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Extending the Range of Wireless LANs by Developing a New Antenna

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ABSTRACT

Wireless networks are extensions of the basic LAN systems. They are used by many people and by many organizations, especially in applications where a workstation needs to be away from the main network for graphical reasons. One of the problems and limiting factors of wireless networks is the distance from a workstation to the main network.

This thesis describes the design and construction of two types of antennas for wireless networks, aimed to increase the range of wireless network communication. Both types of antennas have been developed by the author, they are low cost, and they increase the gain of the received signal considerably, making it possible to connect to networks at far away distances.

The results show that over 10 dBi gain improvement is possible with the simple antennas designed by the author. One advantage of the designed antennas is their relatively low cost and ease of construction.

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INTRODUCTION

Nowadays, the communication technology is mainly considered as a back bone in our life. Thus, the wireless communication is witnessing a rapid progress every day. This communication technology is simply depending on the replacement of the wiring to wireless. On the other hand, the wireless networks have short coverage area from the main network to the workstation. Therefore, our goals in this thesis are:

- To increase the range coverage in Wi-Fi 802.11.
- Getting longer range of distance link.
- Designing and implementing a cheap and high performance antenna.

These points can be achieved by increasing the gain or power of such an antenna.

Chapter one is primarily concerned with definitions and related terminologies. It deals with Local Area Network (LAN), Wide Area Network (WANs) and devices used for network infrastructure such as routers, gateways and switches.

Chapter two presents the theory behind antennas. It discusses some antenna parameters like input impedance, return loss, bandwidth, directivity, gain, radiation pattern and physical construction of antenna.

Chapter three investigates the parabolic dish antenna theory, dish antenna design and related parameters.

Chapter four deals with the design and construction of antennas. Specifically, it covers biquad antenna, sector antenna, parabolic USB antenna, fan cover antenna and the new labeled RB antenna.

Finally chapter five gives the gain and the efficiency results obtained through measurements taken from the designed antennas. The antennas were connected to various Internet Service Providers (ISPs) in Northern Cyprus during these measurements. Every antenna has a gain so we want check our antenna gain by testing it in real life.

Finally we make a few concluding remarks and detail the future works.

Dedicated To

My Family

CHAPTER ONE

LOCAL AREA NETWORKS (LANs)

1.1 Overview

A network is a group of computers, printers, and other devices that are connected together with cables. Information travels over the cables, allowing network users to exchange documents and data with each other, print to the same printers, and generally share any hardware or software that is connected to the network. Each computer, printer, or other peripheral device that is connected to the network is called a node. Networks can have tens, thousands, or even millions of nodes. In the simplest terms, a network consists of two or more computers that are connected together to share information. Principal components of a computer network are:

- Computers (processing nodes or hosts).
- Data communication system (transmission media, communication processors, modems, routers, bridges, radio systems, satellites, switches, etc).

1.2 Importance of Networks (LANs)

The concept of linking a large numbers of users to a single computer via remote terminal is developed at MIT in the late 50s and early 60s. In 1962, Paul Baran develops the idea of distributed, packet-switching networks. The first commercially available Wide Area Network (WAN) was created by the Advances Research Project Agency (APRANET) in 1969. Bob Kahn and Vint Cerf develop the basic ideas of the Internet in 1973.

In early 1980s, when desktop computers began to proliferate in the business world, then intent of their designers was to create machines that would operate independently of each other. Desktop computers slowly became powerful when applications like spreadsheets, databases and word processors included. The market for desktop computers exploded, and dozens of hardware and software vendors joined in the fierce competition to exploit the open opportunity for vast profits. The competition spurred intense technological development, which led to increased power on the desktop and lower prices. Businesses soon discovered that information is useful only when it is communicated between human beings. When large information being handled, it was impossible to pass along paper copies of information and ask each user to reenter it into their computer. Copying files onto floppy disks and passing them around was a little better, but still took too long, and was impractical when individuals were separated by great distances. It was hard to know for sure that the copy received on a floppy disk was the most current version of the information-the other person might have updated it on their computer after the floppy was made.

For all the speed and power of the desktop computing environment, it was sadly lacking in the most important element: communication among members of the business team. The obvious solution was to link the desktop computers together, and link the group to shared central repository of information. To solve this problem, computer manufactures started to create additional components that users could attach to their desktop computers, which would allow them to share data among themselves and access centrally located sources of information. Unfortunately the early designs for these networks were slow and tended to breakdown at critical moments.

Still, the desktop computers continued to evolve. As it became more powerful, capable of accessing larger and larger amounts of information, communications between desktop computers became more and more reliable, and the idea of a Local Area Network (LAN) became practical reality for businesses. Today, computer networks, with all their promise and power, are more complicated and reliable than stand-alone machines. Figure 1.1 shows the network connectivity of the world.

1.3 Goals of Computer Networks

1. Resource sharing and accessing them independently of their location.
2. Providing a universal environment for transmission of all kinds of information: data, speech, video, etc.
3. Supporting high reliability of accessing resources.

4. Distribution of loads according to the requirements very fast main frames, minis, PCs, etc.

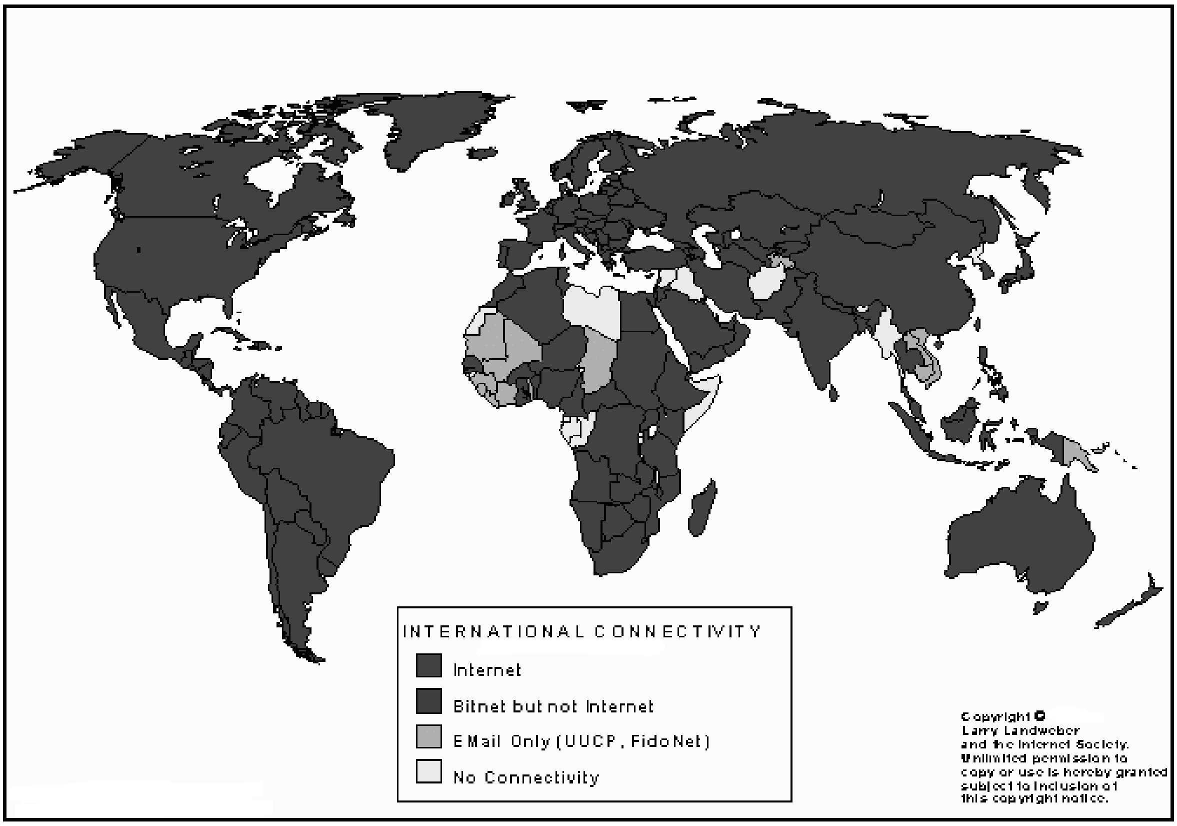


Figure 1.1 Computer network connectivity of the world [1].

1.4 Classification of Computer Networks

Network classification is like snowflakes. No two networks are ever alike. Thus it helps to classify them by some general characteristics for discussion. A given network can be characterized by its:

- Size: The geographic size of the network
- Security and Access: Who can access the network? How is access controlled?
- Protocol: The rules of communication in use on it (e.g. TCP/IP, NetBEUI, AppleTalk, etc.)
- Hardware: The types of physical links and hardware that connect the network

Computer experts generally classify computer network into following categories:

- Local Area Network (LAN): A computer network, with in a limited area, is known as local area network (e.g. in the same building)
- Wide Area Network (WAN): A computer network that spans a relatively large geographical area. Typically, a WAN consists of two or more local-area networks (LANs). Computers connected to a wide-area network are often connected through public networks, such as the telephone system. They can also be connected through leased lines or satellites. The largest WAN in existence is the Internet.
- Metropolitan Area Network (MAN): A data network designed for a town or city. In terms of geographic breadth, MANs are larger than local-area networks (LANs), but smaller than wide-area networks (WANs). MANs are usually characterized by very high-speed connections using fiber optical cable or other digital media.
- Campus Area Network (CAN): The computer network within a limited geographic area is known as campus area network such as campus, military base etc.
- Home Area Network (HAN): A network contained within a user's home that connects a person's digital devices. It connects a person's digital devices, from multiple computers and their peripheral devices to telephones, VCRs, televisions, video games, home security systems, fax machines and other digital devices that are wired into the network.

Figure 1.2 shows the connectivity of LANs to MANs and typical use of MANs to provide shared access to a WAN. Computer networks are used according to specified location and distance. Table 1.1 shows the network types.

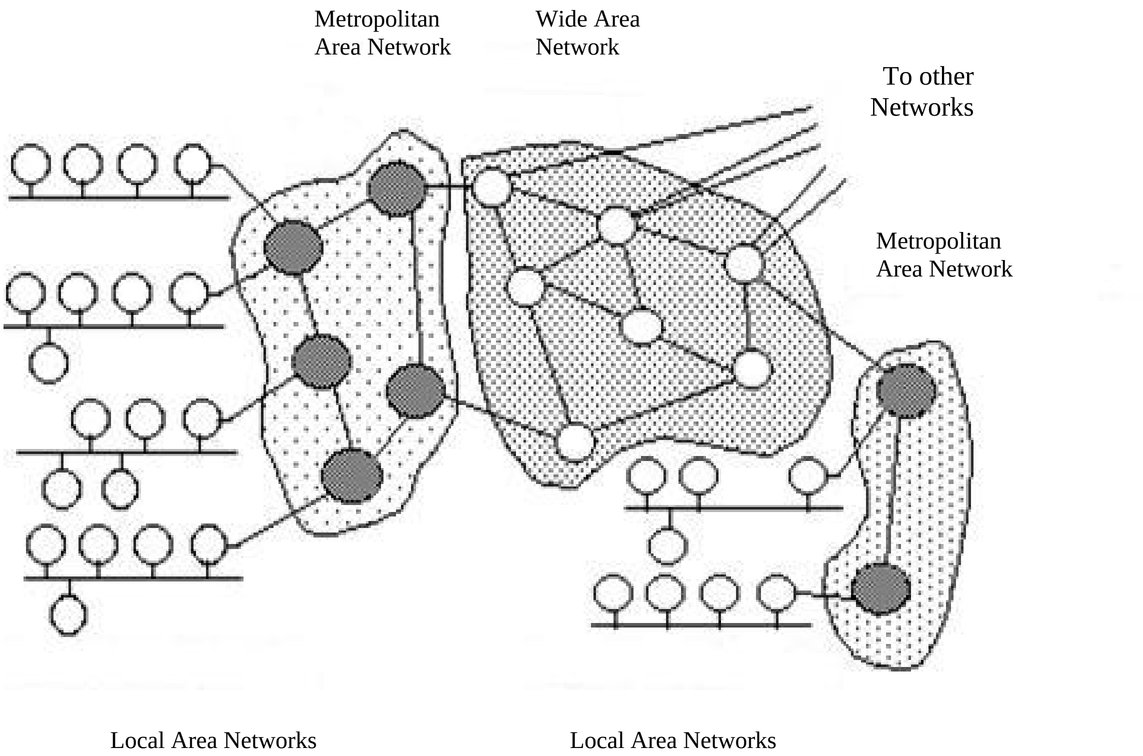


Figure 1.2 A typical use of MANs to provide shared access to a wide area network [2].

Table 1.1 Network technologies that fit in different communication spaces

NETWORK TYPE	**DEFINITION**	**RANGE**	**COMMUNICATION SPACE**
LAN	Local Area Network	$0.1-1km$	Building, floor, room
WAN	Wide Area Network	$100-10000km$	Region, country
MAN	Metropolitan Area Network	$10-100km$	City
CAN	Campus Area Network	$1-10km$	Campus, military base, company site
HAN	Home Area Network	$0.1km$	Home

Figure 1.3 shows a chart that specifies the distances and speeds of different networks.

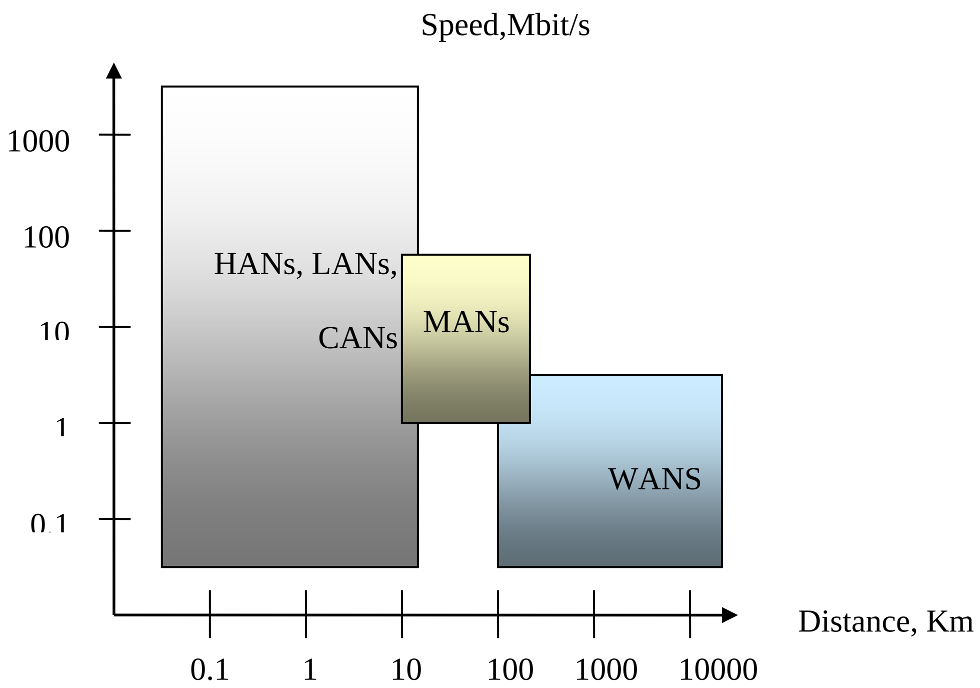


Figure 1.3 Distances and speeds of the different networks

1.5 Local Area Networks

LANs are networks usually confined to a geographic area, such as a single building, office. LANs can be small, linking as few as three computers, but often link hundreds of computers used by thousands of people. The development of standard networking protocols and media has resulted in worldwide proliferation of LANs throughout business organizations. This means that many users can share expensive devices, such as laser printers, as well as data. Users can also use the LAN to communicate with each other, by sending e-mail or engaging in chat sessions. Most LANs are built with relatively inexpensive hardware such as Ethernet cable and network interface cards (although wireless and other options exist). Specialized operating system software is also often used to configure a LAN. For example, some flavors of Microsoft Windows -- including Windows 98 SE, Windows 2000, and Windows ME -- come with a package called Internet Connection Sharing (ICS) that support controlled access to resources on the network.

1.6 Comparison of LANs and WANs

LANs are usually faster than WANs, ranging in speed from 230 Kbps up to and beyond 1 Gbps (billion bits per second) as shown in Figure 1.4. They have very small delays of less than 10 ms.

