3.2.4 Principle of operation**

In the previous section the system overview presented. Here the operational aspect of the system is presented with the algorithm and flow chart.

### **Algorithm (Interrogator/Onboard sub-system)**

- ❖ At initialization the microcontroller generates a pattern (refer Figure 15 and Figure 18), sends to the PLC modem and after it is conditioned by the PLC modem it will be loaded via a filter and coupling circuit to power line.
- ❖ As the microcontroller generates and sends the pattern, it initializes inbuilt 16 bit timer (timer 1 of Atmega MC) and counting starts.
- ❖ It waits until the ground sub-system checks the accuracy of the pattern and reply is received. If reply doesn't arrive on specified time the procedure started again.
- ❖ If reply received, the timer stopped and the counts will be used to calculate the delay.
- ❖ After the total time delay obtained the algorithm starts to find the distance of the train from reference point (ground subsystem).
- ❖ Then the distance information will be sent via USART to the application software to display/visualize the distance /location of the train on map.

The flow chart is shown below.

# PLC based real time train tracking system for A.A LRT

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## Algorithm (Ground sub-system)

- ❖ It waits until interrogation signal is received.
- ❖ If signal is received and demodulated, it checks the accuracy of the pattern by sampling six points.
- ❖ If the pattern is accurate it sends back same pattern to the interrogator.
- ❖ If pattern is not accurate it drops the request.
- ❖ The operation continues iteratively.

From this operation the time taken for a round trip from onboard to the ground reference unit is obtained. Next it will be divided by two in order to find the single path delay. Then system delay which is considered as a delay due to execution process will be subtracted. The obtained result is the delay for the signal to propagate between the two units and this result will be multiplied with signal propagation speed in an overhead conductor(which is determined by the velocity factor that takes a speed of light as a reference) in order to find the distance.

The distance information is calculated in defined time gap (for instance 1sec). Then the two consecutive results are used to find the speed of the train by dividing the distance difference to the time gap used. Also the direction can be determined by inspecting the increment/decrement of the distance value. In other words if the distance value is increasing it can be considered as the unit is going away from the reference and vice versa.

The following flow charts briefly shows the work flow clearly.

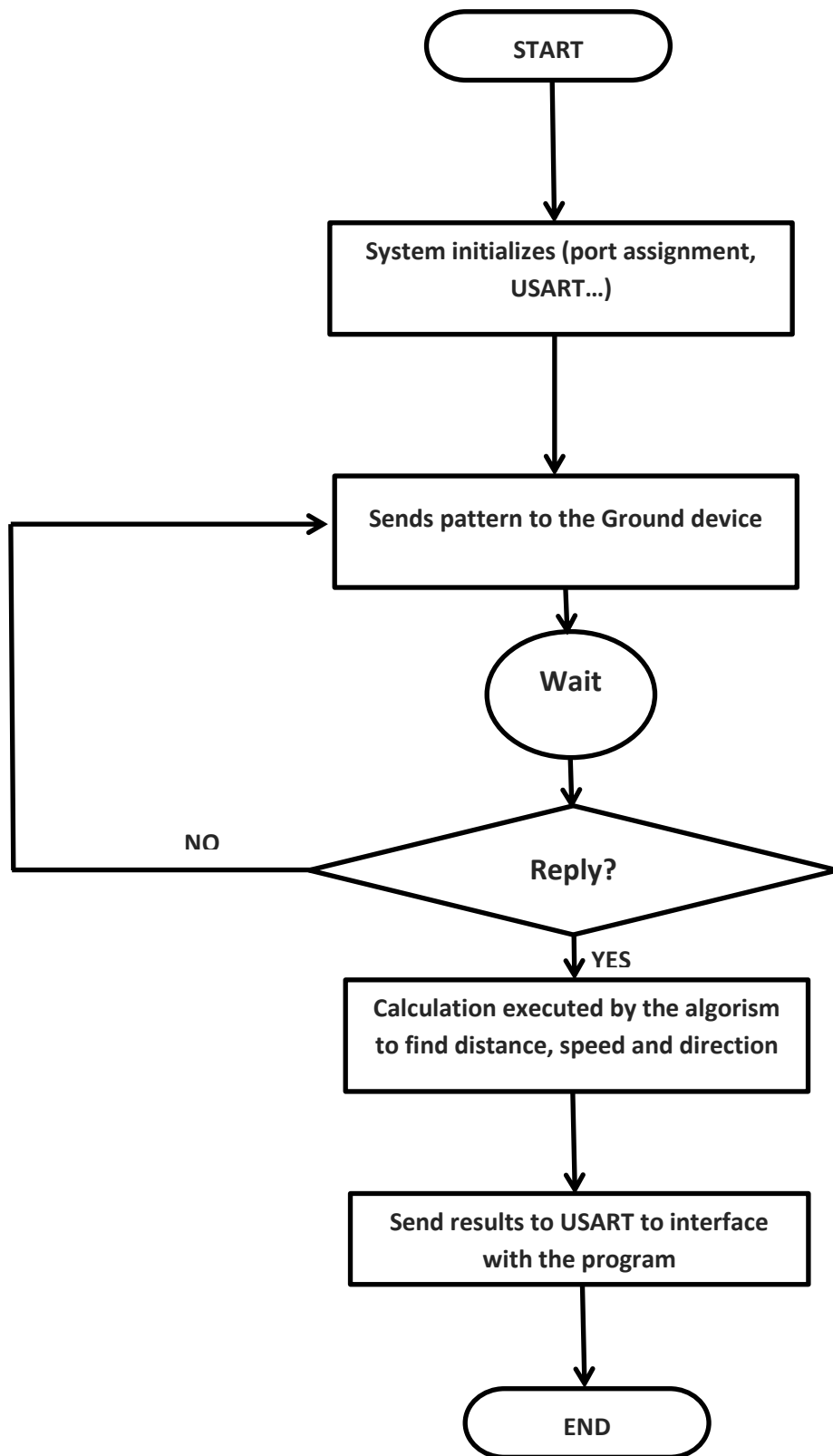


Fig 18: Flow chart for onboard system

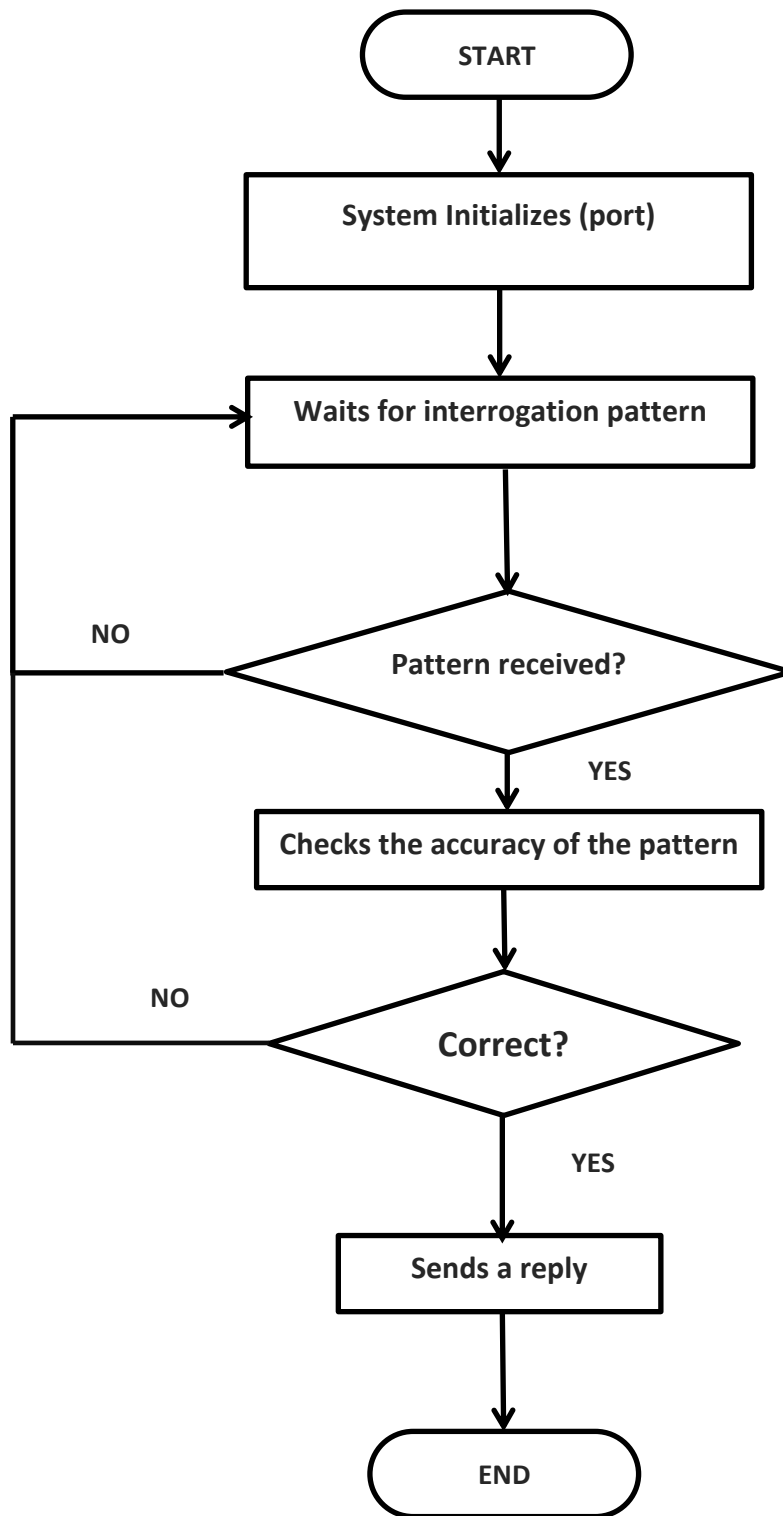


Fig 19: flow chart for Ground/station device

## 3.2.5 Software

The research uses mainly five soft wares for the implementation/design and simulation purposes. The function of the software and other details are presented below.

### 1. AVR STUDIO 5

AVR Studio is a Development Tool for AVR microcontrollers. AVR Studio enables execution of AVR programs on an AVR In-Circuit Emulator or the built-in AVR Instruction Set Simulator. AVR Studio supports source level execution of Assembly programs assembled with the Atmel Corporation's AVR Assembler and C programs compiled with IAR Systems' ICCA90 C Compiler for the AVR microcontrollers.

### 2. VISUAL STUDIO( C#)

C# is a Microsoft product which runs in .NET environment. It is a language free of the backward compatibility curse with a whole bunch of new, existing and promising features. It is an object oriented programming language and has at its core ,many similarities to java , C ++ and VB. In fact , C # combines the power and efficiency of C++, the simple and clean OO design of java and the language simplification of visual basic.

