Automated Microwave Antenna Alignment of Base Transceiver Station

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Examiner : Jorge Sollis
Automated Microwave Antenna Alignment Of Base Transceiver Station

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This thesis is submitted in partial fulfillment of requirements for the Master’s Degree in Electrical Engineering. All material in this thesis which is not done by us has been identified and no material is included for which a degree has previously been conferred.

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ABSTRACT

This master’s thesis is intended for the solution of Microwave (MW) link alignment which has several applications in modern communication systems. MW communication is used for point to point links with small wavelength and simultaneously compact antenna dimensions. Assuring the automated alignment of antennas provides a better communication between switching stations and allow its subscribers to communicate ceaselessly. In the first part of the work; effects of downtime on a network are discussed and at later stage a mechanism is investigated which will reduce the downtime. MW antenna used in communication systems is regularly affected by environmental factor and generally by wear and tear of mounts. These factors cause the precisely directed antennas to be perturbed from respective main lobes. Larger antennas with narrow main lobes require more sophisticated designing while smaller antennas have a broader main lobe. An automated antenna alignment that works without human intervention can decrease the down time and ensure a reliable communication between the near end and far end terminals of the Base Transceiver Station (BTS). The focus has been laid on a system that works autonomously and for that LabVIEW design and RCX Robonics Kit is used. Results are presented to indicate antenna alignment in automatically synchronized manner.
ACKNOWLEDGEMENTS

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Contents

1. Introduction .............................................................................................................................. 1
   1.1 Statement of the Problem ............................................................................................ 1
   1.2 Significance of the Study ............................................................................................. 3
   1.3 Proposed Solution ......................................................................................................... 4
   1.4 Thesis Outline ................................................................................................................ 6

2. Background and Review of Literature ................................................................................ 7
   2.1 Microwave (MW) Link ..................................................................................................... 7
   2.2 Emergence of MW Communication ................................................................................ 7
   2.3 Fundamental Parameters in MW Link ............................................................................. 8
      2.3.1 Line of Sight (LOS) ..................................................................................................... 8
      2.5.2 Free Space Loss ........................................................................................................... 9
      2.5.3 Fresnel Zone ................................................................................................................ 9

3. Antenna Radiation Patterns and Analysis ....................................................................... 10
   3.1 Interference Cancellation ............................................................................................... 10
   3.2 Parameter Estimation of Antennas ................................................................................ 12
      3.2.1 Effective Height of the Antenna .............................................................................. 12
      3.2.2 Inductance (L) of the Loop Antenna .................................................................... 13
      3.2.3 Radiation Resistance ($R_{res}$) of the Antenna ....................................................... 13

4. Automation Control ............................................................................................................. 14
   4.1 Signal Reception and LabVIEW Design ........................................................................ 15
   4.2 Motor Control for Alignment ...................................................................................... 19
   4.3 Possible Challenge for Practical Application .............................................................. 25
      4.3.1 Motor Selection According to Antenna Dimension ................................................ 25
      4.3.2 Control Signal Transfer and Delay ........................................................................ 26

5. Results & Analysis ............................................................................................................... 27
   5.1 Response Time in LabVIEW ...................................................................................... 27
   5.2 Motor Control Using RCX .......................................................................................... 28
5.3 Improvements and Future Works................................................................. 29
6. Conclusion........................................................................................................ 30
References ............................................................................................................ 31
Appendix A: MW Link Budget.............................................................................. 34
Appendix B: Programming for RCX................................................................. 35
## List of Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BTS</td>
<td>Base Transceiver Station</td>
</tr>
<tr>
<td>DAQ</td>
<td>Data Acquisition Card</td>
</tr>
<tr>
<td>DMD</td>
<td>Decision Making Device</td>
</tr>
<tr>
<td>DOF</td>
<td>Degree of Freedom</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
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<tr>
<td>GUI</td>
<td>Graphical User Interface</td>
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<tr>
<td>HBER</td>
<td>High Bit Error Rate</td>
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<tr>
<td>ISI</td>
<td>Inter Symbol Interference</td>
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<tr>
<td>M2M</td>
<td>Man to Man - GSM</td>
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<tr>
<td></td>
<td>Man to Machine - 3G</td>
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<tr>
<td></td>
<td>Machine to Machine - LTE and 4G</td>
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<tr>
<td>NEC</td>
<td>Nippon Electric Company</td>
</tr>
<tr>
<td>NSN</td>
<td>Nokia Siemens Networks</td>
</tr>
<tr>
<td>OMC</td>
<td>Operation and Maintenance Center</td>
</tr>
<tr>
<td>OSS</td>
<td>Operation Support System</td>
</tr>
<tr>
<td>PID</td>
<td>Proportional-Integral-Derivative</td>
</tr>
<tr>
<td>QoS</td>
<td>Quality of Service</td>
</tr>
<tr>
<td>RBS</td>
<td>Radio Base Station</td>
</tr>
<tr>
<td>RSL</td>
<td>Received Signal Level</td>
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<tr>
<td>SNR</td>
<td>Signal to Noise Ratio</td>
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<td>SIR</td>
<td>Signal to Interference Ratio</td>
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1. Introduction

Establishing a MW link and operating it for optimal performance has been pivotal in the present day world because of its enormous industrial applications. Keeping this in mind and to overcome the challenges posed by industrial application, an automated antenna alignment that works without human intervention has been the focus of research.

Concept of wireless communication has been originated by Alexander Graham Bell in 1880 when he did experimentations on modulated light and parabolic reflectors. Guglielmo Marconi made significant advances in origination of a telephonic system that works on electromagnetic wave pattern by investigating lower frequencies usually in the range of Hertz. This was furthered by him in 1895 by making a transmission of three dot Morse code possible for the letter ‘S’ over a distance of three kilometers [1, 2]. Advancements in transmission principles and network architecture have been very significant in the last couple of decades which has seen emergence of M2M networks. Conventional Man-to-Man network of GSM was improved to higher data rates by means of Man-to-Machine Networks and then finally Machine-to-Machine Networks that include 4G and LTE systems [3, 4, 5]. This has been possible gradually by increasing the data rates over the network and focusing on Quality of Service (QoS). Another big difference that has played its role has been transceivers; major industrial vendors such as Ericsson, NSN, NEC etc have channeled their R&D towards making telecommunication systems and transceivers as efficient as possible while giving maximum range and keeping the cost of system as low as possible.

Even with lot of research focused on telecommunications, there is still room for improvements and new innovations. This has prompted the need to use of Automation Control in MW alignment and other wireless systems.