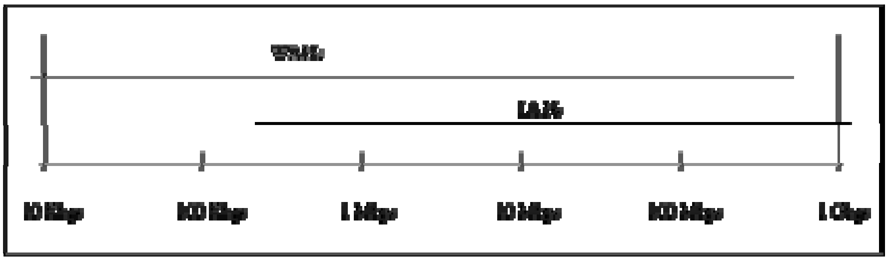


Figure 1.4 Data speeds on LANs and WANs

How does one computer send information to another? It is actually rather simple. Figure 1.5 shows and explains a simple network.

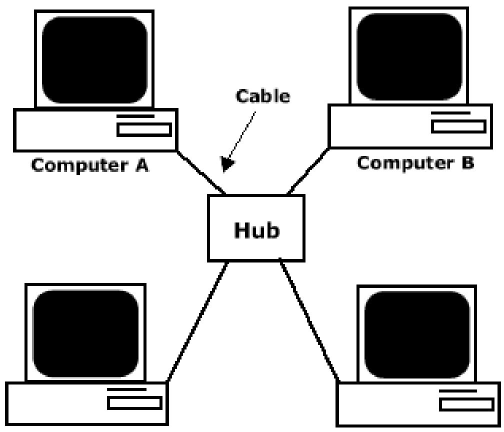


Figure 1.5 Simple network [3].

If Computer A wants to send a file to Computer B, the following would take place:

a) Based on a protocol that both computers use, the NIC in Computer A translates the file (which consists of binary data -- 1's and 0's) into pulses of electricity.
b) The pulses of electricity pass through the cable with a minimum (hopefully) of resistance.

c) The hub takes in the electric pulses and shoots them out to all of the other cables.

d) Computer B's NIC interprets the pulses and decides if the message is for it or not. In this case it is, so, Computer B's NIC translates the pulses back into the 1's and 0's that make up the file.

However, if anything untoward happens along the way, you have a problem, not a network. Thus, if Computer A sends the message to the network using NetBEUI, a Microsoft protocol, but Computer B only understands the TCP/IP protocol, it will not understand the message, no matter how many times Computer A sends it. Computer B also will not get the message if the cable is getting interference from the fluorescent lights etc. or if the network card has decided not to turn on today. Figure 1.6 shows small Ethernet local area network.

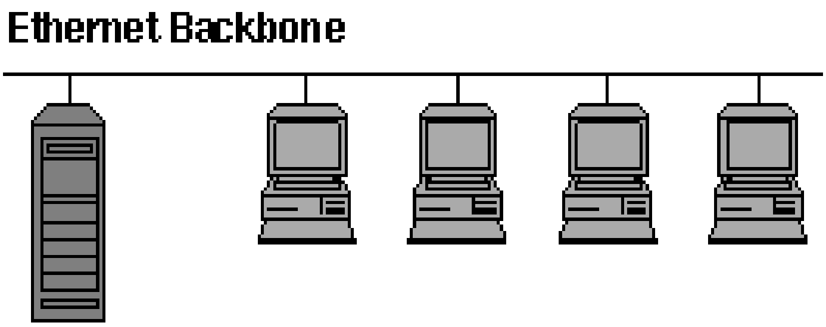


Figure 1.6 Small ethernet LAN

Figure 1.7 shows briefly the interconnection of two LANs.

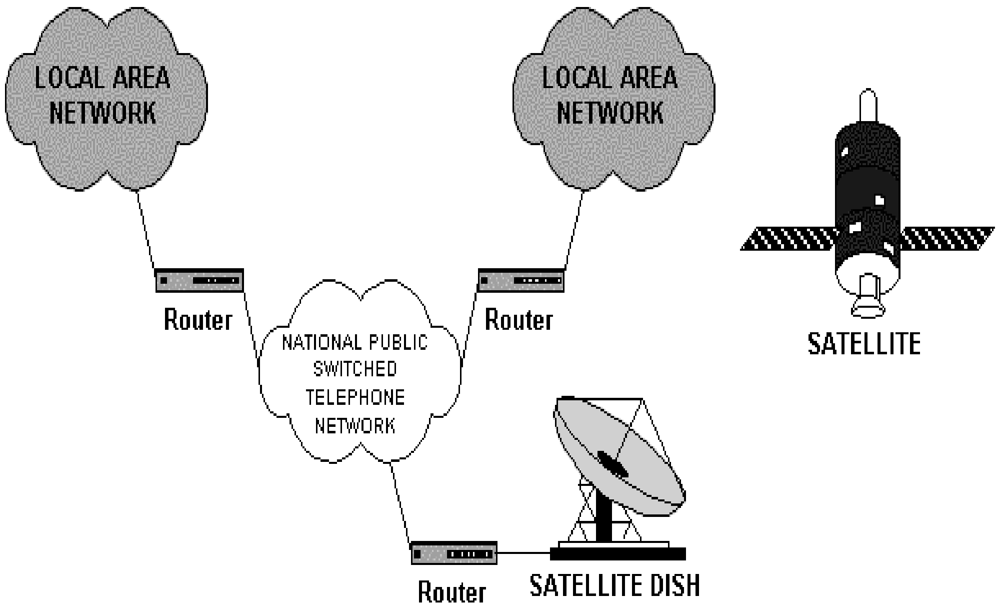


Figure 1.7 Interconnection of two LANs

1.7 Major Components of LANs

- Servers.
- Client / Workstation.
- Media.
- Shared data.
- Shared printers and other peripherals.
- Network interface card.
- Hubs / Concentrator.
- Repeaters, Bridges, Routers, Brouters, Gateways
- Physical connectors.
- Protocols.
- Network operating system

1.8 Types of LANs

LANs are usually further divided into two major types:

1.8.1 Peer-to-Peer

A peer-to-peer network does not have any dedicated servers or hierarchy among the computers. All of the computers on the network handle security and administration for themselves. The users must make the decisions about who gets access to what.

1.8.2 Client-Server

A client-server network works the same way as a peer-to-peer network except that there is at least one computer that is dedicated as a server. The server stores files for sharing, controls access to the printer, and generally acts as the dictator of the network.

1.9 LAN Connectivity Devices

1.9.1 Repeaters

Boost signal in order to allow a signal to travel farther and prevent attenuation. Attenuation is the degradation of a signal as it travels farther from its origination. Repeaters do not filter packets and will forward broadcasts. Both segments must use the same access method, meaning that you can not connect a token ring segment to an Ethernet segment. Repeaters will connect different cable types.

1.9.2 Bridges

Functions the same as a repeater, but can also divide a network in order to reduce traffic problems. A bridge can also connect unlike network segments (i.e. token ring and Ethernet). Bridges create routing tables based on the source address. If the bridge can not find the source address it will forward the packets to all segments.

1.9.3 Routers

A router will do everything that a bridge will do and more. Routers are used in complex networks because they do not pass broadcast traffic. A router will determine the most efficient path for a packet to take and send packets around failed segments. Un routable protocols can not be forwarded.

1.9.4 Brouters

A brouter has the best features of both routers and bridges in that it can be configured to pass the un routable protocols by imitating a bridge, while not passing broadcast storms by acting as a router for other protocols.

1.9.5 Gateways

Often used as a connection to a mainframe or the internet. Gateways enable communications between different protocols, data types and environments. This is achieved via protocol conversion, whereby the gateway strips the protocol stack off of the packet and adds the appropriate stack for the other side.

1.10 LANs in the Work Place and its Advantages

Network allows more efficient management of resources. For example, multiple users can share a single top quality printer, rather than putting lesser quality printers on individual desktops. Also network software licenses can be less costly that separate, stand alone licenses for the same number of users Network helps keep information reliable and up-to-date. A well managed, centralized data storage system allows multiple users to access data from different locations and limit access to data while it is being processed. Network helps speeds up data sharing. Transferring files across a network is almost always faster than other, non-network means of sharing files. Networks help business service their clients more effectively. Remote access to centralized data allows employees to service clients in the field, and clients to communicate directly to suppliers.

Speed is networks provide a very rapid method for sharing and transferring files. Without a network, files are shared by copying them to floppy disks, then carrying or sending the disks from one computer to another. This method of transferring files is very time-consuming.

Security is files and programs on a network can be designated as "copy inhibit," so that you do not have to worry about illegal copying of programs. Also, passwords can be established for specific directories to restrict access to authorized users.

Centralized Software Management is the one of the greatest benefits of installing a local area network is the fact that all of the software can be loaded on one computer (the file server). This eliminates that need to spend time and energy installing updates and tracking files on independent computers throughout the building.

Electronic Mail is the presence of a network that provides the hardware necessary to install an e-mail system. E-mail aids in personal and professional communication for all personnel, and it facilitates the dissemination of general information to the entire school staff. Electronic mail on a LAN can enable students to communicate with teachers and peers at their own school. If the LAN is connected to the internet, people can communicate with others throughout the world. Network allows workgroups to communicate more effectively. Electronic mail and messaging is a staple of most network systems, in addition to scheduling systems, project monitoring, on-line conferencing and groupware, all of which help work teams be more productive. Workgroup Computing is Workgroup software (such as Microsoft BackOffice) allows many users to work on a document or project concurrently. For example, educators located at various schools within a county could simultaneously contribute their ideas about new curriculum standards to the same document and spreadsheets.

1.11 Wi-Fi

Wi-Fi is a brand originally licensed by the Wi-Fi Alliance to describe the underlying technology of wireless local area networks (WLAN) based on the IEEE 802.11 specifications. It was developed to be used for mobile computing devices, such as laptops, in LANs, but is now increasingly used for more services, including Internet and VoIP phone access, gaming, and basic connectivity of consumer electronics such as televisions and DVD players, or digital cameras. More standards are in development that will allow Wi-Fi to be used by cars in highways in support of an Intelligent Transportation System to increase safety, gather statistics, and enable mobile commerce. Wi-Fi and the Wi-Fi certified logo are registered trademarks of the Wi-Fi Alliance the trade organization that tests and certifies equipment compliance with the 802.11x standards.

1.12 Uses

A person with a Wi-Fi enabled device such as a computer, cell phone or PDA and connect to the Internet when in proximity of an access point. The region covered by one or several access points is called a hotspot. Hotspots can range from a single room to many square miles of overlapping hotspots. Wi-Fi can also be used to create a mesh network. Both architectures are used in community networks. Wi-Fi also allows connectivity in peer-to-peer (wireless ad-hoc network) mode, which enables devices to connect directly with each other. This connectivity mode is useful in consumer electronics and gaming applications. When the technology was first commercialized there were many problems because consumers could not be sure that products from different vendors would work together. The Wi-Fi Alliance began as a community to solve this issue so as to address the needs of the end user and allow the technology to mature. The Alliance created the branding Wi-Fi has the intention to show consumers that products are interoperable with other products displaying the same branding. A term for certain types of wireless local area networks (WLAN) that use specifications conforming to IEEE.

1.13 Wi-Fi at Home

The home Wi-Fi infrastructure devices typically fall into the category of a multifunction piece of networking equipment, with wireless being only one of many features. Home Wi-Fi clients come in many shapes and sizes, from stationary PCs to digital cameras. The trend today and into the future will be to enable wireless into every device where mobility is prudent. Wi-Fi devices are often used in home or consumer-type environments in the following manner:

- Termination of a broadband connection into a single router which services both wired and wireless clients
- Ad-hoc mode for client to client connections
- Built into non-computer devices to enable simple wireless connectivity to other devices or the Internet

1.14 Wi-Fi in Gaming

Some gaming consoles and handhelds make use of Wi-Fi technology to enhance the gaming experience:

- The Nintendo DS handheld is Wi-Fi compatible. The majority of its Wi-Fi compatible games use only WEP encryption.
- The PlayStation Portable is Wi-Fi compatible, and uses this for local multiplayer as well as connecting to wireless networks for online game play.
- The Xbox 360 can be made Wi-Fi compatible if the user purchases a separate wireless adapter.
- The PlayStation 3 Premium model features built-in Wi-Fi, while the Basic model can be upgraded with a separate wireless adapter.
- The Wii is Wi-Fi compatible.

1.15 Wi-Fi in Business

Business and industrial Wi-Fi has taken off, with the trends in implementation varying greatly over the years. Current technology trends in the corporate wireless world are:

- Dramatically increasing the number of Wi-Fi Access Points in an environment, in order to provide redundancy and smaller cells.
- Designing for wireless voice applications (VoWLAN or WVOIP)
- Moving toward 'thin' Access Points, with all of the intelligence housed in a centralized network appliance; relegating individual Access Points to be simply 'dumb' radios.
- Outdoor applications utilizing true mesh topologies.

- A proactive, self-managed network that functions as a security gateway, firewall, DHCP server, intrusion detection system, and a myriad of other features not previously considered relevant to a wireless network.

1.16 How Wi-Fi Works?

A typical Wi-Fi setup contains one or more Access Points (APs) and one or more clients. An AP broadcasts its SSID (Service Set Identifier, "Network name") via packets that are called beacons, which are usually broadcast every 100 ms. The beacons are transmitted at 1 Mbit/s, and are of relatively short duration and therefore do not have a significant effect on performance. Since 1 Mbit/s is the lowest rate of Wi-Fi it assures that the client who receives the beacon can communicate at least 1 Mbit/s. based on the settings (e.g. the SSID), the client may decide whether to connect to an AP. If two APs of the same SSID are in range of the client, the client firmware might use signal strength to decide which of the two APs to make a connection to. The Wi-Fi standard leaves connection criteria and roaming totally open to the client. This is strength of Wi-Fi, but also means that one wireless adapter may perform substantially better than another. Since Wi-Fi transmits in the air, it has the same properties as a non-switched wired Ethernet network, and therefore collisions can occur. Unlike a wired Ethernet, and like most packet radios, Wi-Fi cannot do collision detection, and instead uses a packet exchange (RTS/CTS used for Collision Avoidance or CA) to try to avoid collisions.

1.17 Channels

Except for 802.11a, which operates at 5 GHz, Wi-Fi uses the spectrum near 2.4 GHz, which is standardized and unlicensed by international agreement, although the exact frequency allocations vary slightly in different parts of the world, as does maximum permitted power. However, channel numbers are standardized by frequency throughout the world, so authorized frequencies can be identified by channel numbers. The maximum numbers of available channels for Wi-Fi enabled devices are:

- 13 for Europe

- 11 for North America. Only channels 1, 6, and 11 are recommended for 802.11b/g to minimize interference from adjacent channels.
- 14 for Japan

1.18 Modes in Wireless Operations

Wireless Networks can be configured in one of three modes:

- **Ad-Hoc** - No Access Point is used. All communication is client to client.
- **Wireless Infrastructure Network** - An Access Point is central communication agent within the cell
- **LAN-to-LAN** - Two or more Access Point are used as wireless link Connecting wired networks

1.18.1 Ad-Hoc Network

An ad-hoc network is composed solely of clients that communicate among themselves without going through an Access Point. They use PC radio card configured in Ad-Hoc Mode. This is the most basic wireless LAN topology. It is normally a very loose and sometimes spontaneous association of wireless clients within communication range of each other through the wireless medium, as shown in Figure 1.8.

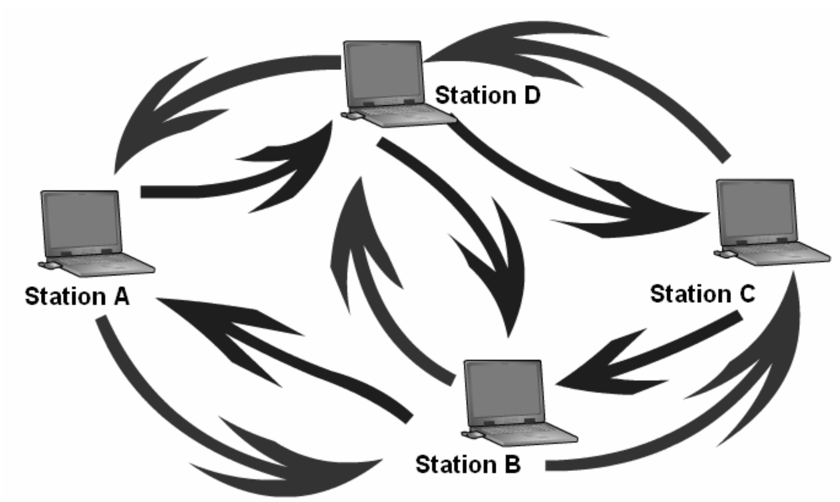


Figure 1.8 Ad-Hoc networks

The size of an ad-hoc network depends on proximity of the clients, obstacles in the environment and network utilization. For example, a large number of clients could use the network for reading e-mail with very good network performance, but a few clients transferring large files could slow the network response time for all the clients.