The research used C# to program the Mapping/visual control aid application. That accepts the distance information from from the microcontroller device on board and excutes simple algorism to find the longitude /latitude information in order to display on the bing map.

### 3. PROTEUS

Proteus is a software kit from Lab center electronics ltd. It is used to design test and simulate electronic circuits and systems. It has tools to design microcontroller based systems with PIC and ATMEL microcontrollers. For this specific research I used to simulate microcontroller (onboard and ground) operation with LCD and virual terminal setups. The setup is shown in next chapter)

### 4. MATLAB [11]

The name MATLAB stands for MATrix LABoratory. It is developed by Math works. MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming environment. Furthermore, MATLAB is a modern programming language environment: it has sophisticated data structures, contains

# PLC based real time train tracking system for A.A LRT

built-in editing and debugging tools, and supports object-oriented programming. These factors make MATLAB an excellent tool for teaching and research.

In this research it is used to simulate the modeled channel responses.

## 5. Virtual serial port Kit (VSPK) [12]

It is a serial virtual serial port application from fabulaTech Software Company. **Virtual Serial Port Kit** allows creating a pair of virtual serial ports connected with virtual null-modem cable. The software provides null-modem connection between two serial communications applications. Communications software interacts with each other via virtual COM-ports in the same way as via hardware COM-ports connected with null-modem cables.

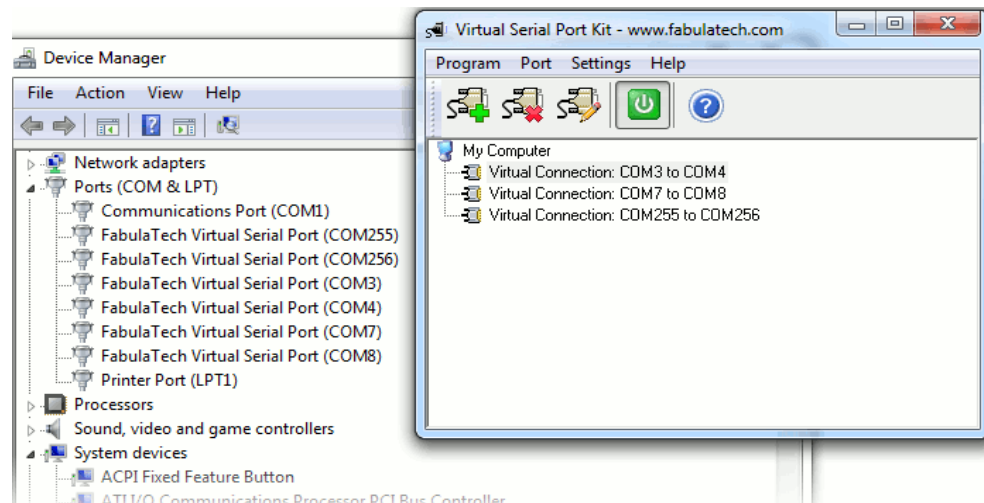


Fig 20: Virtual serial port kit window

As soon as one serial application opens one virtual COM port and the other application opens the second virtual COM-port, the connection between two serial applications will be established. Now serial data can be transmitted over virtual COM ports.

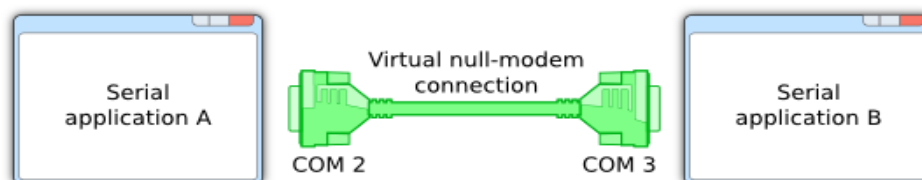


Fig 21 : Serial communication example

## PLC based real time train tracking system for A.A LRT

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As shown in the figure above, the application A occupies COM2 and application B occupies COM3. As soon as the applications open COM2 and COM3, two-way data exchange will be established.

It is used in the demonstration to interface the microcontroller virtual serial port with the map application software serial port.

### **3.3 Multiple Access**

For multiuser communication links, the resources of the channel have to be shared among numerous users. The way in which these limited resources are split between subscribers, namely trains, is crucial for overall system performance and must consider channel properties, as well as requirements concerning acceptable delay times and amounts of data to be transmitted. Real-time requirements for automation tasks call, e.g., for a quasi-continuous data exchange between trains and fixed stations. If inevitable, only very short interruptions are permitted. Thus, it appears advantageous to divide the whole network into several independent logical cells in order to limit the number of subscribers in such a cell and to enable reuse of carrier frequencies.

Among the possible multiple access methods, named:

- a. Fixed multiple access (time division multiple access and frequency division multiple access)
- b. Random access
- c. Demand assignment method

The first one fixed multiple access with frequency multiple access is more favourable for the operation. Since the system sends and receives the signal at any time  $t$ . The control can be done in the ground transponder.

## **Chapter 4**

### **Simulation results and discussion**

In this chapter, simulation setups, assumptions, results, discussion and related issues discussed. As stated above, the overall aim of the research is to utilize the power line infrastructure of A.A LRT traction system for data communication purpose in order to apply for real time train tracking system. The delay of a signal in a specific medium determines the distance between the transmitter and a receiver if the signal speed in the medium is known. The research takes this basic concept to find the time delay between Tx and Rx by sending and receiving a known pattern in the medium that its propagation speed can be guessed. Then the distance is calculated in Microcontroller (MC) with the help of the algorithm loaded. Then the distance information is sent to the application which can be loaded on computers to visually monitor the train position. After the application receives the distance and direction of the train it converts the distance information to latitude and longitude by a simple similar triangle algorithm since the distance is short. This can be achieved by sectioning the whole track to a connected straight lines and treating each line by the algorithm since the starting and ending of the line section GPS coordinate is known. Then the obtained GPS coordinate will be sent to be represented on the known Microsoft map application “Bing map”. This is a brief description.

In order to present the system functionality in simulation the procedures are as follows. First the transmission line characteristics will be simulated by the help of Mat lab and the results are discussed with the help of produced plots. The pantograph impedance value is also simulated in order to understand the impedance seen from the train to the transmission line. Then the microcontroller setup which represents on board and ground/station devices is simulated by proteus 7 and the results are discussed. Finally the application introduced and the integrated operation between microcontroller (generates simulation data for a sake of integration with the map) and the map application. First the transmission line as a communication channel will be treated. The line is originally designed for power transmission with low frequency or DC. When it is used for high frequency application the characteristics or response for the power line differs. With this research, basic parameter which determines the channel for data communication discussed.

## **4.1 Channel simulation using Mat lab**

A power transmission line is originally designed for power transmission with low frequency or DC. When it is used for high frequency application the signal might face difficulty to propagate. This has to be studied in order to provide solution to improve the performance. Here in this section the characteristics or response of the line for a frequency change and length change is presented. Also the variation of the pantograph impedance and the skin effect versus length and frequency, respectively are treated based on the conductor material parameters. Then finally the results will be discussed. The following describes the mat lab code functionality by dividing the operation in to two main blocks Block A and Block B.

### **Block A**

In Block A, the distribution line parameters  $Z_c$  and  $\gamma$  are calculated for each individual cable size, which is obtained from the specification of the material that is used for the overhead contact line for A.A LRT project. The cable specifications (radius  $r$ , separation  $s$ , core conductor conductivity  $\sigma$ , and permeability  $\mu$ ) from the manufacturers data sheet, for each cable size in the channel is used as input to block A. The distributed cable parameters  $R$ ,  $L$ ,  $G$  and  $C$  are then calculated for each cable and the results used to calculate  $Z_c$  and  $\gamma$  for each distribution line segment. This data is then stored in arrays and passed to block B.

### **Block B**

The inputs to block B are the characteristics impedance  $Z_c$  and propagation constant  $\gamma$  for each distribution line segment. In block B, the equivalent Two-port network model for each distribution line segment is first calculated. The equivalent Two-port network model representative of the complete channel path being considered is then calculated by cascading the individual Two-port network models for each segment based on the specific topology of the PLC channel path. The transfer function of the channel is then calculated and the frequency response over the 3-500 KHz range is calculated at a 1 KHz interval. Finally, the frequency response Plots are displayed for result discussion.

The overall operation flow chart is presented below.