1.1 Statement of the Problem

Antenna Alignment is the fundamental principle for all MW and generally wireless links and simultaneously a lot of research and development is in place to further the technology. The process is very sophisticated in nature due the usage of numerous resources ranging from test equipments and processing units to Antenna hardware and ground technicians to engineers [6, 7]. In the existing technology, a collaborative effort that consists of tower technicians as well as Base Station engineers is required to ensure MW alignment. The process of link alignment is quite dangerous and hazardous as it is done at the antenna often as high as 90 meters from the ground.
Tower crews also known as Riggers are responsible for establishing MW alignment on both ends of the transceivers by means of test equipments that take into account the Received Signal Level (RSL). A signal is generated from the transmitting end through In-door unit; here the transmitting power is set before converging the signal to IF physical channel. IF channel serves as the interface between In-door units placed on the ground and Out-door unit which is typically an Antenna or a Radio Device. The signal is then transmitted through the RF source over the free space link. On the far end, a transceiver receives the signal intended for it and it is of the same frequency range that was initially set at the transmitting end. This sets up the basic interconnection between the two stations. The setup for link establishment is shown in the Figure 1.1. The RSL at the receiver end can be measured manually by the rigger at the antenna by means of Digital Multi-Meter (DMM) or through the software package installed on the In-door unit. A link of 38GHz is depicted in figure with low end frequency of 38.1115GHz and high end frequency of 39.3715GHz.

Existing mannerism in which MW alignment is carried out is quite cumbersome. There are number of steps that have to be followed to ensure a proper link alignment. It has to be made sure that both near end and far end terminals have identical polarization and have same frequency band. The alignment is generally done on each end through continuous communication but it cannot be done simultaneously at similar instant of time. If a rigger starts on Near End Antenna; the antenna crew at Far End will hold and vice versa. Moreover on the near end; 2D approach is required in which firstly Azimuth (Horizontal Axis) is adjusted until the best RSL is achieved before starting Vertical Tilt and later the far end technician is informed to do the same process. The whole process is repeated couple of time to get the RSL as high as possible [6, 8].

![Figure 1.1 Link parameters to be adjusted for communication](image-url)
The quality of signal which is received depends upon the optimal direction of the two stations. If the two antennas are directional and are pointed optimally towards each other, highest signal concentration will be received through the main lobe and there will be minimal attenuation and degradation [1, 6]. Figure 1.2 depicts the scenario where MW link is optimally aligned and the main lobes are facing directly towards the intended antenna. On the other hand, if the main lobe is deviated from the receiver end, the link will be intermittent and have High Bit Error Rate (HBER).

![Figure 1.2 MW link between Near & Far End Antenna with main lobe and side lobes](image)

**1.2 Significance of the Study**

MW antenna has played a vital role in Telecommunication Industry and Link Alignment is carried out to ensure good Receive Signal Level (RSL). In the various surveys conducted, it can be deduced that the link alignment is not one off job to complete; in fact, it is critical in roll-out and implementation phase as well as Operation and Maintenance. Even with good quality of mounts, it is noticed that there is a high possibility for antenna to lose its optimal direction and hence misdirect the main beam. There could be multiple reasons behind the misalignment such as environmental conditions, wear and tear of mounts and obstruction in the path of two stations. Figure 1.3 shows a link which has low RSL and needs alignment to ensure a ceaseless communication. This paper deals with the rectification of this problem and also to investigate on methods and techniques by which interference from other nodes can be negated or reduced [2, 9].

![Figure 1.3 A MW link with low RSL and in need of Alignment](image)
The process that is involved in MW link alignment demands very sophisticated staff and test equipment. In addition to high number of man hours that are required to perform link alignment; arranging and mobilizing the equipment is also a concern. Operation and Maintenance Center (OMC) is basically a backbone of the network. Signaling is used to identify the performance of links and reports problematic links to the OMC; in short RSL for all links in the network is visible through IP based setup of Operation Support Systems (OSS) and particularly in OMC. Downtime is referred to the period in which Base Transceiver Station (BTS) is not operational and it is often because of the problematic MW and wireless link. If the RSL is beyond the acceptable range; there are huge losses that are incurred because active link which carries traffic is disrupted. According to a study in Meta Group [10] in 2008, it was reported that the cost of downtime in Telecom Industry is $2 million/hour.

Generally when the link is reported to be down, it takes 4 hours on average to reach and rectify the problem in city and 6 hours on average to fix in distant places. A solution which can reduce the downtime and ultimately reduce the financial and service losses is always desired and this has driven the research conducted on this project.

### 1.3 Proposed Solution

The main purpose of this thesis is to investigate on methods and techniques to improve MW link alignment that is being done conventionally. A system that can work on stand-alone basis and needs no human intervention has been researched. Another significant aspect that has to be considered is to recover link in Time Optimal Manner so that downtime is kept as low as possible. This research paper deals with Wireless principles and interference avoidance of MW links as well as automation control.

Antenna is to be perturbed so that it ensures best suited position for main lobe to be directed at the far end. A modeled solution is to be design and implemented, Figure 1.4 is shown to better explain the research proposal and overall processes involved. The objective is to design an automated MW alignment system in which a transceiver receives a certain RSL at Far End station. A closed loop system makes the basis of Logic for Microprocessor. Assuming that design parameters are set at -45dBm, so if the received RSL is in this range, it will consider the antennas to be in their appropriate directions else alignment will start.
Figure 1.4 Overview of MW alignment using Automation Control

Considering due to weather conditions or other factors affecting the alignment, Far End Antenna receives a lower RSL; in this case an automated system will realign the link until the desired RSL is achieved. This alignment will be on horizontal and vertical axis of the antenna. It is to be noted that antennas are only perturbed from their intended positions because of environmental conditions or wear and tear. Keeping this in mind, the pattern to be devised is such that the alignment should be done within certain arc e.g. ± 45 degree in vertical tilt from starting point and a similar pattern in azimuth. The whole idea is to get Signal to Noise Ratio (SNR) as high as possible by optimally directed antennas. Besides this, it is to be investigated that the interference is avoided and that Signal to Interference Ratio (SIR) is also high. A secondary antenna that is responsible for interference has a main lobe and side lobes as well. Interference can be greatly reduced by antenna positioning through automation such that the space between main lobe and side lobe of interference source is benefited from.
1.4 Thesis Outline

Chapter 2 The basic idea of Microwave link and how it works is discussed in this chapter. The reasons behind the emergence of ICT and its usefulness in modern day world are discussed. Fundamental parameters for link establishment are briefly described as well.

Chapter 3 Antenna radiation patterns and its orientation for different lobes are described. For the link establishment, the major part of the lobe and how it should be done are also elaborated. Side by side we have given the modeled loop antenna radiation analysis and method to avoid the interference between the links by making use of deep nulls.

Chapter 4 In this chapter we have elaborated the proposed solution of MW link alignment in automated way with a logical flow chart. This process is developed by LabVIEW design and can be translated to industrial applications. LEGO Mindstorms RCX is used for Prototyping purpose in this project since it provides a complete set of resources and programmable controllers to carry out desired activity.