1.18.2 Wireless Infrastructure Network

In the Wireless Infrastructure Network mode of operation, an Access Point is located in the logical center of a wireless cell and communicates with wireless clients within cell. A wireless infrastructure (the BSS "Basic Service Set) is a network consisting of Access Point and wireless clients. Workgroup is the bridge mode an AP is configured for when in a wireless infrastructure network. Typically, Access Point is also connected to wire Ethernet Network (Figure 1.9).

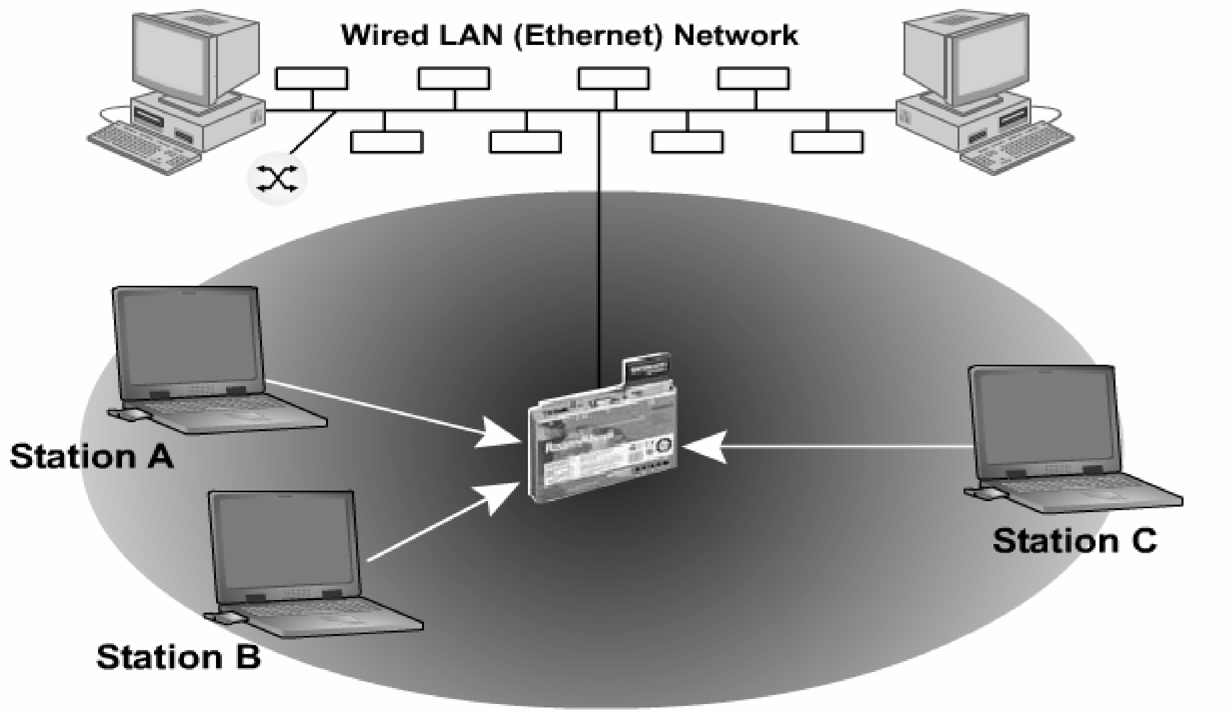


Figure 1.9 Wireless infrastructure network

At a minimum, the Access Point receives buffers and transmits data between the wireless LAN and the wired network. The Access Point forwards packets to multicast addresses, broadcast addresses, and know addresses on the wireless LAN.

1.18.3 LAN-to-LAN Mode-Point-to-Point

Point-to-point mode connects two wired LANs over a wireless link. In a typical installation, the Access Points are connected to outdoor directional as antenna on two buildings. The two antennas must NOT have obstructions between them – Line of Sight is required. The two Access Point are configured to communicate with each other, not with clients. To configure each Access Point for Point-to-point mode, the wireless MAC address of the opposite Access Point is required (Figure 1.10).

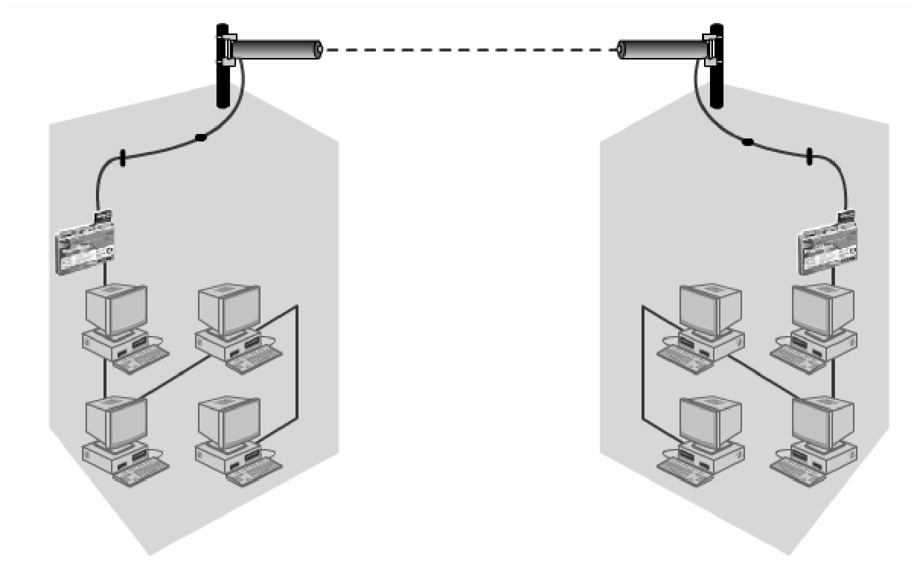


Figure 1.10 LAN-to-LAN modes – point-to-point

1.18.4 LAN-to-LAN Mode –Point-to-Multipoint

In point-to-multipoint mode, a Central Access Point is connected to an Omni-directional antenna so that it can communicate with up to remote Access Points in all directions 360 degree. The remote Access Points are configured as endpoints and generally use directional antennas. The endpoint APs can only communicate with other endpoint APs to only communicate with the Central AP, as shown in Figure 1.11.

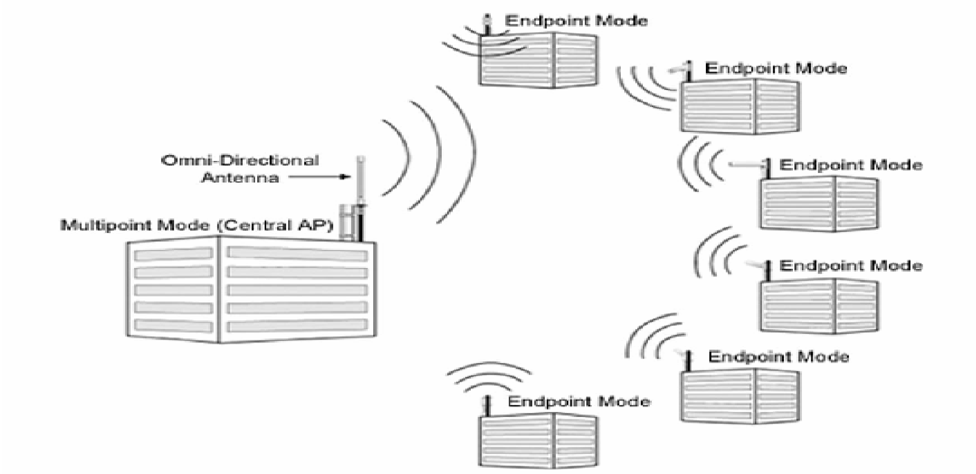


Figure 1.11 LAN-to-LAN modes – point-to-multipoint

1.18.5 LAN-to-LAN Mode – Point-to-Multipoint-to-Multipoint

Point-to-Multipoint-to-Multipoint is configured similar to the Point-to-Multipoint setting in the pervious slide. However, the difference is that one of the Access Points which is central to both areas is configured in LAN-LAN Multipoint mode. The same point rules still apply where seven Access Points can not be exceeded in a Multipoint configuration (Figure 1.12).

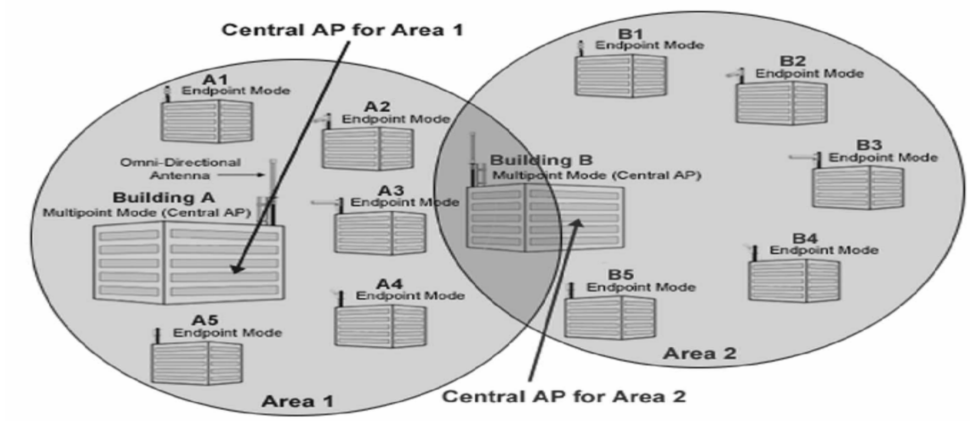


Figure 1.12 LAN-to-LAN modes – point-to-multipoint-to-multipoint

1.19 Advantages of Wi-Fi

- Allows LANs to be deployed without cabling, typically reducing the costs of network deployment and expansion. Spaces where cables cannot be run, such as outdoor areas and historical buildings, can host wireless LANs.
- Built into all modern laptops.
- Wi-Fi chipset pricing continues to come down, making Wi-Fi a very economical networking option and driving inclusion of Wi-Fi in an ever-widening array of devices.
- Wi-Fi products are widely available in the market. Different brands of access points and client network interfaces are interoperable at a basic level of service. Products designated as Wi-Fi certified by the Wi-Fi Alliance are interoperable and include WPA2 security.
- Wi-Fi is a global set of standards. Unlike cellular carriers, the same Wi-Fi client works in different countries around the world.
- Widely available in more than 250,000 public hot spots and millions of homes and corporate and university campuses worldwide.
- As of 2006, WPA and WPA2 encryption are not easily crack able if strong passwords are used.
- New protocols for Quality of Service (WMM) and power saving mechanisms (WMM Power Save) make Wi-Fi even more suitable for latency-sensitive applications (such as voice and video) and small form-factor devices.

1.20 Disadvantages of Wi-Fi

- Spectrum assignments and operational limitations are not consistent worldwide; most of Europe allows for an additional 2 channels beyond those permitted in the US (1-13 vs. 1-11); Japan has one more on top of that (1-14) - and some countries, like Spain, prohibit use of the lower-numbered channels. Furthermore some countries, such as Italy, used to require a 'general authorization' for any Wi-Fi used outside an operator's own premises, or require something akin to an operator registration.

- Equivalent isotropically radiated power (EIRP) in the EU is limited to 20 dBm (0.1 W).
- Power consumption is fairly high compared to some other standards, making battery life and heat a concern.
- The most common wireless encryption standard, Wired Equivalent Privacy or WEP, has been shown to be breakable even when correctly configured. Wi-Fi Protected Access (WPA and WPA2) which began shipping in 2003 aims to solve this problem and is now generally available.
- Wi-Fi Access Points typically default to an open (encryption-free) mode. Novice users benefit from a zero configuration device that works out of the box but might not intend to provide open wireless access to their LAN.
- Many 2.4 GHz 802.11b and 802.11g Access points default to the same channel, contributing to congestion on certain channels.
- Wi-Fi networks have limited range. A typical Wi-Fi home router using 802.11b or 802.11g with a stock antenna might have a range of 45 m indoors and 90 m outdoors. Range also varies with frequency band, as Wi-Fi is no exception to the physics of radio wave propagation. Wi-Fi in the 2.4 GHz frequency block has better range than Wi-Fi in the 5 GHz frequency block, and less range than the oldest Wi-Fi (and pre-Wi-Fi) 900 MHz block. Outdoor range with improved antennas can be several kilometers or more with line-of-sight.
- Wi-Fi pollution, meaning interference of a closed or encrypted access point with other open access points in the area, especially on the same or neighboring channel, can prevent access and interfere with the use of other open access points by others caused by overlapping channels in the 802.11g/b spectrum as well as with decreased signal-to-noise ratio (SNR) between access points. This can be a problem in high-density areas such as large apartment complexes or office buildings with many Wi-Fi access points.
- It is also an issue when municipalities or other large entities such as universities seek to provide large area coverage. Everyone is considered equal when they use the band (except for amateur radio operators who are the primary licensee). This openness is also important to the success and widespread use of Wi-Fi, but makes it unsuitable for "must have" public service functions.

- Interoperability issues between brands or deviations from the standard can disrupt connections or lower throughput speeds on other user's devices within range. Wi-Fi Alliance programs test devices for interoperability and designate devices which pass testing as certified Wi-Fi.
- Wi-Fi networks can be monitored and used to read and copy data (including personal information) transmitted over the network unless encryption such as WPA or VPN is used.

CHAPTER TWO
ANTENNA BASICS

2.1 Overview

Antennas are a very important component of communication systems. By definition, an antenna is a device used to transform an RF signal, traveling on a conductor, into an electromagnetic wave in free space. Antennas demonstrate a property known as reciprocity, which means that an antenna will maintain the same characteristics regardless if it is transmitting or receiving. Most antennas are resonant devices, which operate efficiently over a relatively narrow frequency band. An antenna must be tuned to the same frequency band of the radio system to which it is connected; otherwise the reception and the transmission will be impaired. When a signal is fed into an antenna, the antenna will emit radiation distributed in space in a certain way. A graphical representation of the relative distribution of the radiated power in space is called a Radiation Pattern.

2.2 Antenna Glossary

Before we talk about specific antennas, there are a few common terms that should be useful to define and explain:

2.3 Input Impedance

For an efficient transfer of energy, the impedance of the radio, of the antenna and of the transmission cable connecting them must be the same. Transceivers and their transmission lines are typically designed for $50\ \Omega$ impedance. If the antenna has impedance different from $50\ \Omega$, then there is a mismatch and an impedance matching circuit is required.

2.4 Return Loss

The return loss is another way of expressing mismatch. It is a logarithmic ratio measured in dB that compares the power reflected by the antenna to the power that is fed into the antenna from the transmission line. The relationship between SWR and return loss from the following equation:

$$R_L \quad (in \quad dB) \; = \; 20\log_{10}\frac{SWR}{SWR-1}, \tag{2.1}$$

where R_L is the return loss and SWR is the standing wave ratio.

2.5 Bandwidth

The bandwidth of an antenna refers to the range of frequencies over which the antenna can operate correctly. The antenna's bandwidth is the number of Hz for which the antenna will exhibit an SWR less than 2:1. The bandwidth can also be described in terms of percentage of the center frequency of the band as shown in the following equation:

$$BW = \; 100\times\frac{F_H - F_L}{F_C}, \tag{2.2}$$

where F_H the highest frequency in the band, F_L is the lowest frequency in the band, F_c is the center frequency in the band and BW is the bandwidth. In this way, bandwidth is constant relative to frequency. If bandwidth was expressed in absolute units of frequency, it would be different depending upon the center frequency. Different types of antennas have different bandwidth limitations.

2.6 Directivity and Gain

Directivity is the ability of an antenna to focus energy in a particular direction when transmitting, or to receive energy better from a particular direction when receiving. In a static situation, it is possible to use the antenna directivity to concentrate the radiation beam in the wanted direction. However in a dynamic system where the transceiver is not fixed, the antenna should radiate equally in all directions, and this is known as an omni-directional antenna. Gain is not a quantity which can be defined in terms of a physical quantity such as the Watt or the Ohm, but it is a dimensionless ratio. Gain is given in reference to a standard antenna. The two most common reference antennas are the isotropic antenna and the resonant half-wave dipole antenna. The isotropic antenna radiates equally well in all directions. Real isotropic antennas do not exist, but they provide useful and simple theoretical antenna patterns with which to compare real antennas. Any real antenna will radiate more energy in some directions than in others. Since it cannot create energy, the total power radiated is the same as an isotropic antenna, so in other directions it must radiate less energy.