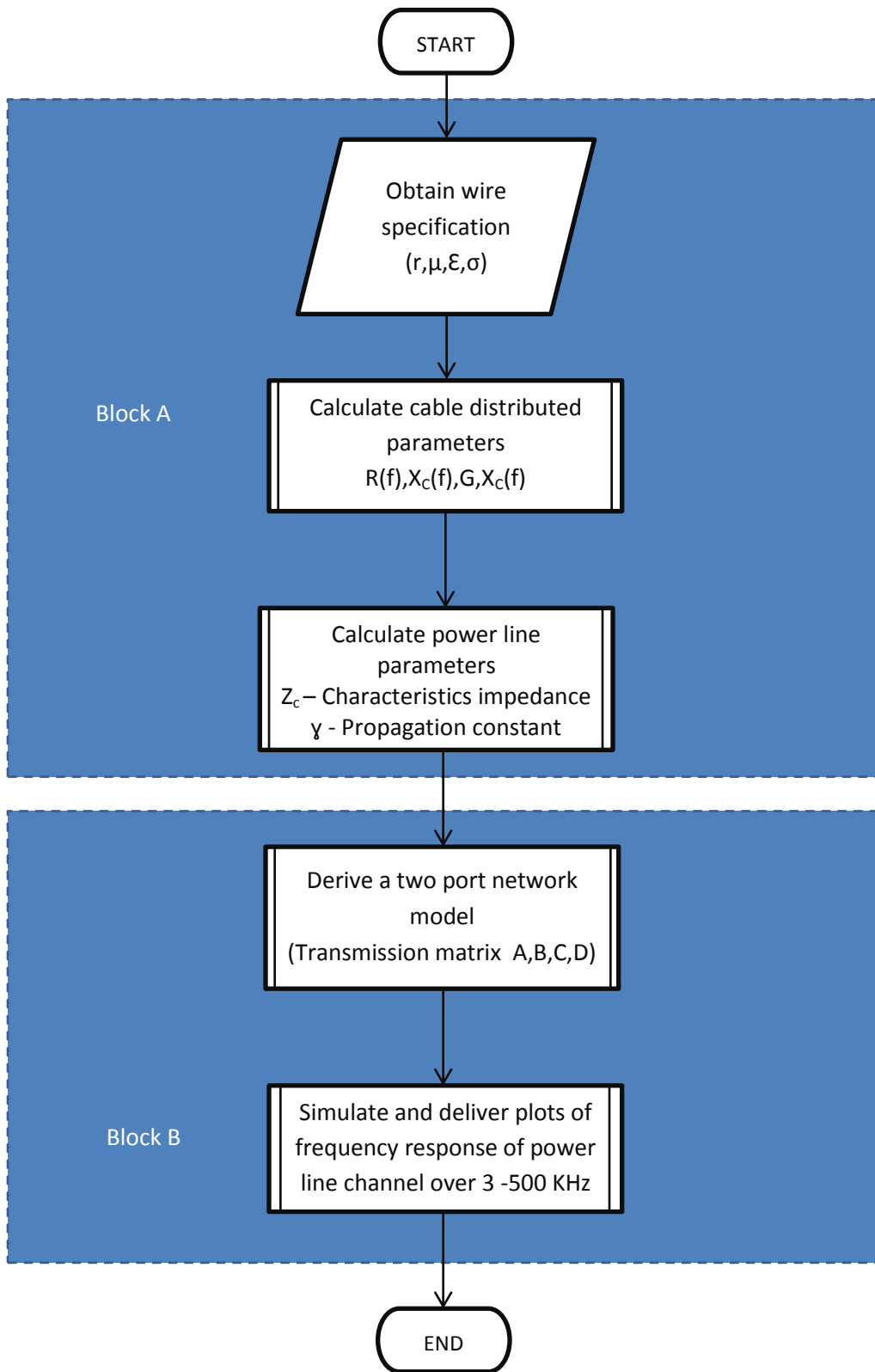


Fig 22: mat lab code flow chart

# PLC based real time train tracking system for A.A LRT

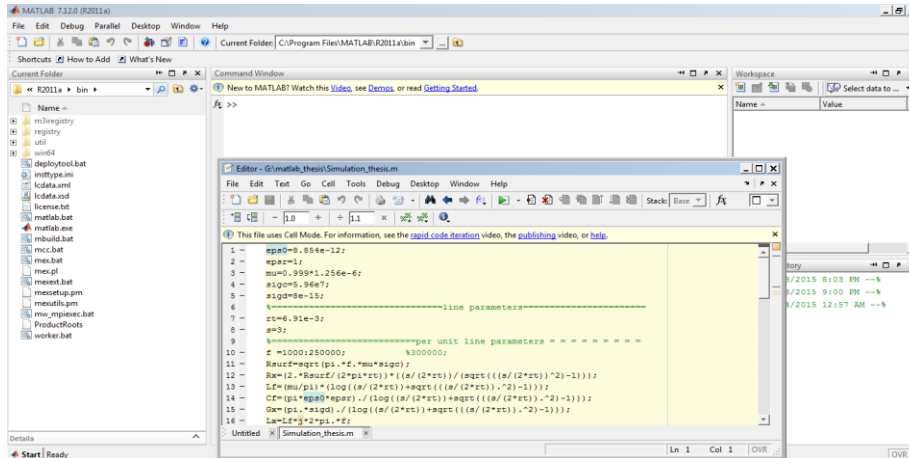


Fig 23: Mat lab window

## Assumptions

The material used for A.A LRT is Copper –silver alloy with a type no CTAH 150, 150 mm<sup>2</sup>. But the specification of the material cannot be obtained so it is assumed that the material is copper with 150 mm<sup>2</sup>.

### Line parameters used

$$\text{Cross section} = 150 \text{ mm}^2$$

$$\text{Radius} = 6.91 \times 10^{-3} \text{ m}$$

$$\epsilon_0 = 8.854 \times 10^{-12}$$

$$\epsilon_r = 1$$

$$\mu = 1.256 \times 10^{-6}$$

$$\sigma_c = 5.96 \times 10^7 \text{ (conductivity of conductor)}$$

$$\sigma_d = 8 \times 10^{-15} \text{ (conductivity of air dielectric)}$$

$$s = 3 \text{ m (distance between line and return)}$$

Refer the code attached in

After taking these parameters the parameters R, L, G and C are calculated. The mat lab code takes these parameters and manipulation done according to the procedure and the after the transfer function has obtained, the plots will be generated with variation of some parameters. The following plots are generated.

## Gain Vs frequency

When this plot is done, the length is assumed to be at 500 m and frequency to vary from 1 KHz to 500 KHz with 1KHz spacing.

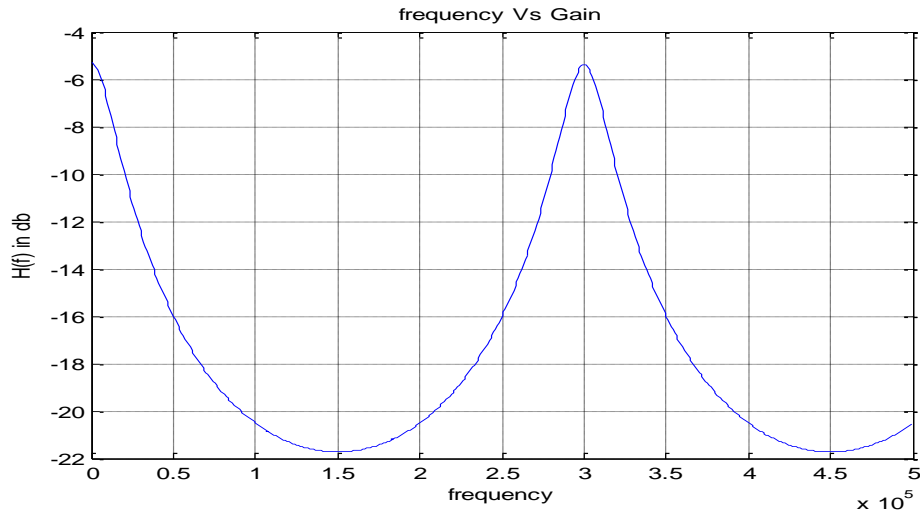


Fig 24: Frequency Vs Gain

As shown on Fig 24 above, the gain decreases as frequency increases to 150 KHz the starts increasing to 300 KHz and repeats with same manner. From this we can conclude that the gain varies according to the frequency selected and this is due to resonance. From the plot it is required to select a frequency range with better gain in order to have better SNR since the attenuation is small. To suggest one, a frequency range around 300 KHz is recommended due to the better gain.

### **Gain Vs Length**

For this simulation, frequency is set to 300 KHz and length to vary from 0 to 500 m. then the following plot obtained.

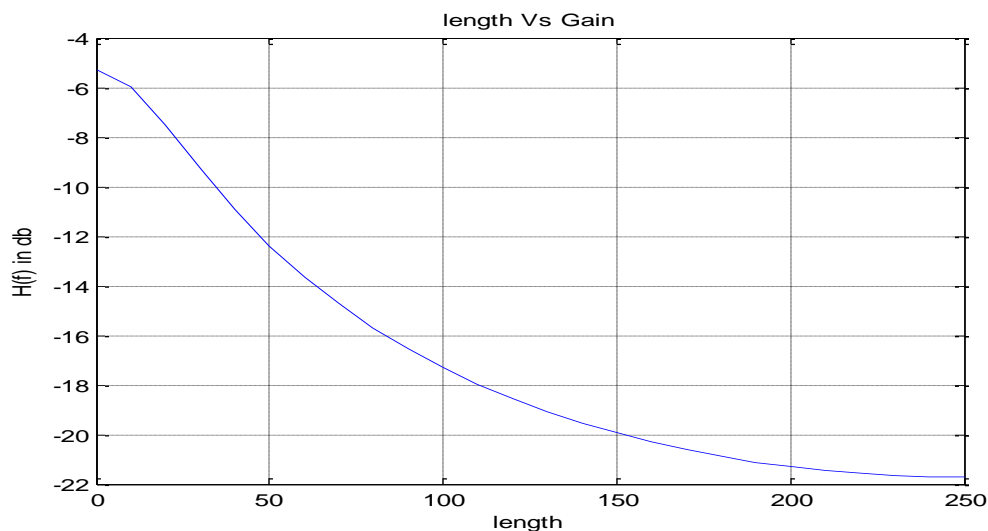


Fig 25: Length Vs gain

# PLC based real time train tracking system for A.A LRT

As we can observe from the plot the gain decreases with distance and it is recommended to implement signal repeaters to boost the signal to the level which enables a system to cover a range of distance (like 2 Km of section)

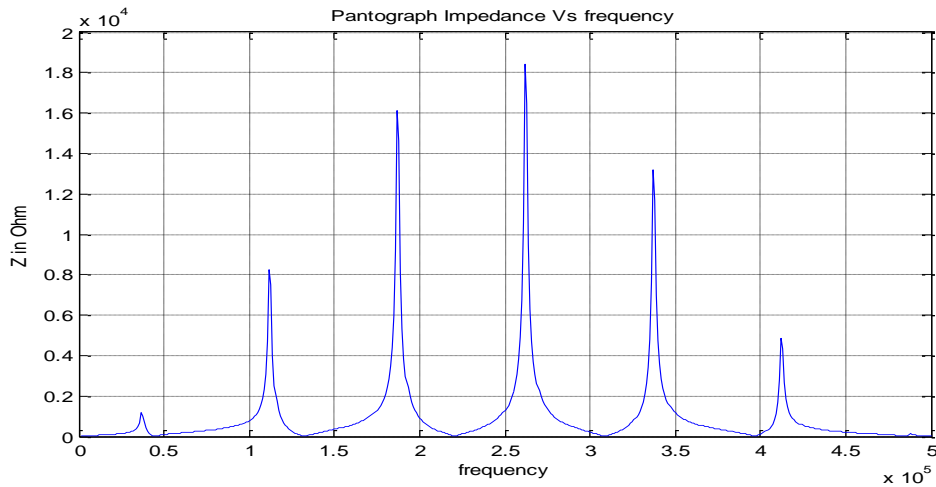
## Pantograph Impedance , $Z_p$

The simulation result for pantograph impedance is presented below that shows the impedance values versus frequency and the pantograph position along the track.

### $Z_p$ Vs frequency

The simulation is done for the length of 1Km and 2 Km and fixing x values less than the given length. The frequency varies from 1 KHz to 500 KHz range and the following plots found.