Chapter 5 In this section we have portrayed the response time between the software and hardware standalone units and response time after integration. Limitations and future works are shown in the end.

Chapter 6 Summary of this thesis and the probable future advancement in this field are discussed here.
2. Background and Review of Literature

2.1 Microwave (MW) Link
Generally a microwave link means a beam of radio wave in microwave frequency range enabling a transmitter and receiver to communicate. Different forms of microwave link applications are available in modern communication system. Broadcasters use microwave links to send programs from the studio to the transmitter location, which might be miles away. Microwave link is the backbone in latest telecommunication system which makes our life easier. Wireless Internet service is another development where service provider can give facility of internet service without any cable. Most of the telecommunication companies communicate between their switching centers through this link although recently it is done by fiber optic cables as well. Many government and private organization use this technology to link up their corporate offices for easy and fast access to the main server.

One of the reasons for the adaptability of microwave links is because they are broadband; meaning they can transfer large amount of information at high speeds. Another important quality of microwave links is that they require no equipment or facilities between the two terminal points. Often a repeater station is installed if the clear LOS in not available to maintain the signal in required RSL level. Installing a microwave link is often faster and less costly than a wired connection. Finally, they can be used anywhere as long as the distance to be spanned is within the operating range of the equipment and there is clear path between the locations [11]. Microwave link is seldom interrupted by rain, fog, and snow; though in harsh weather conditions, it can be disrupted at some instants.

2.2 Emergence of MW Communication
With the 21st century, it can be said that the world has closer means. In this age we can talk, chat, meet, greet people and our friends from every part and corner of the world within a click. The click can be over the cell phone for having a talk or over the keyboard or mouse of a computer to have an online chat with our near and dear ones. It is possible only because of the technology called microwave communication. Internet usage in modern life is very essential job and with it even the remotest of areas are connected. Cell phone is the most dominating technology in terms of consumption and revenue and it is emerging day by day with due credit to MW communication. Security systems are also advancing with the help of MW link.
Satellite communication, data communication, bio-medical engineering and cellular networks are the main domains for MW communication. Due to following advantages microwave communication is emerging day by day [12, 13].

- Large bandwidth
- Line of sight propagation
- Antenna size reduction
- Can accommodate large number of channels
- Less Power requirement especially in case of repeaters
- Environmentally Stable

2.3 Fundamental Parameters in MW Link

2.3.1 Line of Sight (LOS)
For any point-to-point radio communication; the general setup requires Microwave antennas to be placed in a high position so that there are no obstacles in between. This direct link is usually referred as Line of Sight (LOS) [14]. It is very important to find out a visible path between sites before establishing those links. Now a day, LOS and other parameters are designed in special RF virtual instruments. Moreover only seeing a visible path does not always confirm that LOS will give a sufficient level of signal, it should satisfy other parameter such as the terrain for wave propagation. Figure 2.1 shows a Line of Sight (LOS) where one microwave antenna has a direct link to another antenna placed at far end.

Figure 2.1 A typical Line of Sight (LOS) of a MW link
2.5.2 Free Space Loss

When a signal is spread from an antenna, it gets weaker with the distance and this phenomenon is generally referred as Free Space Loss (FSL). The FSL calculations only look at the loss of the path only and do not contain any factors relating to the transmitter power, antenna gains or receiver sensitivity level. These factors are normally addressed when designing a link budget and are used within radio and wireless survey tools [2, 14]. A model of link budget is shown in Appendix A.

2.5.3 Fresnel Zone

When LOS is measured, it should be kept in mind that only a visible position of link does not confirm that link will provide enough RSL. The clearance area from one site to another would also need the strongest signal beam to have an obstacle free propagation of signal. The strongest signals are often accounted within an angular sphere often termed as Fresnel Zone. In [15] it is said that, to make a line of sight; the main beam has to be clear about 60% in the 1st Fresnel Zone.

There are some other parameters in microwave link which are significant in design phase of link establishment.

- Antenna Gain
- Multi-path Reflections
- Precipitation loss
- Fading
- Link budget calculation
- Atmospheric Refraction
3. Antenna Radiation Patterns and Analysis

A comprehensive and elaborative definition of Antenna Radiation Pattern is cited from [17] as

“A mathematical function or graphical representation properties of the antenna as a function of space coordinates. In most cases, the radiation pattern is determined in the far field region and is represented as a function of the directional coordinates. Radiation properties include power flux density, radiation intensity, field strength, directivity, phase or polarization.”

There are a number of articles [18, 19] and books [17, 20] published with the in depth analysis of various kinds of Antenna design. Similarly a lot of research has been conducted in this area beforehand and the purpose of this report is not to bring about a new antenna design but to work on a model solution that could serve in the automation part of the project. Radiation patterns are discussed and methods are investigated to cancel or minimize the interference affect.

3.1 Interference Cancellation

Practically speaking, Interference is quite prevalent in congested networks designed for dense areas. It affects the link and the communication often becomes intermittent depending on the level of undesired carrier. If it is determined that interference is present, then the antenna can be adjusted to minimize it. The antenna data sheets will specify the antenna polarization which is either horizontal or vertical. Polarization selection is very significant to overcome Inter Symbol Interference (ISI) caused by diffraction or reflection of carrier.

There are numerous ways in which Interference on the link can be identified [6, 9]. Ideally, if the transmitter at the “far end” terminal is turned off, the RSL at the “near end” should be in -90 dBm range which can be checked through DMM or via software interface with Indoor Unit. The same should hold for “far end” if “near end” transmitter is turned off. In either case, if signal level is less than -80 dBm, it will indicate a presence of unwanted carrier. An actual MW link affected by interference is shown in Figure 3.1. It can be seen that the RSL is -37.3 dBm on the link which is very good and ideally provide an error free communication but still Error Seconds (ES) and Background Block Errors (BBE) are counting with time. MW systems consider only relevant frequency intended for it and discard other frequencies as Background noise. During Interference, MW fails to block unwanted signal thus generating BBE and ES.
Figure 3.1 Link affected by interference (Unwanted carrier)

There are couples of approaches which can be worked out to clear the issue of interference. Firstly it can be done by re-assigning new frequencies at both ends. This requires a need for a new design in accordance with International Telecommunication Union (ITU) and physical presence of field staff for implementation and thus it is not autonomous and hence not relevant to this project.

The second approach has more to do with radiation pattern and slight tilting in accordance with RSL peaks and dips. For a generic antenna, the radiation pattern in Cartesian plot can be expressed as [21]

\[
radiation (dB) \propto 10\log_{10} \left( 2 \left| \frac{J_1(X)}{X} \right|^2 \right)
\]

(3.1)

An antenna systems work on reception by means of concentration points termed as main-lobe and side-lobes as shown in Figure 3.2. There is a marginal space between main-lobe and side-lobe referred as deep null. This deep null can be used to avoid interference with the help of slight antenna tilt that will still hold the main lobe of intended signal but the reception from external source will be at deep null and thus it will not affect the service.