The gain of an antenna in a given direction is the amount of energy radiated in that direction compared to the energy an isotropic antenna would radiate in the same direction when driven with the same input power. Usually we are only interested in the maximum gain, which is the gain in the direction in which the antenna is radiating most of the power. An antenna gain of $3\ dB$ compared to an isotropic antenna would be written as 3 dBi. The resonant half-wave dipole can be a useful standard for comparing to other antennas at one frequency or over a very narrow band of frequencies. To compare the dipole to an antenna over a range of frequencies requires a number of dipoles of different lengths. An antenna gain of $3\ dB$ compared to a dipole antenna would be written as $3\ dB$. The method of measuring gain by comparing the antenna under test against a known standard antenna, which has a calibrated gain, is technically known as a gain transfer technique. Another method for measuring gain is the three antennas method, where the transmitted and received power at the antenna terminals is measured between three arbitrary antennas at a known fixed distance.

2.7 Radiation Pattern

The radiation or antenna pattern describes the relative strength of the radiated field in various directions from the antenna, at a constant distance. The radiation pattern is a reception pattern as well, since it also describes the receiving properties of the antenna. The radiation pattern is three-dimensional, but usually the measured radiation patterns are a two dimensional slice of the three-dimensional pattern, in the horizontal or vertical planes. These pattern measurements are presented in either a rectangular or a polar format. Figure 2.1 shows a rectangular plot presentation of a typical 10 element Yagi-Uda. The detail is good but it is difficult to visualize the antenna behavior at different directions.

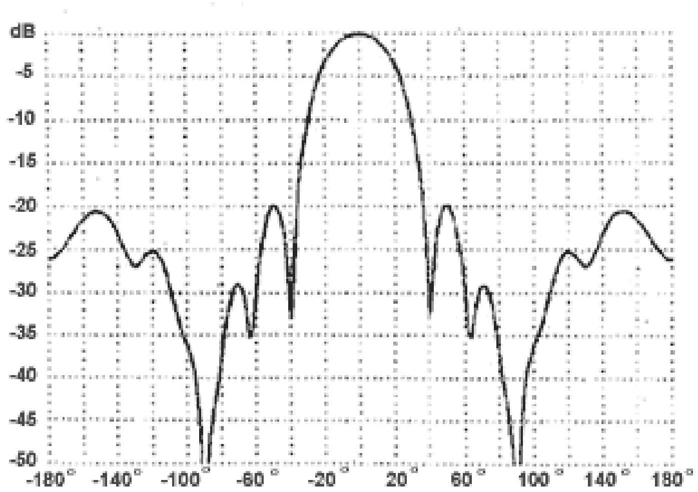


Figure 2.1 Rectangular plot presentation of a typical element Yagi-Uda [4].

Polar coordinate systems are used almost universally. In the polar coordinate graph, points are located by projection along a rotating axis (radius) to an intersection with one of several concentric circles. Figure 2.2 shows a polar plot of the same 10 element Yagi-Uda antenna. Polar coordinate systems may be divided generally in two classes: linear and logarithmic. In the linear coordinate system, the concentric circles are equally spaced, and are graduated. Such a grid may be used to prepare a linear plot of the power contained in the signal. For ease of comparison, the equally spaced concentric circles may be replaced with appropriately placed circles representing the decibel response, referenced to $0\ dB$ at the outer edge of the plot. In this kind of plot the minor lobes are suppressed. Lobes with peaks more than $15\ dB$ or so below the main lobe disappear because of their small sizes.

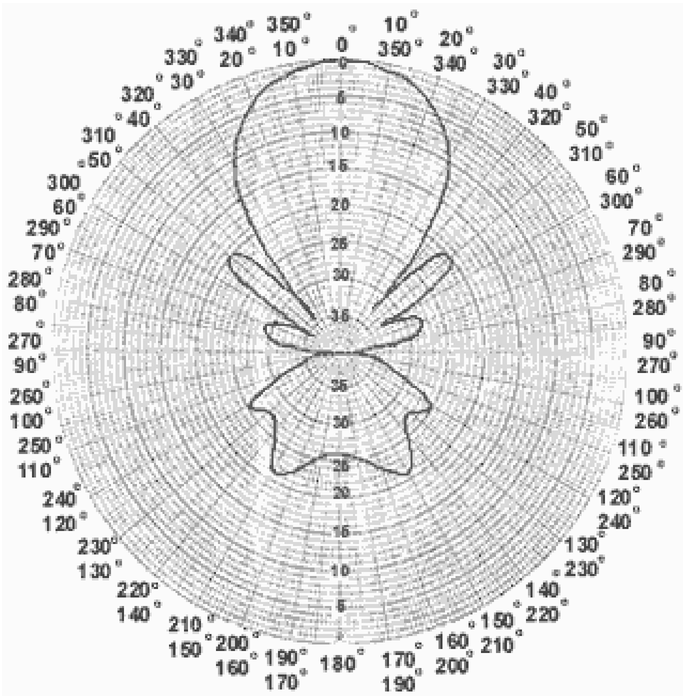


Figure 2.2 A polar plot for 10 element Yagi-Uda-Uda antenna [4].

This grid enhances plots in which the antenna has a high directivity and small minor lobes. The voltage of the signal, rather than the power, can also be plotted on a linear coordinate system. In this case, too, the directivity is enhanced and the minor lobes suppressed, but not in the same degree as in the linear power grid. In the logarithmic polar coordinate system the concentric grid lines are spaced periodically according to the logarithm of the voltage in the signal. Different values may be used for the logarithmic constant of periodicity, and this choice will have an effect on the appearance of the plotted patterns. Generally the $0\ dB$ reference for the outer edge of the chart is used. With this type of grid, lobes that are $30\ or\ 40\ dB$ below the main lobe are still distinguishable. The spacing between points at $0\ dB$ and at $-3\ dB$ is greater than the spacing between $-20\ dB$ *and* $-23\ dB$ which is greater than the spacing between $-50\ dB$ *and* $-53\ dB$ The spacing thus corresponds to the relative significance of such changes in antenna performance, as shown in Figure 2.3.

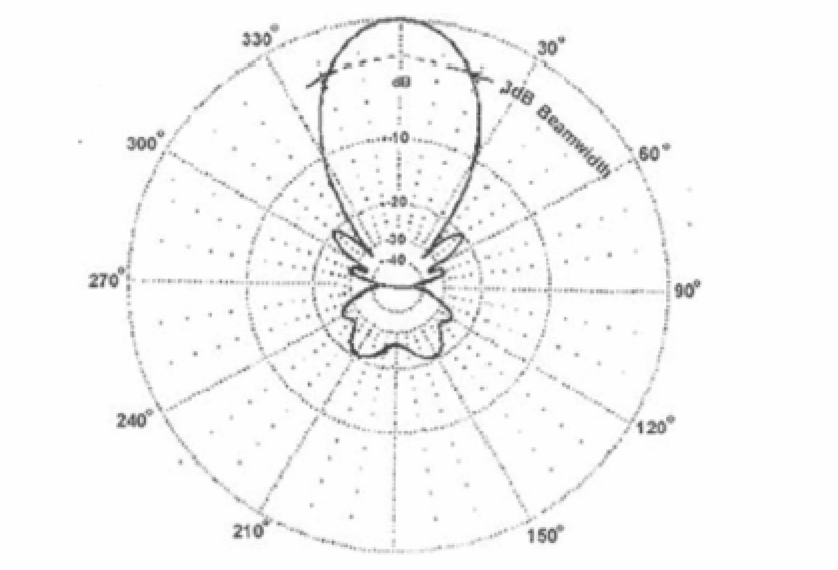


Figure 2.3 A plot in polar coordinate [5].

A modified logarithmic scale emphasizes the shape of the major beam while compressing very low-level $(> 30\ dB)$ Sidelobes towards the center of the pattern. There are two kinds of radiation pattern: absolute and relative. Absolute radiation patterns are presented in absolute units of field strength or power. Relative radiation patterns are referenced in relative units of field strength or power. Most radiation pattern measurements are relative to the isotropic antenna, and then the gain transfer method is then used to establish the absolute gain of the antenna. The radiation pattern in the region close to the antenna is not the same as the pattern at large distances. The term near-field refers to the field pattern that exists close to the antenna, while the term far-field refers to the field pattern at large distances. The far-field is also called the radiation field, and is what is most commonly of interest. Ordinarily, it is the radiated power that is of interest, and so antenna patterns are usually measured in the far-field region. For pattern measurement it is important to choose a distance sufficiently large to be in the far-field, well out of the near-field. The minimum permissible distance depends on the dimensions of the antenna in relation to the wavelength. The distance is given by

$$r_{\min} = \frac{2d^2}{\lambda}, \qquad (2.3)$$

where $r_{\min}$ the minimum distance from the antenna, d is the largest dimension of the antenna, and λ is the wavelength.

2.8 Beamwidth

An antenna's beamwidth is usually understood to mean the half-power beamwidth. The peak radiation intensity is found and then the points on either side of the peak which represent half the power of the peak intensity are located. The angular distance between the half power points is defined as the beamwidth. Half the power expressed in decibels is -3 dB, so the half power beamwidth is sometimes referred to as the 3 dB beamwidth. Both horizontal and vertical beamwidth are usually considered. Assuming that most of the radiated power is not divided into sidelobes, and then the directive gain is inversely proportional to the beamwidth: as the beamwidth decreases, the directives gain increases.

2.9 Sidelobes

No antenna is able to radiate all the energy in one preferred direction. Some is inevitably radiated in other directions. The peaks are referred to as Sidelobes, commonly specified in dB down from the main lobe.

2.10 Nulls

In an antenna radiation pattern, a null is a zone in which the effective radiated power is at a minimum. A null often has a narrow directivity angle compared to that of the main beam. Thus, the null is useful for several purposes, such as suppression of interfering signals in a given direction.

2.11 Polarization

Polarization is defined as the orientation of the electric field of an electromagnetic wave. Polarization is in general described by an ellipse. Two special cases of elliptical polarization are linear polarization and circular polarization. The initial polarization of a radio wave is determined by the antenna. With linear polarization the electric field vector stays in the same plane all the time. Vertically polarized radiation is somewhat less affected by reflections over the transmission path. Omnidirectional antennas always have vertical polarization. With horizontal polarization, such reflections cause variations in received signal strength. Horizontal antennas are less likely to pick up man-made interference, which ordinarily is vertically polarized.

In circular polarization the electric field vector appears to be rotating with circular motion about the direction of propagation, making one full turn for each RF cycle. This rotation may be right-hand or left-hand. Choice of polarization is one of the design choices available to the RF system designer.

2.12 Polarization Mismatch

In order to transfer maximum power between a transmit and a receive antenna, both antennas must have the same spatial orientation, the same polarization sense and the same axial ratio. When the antennas are not aligned or do not have the same polarization, there will be a reduction in power transfer between the two antennas. This reduction in power transfer will reduce the overall system efficiency and performance. When the transmit and receive antennas are both linearly polarized, physical antenna misalignment will result in a polarization mismatch loss which can be determined as:

$$PML \quad (dB) = 20\log(\cos\theta), \tag{2.4}$$

where PML is the polarization mismatch loss and θ is the misalignment angle between the two antennas For 15^o we have a loss of $0.3\,dB$, for 30^o we have $1.25\,dB$, for 45^o we have $3\,dB$ and for 90^o we have an infinite loss.

The actual mismatch loss between a circularly polarized antenna and a linearly polarized antenna will vary depending upon the axial ratio of the circularly polarized antenna. If polarizations are coincident no attenuation occurs due to coupling mismatch between field and antenna, while if they are not, then the communication can not even take place.

2.13 Front-to-Back Ratio

It is useful to know the front-to-back ratio that is the ratio of the maximum directivity of an antenna to its directivity in the rearward direction. For example, when the principal plane pattern is plotted on a relative dB scale, the front-to-back ratio is the difference in dB between the level of the maximum radiation, and the level of radiation in a direction 180^o.

2.14 Types of Antennas

Classification of antennas can be based on the following factors:

2.14.1 Frequency and Size

Antennas used for HF are different from the ones used for VHF, which in turn are different from antennas for microwave. The wavelength is different at different frequencies, so the antennas must be different in size to radiate signals at the correct wavelength. We are particularly interested in antennas working in the microwave range, especially in $2.4\,GHz$ and $5\,GHz$ frequencies. At $2.4\,GHz$ the wavelength is $0.125\,m$, while at $5\,GHz$ it is $0.06\,m$.

2.14.2 Directivity

Antennas can be Omnidirectional, sectorial or directive. Omnidirectional antennas radiate the same pattern all around the antenna in a complete 360^o pattern. The most popular types of omnidirectional antennas are the Dipole-Type and the Ground Plane. Sectorial antennas radiate primarily in a specific area. The beam can be as wide as 180^o, or as narrow as 60^o. Directive antennas are antennas in which the Beamwidth is much narrower than in sectorial antennas. They have the highest gain and are therefore used for long distance links. Types of directive antennas are the Yagi-Uda, the horn, the helix, the patch antenna, the parabolic dish and many others.

2.15 Physical Construction

Antennas can be constructed in many different ways, ranging from simple wires to parabolic dishes, up to coffee cans. When considering antennas suitable for $2.4\,GHz$ WLAN use, another classification can be used:

2.15.1 Application

We identify two application categories which are Base Station and Point-to-Point. Each of these suggests different types of antennas for their purpose. Base Stations are used for multipoint access. Two choices are Omni antennas which radiate equally in all directions, or Sectorial antennas, which focus into a small area. In the Point-to-Point case, antennas are used to connect two single locations together. Directive antennas are the primary choice for this application. A brief list of common type of antennas for the $2.4\,GHz$ frequency is presented now, with a short description and basic information about their characteristics.

2.15.2 1/4 Wavelength Ground Plane

The 1⁄4 Wavelength Ground Plane antenna is very simple in its construction and is useful for communications when size, cost and ease of construction are important. This antenna is designed to transmit a vertically polarized signal. It consists of a 1⁄4 wave element as half-dipole and three or four 1⁄4 wavelength ground elements bent $30^o - 45^o$ down. This set of elements, called radials, is known as a ground plane. This is a simple and effective antenna that can capture a signal equally from all directions. To increase the gain, however, the signal can be flattened out to take away focus from directly above and below, and providing more focus on the horizon. The vertical Beamwidth represents the degree of flatness in the focus.

This is useful in a Point-to-Multipoint situation, if all the other antennas are also at the same height. The gain of this antenna is in the order of $2-4\,dBi$ as shown in Figure 2.4.

Figure 2.4 1/4 Wavelength ground plane [6].

2.15.3 Yagi-Uda Antenna

A basic Yagi-Uda consists of a certain number of straight elements, each measuring approximately half wavelength. The driven or active element of a Yagi-Uda is the equivalent of a center-fed, half-wave dipole antenna. Parallel to the driven element, and approximately $0.2-0.5$ wavelength on either side of it, are straight rods or wires called reflectors and directors, or passive elements altogether. A reflector is placed behind the driven element and is slightly longer than half wavelength; a director is placed in front of the driven element and is slightly shorter than half wavelength. A typical Yagi-Uda has one reflector and one or more directors. The antenna propagates electromagnetic field energy in the direction running from the driven element toward the directors, and is most sensitive to incoming electromagnetic field energy in this same direction. The more directors a Yagi-Uda has, the greater the gain. As more directors are added to a Yagi-Uda, however, it becomes longer. Figure 2.5 shows a Yagi-Uda antenna with 6 directors and one reflector [8].

Figure 2.5 Yagi-Uda antenna [7].

Yagi-Uda antennas are used primarily for Point-to-Point links, have a gain from 10 to 20 dBi and a horizontal Beamwidth of 10 to 20 degrees.

2.15.4 Other Antennas

Many other types of antennas exist and new ones are created following the advances in technology.

Sector or Sectorial antennas: they are widely used in cellular telephony infrastructure and are usually built adding a reflective plate to one or more phased dipoles. Their horizontal Beamwidth can be as wide as 180^o or as narrow as 60^o, while the vertical is usually much narrower. Composite antennas can be built with many Sectors to cover a wider horizontal range (multi-sectorial antenna).

Panel or Patch antennas: they are solid flat panels used for indoor coverage, with a gain up to $20\ dB$.

CHAPTER THREE
ANTENNA TYPES

3.1 Overview

This chapter describes some antennas types such as parabolic dish and horn antenna.