#### For 2Km length



#### For 1Km length

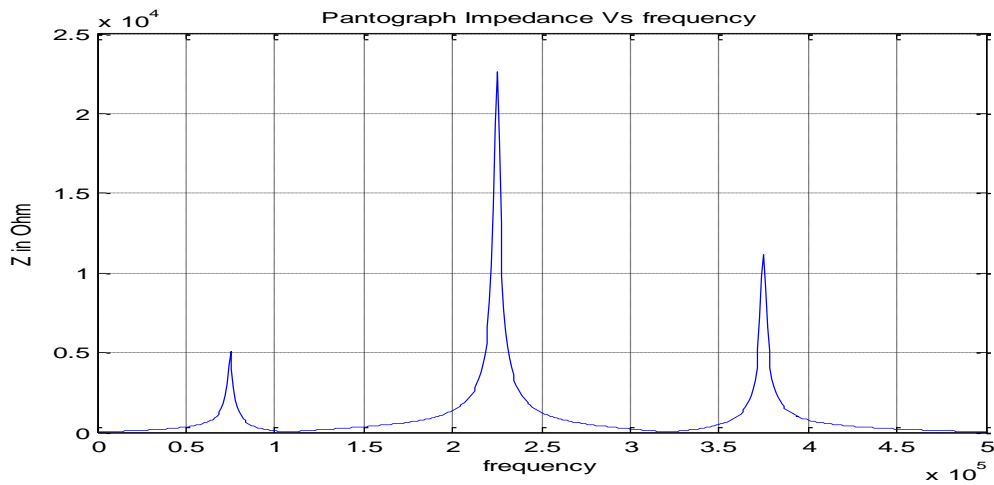


Fig 26: Pantograph impedance Vs Frequency a) 2 Km b) 1 Km

## PLC based real time train tracking system for A.A LRT

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As it is possible to observe on both plots (Length = 1Km and length =2 Km) from the above figures, the impedance value is high for some ranges of frequency. So according to the obtained result we can pick those frequency ranges with lower impedance value to use them as a carrier frequency for the operation. This helps to reduce the voltage standing wave ratio generated due to impedance mismatch.

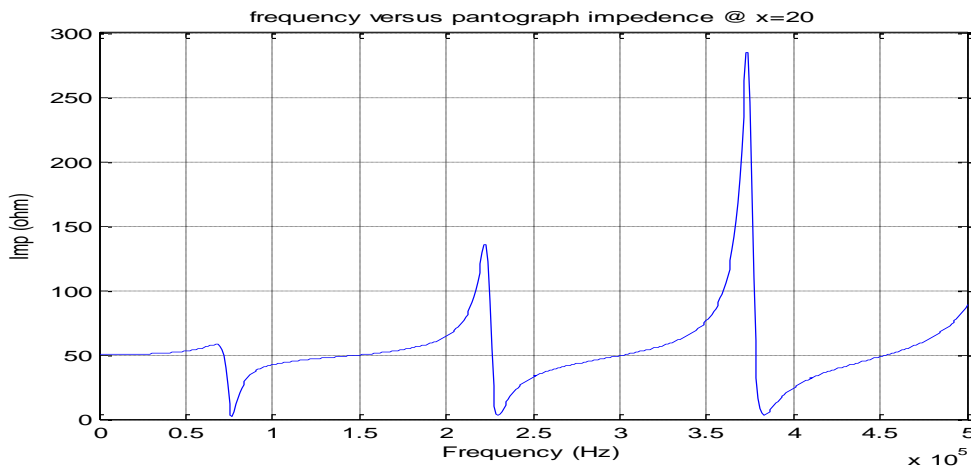
Besides, from the plot it is possible to decide on the section length based on the frequency range availability for operation. As it is possible to observe on the plot 1 Km section has better range for frequencies for operation.

### **$Z_p$ Vs pantograph position along the track (x)**

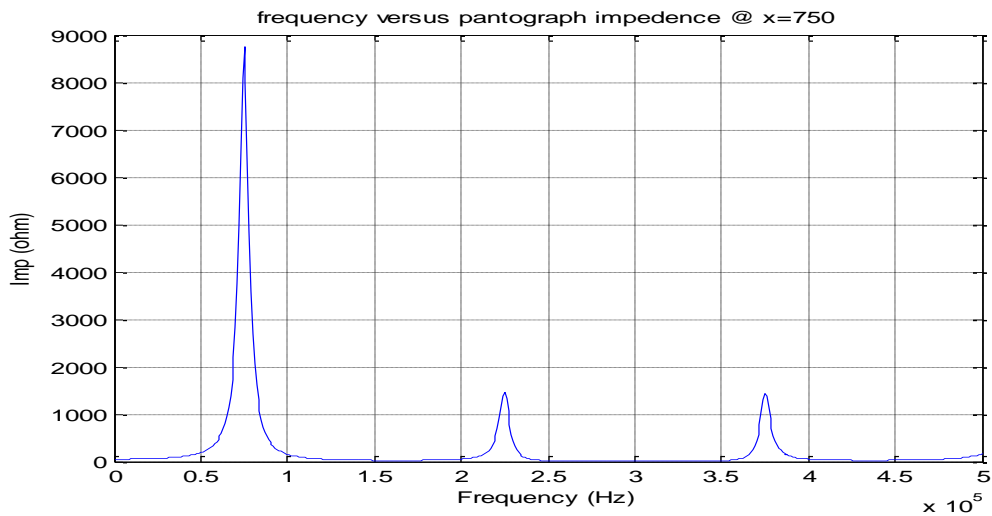
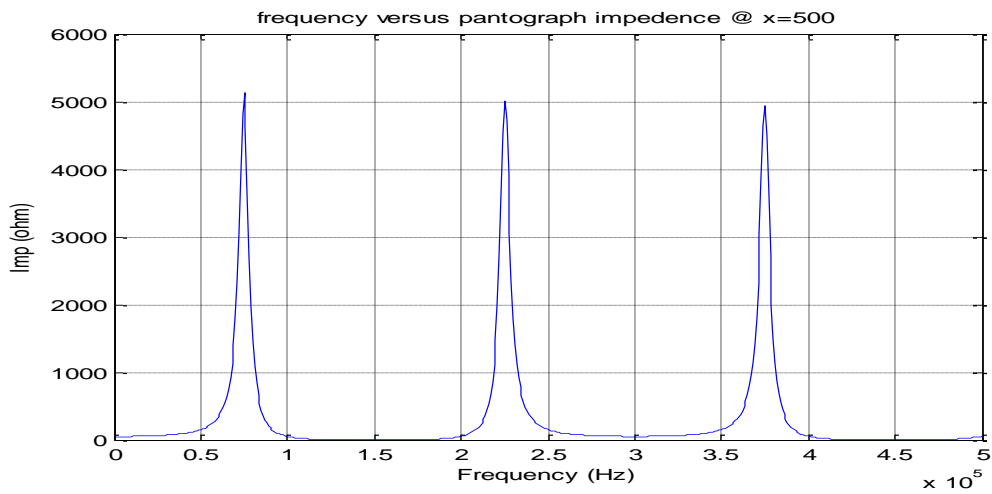
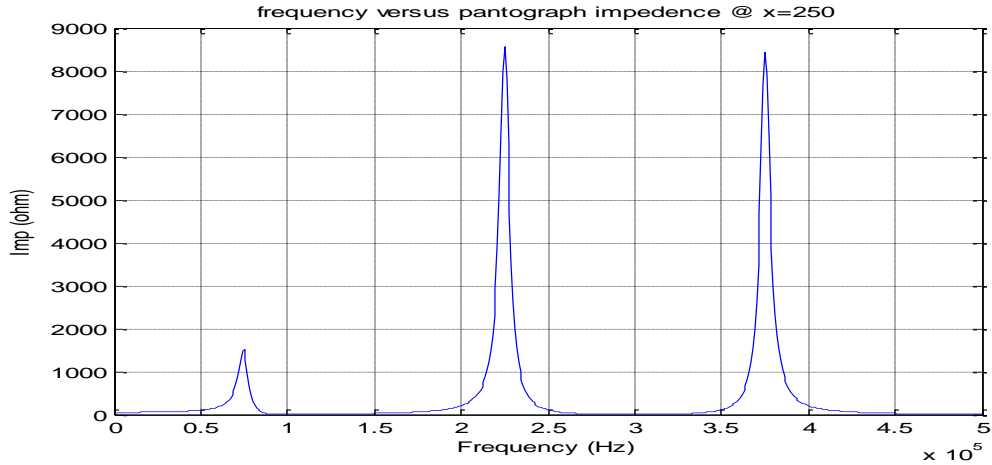
This is done with setting length 2 Km and the frequency at 300 KHz where one of the lower impedance has achieved as per the above graph.

### **Frequency Vs pantograph impedance**

The following plots show the relation between frequency with pantograph impedance at different train position in a given section. For this simulation, it is taken section length  $l = 1\text{Km}$  and varying  $x$  for 20m, 250m, 500m, 750m and 990 m from the ground reference unit equipment.



# PLC based real time train tracking system for A.A LRT



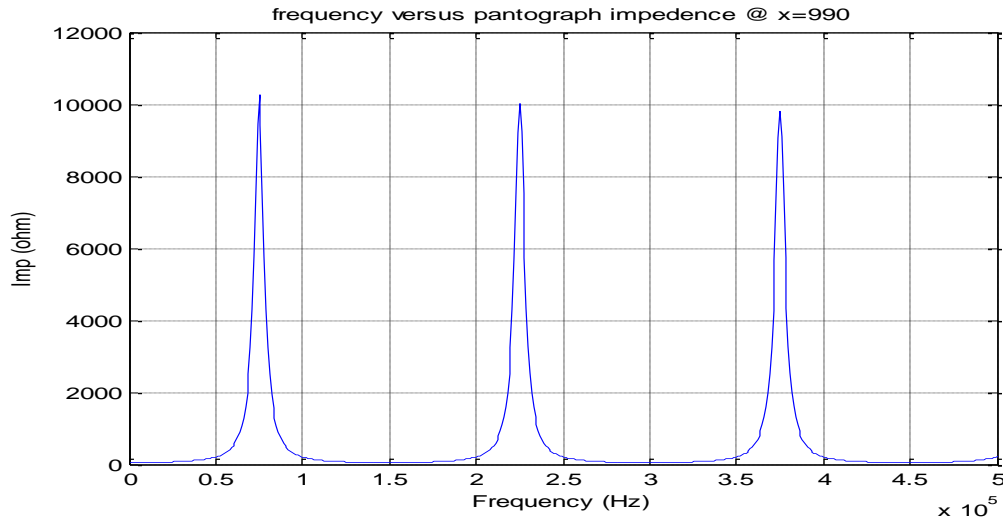


Fig 27: frequency Vs pantograph impedance

As it can be seen from the results found all plots show high impedance at the same carrier frequency. Only the magnitude is different for different train positions. This variation shows that the impedance value depends not only on the frequency but also on the position of the train.

From the above results, it is possible to select operating frequency with a minimum impedance value ranges. In other words, it is recommended to avoid frequency ranges with higher impedance. Because at these frequencies it is difficult to match impedance.

### **Voltage(rms) Vs distance**

According to *Reference [6]*, PLC for 750 VDC, a research conducted in Germany by Siemens Company, suggested the following after practical measurement is done for data transmission.

### **First Implementation of data transmission with OFDM [6]**

Based on the initial findings an OFDM-transmitter with QPSK modulation using the bandwidth  $B_s = 80 \dots 100$  kHz has been built which sends 512 bits of data within a block of 12.5 ms from one substation to the next over a distance of 2.5 km.