Figure 3.2 Interference avoidance through antenna tilting towards deep-null
3.2 Parameter Estimation of Antennas

To have a feeling of the practical problem, a model of transmitting and receiving section is designed and developed. The circuitry used for modeling consists of simple connection board that includes a PNP transistor, capacitors, diodes and resistors which is later connected with loop antenna. Figure 3.3 shows transmitter and receiver circuits and antenna installed on the connection board. The input port on the transmitter side is connected to power source while the port on receiver side indicates the RSL level. Various design parameters for transmitter and receiver units are discussed in the following sub-sections.

![Figure 3.3 Transmitter and receiver antenna used in antenna model](image)

3.2.1 Effective Height of the Antenna

Effective height $h_{eff}$ of the antenna is a parameter to define the center of radiation pattern of antenna above the effective ground level and it can be determined with the help of following expression [22].

$$h_{eff} = \frac{2\pi n A \cos \theta}{\lambda} \quad \text{.................................. (3.2)}$$

Where, $n$ is number of turns and in our model ($n = 8$)
$A$ is the area of Loop Antenna and it is $A = 7.09 \times 10^{-3}\text{m}^2$
$\theta$ is the angle of transmitter with Loop Plane and it is $0^\circ$
$\lambda$ is the wavelength and it is found out to be 440 meters

The number of turns “$n$” determines the size of loop antenna and the loop size alongside a capacitor used can tune a particular frequency. In the given model with 8
turns, the frequency range was around 665 kHz. Thus by inserting the values we get effective height $h_{eff}$ of the antenna as

$$h_{eff} = 8.1 \text{ mm}$$

Now the effective ground level is considered as the base of Circuit board and the center of radiation indicating the effective height of antenna shown in Figure 3.3 is theoretically measured to be 8.1mm. It can be seen that the effective height $h_{eff}$ is bit on the lower side and this can be improved by increasing the number of turns in the loop antenna from 8 to 100 or more.

### 3.2.2 Inductance (L) of the Loop Antenna

In the design formulated, a circular loop antenna is fabricated with 8 numbers of turns “n” and diameter of 9.5 cm and hence the radius “r” is 4.75 cm while giving the total loop length “l” to be around 120cm. A formula can be generated for this kind of parameters and can be generalized as [23]

$$L = \frac{r^2 \times n}{9r + 10l} = 0.5 \mu \text{H} \quad \text{......................... (3.3)}$$

### 3.2.3 Radiation Resistance ($R_{res}$) of the Antenna

In the present case the antenna loop is electrically small indicating that the perimeter of the antenna is less than 0.3 $\lambda$. With the help of cross-sectional area “A” an expression for radiation resistance ($R_{res}$) is formulates as [23].

$$R_{res} = 320\pi^4 \frac{\lambda^2}{A^4} = 8.1E6 \Omega \quad \text{......................... (3.4)}$$
4. Automation Control

There are two major disciplines in which this report is carried out. The first part is setting up a model of MW antenna which is discussed in last chapter, the second section deals with Automation Control. Now consider that a problematic link is reported in OMC and a solution is required to get it fixed as soon as possible and ideally without human intervention. This could be done by means of Motors, PID controllers, Gears, Microprocessor and closed loop feedback systems. The mechanism that has been approached in building up the automation system in our model consists of LabVIEW and Robotics RCX. These standalone units are interfaced at the later stage to get the system running. It is to be noted that both units are programmed independently and then interfaced with each other by electrical and mechanical means. A descriptive sequence of processes is described in the flow chart.

![Flow Chart of the System Automation](image)

Figure 4.1 Flow Chart of the System Automation
Inside the RCX Robonics there is a PID controller which basically administers the controller to reach a point \( R(t) \), in this model it is the RSL value which should be achieved by the antenna. It actuates the motor with a command \( U(t) \) that is rotate horizontally or vertically, measuring its position \( Y(t) \) with a built in encoder and thus calculates the error \( E(t) = R(t) - Y(t) \) as a closed loop feedback system so that the \( E(t) \) become zero and the system can achieve \( R(t) \). A well known general equation can be presented as

\[
U(t) = P(t) + I(t) + D(t) \tag{4.1}
\]

A simple block diagram below shows where the measured RSL signal is fed as an input to Decision Making Device (DMD) which is based on PID control operation discussed above, in the given model LEGO Mindstorms RCX is used for this purpose. DMD basically develops the logical decision using different criteria evaluating some mathematical equations and logics. Like all other microcontroller this DMD continuously check its logical expression. After that PID operation continues so that the error become minimizes and we can get the required output. Two logic output will trigger both motors as we have used relay and servo motors for alignment in prototype. The output from DMD come sequentially as logic output 1 for horizontal alignment trigging motor and logic output 2 for vertical one. Alignment triggering in both directions will make a change in RSL and this value will be forwarded to DMD to make further logical decision.

![Block diagram of the implemented control system](image)

**Figure 4.2 Block diagram of the implemented control system**

### 4.1 Signal Reception and LabVIEW Design

MW antenna alignment is basically a closed loop system that deals with a continuous time varying input which is then fed to decision device. The system works on “Cause and Affect” principle by making a processor to work as a digital gate between the devices. To avoid complications of arranging sophisticated set-up and using microcontrollers, LabVIEW has been used instead. LabVIEW is a product of National Instruments (NI) and it has enormous applications while the test bench is a Graphical User Interface (GUI) [25, 26].
The Input device that is interfaced with the LabVIEW is Tektronix real time oscilloscope which is connected by means of GPIB cable. The data rates of GPIB interfacing cable is 1 MByte/sec which is not very high but at the same time enough to build a solution of acceptable response time. The RSL level from the receiver unit is measured in Tektronix oscilloscope. The oscilloscope in use; supports dual channel inputs and hence can support diversity for Multiple Input Multiple Output (MIMO) antennas. An “Instrument I/O Assistant” palette is used to write the oscilloscope data on LabVIEW and it is set to measure the peak to peak voltage. This palette is kept outside the operational loop to give a continuous feed to the system and enhance autocorrecting mechanism. Apart from Instrument I/O palette, the remaining building blocks are kept inside the While Loop. This is done to repeat certain operations until the input terminal receive a particular Boolean Value and hence determines the behavior of the loop. Figure 4.3 indicates the flow of information from receiver to LabVIEW while the LabVIEW design is shown in Figure 4.4. Ideally auto-correction mechanism should be installed on both near end terminal as well as far end terminal depending upon the customer request and available resources. The figure below shows a process in which near end Base Transceiver Station (BTS) is connected with Far End terminal through a MW link. Antenna gets a certain level of RSL which is measured in the oscilloscope connected through an IF cable and this reading is written in Instrument I/O palette. In practice the In-door transmission unit generally graphical based software keeps track of RSL; Traffic Node (TN) is one such product of Ericsson.