3.2 Overview of Parabolic Dish

A dish antenna works the same way as a reflecting optical telescope. Electromagnetic waves, light or radio, arrive on parallel paths from a distance source and are reflected by a mirror to a common point, called the focus. When a ray of light reflects from a mirror or flat surface, the angle of the path leaving (angle of reflection) is the same as the angle of the path arriving (angle of incidence). This optical principle is familiar to anyone who misspent part of his youth at a pool table! If the mirror is a flat surface, then two rays of light leave in parallel paths; however, if the mirror is curved, two parallel incident rays leave at different angles. If the curve is parabolic ($y = ax^2$) then all the reflected rays meet at one point, as shown in Figure 3.1. A dish is a parabola of rotation, a parabolic curve rotated around an axis which passes through the focus and the center of carve. A transmitting antenna reverses the path: the light or radio wave originates from a point source at the focus and is reflected into a beam of rays parallel to the axis of the parabola, as shown in Figure 3.1.

3.2.1 Illumination

Some of the difficulties found in real antennas are easier to understand when considering the transmitting antenna, but are also present in receiving antennas, since antennas are reciprocal. One difficulty is finding a point source, since any antenna, even a half-wave dipole at $10\,GHz$, is much bigger than a point. Even if we were able to find a point source, it would radiate equally in all directions, so the energy that was not radiated toward the reflector would be wasted. The energy radiated from the focus toward the reflector illuminates the reflector, just as a light bulb would. Thus, we are looking for a point source that illuminates only the reflector.

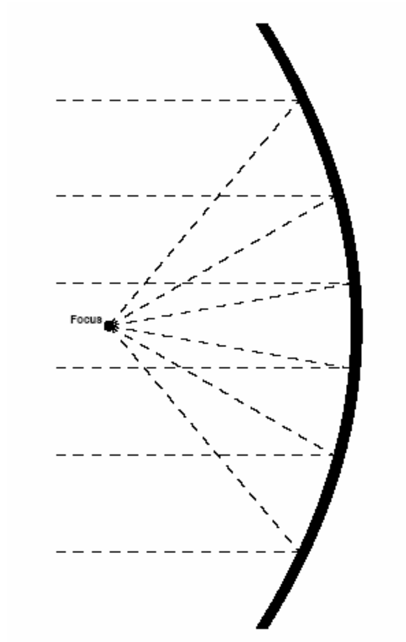


Figure 3.1 Geometry of parabolic dish antenna

3.2.2 Aperture, Gain, and Efficiency

The aperture **A** of a dish antenna is the area of the reflector as seen by a passing radio wave, and is given by

$$A = \pi r^2, \tag{3.1}$$

where r is the radius, half of the diameter of the dish. If we replace a dish antenna with a much larger one, the greater aperture of the larger one captures much more of the passing radio wave, and thus larger dish has more gain than a smaller one. If we do a little geometry, we find that the gain is proportional to the aperture. The gain of a dish as:

$$G_{dbi} = 10\log_{10}\left(\eta \frac{4\pi}{\lambda^2} A\right), \tag{3.2}$$

where η is the efficiency of the antenna, λ is wavelength and A is area the reflector.

3.2.3 Practical Dish Antennas

When we first described a parabolic dish antenna, we put a point source at the focus, so that energy would radiate uniformly in all directions both in magnitude and phase. The problem is that the energy that is not radiated toward the reflector will be wasted. What we really want is a feed antenna that only radiates toward the reflector, and has a phase pattern that appears to radiate from a single point.

3.2.4 Feed Patterns

We have already seen that efficiency is a measure of how well we use the aperture. If we can illuminate the whole reflector, then we should be using the whole aperture. Perhaps our feed pattern should be as shown in Figure 3.2, with uniform feed illumination across the reflector. But when we look more closely at the parabolic surface, we find that the focus is farther from the edge of the reflector than from the center. Since radiated power diminishes with the square of the distance (inverse-square law), less energy is arriving at the edge of the reflector than at the center; this is commonly called space attenuation or space taper.

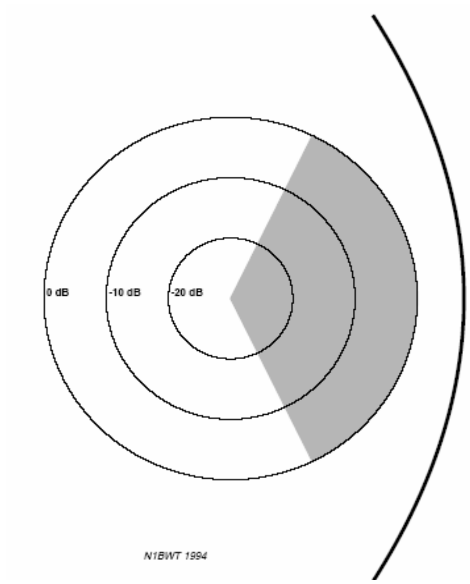


Figure 3.2 Parabolic dish antenna with uniform feed illumination [9].

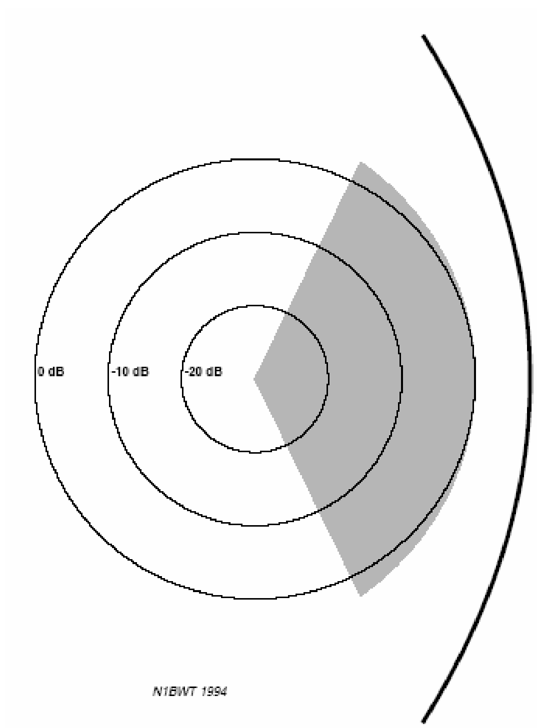


Figure 3.3 Desired dish illumination - uniform reflector illumination [9].

In order to compensate, we must provide more power at the edge of the dish than in the center by adjusting the feed pattern as shown in Figure 3.3 in order to have constant illumination over the surface of the reflector.

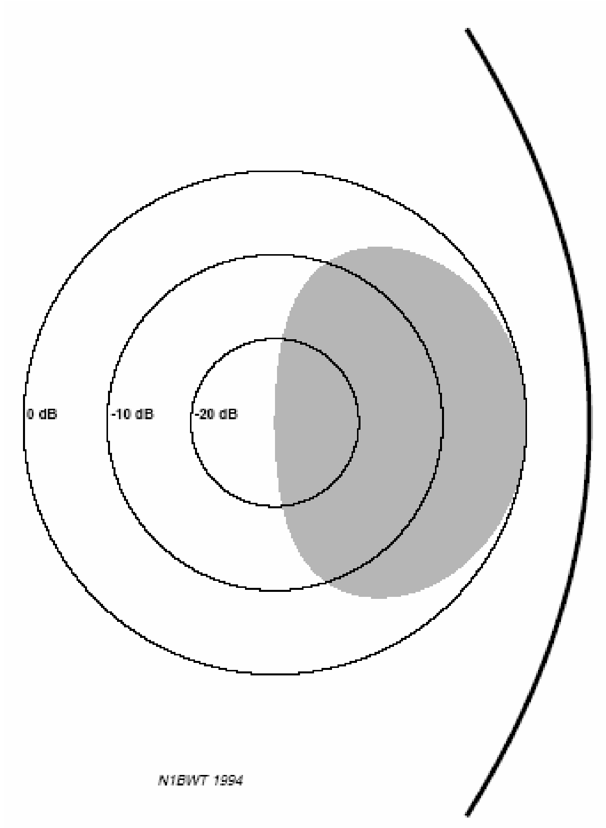


Figure 3.4 Parabolic dish antenna with typical feed horn illumination [9].

Simple feed antennas, like a circular horn (coffee-can feed) that many hams have used, have a pattern which can be approximated by an idealized $\cos\theta^n$ pattern like the one shown in Figure 3.4. In Figure 3.5 we superimpose the idealized pattern on our desired pattern; we have too much energy in the center, not enough at the edges, and some misses the reflector entirely. The missing energy at the edges is called illumination loss and the energy that misses the reflector is called spillover loss. The more energy we have at the edge, the more spillover we have, but if we reduce spillover, then the outer part of the dish is not well illuminated and is not contributing to the gain. Therefore, simple horn feeds are not ideal for dish feeds (although they are useful and work very well in some applications). In order to have very efficient dish illumination we need to increase the energy near the edge of the dish and have the energy drop off very quickly beyond the edge.

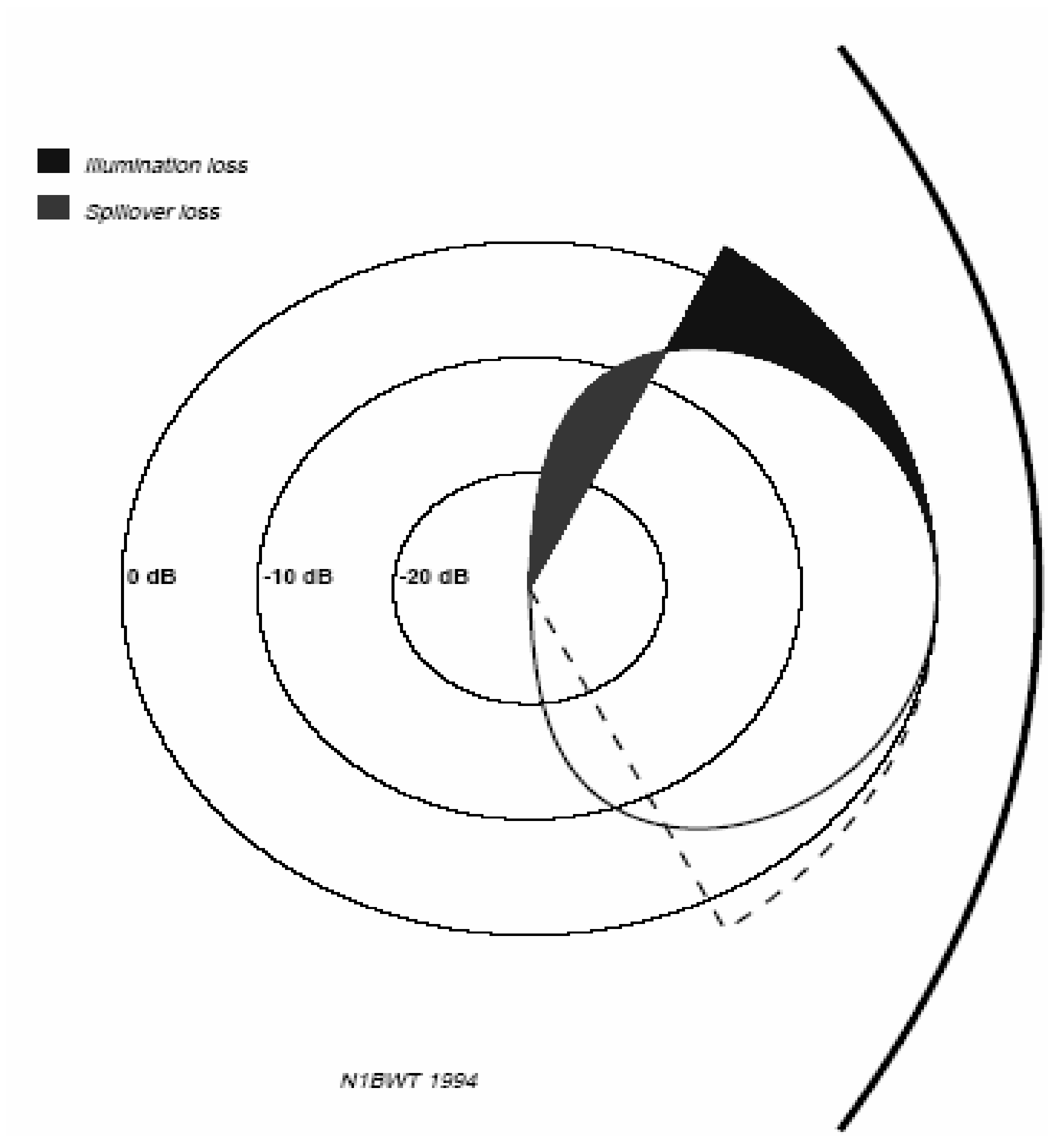
3.2.5 Edge Taper

Almost all feedhorns will provide less energy at the edge of dish than at the center, like Figure 3.4. The difference in power at the edge is referred to as the edge taper. With different feedhorns, we can vary the edge taper with which a dish is illuminated. Different edge tapers produce different amounts of illumination loss and spillover loss, as shown in Figure 3.6. Small edge taper results in larger spillover loss, while a large edge taper reduces the spillover loss at the expense of increased illumination loss.

If we plot these losses versus the energy at the edge of the dish, as in Figure 3.7, we find that the total efficiency of a dish antenna peaks with an illumination taper, like Figure 3.6, so that the energy at the edge is about $10\,dB$ lower than the energy at the center. This is often referred to as $10\,dB$ edge taper or edge illumination often recommended but not explained.

3.2.6 G/T

When an antenna is receiving a signal from space, like a satellite or EME signal, there is very little background noise emanating from the sky compared to the noise generated by the warm 300K earth during terrestrial communications. Most of the noise received by an antenna pointed at the sky is earth noise arriving through feed spillover. As shown in Figure 3.6, the spillover can be reduced by increasing the edge taper, while Figure 3.7 shows the efficiency, and thus the gain, decreasing slowly as edge taper is increased. The best compromise is reached when G/T, the ratio of gain to antenna noise temperature, is the maximum. This typically occurs with an edge taper of about $13\,dB$.



f/D = 0.4

Illumination taper = 10 dB

Figure 3.5 Typical vs. desired dish illumination [9].

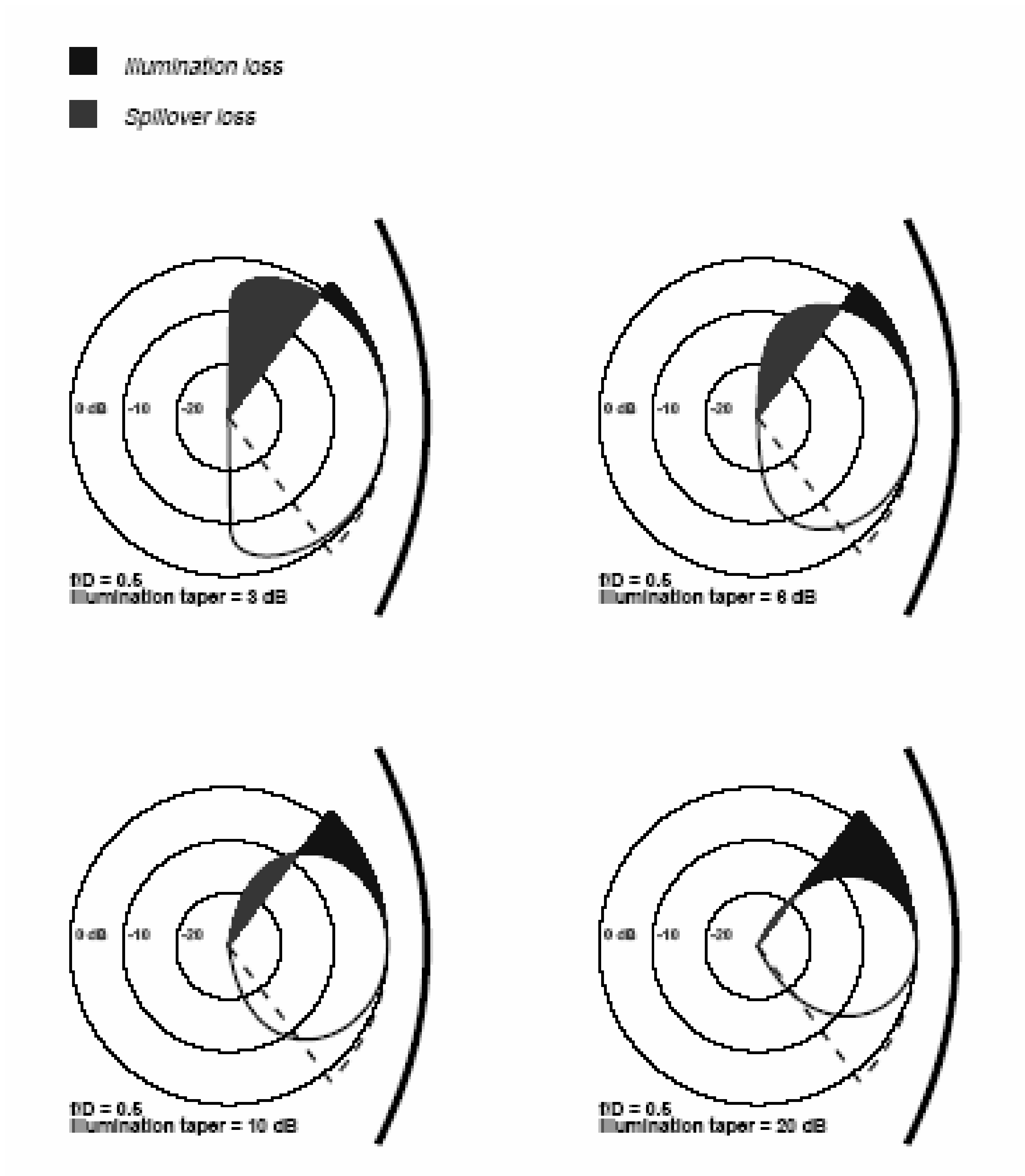


Figure 3.6 Dish illuminations with various illumination tapers [9].