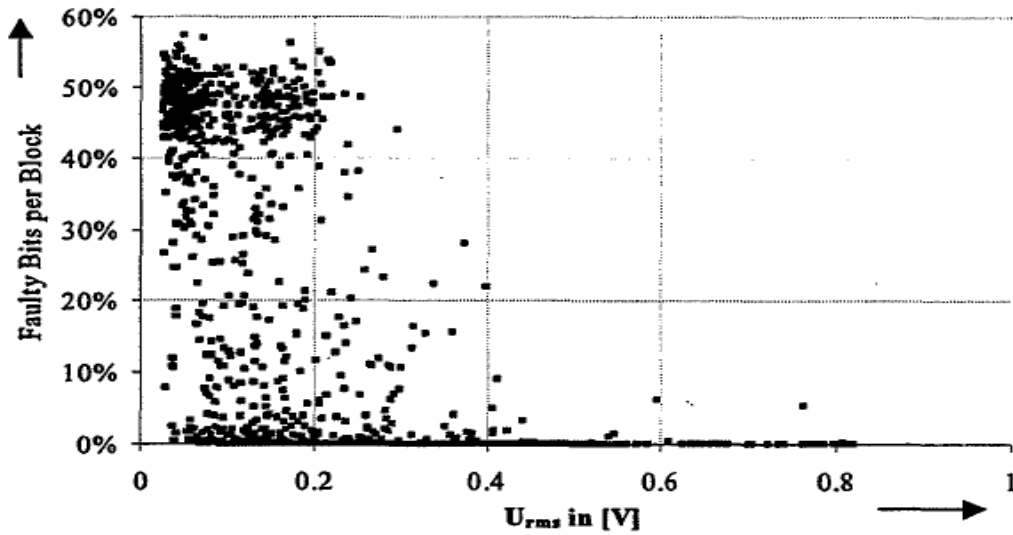


Fig 28: Faulty bits per block as a function of the voltage (RMS) of the received OFDM-frames[6]

During this measurement the transmission power was modified. Thus, the bit error rate could be determined at a varying signal power at the receiver (Refer the figure above).

From Fig 28, It can be deduced that the voltage level (RMS) of the received OFDM-frames has to exceed 0.5  $V_{rms}$  to demodulate data reliably (few flawed bits are correctable by applying a forward error correction method).[6]

Taking this result and used on the obtained transfer function in order to find the recommended voltage level at the receiver, the following plot is found with varying frequency.

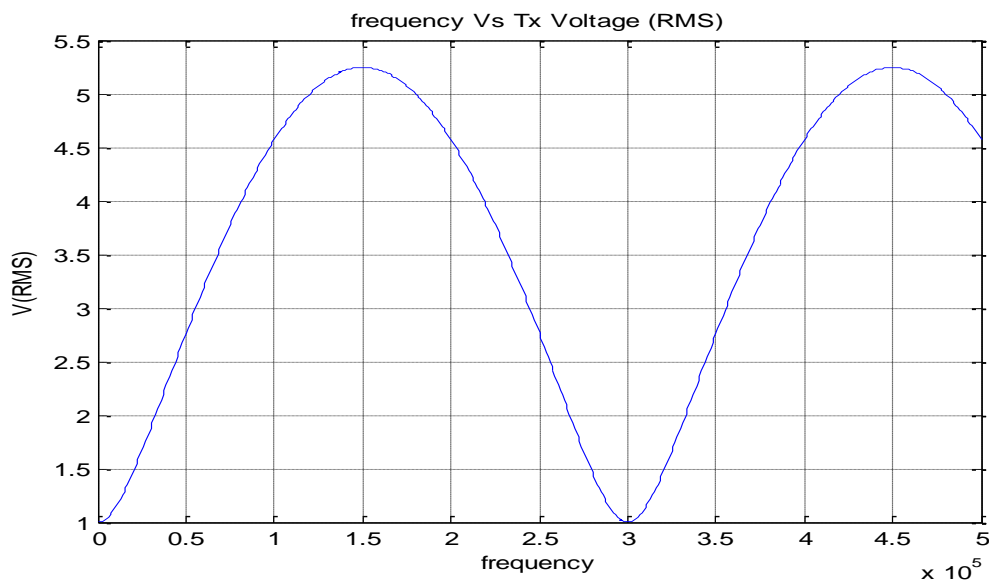


Fig 29: frequency Vs source voltage (rms)

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## PLC based real time train tracking system for A.A LRT

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As shown on the figure above, the voltage required to achieve 0.5 V rms at the receiver gets maximum at the minimum gain or maximum attenuation and vice versa. So to operate with a voltage level or a minimized power for the data transmission it is recommended to use a frequency range around a lower voltage level this in turn indicates the power required since both have direct proportional relations.

### **Length Vs transmitter V rms**

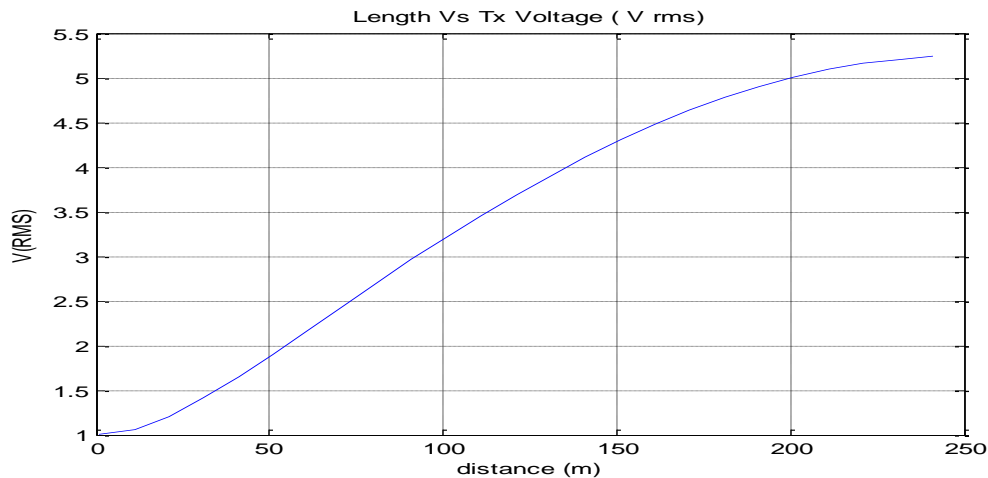


Fig 30: Distance Vs voltage(rms)

The plot shows that the voltage level raises as the distance increases. As discussed above it is recommended to implement repeaters between Tx and Rx.

### **4.2 Proteus simulation**

The purpose of the simulation is to verify the microcontroller function and to determine whether the program loaded on the microcontrollers is performing the intended action or not. To achieve this, circuit set up as shown on the Fig 31 below has done.

Proteus has a feature to integrate microcontroller to a circuit and accepts the hex file generated after compiling the code written. Then it is possible to check the functionality of the microcontroller contained circuit as a real. As it is seen on the picture the "onboard device" represents the module to be loaded on the train which serves as an interrogator and "station device" represents the module which replies as interrogated by the onboard unit. Both are loaded by their respective .hex file which is compiled and generated by studio 5 (Microcontroller compiler). The direct connection between the MCs represents the Power line. LCD is used to



# PLC based real time train tracking system for A.A LRT

To check the pattern accuracy, the program checks at 6 points ( three at high and 3 at low) with a spacing of 10  $\mu$ s Spacing. This increases the level of accuracy for the operation.

The delay on the transmission line to propagate the signal in real operation is simulated by setting the delay in the microcontroller code at the ground/station device. It expected to vary the distance information as we change the delay time in the program.

After the circuit has done and the programs (hex file) are loaded on the microcontroller the proteus program runs and the following has found on the oscilloscope.

The operation in brief is as follows. First the interrogator (onboard device) sends a defined pattern to the replier or station device. The station device checks the accuracy of the pattern and if accurate it sends back the pattern to the onboard device.

The accuracy check performance is measured by changing the interrogator pattern to different types whether the replier replies or not but doesn't reply for this scenarios. This shows that the accuracy check is functional.

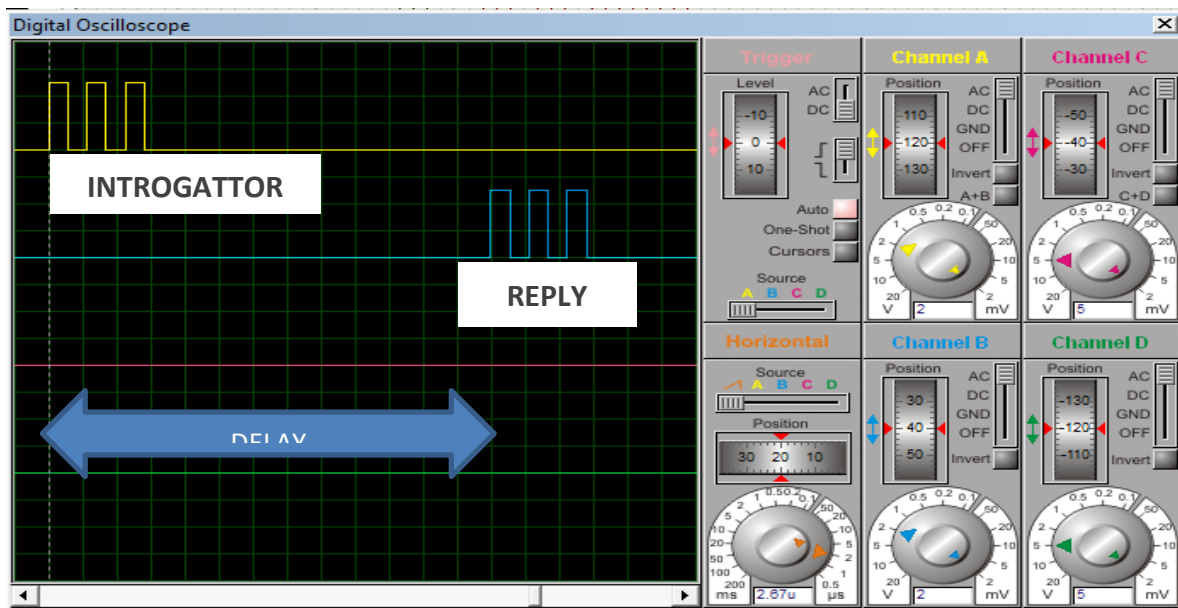


Fig 33: Simulation results

The interrogator starts timer while transmission and stops the timer while receiving the accurate patterns. The delay is used to process the distance with the following simple algorithm.