![Figure 4.3 RSL measurement of MW Antenna through Oscilloscope](image1)

![Figure 4.4 LABVIEW Program and simulation](image2)
The motive behind the LabVIEW program was to come up with a virtual and graphical system that works with Boolean Logic and which is able to simulate the output. A comparator is used to measure the RSL or voltage level and then compare it with a set range and gives an output signal accordingly. There are multiple factors that had to be considered and most significant of it is to minimizing the response time as more the delay the higher the difficulty in stopping automation at optimal direction of antenna. Delay time is minimized by write and read palettes of the program. Firstly “Instrument I/O Assistant” is used to specifically write the data of oscilloscope and is kept outside the operational loop. It should be noted that there is possibility of reading value in the same “Instrument I/O Assistant” but it operates for three cycles in writing and one cycle in reading and hence causes the undesirable delay. For reading purpose a separate “GPIB Read/Write” palette is indicated inside the loop and the output is basically a data in string. This string data is then converted to numerical data by a separate palette for logical operations and comparison with reference values. Since the RSL measurement is to be done continuously and antenna must be aligned at all times, a While Loop is used.

Waveform chart is probed with string converter to display Voltage level on a standard scale and it is basically an indication of the level of RSL for antenna at its current position. A comparator is used with variable reference signal level and in Figure 4.4 it is set at 3.5V. LED is linked with the output of Comparator which glows if the signal drops below the set reference level and turns off at higher voltage levels. Figure 4.5 indicates the Amplitude level of the signal from Receiver at continuous time and represents a signal below the threshold while Figure 4.6 shows that the RSL is within the acceptable range.

![Waveform Chart](image)

Figure 4.5 Signal Level below the the Set Reference – LED On
There are two reasons for which the threshold value of 3.5V has been selected. Firstly on the receiver end, an LED has been soldered as shown in Figure 3.3 which glows once this voltage level is reached and hence an indication of strong signal can be observed. Secondly, the measurement of voltage is taken by means of a digital oscilloscope with a reasonable response time (not too sensitive) and hence this voltage level gives enough span of voltage measurement for LabVIEW to compare with a set threshold. Figure 4.6 indicates the level of fluctuations for voltage level with peak well over 3.5V.

A different setup can be used with the help of adaptive comparator. This would mean that there is no set threshold level and the system will rotate through the whole horizontal and vertical axis initially. It will keep a record for best value and this will be adapted as a threshold level and an alignment procedure will begin for the second time to attain the best value searched previously. The can help in getting the best RSL possible but this setup requires a very sensitive device for signal reception and highly complex programming.

LEDs are simulation indicating the instance to trigger the automation and when it should be stopped. The comparator basically generates a unit step signal at the output depending on the input and it is to be linked with second part of automation which is Robonics RCX. To do so, a Data Acquisition Card (DAQ) is used as indicated in Figure 4.4 and it is set to work as digital input output device. DAQ card used in the setup is PCI 6024E which has 16 single ended channels and sampling rate of 200 kS/s. DAQ card contains eight lines for Digital I/O and can very well be used for diversity purposes in MIMO applications. PCI card is later connected with NI CB-50LP through a Ribbon cable. The output from DAQ is a control signal that communicates to RCX. The CB-50LP which provides both analog pins as well as digital ones and in the present case a digital ground of pin 33 is used and positive peak signal is extracted from pin 25.
4.2 Motor Control for Alignment

Automation through which the antenna is actually repositioned and automatically directed to Far End Terminal need motors, PID controllers, drive circuits, gears for rotational shafts and programmable microprocessor. LEGO Mindstorms RCX is used for modeling purpose in this project since it provides a complete set of resources and programmable controllers to carry out desired activity. Another process that could have been used instead of RCX was PIC microcontroller but it would make the automation setup very complicated and the system would not have been robust.

LEGO Mindstorms RCX consists of Sensors and Actuators. The first part of sensors consists of touch sensor and light sensor while actuating unit consists of three output ports that can be connected to motors. In the previous sub-section, LabVIEW design was shown and a DAQ device was used to give a digital output depending on the Receiver RSL [27, 28, 29]. A digital signal can be connected to touch sensor rather simply then using the light sensor. It is to be noted that the LabVIEW generated a 5V DC signal and it cannot be directly connected to touch sensor input. Touch sensor of RCX robotics work on open and short circuit principle, if the button indicating touch is pressed, it will make a short and RCX will work as programmed. Similarly if it is released indicating open circuit; a different set of operation will be performed. The ampere rating of LabVIEW CB-50LP output port and touch sensor is different and to enable a smooth operation, an SPDT relay is used to reliably pass the control signal to RCX through touch sensor.

The system which had to be designed needed to do azimuth (horizontal axis) as well as vertical movement in such a manner that a single antenna is aligned. Prototyping for diversity and MIMO antennas have not been done but it similar in design however needs additional resources. In this project horizontal shift and vertical shift have been build independently and then integrated together. In Figure 4.7, at a glance we can see the implemented model mechanism so that we can get the feeling of what’s going on. A couple of servo motors are used to rotate the antenna in horizontal axis with one moving in forward direction while the other in reverse direction so that a single point rotating antenna can be realized. The servo motors used needs no external PID controller and it is readily in-built in the LEGO Mindstorms RCX. The Azimuth alignment setup is installed at the bottom of the RCX microprocessor. In building the hardware for Vertical tilt, a similar servo motor is used and a single motor in combination with gears is sufficient to move the receiver antenna up and down. Since the antenna has to be aligned on a single point by means of horizontal and vertical movement, no effort is made to drag the antenna itself in different position. In industrial applications a similar setup with high power motors can be used.
In the modeled solution, we have a mobile platform capable of moving in rotational axis for horizontal tilting of end-effector which in our case is the Receiver Loop Antenna “R”. The means of rotational movement is a double sided conveyor belt located on either side of the model solution. By appropriately programming the controller, both back and forth movement as well as rotational movement can be achieved but in our case the focus has only been on the later. Now the second desired task is vertical tilting and for that another motor is used for automation. End-effector “R” is connected with a “Revolt Joint” which actuates for lateral movement. The divisional analysis for the structure is shown in the Figure 4.8.
In order to understand the position and target point of “R”, we have to analyze Denavit-Hartenberg parameters [30]. The model shown in Figure 4.8 is synthesized into D-H frames to analyze the mechanics involved for overall automation. In the present system, we have a mobile base and a manipulator consisting of 1 joint for vertical tilting. The number of links can be found by adding a unitary value to the total number of joints and this makes our model solution to be a “2 Link Manipulator on a Mobile Base”. The manipulator design with reference to D-H frames is shown in the Figure 4.9. To better understand the system, a reference frame “Pr” is used to take into account the mobile base. From [31, 32] a generic homogeneous transformation can be formulated using D-H parameters presented in Table 4.1. Since the offset distance is variable due to the mobile base of unit, it is represented by $X_{\text{base}}$ and $Y_{\text{base}}$ respectively. The length of the link “l” for end-effector is considered of unit length to address the position in simplified manner.