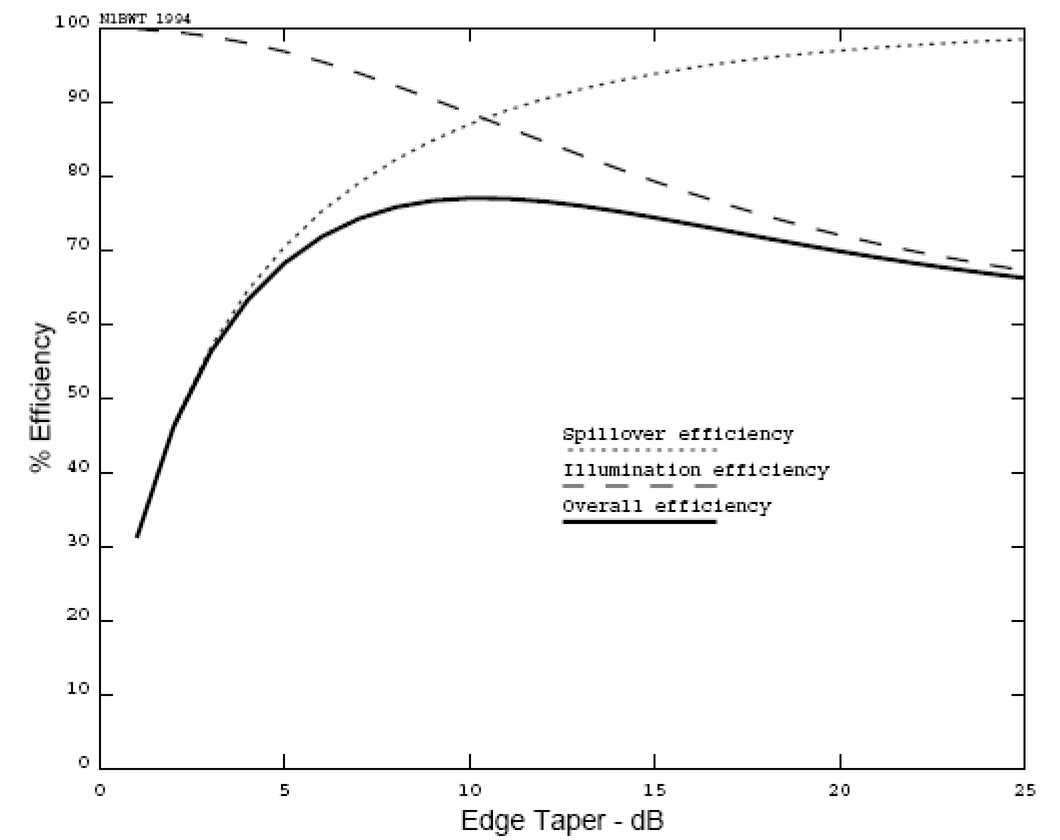


Figure 3.7 Efficiency vs. edge taper for a dish [9].

Edge taper for G/T is a function of receiver noise temperature and sky noise temperature at any given frequency.

3.2.7 Focal Length and f/D ratio

A convenient way to describe how much of the parabola is used is the f/D ratio, the ratio of the focal length f to the diameter D of the dish. All dishes with the same f/D ratio require the same feed geometry, in proportion to the diameter of the dish. The figures so far have depicted one arbitrary f/D. Figure 3.8 shows the relative geometries for commonly used

f/D ratios, typically from 0.25 to 0.65, with the desired and idealized feed patterns for each. Notice the feed horn patterns for the various f/D ratios in Figure 3.8. As f/D becomes smaller, the feed pattern to illuminate it becomes broader, so different feedhorns are needed to properly illuminate dishes with different f/D ratios. The feedhorn pattern must be matched to the reflector f/D. Larger f/D dishes need a feed horn with a moderate beam width, while a dish with an f/D of 0.25 has the focus level with the edge of the dish, so the subtended angle that must be illuminated is 180 degrees. Also, the edge of the dish is twice as far from the focus as the center of the dish, so the desired pattern would have to be $6\,dB$ stronger (inverse-square law) at the edge as in the center. This is an extremely difficult feed pattern to generate, and consequently, it is almost impossible to efficiently illuminate a dish this deep.

3.2.8 Phase Center

A well designed feed for a dish or lens has a single phase center, thus that the feed radiation appears to emanate from a single point source, at least for the main beam, the part of the pattern that illuminates the dish or lens. Away from the main beam, the phase center may move around and appear as multiple points, as stray reflections and surface currents affect the radiation pattern. Also, the phase center will move with frequency, adding difficulty to broadband feed design. Fortunately, we are only considering narrow frequency ranges here.

3.2.9 Symmetry of E-plane and H-Plane

On paper, we can only depict radiation in one plane. For a simple antenna with linear polarization, like a dipole, this is all we really care about. A dish, however, is three-dimensional, so we must feed it uniformly in all planes. The usual plane for linear polarization is the E-plane, while the plane perpendicular to it is the H-plane. Unfortunately, most antennas not only have different radiation patterns in the E- and H-planes, but also have different phase centers in each plane, so both phase centers cannot be at the focus.

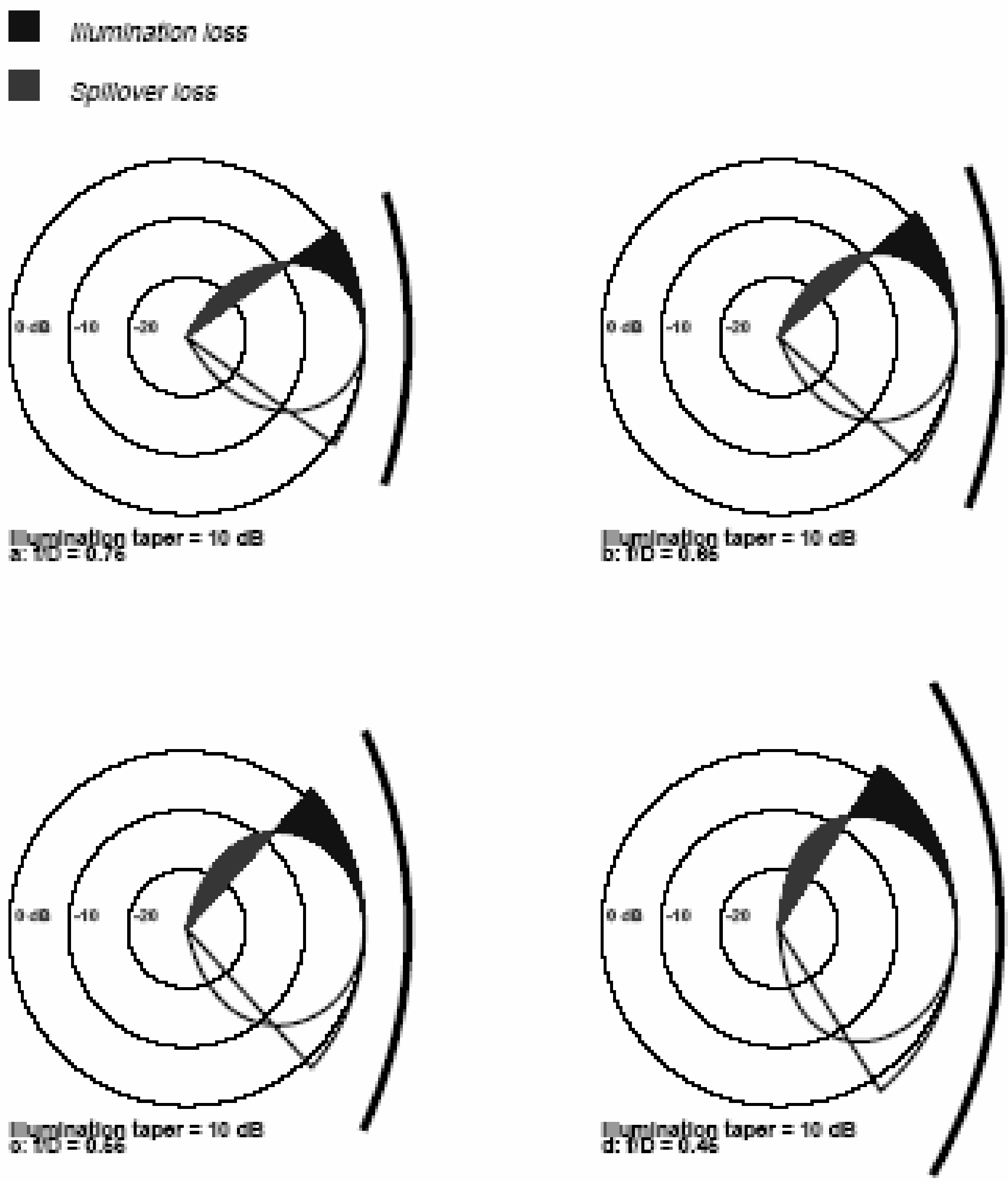


Figure 3.8 Dish illuminations for various f/D ratios [9].

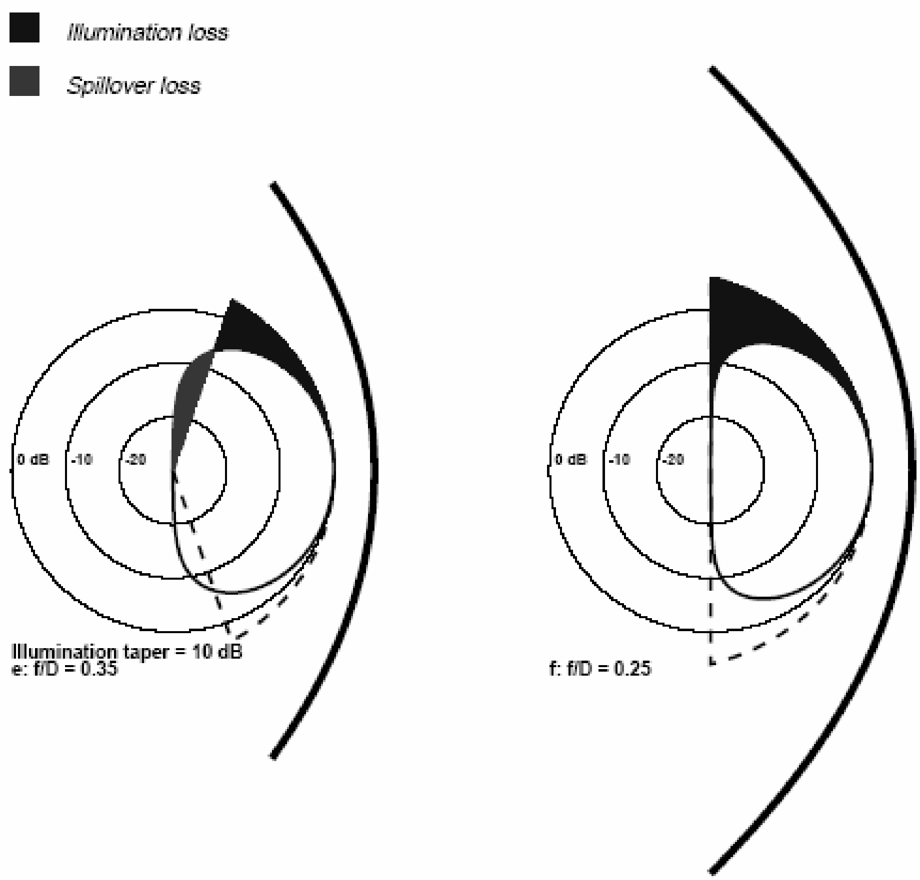


Figure 3.9 Dish illumination for various f/D ratios [9].

3.2.10 Calculation of the Focal Point for the Parabolic Dish

Calculating the correct focal point of a dish is important when installing a feed. Even if the dish is a standard manufactured unit, the focal point will vary from dish to dish due to manufacturing tolerances. To calculate the focal point (F) of a dish, one needs to measure the diameter (D) and depth (d) of the dish (Figure 3.10).

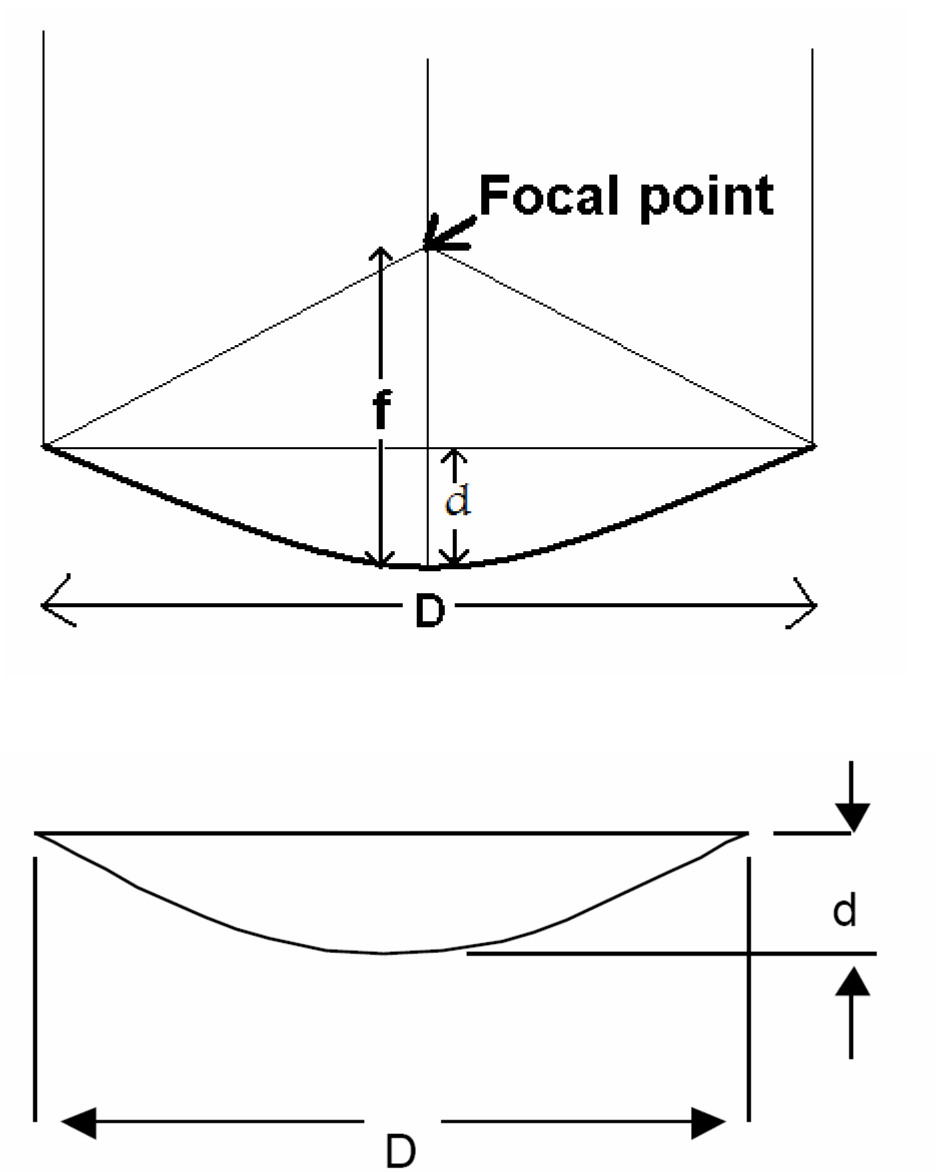


Figure 3.10 Focal point calculation

The steps are as follows: Place a rigid straight edge across the dish and measure the depth to the center of the dish keeping the measuring instrument square to the straight edge. The measurements should be of the actual parabola. Do not include the rolled edge of the dish in your measurement (Figure 3.11).