## PLC based real time train tracking system for A.A LRT

- Let say  $T_d$  is a time delay for the round trip which is obtained from the timer.
- To find the time for single trip  $T_s$ , we simply divide the time delay to 2.
- The signal propagation speed is assumed to be 50 % (0.5: Velocity factor) of the speed of light  $C$  which is  $300 \text{ m}/\mu\text{s}$  or  $300 \times 10^8 \text{ m/s}$ .
- Multiplication done as follows to find  $S$  and the result sent to LCD and virtual terminal.

$$S = T_s \times C$$

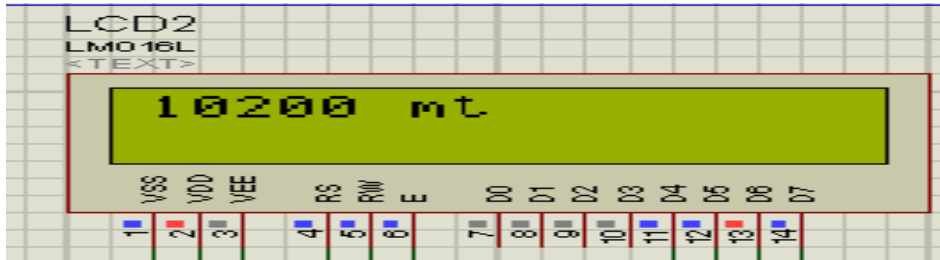


Fig 34: Distance shown on LCD

Regarding the virtual terminal, it needs a configuration on the microcontroller and also on the virtual terminal in proteus for proper communication. The configuration has done on both side as follows.

- Baud rate = 9600
- Data bit = 8
- Parity = none
- Stop bit = 1

Then it works well and displays as shown below.

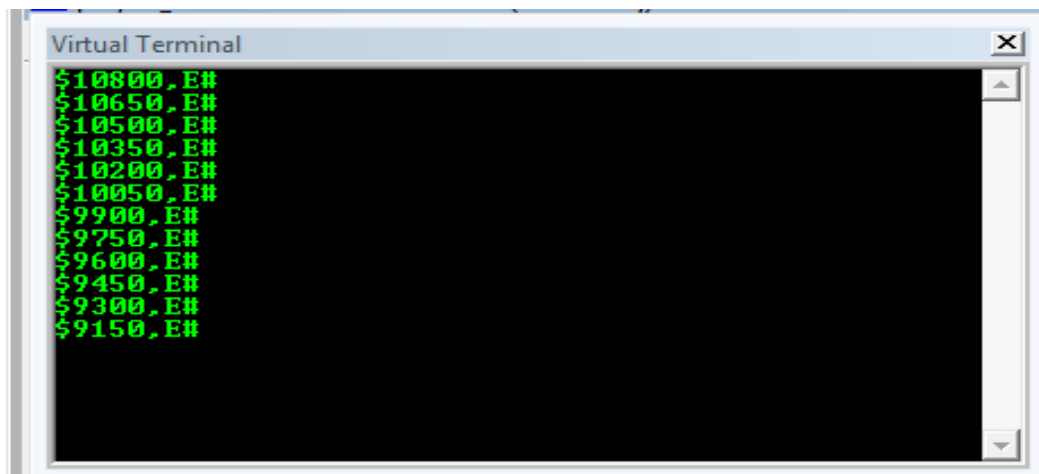


Fig 35: Virtual Terminal output

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From the simulation, It is observed that the codes are working codes which perform the intended operation. The pattern generated in a required manner and the accuracy check performs well as required. Also the mathematical manipulation code, the interfaced devices performed as required to perform.

## 4.3 Map Application [23]

The application is designed to convert the distance information to longitude/latitude information in order to suite for the display on the map (Bing map). The application window is shown below.

It is interfaced with onboard microcontroller circuit via a virtual com port kit in RS232 serial communication setup. It is primarily to be loaded on the computer onboard and interfaced with the detection system (onboard device). It has a setting feature to set for ports and path setting. The line from St. George to merkato is selected for demonstration purpose. A train is represented by a blue shape and expected to move along the line defined as a track on the map. While it is stopped from the circuit (train stop for real scenario) the movement on the map also should stop.

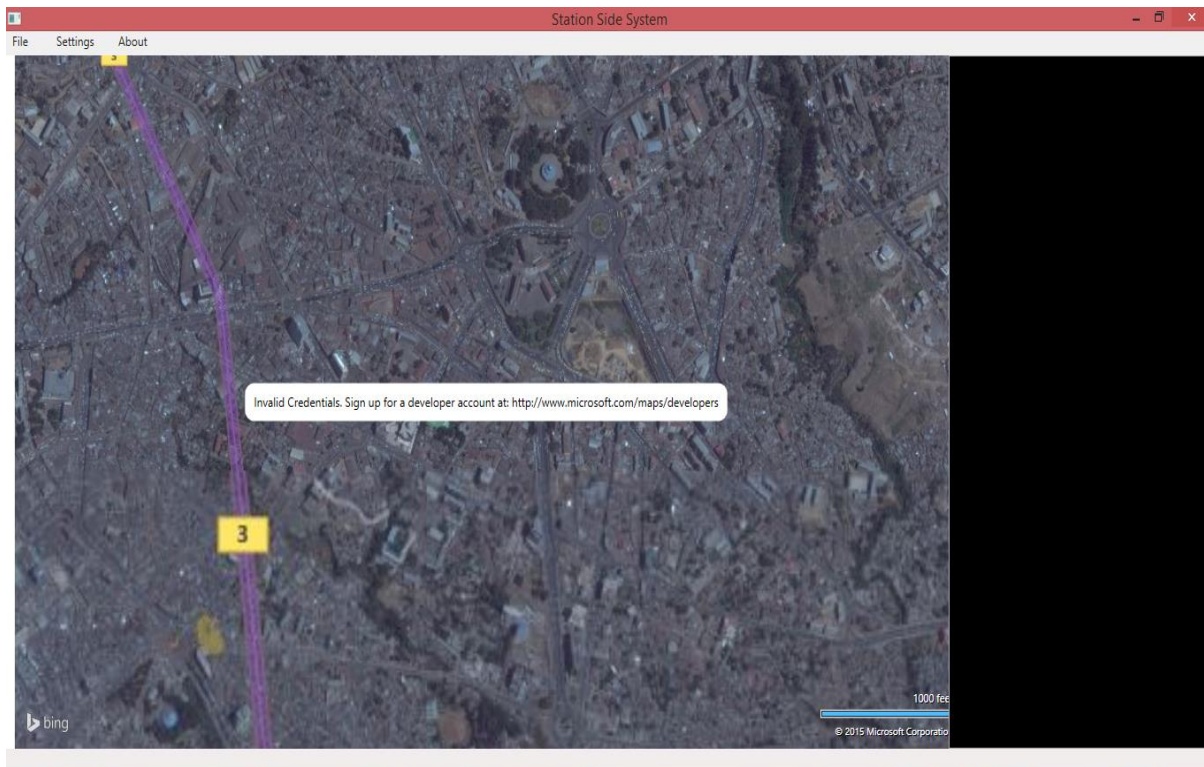


Fig 36: Application window

# PLC based real time train tracking system for A.A LRT

---

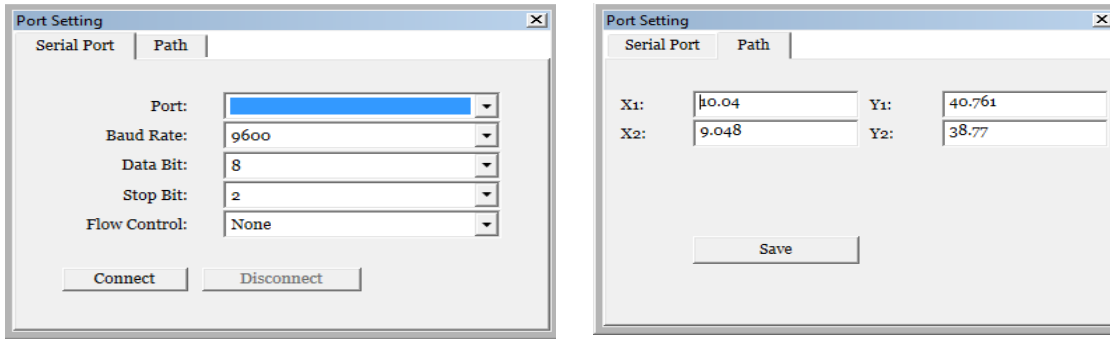


Fig 37: Application setup Windows a) serial port setup b) path setup

Finally the above integrated system checked to perform as system. The Virtual serial port kit interfaced the micro controller circuit with com2 port and application with com3 port. Then the connection is secured between them.

For simulation purpose the microcontroller is done to produce distance information continuously by iteration based on the proper distance information obtained by using the algorithm. As the distance information received by the application, the point (train) moves accordingly.

## Chapter five

### Conclusion and Recommendation

#### 5.1 Conclusion

The research is done to utilize the existing power line grid for train tracking application by using the concept power line communication. The research made analysis on the existing system and proposed hardware components for PLC functionality. Then modeling for the transmission line is done by using two port network method and the pantograph impedance is also modeled by the parallel impedance model. By using these models MATLAB simulation is done on the transmission line parameters like gain Vs frequency and Gain Vs length. Also simulation is done for pantograph impedance parameters like pantograph impedance Vs frequency, train position Vs impedance etc. In addition to the above mentioned simulations , Transmitter Vrms for the proper data retrieve at the receiver is simulated by taking the research result by reference [6]. According to the results obtained from simulation , PLC for train tracking is feasible by selecting operating parameters like frequency, section length ...etc for better performance.

Regarding the hardware, Atmega microcontroller selected and code written with C to generate pattern , check accuracy of the pattern and manipulate distance. Simulation is done by using proteus. From the result it is found that the microcontroller code written for both units (onboard and ground units) are functioning as required. The expected operations like generating pattern, patter accuracy checking and pattern reply investigated. Besides the algorithm coded on the MC manipulates the distance calculation for the simulated delay time correctly.

Map application which is developed by C# and uses Bing map is tested separately by simulation values. The pointer on the map moves well according to the data supplied. At last the microcontroller circuit integrated with the map by using visual serial port and tested.

In general, the research tried to deliver full package of PLC based real time train tracking system as a system. In order to study the feasibility in more real situation, site measurement and testing required. This will enable to proof the proposed system functions practically.

## **5.2 Future work**

1. EMC effect: As it is known the transmission line is long bare wire and is proposed to use in application for higher frequencies, it is obvious that it will act as an antenna. This will create interference on surrounding and also it is vulnerable for other interferences from the surrounding. In order to minimize the effect and to assure that the operation is in allowable range it needs further study regarding EMC.
2. It is recommended on different literatures that OFDM is ideal for power line communication technology. It is also proposed for this system from the advantage of OFDM combating noises since the traction power system a very notorious channel. It is recommended for future works that the efficiency of OFDM with different modulation types to be studied with simulation and tests for this application.
3. For the modeling of the channel there are points to be considered for close approximation for a real scenarios like Doppler Effect, the return path, earth conductivity and the moisture state of the earth. It is recommended to study on future studies in order to utilize the channel for other applications and train automations.