![Figure 4.9 D-H frames for Automation System](image)

<table>
<thead>
<tr>
<th>Link</th>
<th>$\Theta_i$</th>
<th>$\alpha_i$</th>
<th>$a_i$</th>
<th>$d_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Degree</td>
<td>Millimeter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>$\pi/2$</td>
<td>$\pi/2$</td>
<td>0</td>
<td>$X_{\text{base}}$</td>
</tr>
<tr>
<td>2</td>
<td>$\pi/2$</td>
<td>$\pi/2$</td>
<td>0</td>
<td>$Y_{\text{base}}$</td>
</tr>
<tr>
<td>3</td>
<td>$\Theta_1$</td>
<td>$\pi/2$</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>$\Theta_2$</td>
<td>0</td>
<td>$l = 1$</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 4.1 D-H parameters for Automation System

Parameters $\Theta_i$ and $\alpha_i$ are the joint angle and link twist angle while $a_i$ and $d_i$ are the link length and link offset distance respectively [30]. $\Theta_i$ is usually the only variable but with the specific case of mobile base, $d_i$ values also change. $\alpha_i$ and $a_i$ are always constants.
Using Homogenous transformation matrices, the position and orientation of end-effector with respect to the reference “P_r” can be generalized as [32]

\[ A = \text{Rot}_{z, \theta_i} \text{Trans}_{z, d_i} \text{Trans}_{x, a_i} \text{Rot}_{x, a_i} \] \hspace{1cm} (4.2)

\[
A = \begin{bmatrix}
\cos \theta_i & -\sin \theta_i \cdot \cos a_i & \sin \theta_i \cdot \sin a_i & ai \cdot \cos \theta_i \\
\sin \theta_i & \cos \theta_i \cdot \cos a_i & -\cos \theta_i \cdot \sin a_i & ai \cdot \sin \theta_i \\
0 & \sin a_i & \cos a_i & d_i \\
0 & 0 & 0 & 1
\end{bmatrix} \hspace{1cm} (4.3)
\]

Now, by inserting the D-H parameters presented in Table 4.1, we can arrive at the following 4X4 homogenous transformation matrices as

\[
A_1 = \begin{bmatrix}
0 & 0 & 1 & 0 \\
1 & 0 & 0 & 0 \\
0 & 1 & 0 & X_b \\
0 & 0 & 0 & 1
\end{bmatrix} \hspace{1cm} (4.4)
\]

\[
A_2 = \begin{bmatrix}
0 & 0 & 1 & 0 \\
1 & 0 & 0 & 0 \\
0 & 1 & 0 & Y_b \\
0 & 0 & 0 & 1
\end{bmatrix} \hspace{1cm} (4.5)
\]

\[
A_3 = \begin{bmatrix}
\cos \theta_1 & 0 & \sin \theta_1 & 0 \\
\sin \theta_1 & 0 & -\cos \theta_1 & 0 \\
0 & 1 & 0 & 0 \\
0 & 0 & 0 & 1
\end{bmatrix} \hspace{1cm} (4.6)
\]

\[
A_4 = \begin{bmatrix}
\cos \theta_2 & -\sin \theta_2 & 0 & l_1 \cdot \cos \theta_2 \\
\sin \theta_2 & \cos \theta_2 & 0 & l_1 \cdot \sin \theta_2 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1
\end{bmatrix} \hspace{1cm} (4.7)
\]

Using dot product of A1, A2, A3 and A4 matrices, we arrive at the position and orientation of the toll frames indicated in Figure 4.9 as

\[
T = \begin{bmatrix}
\sin \theta_1 \cdot \cos \theta_2 & -\sin \theta_1 \cdot \sin \theta_2 & -\cos \theta_1 & \sin \theta_1 \cdot \cos \theta_2 + Y_b \\
\sin \theta_2 & \\
\cos \theta_1 \cdot \cos \theta_2 & -\sin \theta_1 \cdot \sin \theta_2 & \sin \theta_1 & \cos \theta_1 \cdot \cos \theta_2 + X_b \\
0 & 0 & 0 & 1
\end{bmatrix} \hspace{1cm} (4.8)
\]

Equation 4.8, points to the position and orientation of Loop Antenna “R” in base coordinate system. Since the overall setup is adaptive in a sense that that alignment will be stopped after getting the desired RSL, hence \( \theta_1 \) and \( \theta_2 \) will constantly change with varied positions of \( X_{\text{base}} \) and \( Y_{\text{base}} \). The work space is set using RCX controller through an inbuilt programming package.
Once the hardware has been built, second phase that deals with programming is worked on. There are couples of methods in which RCX can be programmed. Firstly; it can be done using Java script which can be burnt on the RCX processing unit while the other option is of using a custom made graphical programmer which comprises of numerous building blocks. A later approach is used as it gives both a graphical representation as well as the converted written code. A compete code for operation is given in Appendix B and can be looked at as a reference. The code is burnt on the RCX processor by means of an infrared channel; this is done by linking RCX with an IR tower connected to the computer.

RCX unit is linked with LabVIEW and RCX gets all information and control signals solely from it through a sensor and relay circuitry. If the alignment is out and LabVIEW generates a digital 5V signal, automation should start both in horizontal and vertical direction through three motors shown in Figure 4.8. Initially for an indication of digital high from LabVIEW, RCX is programmed to actuate motors connected on output A and C of RCX board. Motor A is set to move in forward direction while motor B moves in reverse direction. Another consideration that is significant is setting the power for two motors. For optimal performance both motors should have same power but at the same time power should not be so high that it experience difficulty in stopping once the desired RSL is reached. Keeping this in mind, the power is set to be low and delay for a power is set to 0.01 seconds so that there is no continuous feed and hence controlling motors is rather easy. This is shown in Figure 4.10 where a “Wait For” command is used for controller 1. Horizontal alignment is done using controller 1 alone while vertical tilt which is done through controller 2 and controller 3.