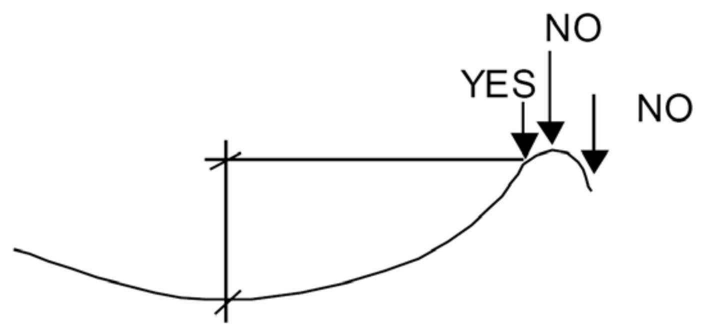


Figure 3.11 Focal point calculation

When measuring, one should be as precise possible. Maintain 1 mm accuracy if using metric, and .01” accuracy if using inches for measurements. Now, focal point can be calculated from

$$f = \frac{D^2}{16d}, \tag{3.3}$$

where f is the focal point of the dish, D is the diameter and d is depth.

Refer to the data sheet that comes with the feed to determine its actual focal point. Use both pieces of data to properly install the feed on the antenna system. If all measurements are correct it should be very close to optimum, but further optimization could be done with a “on the air signal” or use sun noise measurements.

3.3 Horn Antenna

The horn antenna derives its name from the characteristic flared appearance. The flared portion can be square, rectangular, cylindrical or conical. The direction of maximum radiation corresponds with the axis of the horn. It is easily fed with a waveguide, but can be fed with a coaxial cable and a proper transition. Horn antennas are commonly used as the active element in a dish antenna. The horn is pointed toward the center of the dish reflector. The use of a horn, rather than a dipole antenna or any other type of antenna, at the focal point of the dish minimizes loss of energy around the edges of the dish reflector. At $2.4\,GHz$, a simple horn antenna (see Figure 3.12) made with a tin can has a gain in the order of $10-15\,dBi$.

Figure 3.12 Horn antenna

CHAPTER FOUR
PLANNING AND DESIGN OF ANTENNAS

4.1 Overview

This chapter shows how we can extend the range in Wi-Fi 802.11. Actually, to extend the range in Wi-Fi there are many steps one has to follow. The range of coverage depends on the following points:

- the power of sending and receiving equipments such as access point
- the gain of the antenna

To extend the range, we have to find out the transmitted and received intensity of power, the antenna gain or both. The transmitting or receiving gains can be increased by adding power amplifier circuits. Unfortunately this is an expensive process requiring specialized equipment. In this thesis, only the gain of the antenna has been increased which is probably the cheapest way of extending the range of a Wi-Fi wireless system.

4.2 Antenna Construction

It is important to realize that:

- An antenna is a device that:

    a. Converts RF power applied to its feed point into electromagnetic radiation.
    b. Intercepts energy from a passing electromagnetic radiation, which then appears as RF voltage across the antenna's feed point.

- Any conductor, through which an RF current is flowing, can be an antenna.
- Any conductor that can intercept an RF field can be an antenna.

4.2.1 Biquad Antenna Implementation

The biquad antenna is very easy to build, very cheap and provides a reliable 11dBi gain improvement. The design described in this section was taken from [11].

Antenna specifications and advantage:

- Compatible with 802.11 b/g
- Can send and receive data up to 54 Mbs
- High gain
- High stability
- Easy to construct
- Home made
- Very cheap

4.2.1.1 Antenna Calculations

The antenna is designed to optimally operate at the center of the $802.11 \ 2.4 \ GHz$ band. The center of the band is determined by Table 4.1. The center frequency can be found using

$$f_c = \frac{f_l + f_u}{2}, \tag{4.1}$$

where f_l is the lower frequency and f_u is upper frequency.

The wavelength is given by

$$\lambda = \frac{c}{f_c}, \tag{4.2}$$

where c is the speed of light and f_c is the center frequency.

Table 4.1 Standard IEEE 802.11 2.4 GHz band

Channel	f_l	f_c	f_u
1	2.401	2.412	2.423
2	2.404	2.417	2.428
3	2.411	2.422	2.433
4	2.416	2.427	2.438
5	2.421	2.432	2.443
6	2.426	2.437	2.448
7	2.431	2.442	2.453
8	2.436	2.447	2.458
9	2.441	2.452	2.463
10	2.446	2.457	2.468
11	2.451	2.462	2.473
12	2.456	2.467	2.478
13	2.461	2.472	2.483

Now we will apply Equations (4.1) and (4.2) to design the biquad antenna.

$$f_c = 2.441\,GHz$$

$$\lambda = \frac{3\times 10^8}{2441\times 10^6} = 122\,mm$$

4.2.1.2 Parts Required

The following parts will be required for the antenna:

- 122x122 mm square section of blank PCB Printed Circuit Board
- 50 mm length of 0.5 inches copper pipe
- Short length of CNT-400 or LMR-400 low loss coax or RG/58 maximum 2 meters
- 250 mm of 2.5 mm^2 copper wire (approx 1.5mm diameter)
- N connector

It is worth to note that there is no need to use blank PCB for the reflector. One can use any material that is electrically conductive. It can be electrically connected to the coax braid, and will reflect microwaves (e.g., any metal plate will do fine). The copper and aluminum are better than other materials especially with antenna. Thus, it is better to use copper or aluminum.

4.2.1.3 Reflector

Cut 122 x122 mm square piece of blank printed circuit board (Figure 4.1).

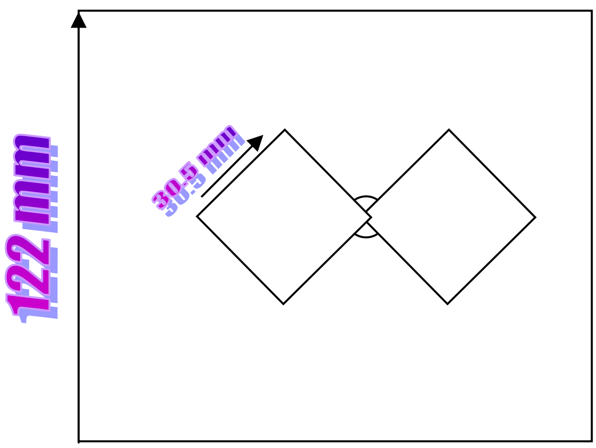


Figure 4.1 Biquad antenna

It is recommended to attach some lips to two sides of the reflector, to reduce radiation from the rear lobes. Use some steel wool to remove any tarnish and polish it up. Cleaning the copper in this way will make it easier to solder.

Cut a 50 mm section of copper pipe, and file both ends smooth. Using some sandpaper and/or some files, polish up the copper pipe (including the inside of the copper pipe, to ensure a good connection with the coax braid).

Cut a notch into one end of the copper pipe, removing approximately 2 mm from half the circumference, a short section of copper pipe, notched at one end, as shown in Figure 4.2.

Figure 4.2 Copper pipe [10].

Drill a hole in the centre of the blank PCB so that the copper pipe is a tight fit in the hole. We found a reamer to be very useful for enlarging the hole to the correct size (Figure 4.3).

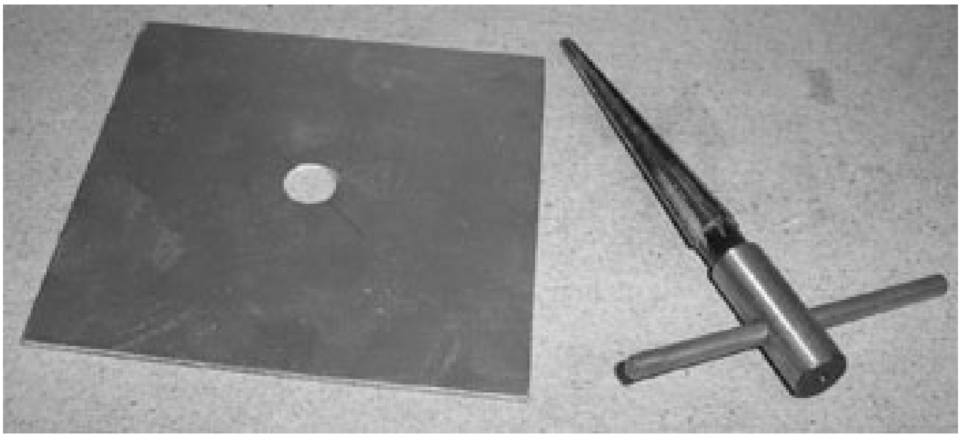


Figure 4.3 Making a hole in the center [10].

Insert the copper pipe into the hole, as shown in Figure 4.4, with the notched end on the copper side of the blank PCB. The copper pipe should be protruding approximately 16 mm through the hole, measured on the copper side of the PCB.

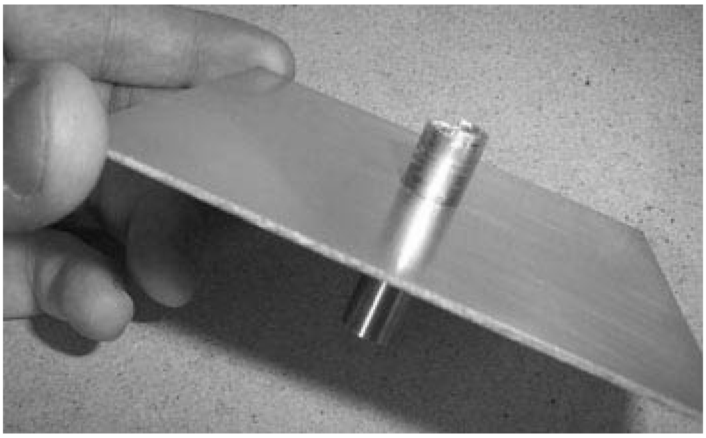


Figure 4.4 Insert the copper pipe into the reflector [10].

Solder the copper pipe to the PCB as shown in Figure 4.5, to ensure a good physical and electrical connection.

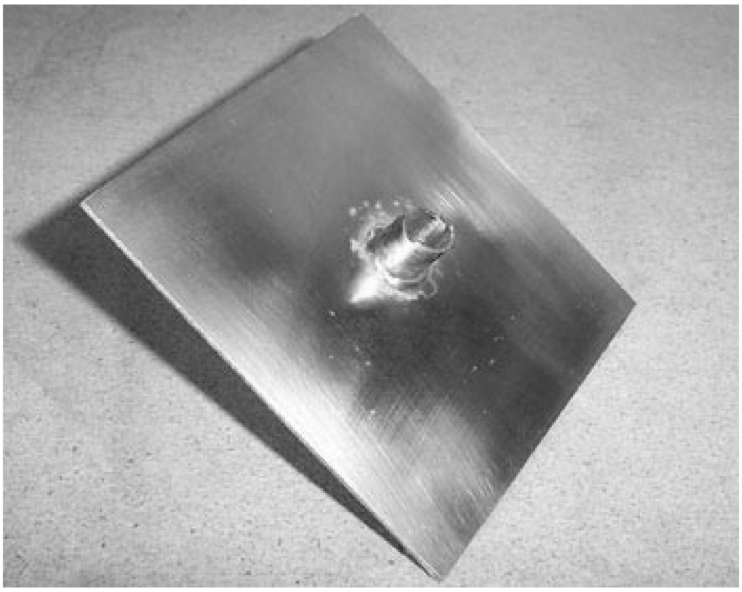


Figure 4.5 Solder the copper pipe to the PCB [10].

Quite a bit of heat is needed, due to the thickness of the copper pipe, and an electrical soldering iron probably will not be able to deliver sufficient heat. A small gas torch may work quite well.

4.2.1.4 Making the Element

The element is made from a length of copper wire, bent into the appropriate shape. Note that the length of each side should be as close to 30.5 mm as possible (measured from the centre of the copper wire to the centre of the copper wire), which is a quarter of a wavelength at 2.4 GHz. Measure and cut a 244 mm length the copper wire, and straighten it as best as possible (Figure 4.6).

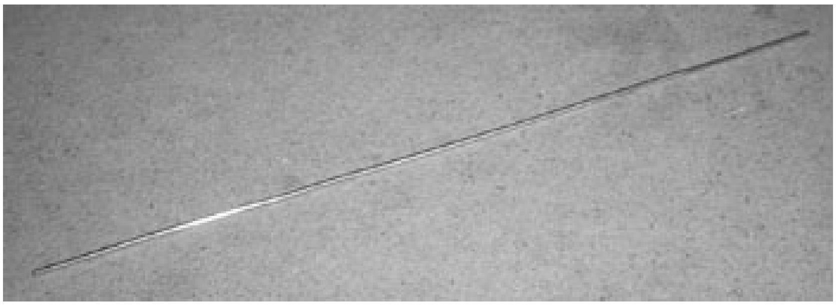


Figure 4.6 Straighten the copper wire [10].

Measure the mid-point of the wire, and make a 90 degree bend. The bend should be quite sharp and pronounced (Figure 4.7).

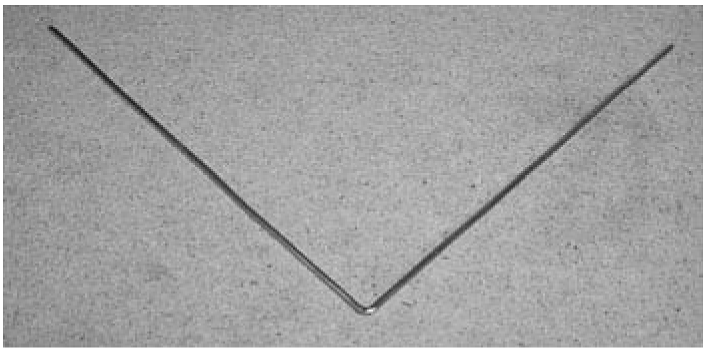


Figure 4.7 90 Degree bend [10].

Measure the midpoints of each half, and make two more 90 degree bends in the wire, so that it looks like that shown in Figure 4.8.

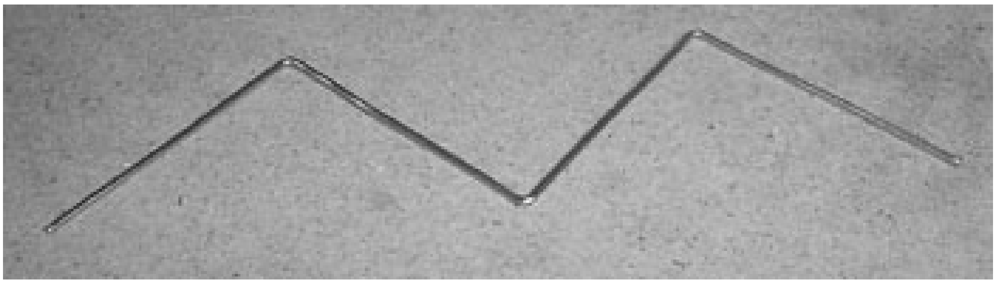


Figure 4.8 Another two bends [10].

Once again, measure the midpoints of each section, and make some more 90 degree bends, as shown in Figure 4.9.

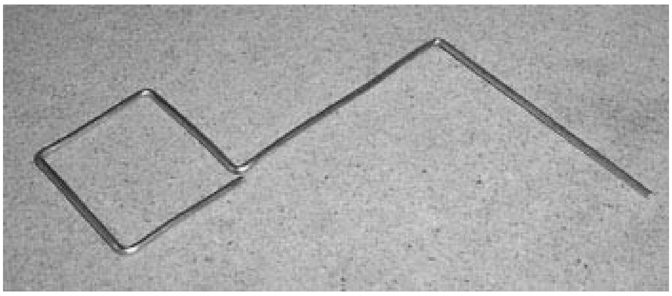


Figure 4.9 Bend it some more [10].

Do the same to the other side, resulting in the biquad shape shown in Figure 4.10.