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## Appendix

### A. Matlab code

#### Transfer function

```
eps0=8.854e-12;
epsr=1;
mu=0.999*1.256e-6;
sigc=5.96e7;
sigd=8e-15;
%=====line parameters=====
rt=6.91e-3;
s=3;
%=====per unit line parameters = = = = = = = = =
f = 1000:1000:500000;
Rsurf=sqrt(pi.*f.*mu/sigc*sigd);
Rx=(2.*Rsurf/(2*pi*rt))*((s/(2*rt))/(sqrt(((s/(2*rt))^2)-1)));
Lf=(mu/pi)*(log((s/(2*rt))+sqrt(((s/(2*rt)).^2)-1)));
Cf=(pi*eps0*epsr)./(log((s/(2*rt))+sqrt(((s/(2*rt)).^2)-1)));
Gx=(pi.*sigd)./(log((s/(2*rt))+sqrt(((s/(2*rt)).^2)-1)));
Lx=Lf*j*2*pi.*f;
Cx=Cf*j*2*pi.*f;
length =1000;
Vl=0.5;
Zs = 70;
Zl=70;
%x=100;
%%
Zc = sqrt((Rx + Lx)./(Gx + Cx));
gc = sqrt((Rx + Lx).*(Gx + Cx));
A = cosh(gc.*length);
D =A;
B = Zc.*sinh(gc.*length);
C = (sinh(gc.*length))./Zc;
T=[A B;C D];
H = Zl./ (A.*Zl + B + C.*Zs.*Zl + D.*Zs);
Vs=Vl./H;
figure;
plot(f,(20*log10(abs(H))))
title('frequency Vs gain in DB');
xlabel('frequency(Hz)')
ylabel('Gain in db')
grid on
figure;
plot(f,abs(Vs))
title('frequency Vs Tx Voltage ( V rms)');
xlabel('frequency (Hz)')
ylabel('V(RMS)')
grid on
```

#### Pantograph Impedance

```
eps0=8.854e-12;
epsr=1;
mu=0.999*1.256e-6;
sigc=5.96e7;
sigd=8e-15;
%=====line parameters=====
rt=6.91e-3;
s=3;
%=====per unit line parameters = = = = = = = = =
f =1000:1000:500000; %300000;
Rsurf=sqrt(pi.*f.*mu/(sigc));
Rx=(2.*Rsurf/(2*pi*rt))*((s/(2*rt))/(sqrt(((s/(2*rt))^2)-1)));
Lf=(mu/pi)*(log((s/(2*rt))+sqrt(((s/(2*rt)).^2)-1)));
Cf=(pi*eps0*epsr)./(log((s/(2*rt))+sqrt(((s/(2*rt)).^2)-1)));
Gx=(pi.*sigd)./(log((s/(2*rt))+sqrt(((s/(2*rt)).^2)-1)));
Lx=Lf*j*2*pi.*f;
```

# PLC based real time train tracking system for A.A LRT

---

```
Cx=Cf*j*2*pi.*f;
length = 1000;
Zs = 50;
x= 990;          %variable distance
%%
Zc = sqrt((Rx + Lx)./(Gx + Cx));
gc = sqrt((Rx + Lx).*(Gx + Cx));
A = cosh(gc.*length);
D =A;
B = Zc.*sinh(gc.*length);
C = sinh(gc.*length)./Zc;
Zl=Zc.*(Zs*cosh(gc.*x)+Zc.*sinh(gc.*x))./(Zc.*cosh(gc.*x)+Zs*sinh(gc.*x));
Zr=Zc.*(cosh(gc.*(length-x))./sinh(gc.*(length-x)));
Zp=(Zl.*Zr)./(Zl+Zr);
figure;
plot(f,Zp)
grid on
title('frequency versus pantograph impedance @ x=990')
xlabel('Frequency (Hz)')
ylabel('Imp (ohm)')
```

## MicroController code (AVR studio 5)

### Onboard Device code

```
#include <avr/io.h>
#include <util/delay.h>
#include "lcd.h"
#define F_CPU 8000000 //the CPU is running at 8MHZ
uint32_t number;
int n;
int *numberArray[];
void USARTInit(uint16_t ubrr_value)
{
    //Set Baud rate
    UBRRL =(uint8_t) ubrr_value;
    UBRRH = (uint8_t)(ubrr_value>>8);
    /*Set Frame Format
    >> Asynchronous mode
    >> No Parity
    >> 1 StopBit
    >> char size 8
    */
    UCSRC=(1<<URSEL)|(3<<UCSZ0);
    //Enable transmitter
    UCSRB=(1<<TXEN);
}

void usart_nbr(int *s) {

    // loop through entire string

    while (*s) {
        usart_putchar(*s);
        s++;
    }
}

void usart_char(char *s) {

    // loop through entire string

    while (*s) {
        usart_putchar(*s);
        s++;
    }
}

void pulse() //interrogation pulse
{
```

# PLC based real time train tracking system for A.A LRT

---

```
    TCNT1=0x00;
    PORTA |= (1 << PA6);           //set PA6 on logic value 1
    _delay_us(10);                 //we wait for 10 micro second
    PORTA &= ~ (1 << PA6 );
    _delay_us(10);
    PORTA |= (1 << PA6);
    _delay_us(10);
    PORTA &= ~ (1 << PA6 );
    _delay_us(10);
    PORTA |= (1 << PA6);
    _delay_us(10);
    PORTA &= ~ (1 << PA6 );
    _delay_us(10);
}
void Wait()
{
    uint8_t i;
    for(i=0;i<10;i++)
        _delay_loop_2(0);
}
uint32_t get_time()
{
    uint32_t i, result;
    for(i=0;i<600000;i++)
    {
        if (bit_is_set(PIND,2)) break;
        else
            continue;
    }
    if (i>=600000) result=0;
    result=TCNT1;
    TCCR1B=0x00;
    // PORTA &= ~ (1 << PA4 );
    return (result>>1);
}

int * toArray(uint32_t number)           // converts Ascii code to decimal
{
    int n = log10(number) + 1;
    int i;
    int *numberArray = calloc(n, sizeof(int));
    for ( i =n-1; i>=0;i--, number /= 10 )
    {
        numberArray[i] = number % 10;
        numberArray[i] = numberArray[i]+48;
    }
    return numberArray;
}
void System_initial()
{
    DDRD=0x00;
    DDRA |= ( 1 << PA6 ); //set PA6 as output
    DDRA |= ( 1 << PA5 );
    DDRA |= ( 1 << PA4 );
    DDRD &= ~(1 << PD2);           // portD pin 2 as input
    DDRA &= ~(1 << PA0);
    LCDInit(LS_NONE);
    USARTInit(51);
    //TCCR1A=0x00;
    //TCCR1B=(1<<CS10);
    TCCR1A=0x00;                   // timer set up
    TCCR1B=(1<<CS10);             //time start
}

int main()                           //this is the main function that is being executed when the program
starts
{
```

# PLC based real time train tracking system for A.A LRT

---

```
uint32_t i,t,temp,v,d,w;
System_initial();
LCDClear();
LCDWriteString("PLC Based train");
LCDWriteStringXY(0,1,"tracking system");
Wait();
Wait();
Wait();
// Wait();
LCDClear();
LCDWriteString("AAIT/ERC");
LCDWriteStringXY(0,1,"Solomon Firew");
Wait();
Wait();
LCDClear();
pulse(); //interrogation pulse sent
v=get_time(); //routine to find the delay

while (temp>=0) //iterates for simulation
{
    LCDWriteIntXY(0,0,v,3);
    LCDWriteString(" ticks");
    t=v/2;
    temp=t*150;
    LCDClear();
    LCDWriteIntXY(0,0,temp,5);
    LCDWriteString(" mt");
    Wait();
    int *nn = toArray(temp);
    usart_char("$");
    usart_nbr(nn);
    usart_char(",");
    usart_char("E");
    usart_char("# \n\r");
    v=v-2;
    if (temp<1000) break;
    else continue;
}
}
```

## Ground /station device code

```
/*
 * Ground_station_code.c
 *
 * Created: 1/31/2015 8:05:45 AM
 * Author: Solomon Firew
 */

#include <avr/io.h>
#include <util/delay.h>
#define F_CPU 8000000 //the CPU is running at 8MHZ
uint16_t p;
int j;
void pulse()
{
    PORTA |= (1 << PA6); //set PA6 on logic value 1
    _delay_us(10); //we wait for 10 micro second
    PORTA &= ~ (1 << PA6 ); //set PA6 on logic value 0
    _delay_us(10);
    PORTA |= (1 << PA6);
    _delay_us(10);
    PORTA &= ~ (1 << PA6 );
    _delay_us(10);
    PORTA |= (1 << PA6);
    _delay_us(10);
    PORTA &= ~ (1 << PA6 );
    _delay_us(10);
}
```

# PLC based real time train tracking system for A.A LRT

---

```
void check()
{
    if (bit_is_set(PIND,2))          //(PIND & (1<<PD2))
    {
        _delay_us(11);
        if (bit_is_clear(PIND,2))
        {
            _delay_us(11);
            if (bit_is_set(PIND,2))
            {
                _delay_us(11);
                if (bit_is_clear(PIND,2))
                {
                    _delay_us(11);
                    if (bit_is_set(PIND,2))
                    {
                        _delay_us(11);
                        if (bit_is_clear(PIND,2))
                        {
                            _delay_us(200);
                            pulse();
                        }
                    }
                }
            }
        }
    }
}

int main()                          //this is the main function that is being executed when the program starts
{
    DDRD=0x00;
    DDRA |= ( 1 << PA6 );           //set PA6 as output
    DDRA |= ( 1 << PA5 );           //set PA5 as output
    DDRD &= ~(1 << PD2);           // portD pin 2 as input
    DDRA &= ~(1 << PA1);           // portA pin 1 as input
    while(1)
    {
        check();
    }
}
```

## C# Code for map Application

### Main window application

```
using System;
using System.Windows;
using System.IO.Ports;
using System.Windows.Documents;
using System.Windows.Threading;
using MapInterface.Helpers;
using Microsoft.Maps.MapControl.WPF;
using System.Device.Location;
namespace MapInterface
{
    /// <summary>
    /// Interaction logic for MainWindow.xaml
    /// </summary>
    public partial class MainWindow
    {
        private PortSetting _portSettingWindow;
        private readonly MapHelper _mapHelper;
    }
}
```