Considering industrial application for antenna alignment; a complete rotation for vertical tilt is undesirable and instead a shift of ±45 degree from starting position is more appropriate to reach the desired direction. By narrowing the angle, desired direction is reached in time optimal manner as well. The specific movement is realized by a delay time of 0.05 second and power feed for two consecutive cycles in either direction simultaneously. The motors are set to turn off and not coarse as the installation and antenna weight can affect the alignment process and misalign once the alignment process completes. When the desired RSL is reached; the locomotion of antenna in both axes should stop.
Figure 4.10 Graphical design for RCX Mindstorm processor
4.3 Possible Challenge for Practical Application

The proposed solution mentioned has been demonstrated to work on a model and do alignment autonomously. Now the question is the mechanism of translating the model solution to a practical scenario. With limited resources, the actual MW antenna could not have been arranged and tested. This section discusses a general guideline to address industrial problem using some data from practical antenna dimension, motor specification etc. so that the feeling of practical scenario may be approached. A hypothetical model is discussed in the following sections.

4.3.1 Motor Selection According to Antenna Dimension

Considering that an actual antenna is perturbed from its actual position due to wind. Now in this case there are two factors which are to be taken into account. First is the weight of antenna and the second is the wind force on the antenna. In such cases following considerations must be taken

- Motor could operate at variable speed
- Speed regulation of that motor must be precise
- Response time should be minimal.

Usually in telecommunication sector; a solid parabolic antenna is generally used by service providers. Depending on the design and coverage area; dimensions of antenna varies a great deal and so does the weight. Diameter of antenna ranges from 0.3 meters to 2.4 meters and its weight from 7 kg to 110 kg respectively [15]. For a generic case, let us consider an antenna with dimensions of 0.3m x 0.6m and Frontal Area exposed to wind be two third of total area, the Cross-sectional area is [33]

\[
\text{Cross-sectional Area (A)} = \text{Dimensions} \times \text{Frontal Area of Antenna} \ldots (4.9)
\]

\[
\text{Cross-sectional Area (A)} = (0.3 \text{m} \times 0.6 \text{m}) \times \left(\frac{2}{3}\right)
\]

\[
\text{Cross-sectional Area (A)} = 0.18 \text{m}^2
\]

Normally the structural design should hold for windy situation. In harsh conditions, the operating wind force for solid parabolic antennas placed at tower varies from 190-230 kph; the actual wind pressure by considering the drag coefficient of 1 and wind speed of 53 m/s (app. 190kph) can be simplified as [33, 34].

\[
\text{Pressure (P)} = \left(\frac{\text{Density of Air}}{2}\right) \times (\text{Wind Speed})^2 \ldots \ldots (4.10)
\]

\[
\text{Pressure (P)} = 1405 \text{ Pa}
\]
Now using the wind speed of 190 kph and keeping the drag coefficient at 1, the resultant wind load \( W \) can be calculated as

\[
\text{Wind Load (W)} = \text{Cross-sectional Area (A)} \times \text{Pressure (P)} \quad \ldots \ldots \quad (4.11)
\]

\[
\text{Wind Load (W)} = 253 \, \text{N}
\]

Hence the resultant weight can be approximated to 26 kg for a small sized antenna. If we have bigger antennas as used in remote places for a distant link, the resultant weight will increase dramatically. Figure 4.11 indicates the resultant force acting on antenna at operating time in an arbitrary moment.

![Figure 4.11 Schematic View to calculate resultant force on antenna](image)

**4.3.2 Control Signal Transfer and Delay**

It is desirable that the signal transfer between LabVIEW design integrated with transmission system and outdoor antenna setup communicate with minimal losses. When the link will be down; the feedback signal coming to indoor unit will be of low amplitude. This signal should come without any distortion and interference. Delay is another factor that has to be minimized and it can be triggered by motor miss regulation, motor not giving required step angle, noise added in control signal etc.

All the above discussion can be furthered with industrial resources used in telecommunication industry but in the meanwhile essence of antenna set-up at the impetus stage is carried out.
5. Results & Analysis

Antenna alignment consists of many sub-problems that include automation control and locomotive units as well as antenna prototyping. Each problem is separately dealt with and then integrated to form a system at the later stage. Following sections describe significant design parameters for both motor control and antenna design subsystems.

5.1 Response Time in LabVIEW

Response time is very significant for the overall system because the antenna alignment is done in real time. Response time depends on the time delay factor which can be separately added as a palette. Time delay is measure of how fast a signal received can be read into the system. Since LabVIEW is the first section of automation control, therefore if the response time to Received Signal Level (RSL) is low, motor units will be unable to stop at desired RSL level.

Initially the RSL was measured at Instrument I/O Assistant kept inside the while loop and both write and read commands were programmed in it. There were three cycles of “write” operation followed by a single “read” command and hence the time delay for any single value lasted for as long as 3 sec. This was undesirable as the motor should stop immediately once the required RSL is achieved. At the later stage Instrument I/O Assistant was kept outside the loop and similarly separate GPIB write and read palette was kept inside the while loop. By doing so, the response time was improved a great deal as samples from real time being read at every 50 msec. Response time with respect to rotations is given in Figure 5.1.

![Figure 5.1 Response Time for different set of LabVIEW palettes](image)

Figure 5.1 Response Time for different set of LabVIEW palettes
5.2 Motor Control Using RCX

The second section relating to automation part is built on RCX robotics that includes software as well as hardware. There are various parameters to be adjusted to find optimal direction. Firstly it is to be noted that the 360° is not desired and only a tilt within 90° or even lesser can achieve the appropriate polarization in time optimal manner. For instance a delay is set for 2 sec to move in upward direction and another 2 sec in downward direction during the course of alignment. Considering that the position of the antenna is steered between ± 45°; the system’s response time varies accordingly to make necessary alignment. If the antenna position is within ±5° to ±20° arc, then response time is exceptional. With an increase in rotating arc; for antenna the response time gets slower. In Figure 5.2 we can see the response with respect to antenna position change.

![Effect of Antenna Position in Response Time](image)

Figure 5.2 Antenna position effect with respect to Response Time

Power for the motor is also very significant and it is to be synchronized with the response time. If the power is too high and the response time is low, the antenna will cease to stop and the power will over rotate the antenna. Therefore the power in the motors for horizontal alignment is kept low thus making the alignment process slow but at the same time the motors will stop at the best RSL level.
5.3 Improvements and Future Works

The basic idea of designing an antenna that aligns itself without human intervention has been presented but there is a huge potential for advancements and future works.

1. The system is designed and tested on a single station while other is kept stationary. This can be furthered by making a dynamic design which can fine tune on both BTSs rather than one side. It is to be noted that the automation is to be programmed in such a way that one BTS starts alignment only when other ceases.

2. The platform provided is for a solo system but it can be advanced to MIMO application with multiple antennas on both ends. This would require a bit complex programming and automation system.

3. The arc for antenna tilting in the system is designed for 45 degree which does marginalize if compared with a generic sphere but in actual scenario the antennas are often perturbed by only a small degree. To fully translate the model system onto an actual telecom network, the arc of antenna tilting has to be minimized.

4. The response time for antenna alignment noticed is better than compared with manual alignment conventionally done but there is still a space to cover and the alignment can be accelerated even more.

5. Loop antenna is used for demonstration purpose, actual MW antennas are entirely different and designing those would make the model more industrial based.
6. Conclusion

Modern communication system is equipped with lot of sophisticated devices and the system must be immune to all critical situations to give a reliable and robust service. It is essential to maximize the network availability at all times. In this paper, an automated antenna alignment has been made possible by means of an automation system and modeled loop antennas. MW link works on LOS while directional antennas of BTS terminals can ensure a lossless transmission. Multiple factors that account for response time of automation system are devised and measurements have been taken for locomotion in both azimuth as well as vertical tilting. A system has been presented which ensures that the antenna and its corresponding main lobes are set to get maximum RSL. Since the alignment is done autonomously, therefore it will make sure that the down time is kept at minimal level. Interference avoidance is also a significant for a network especially if multiple stations are clustered together. Interference reduction by making use of deep nulls between two nodes is examined. All the experiment and implementation is done on a modeled solution though software design used can easily be replicated on active network; hardware tolls do give a feel of actual ICT atmosphere.
References


[25]. NI Team, “Introduction to LabVIEW; Three-Hour Course,” Part Number 323668B-0, Year 2009.


Appendix A: MW Link Budget

A sample of MW Link Budget between Near End and Far End Terminals of Nokia Siemens Network (NSN) Radio Unit. This shows the different parameters need to consider practically.

<table>
<thead>
<tr>
<th>Polarization</th>
<th>Radio Equipment</th>
<th>Link Capacity</th>
<th>Link Channel</th>
<th>Distance (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HORIZONTAL</td>
<td>NSN 8x2</td>
<td>18.0</td>
<td>NA</td>
<td>2.81</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Site</th>
<th>Near End</th>
<th>Far End</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>XXXX</td>
<td>XXXX</td>
</tr>
<tr>
<td>Address</td>
<td>XXXX</td>
<td>XXXX</td>
</tr>
<tr>
<td>Site Access</td>
<td>XXXX</td>
<td>XXXX</td>
</tr>
<tr>
<td>Longitude</td>
<td>21.49910</td>
<td>21.41816</td>
</tr>
<tr>
<td>Latitude</td>
<td>39.81370</td>
<td>39.20854</td>
</tr>
</tbody>
</table>

**Site Data**

<table>
<thead>
<tr>
<th>Site</th>
<th>Frequency (GHz)</th>
<th>Link and</th>
<th>Antenna</th>
<th>Protection Type</th>
<th>Dish Height (m)</th>
<th>Dish Size (m)</th>
<th>Tx Power (dBm)</th>
<th>Tx Attenu (dB)</th>
<th>Rx Level (dBm)</th>
<th>Flat Fade (dB)</th>
<th>Availability (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>32.004</td>
<td>Lo</td>
<td>215.25</td>
<td>Single</td>
<td>12.0</td>
<td>0.20</td>
<td>16.0</td>
<td>0.00</td>
<td>-40</td>
<td>43</td>
<td>99.999994</td>
</tr>
<tr>
<td>B</td>
<td>32.816</td>
<td>High</td>
<td>55.15</td>
<td>Single</td>
<td>12.0</td>
<td>0.20</td>
<td>16.0</td>
<td>0.00</td>
<td>-40</td>
<td>43</td>
<td>99.999991</td>
</tr>
</tbody>
</table>
Appendix B: Programming for RCX
Program for LEGO Mindstorms RCX 1.0

0BEGINFILE
#include <RCX2.h>
#include <RCX2MLT.h>
#include <RCX2Sounds.h>
#include <RCX2Def.h>

 MACRONAME MOTOR1
 program test { 
 #include <RCX2.h>
 #include <RCX2MLT.h>
 #include <RCX2Sounds.h>
 #include <RCX2Def.h>
 macro MOTOR1 { 
 direction [ A  ] [ C ]
 on [ A C ]
 wait 1
 off [ A C ]
 }
 main { 
 MOTOR1
 }
 }
0ENDMACRONAME

 MACRONAME MOTOR2
 program test { 
 #include <RCX2.h>
 #include <RCX2MLT.h>
 #include <RCX2Sounds.h>
 #include <RCX2Def.h>
 sensor touch1 on 1
}
0BEGINFILE
#include <RCX2MLT.h>
#include <RCX2Sounds.h>
#include <RCX2Def.h>

 MACRONAME MOTOR1
 program test { 
 #include <RCX2.h>
 #include <RCX2MLT.h>
 #include <RCX2Sounds.h>
 #include <RCX2Def.h>
 sensor touch1 on 1
}
0BEGINFILE
#include <RCX2MLT.h>
#include <RCX2Sounds.h>
#include <RCX2Def.h>

 MACRONAME MOTOR2
 program test { 
 #include <RCX2.h>
 #include <RCX2MLT.h>
 #include <RCX2Sounds.h>
 #include <RCX2Def.h>
 sensor touch1 on 1
}
touch1 is switch as boolean

macro MOTOR2B {
  direction [ ] [ B ]
  if touch1 is closed {
    on [ B ]
    wait 50
    off [ B ]
  }
  on [ B ]
  wait 50
  main {
    off [ B ]
  }
}

main {
  MOTOR2B
}

program test {
  #include <RCX2.h>
  #include <RCX2MLT.h>
  #include <RCX2Def.h>
  sensor touch1 on 1
  touch1 is switch as boolean
  }
  macro MOTOR2A {
    direction [ B ] [ ]
    on [ B ]
    wait 50
    off [ B ]
  }
  main {
    MOTOR2A
  }
  main {
    CONTROLLER1
  }

#include <RCX2.h>
#include <RCX2MLT.h>
#include <RCX2Sounds.h>
#include <RCX2Def.h>

macro CONTROLLER1 {
  direction [ A ] [ C ]
  on [ A C ]
  wait 1
  main {
    off [ A C ]
    }
}

```c
#include <RCX2.h>
#include <RCX2MLT.h>
#include <RCX2Sounds.h>
#include <RCX2Def.h>

sensor touch1 on 1
touch1 is switch as boolean

macro CONTROLLER2 {
direction [ B ] [ ]
if touch1 is closed {
on [ B ]
wait 10
off [ B ]
}
else {
bb_PlayNote( 659, 20, 20 )
}
}

main {
CONTROLLER2
}

0ENDMACRONAME
0MACRONAME

#include <RCX2.h>
#include <RCX2MLT.h>
#include <RCX2Sounds.h>
#include <RCX2Def.h>

sensor touch1 on 1
touch1 is switch as boolean

macro CONTROLLER3 {
direction [ ] [ B ]
if touch1 is closed {
on [ B ]
wait 10
off [ B ]
}
else {
bb_PlayNote( 659, 20, 20 )
}
}

main {
CONTROLLER3
}

0ENDMACRONAME
0MACRONAME
0ENDFI
```