# PLC based real time train tracking system for A.A LRT

---

```
private readonly FileHelper _fileHelper = new FileHelper();

private readonly FlowDocument _mcFlowDoc = new FlowDocument();
private readonly Paragraph _paragraph = new Paragraph();
//Serial
private readonly SerialPort _serialPort = new SerialPort();

//Line
private readonly LocationCollection _pathCoordinates;
private double _totalDistance;
private double _deltaX, _deltaY;

public MainWindow()
{
    InitializeComponent();

    MyMap.ZoomLevel = 15.0;
    _portSettingWindow = new PortSetting(this);
    _mapHelper = new MapHelper(MyMap);

    _pathCoordinates = _fileHelper.GetPathCoordinates();

    var centroid = GetCentroid(_pathCoordinates);
    MyMap.Center = centroid ?? new Location(9.0408, 38.7628);
    _mapHelper.PlotPathInfo(_pathCoordinates);
    _totalDistance = GetDistance(_pathCoordinates[0], _pathCoordinates[1]);
    _deltaX = Math.Abs(_pathCoordinates[0].Latitude - _pathCoordinates[1].Latitude);
    _deltaY = Math.Abs(_pathCoordinates[0].Longitude - _pathCoordinates[1].Longitude);
}
#region Recieving

private delegate void UpdateUiTextDelegate(string text);
private void Receive(object sender, SerialDataReceivedEventArgs e)
{
    // Collecting the characters received to our 'buffer' (string).
    string receivedData = _serialPort.ReadLine();
    Dispatcher.Invoke(DispatcherPriority.Send, new UpdateUiTextDelegate(WriteData), receivedData);
}
private void WriteData(string text)
{
    TxtStatus.Text = string.Format("Data Received: {0}", text);
    // Assign the value of the recieved_data to the RichTextBox.
    _paragraph.Inlines.Add(text);
    _mcFlowDoc.Blocks.Add(_paragraph);
    TxtConsole.Document = _mcFlowDoc;
    text = text.Replace("\r", string.Empty).TrimEnd();
    if (text.StartsWith("$") && text.EndsWith("#"))
    {
        var distanceInfo = text.TrimEnd('#').TrimStart('$').Split(',');
        var location = GetCurrentLocation(Convert.ToDouble(distanceInfo[0]),
Convert.ToChar(distanceInfo[1]));
        _mapHelper.RemoveDots();
        _mapHelper.PlotSingleDot(location);
    }
}
#endregion

#region Menus
private void PortSettingMenu_Click(object sender, RoutedEventArgs e)
{
    _portSettingWindow = new PortSetting(this);
    _portSettingWindow.ShowDialog();
}

private void ExitMenu_Click(object sender, RoutedEventArgs e)
{

```

# PLC based real time train tracking system for A.A LRT

---

```
        this.Close();
    }

    private void AboutMenu_Click(object sender, RoutedEventArgs e)
    {
        throw new NotImplementedException();
    }

    private void Window_Closing(object sender, System.ComponentModel.CancelEventArgs e)
    {
        _portSettingWindow.Close();
        _serialPort.Close();
        Properties.Settings.Default.IsPortOpened = false;
    }
    #endregion

    public void UpdatePortStatus()
    {
        if (Properties.Settings.Default.IsPortOpened)
        {
            //Sets up serial port
            _serialPort.PortName = Properties.Settings.Default.PortName;
            _serialPort.BaudRate = Properties.Settings.Default.BaudRate;
            _serialPort.Handshake = Handshake.None;
            _serialPort.Parity = Parity.None;
            _serialPort.DataBits = Properties.Settings.Default.DataBits;
            _serialPort.StopBits = StopBits.Two;
            _serialPort.ReadTimeout = 200;
            _serialPort.WriteTimeout = 50;
            _serialPort.Open();
            TxtStatus.Text = string.Format("Serial port {0} is opened.",
Properties.Settings.Default.PortName);

            //Sets button State and Creates function call on data recieved
            _serialPort.DataReceived += Receive;

        }
        else
        {
            try // just in case serial port is not open could also be acheved using if(serial.IsOpen)
            {
                _serialPort.Close();
                TxtStatus.Text = string.Format("Serial port {0} is closed.",
Properties.Settings.Default.PortName);
            }
            catch (Exception e)
            {
                TxtStatus.Text = e.Message;
                MessageBox.Show(e.Message, "Error");
            }
        }
    }

    private Location GetCentroid(LocationCollection collection)
    {
        return new Location()
        {
            Latitude = (collection[0].Latitude + collection[1].Latitude) / 2,
            Longitude = (collection[0].Longitude + collection[1].Longitude) / 2
        };
    }

    private Location GetCurrentLocation(double distance, Char direction)
    {
        var startingPoint = direction == 'E' ? _pathCoordinates[0] : _pathCoordinates[1];
        var lat = startingPoint.Latitude + ((distance * _deltaX) / _totalDistance);
    }
}
```

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```
        var lon = startingPoint.Longitude + ((distance * _deltaY) / _totalDistance);
        return new Location(lat, lon);
    }

    double GetDistance(Location startLocation, Location endLocation)
    {
        var p1 = new GeoCoordinate(startLocation.Latitude, startLocation.Longitude);
        var p2 = new GeoCoordinate(endLocation.Latitude, endLocation.Longitude);
        return p1.GetDistanceTo(p2);
    }
}
}
```

## Port setting

```
using System;
using System.Globalization;
using System.Windows;
using System.Windows.Controls;
using MapInterface.Helpers;
using MapInterface.Properties;

namespace MapInterface
{
    /// <summary>
    /// Interaction logic for PortSetting.xaml
    /// </summary>
    public partial class PortSetting : Window
    {
        private readonly MainWindow _mainWindow;
        private FileHelper _fileHelper = new FileHelper();
        public PortSetting()
        {
            InitializeComponent();
        }

        public PortSetting(MainWindow mainWindow)
        {
            InitializeComponent();
            _mainWindow = mainWindow;

            this.ComboCOMPort.SelectedItem = Properties.Settings.Default.PortName;
            this.ComboBaudRate.Text =
Properties.Settings.Default.BaudRate.ToString(CultureInfo.InvariantCulture);
            this.ComboDataBit.Text =
Properties.Settings.Default.DataBits.ToString(CultureInfo.InvariantCulture);
            this.ComboFlowControl.Text = Properties.Settings.Default.FlowControl;
            this.ComboStopBit.Text =
Properties.Settings.Default.StopBits.ToString(CultureInfo.InvariantCulture);

            var pathCoordinates = _fileHelper.GetPathCoordinates();
            this.TxtX1.Text = Convert.ToString(pathCoordinates[0].Latitude);
            this.TxtY1.Text = Convert.ToString(pathCoordinates[0].Longitude);
            this.TxtX2.Text = Convert.ToString(pathCoordinates[1].Latitude);
            this.TxtY2.Text = Convert.ToString(pathCoordinates[1].Longitude);
            ToggleButtonVisibility();
        }

        private void BtnDisconnect_Click(object sender, RoutedEventArgs e)
        {
            Properties.Settings.Default.IsPortOpened = false;
            ToggleButtonVisibility();
            _mainWindow.UpdatePortStatus();
        }
    }
}
```

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```
private void BtnConnect_Click(object sender, RoutedEventArgs e)
{
    Properties.Settings.Default.IsPortOpened = true;
    ToggleButtonVisibility();
    _mainWindow.UpdatePortStatus();
}

private void ToggleButtonVisibility()
{
    this.BtnConnect.IsEnabled = !Properties.Settings.Default.IsPortOpened;
    this.BtnDisconnect.IsEnabled = Properties.Settings.Default.IsPortOpened;
}

private void ComboCOMPort_SelectionChanged(object sender,
System.Windows.Controls.SelectionChangedEventArgs e)
{
    Properties.Settings.Default.PortName =
((ComboBoxItem)ComboCOMPort.SelectedItem).Content.ToString();
}

private void ComboBaudRate_SelectionChanged(object sender,
System.Windows.Controls.SelectionChangedEventArgs e)
{
    if (this.ComboBaudRate.SelectedItem != null)
    {
        Properties.Settings.Default.BaudRate =
Convert.ToInt32(((ComboBoxItem)ComboBaudRate.SelectedItem).Content.ToString());
    }
}

private void BtnSave_Click(object sender, RoutedEventArgs e)
{
    string text = string.Format("{0},{1}{2}{3},{4}",
        this.TxtX1.Text,
        this.TxtY1.Text, Environment.NewLine,
        this.TxtX2.Text,
        this.TxtY2.Text);
    _fileHelper.WriteToFile(text);
}
}
```

## **Map Helper**

```
using System.Collections.Generic;
using System.Windows;
using System.Windows.Controls;
using System.Windows.Media;
using System.Windows.Shapes;
using Microsoft.Maps.MapControl.WPF;

namespace MapInterface.Helpers
{
    public class MapHelper
    {
        private readonly Map _map;

        public MapHelper(Map map)
        {
            _map = map;
        }

        public void PlotSingleDot(Location location)
        {
            var dot = new Ellipse { Fill = new SolidColorBrush(Colors.Yellow) };
            const double radius = 6.0;
            dot.Width = radius * 2;
            dot.Height = radius * 2;
            var tt = new ToolTip { Content = "Location = " + location };
        }
    }
}
```

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---

```
dot.ToolTip = tt;
Point p0 = _map.LocationToViewportPoint(location);
var p1 = new Point(p0.X - radius, p0.Y - radius);
location = _map.ViewportPointToLocation(p1);
MapLayer.SetPosition(dot, location);
_map.Children.Add(dot);
}

public void PlotDots(LocationCollection collection)
{
    foreach (var location in collection)
    {
        PlotSingleDot(location);
    }
}

public void RemoveDots()
{
    _map.Children.RemoveRange(3, _map.Children.Count);
}

public void PlotPathInfo(LocationCollection pathCollection)
{
    var pinList = new List<Pushpin>();

    for (int i = 0; i < pathCollection.Count; i++)
    {
        var pins = new Pushpin {Location = new Location(pathCollection[i])};
        pinList.Add(pins);
        _map.Children.Add(pinList[i]);
    }

    var polyLine = new MapPolyline
    {
        Stroke = Brushes.LightBlue,
        StrokeThickness = 5,
        Locations = pathCollection,
        Opacity = 0.7
    };
    _map.Children.Add(polyLine);
}
}
}
```

## **File helper**

```
using System;
using System.IO;
using Microsoft.Maps.MapControl.WPF;

namespace MapInterface.Helpers
{
    public class FileHelper
    {
        const string File = "PATHINFO.txt";

        public string[] ReadFile(string file)
        {
            using (var sr = new StreamReader(file))
            {
                string wholeDoc = sr.ReadToEnd();
                string[] lines = wholeDoc.Split('\n');

                return lines;
            }
        }
    }
}
```

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---

```
public void WriteToFile(string text)
{
    using (var outfile = new StreamWriter(File))
    {
        outfile.Write(text);
    }
}

public LocationCollection GetPathCoordinates()
{
    var collection = new LocationCollection();

    var pathInfo = ReadFile(File);
    foreach (var p in pathInfo)
    {
        var splitted = p.Split(',');
        collection.Add(new Location(Convert.ToDouble(splitted[0]), Convert.ToDouble(splitted[1])));
    }
    return collection;
}
}
```