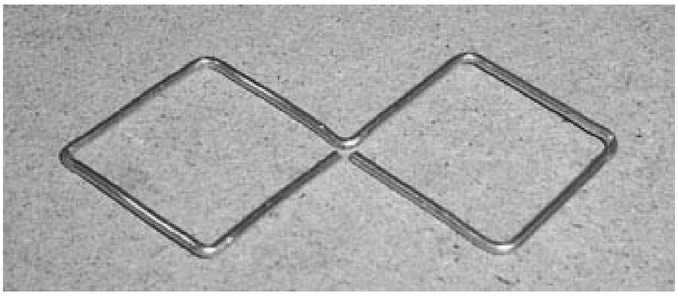


Figure 4.10 Make it symmetrical [10].

Clean up all the bends, and ensure each side of the element is as straight as possible, and as close to 30.5 mm as possible.

Note that it may be necessary to trim a small amount off each end of the wire to achieve the final shape (Figure 4.10).

4.2.1.5 Assembly

The element must now be attached to the reflector. Note that only the two ends of the copper wire are to be attached to the copper pipe - the centre of the copper wire must not touch the copper pipe (hence the notch which was cut into the end of the copper pipe). The copper wire should be approximately 15 mm away from the reflector (Figure 4.11).

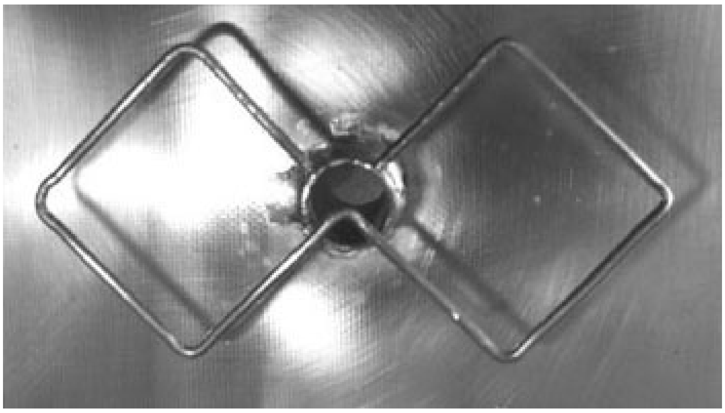


Figure 4.11 The element soldered on to the copper pipe [10].

Strip approximately 30 mm of the outer sheath from the end of the coax, as shown in Figure 4.12.

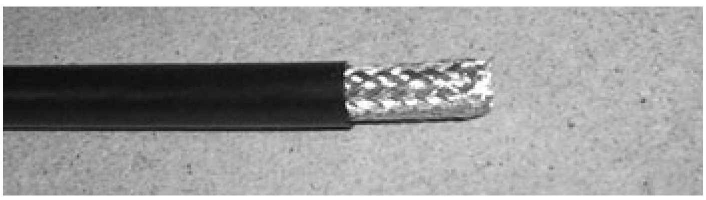


Figure 4.12 Strip the cuter sheath [10].

Fold the braid back over the outer sheath, and trim the centre conductor, so that about 4mm is protruding (Figure 4.13).

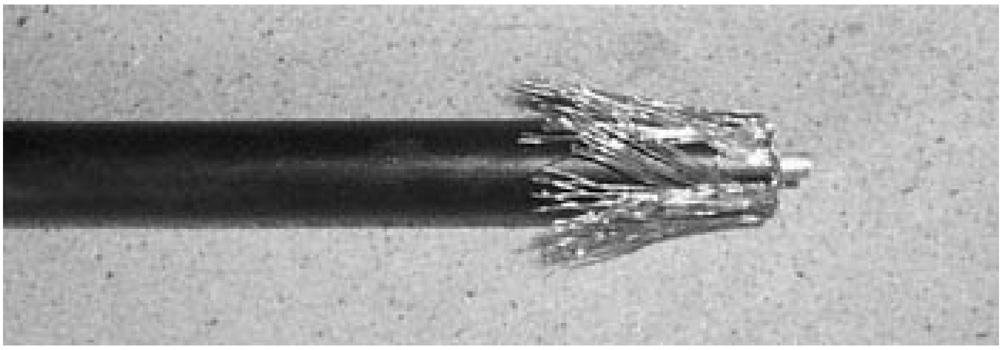


Figure 4.13 Fold the braid back, trim the centre conductor [10].

Insert the braid into the copper pipe, so that the end of the centre conductor lines up with the extreme end of the copper pipe, and solder the centre of the element to it, ensuring the centre of the element is not in contact with the copper pipe (Figure 4.14).

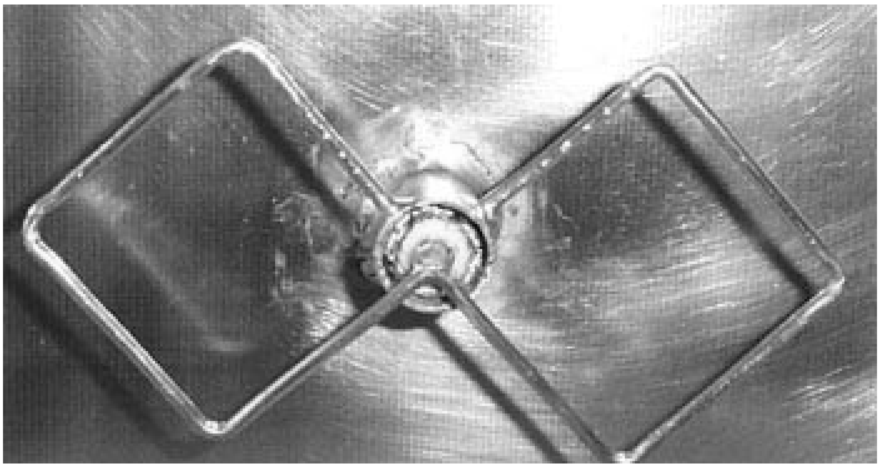


Figure 4.14 Solder the centre conductor to the element [10].

4.3 Sector Antenna Implementation

It is well known that sector antennas are very important for wireless base stations. After searching and reading about antenna theory, the author discovered that it is very easy to build a sector antenna. The sector antenna theory depends on the same theory as the biquad antenna. Figure 4.15 shows the sector antenna.

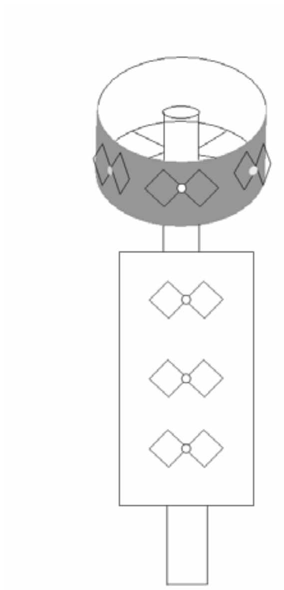


Figure 4.15 Sector antenna with 120 degree

4.3.1 Antenna Theory and Calculations

Although the sector antenna theory depends on the same theory as the biquad antenna theory, the author made some enhancement to the performance and has increased the gain of a typical sector antenna.

The sector antenna is designed to optimally operate at the center of the 802.11 b/g 2.4 GHz band. The center of the band is determined by Table 4.1.

Now we will apply Equations (4.1) and (4.2) to design the sector antenna.

$$f_c = 2.441\,GHz$$

$$\lambda = \frac{3\times10^{8}}{2441\times10^{6}} = 122\,mm$$

Figure 4.16 and Figure 4.17 show the segments length we have to calculate.

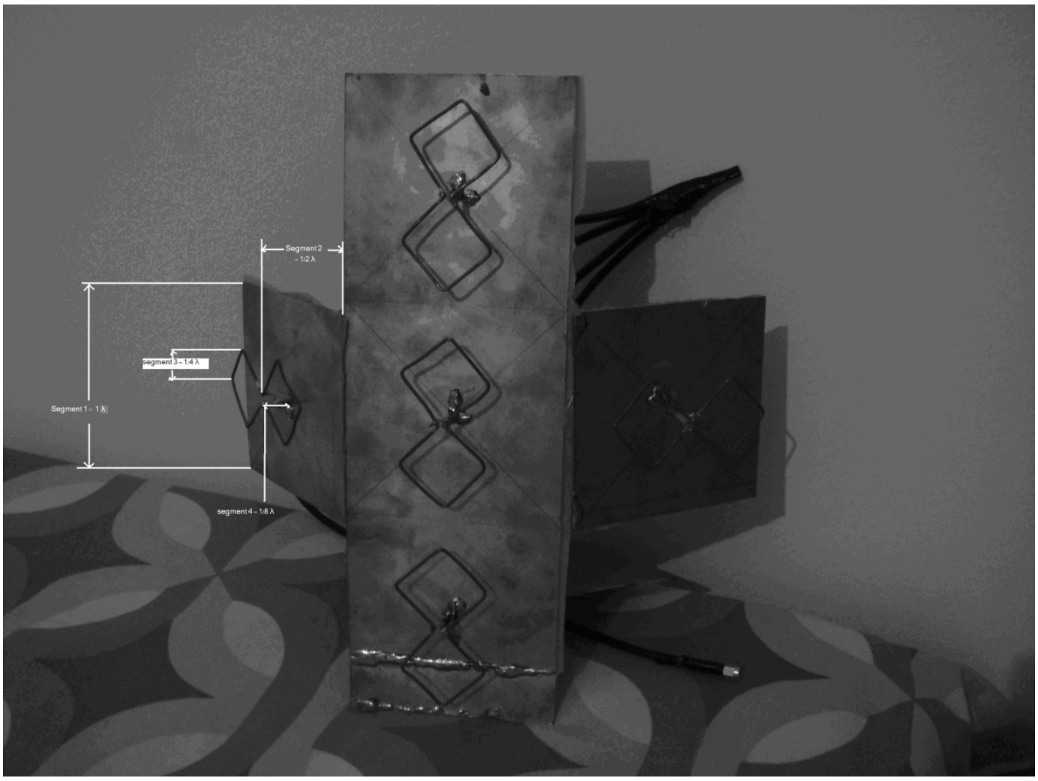


Figure 4.16 Segment length calculations

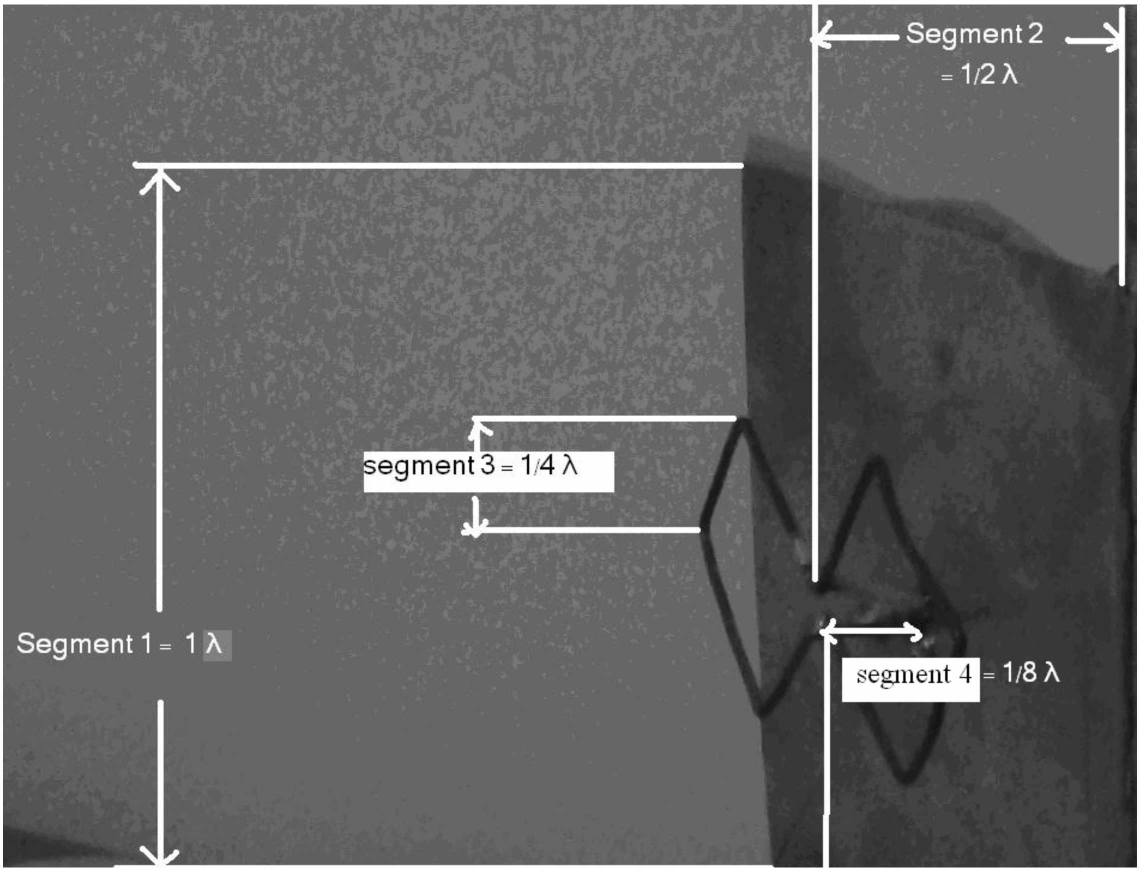


Figure 4.17 Segment length calculations in detail

Calculation of λ is of much concern to us since it is used for every segment in Figure 4.17. Hence we may calculate λ for every segment as follows:

$$\text{Segment 1} = \lambda = 122\ mm$$

$$\text{Segment 2} = \frac{1}{2}\lambda = 61\ mm$$

$$\text{Segment 3} = \frac{1}{4}\lambda = 30.5\ mm$$

$$\text{Segment 4} = \frac{1}{8}\lambda = 15.8\ mm$$

4.3.2 Parts Required

- 366 mm x 122 mm section of blank PCB "Printed Circuit Board"
- Three parts of 50 mm length of 0.5 inches copper pipe
- short length of CNT-400 or LMR-400 low loss coax or RG/58 maximum 3 meters
- Six of 250 mm of 2.5 mm^2 copper wire (approx 1.5 mm diameter)
- N Connector
- 366 mm x 122 mm of copper paper A4 copper paper

4.3.3 Implementation

Cut 3 parts of a 50 mm section of copper pipe, and file both ends smooth. Using some sandpaper and/or some files, polish up the copper pipe (including the inside of the copper pipe, to ensure a good connection with the coax braid). Cut a notch into one end of the copper pipe, removing approximately 2mm from half the circumference for each part, as shown in Figure 4.18.

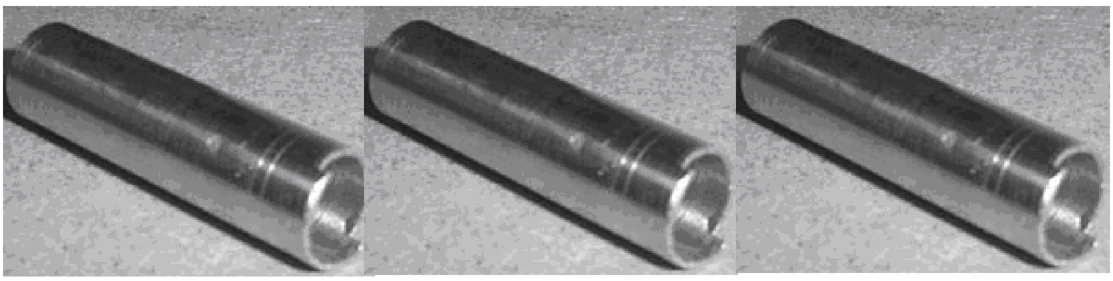


Figure 4.18 Three copper pipe

Now bring 366 mm x 122 mm section of blank PCB Printed Circuit Board and drill holes in three centers, as shown in Figure 4.19.

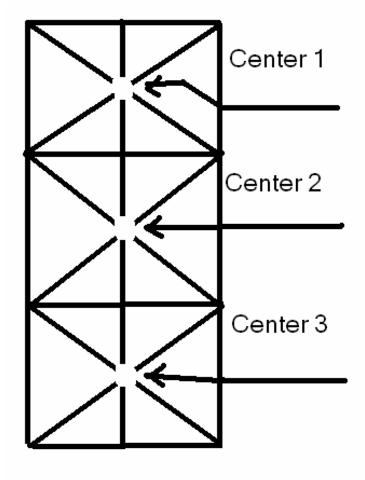


Figure 4.19 Doing three centers in PCB

The distance between each center will be 122 mm as we calculated. Segment 1 = 122 mm (Figure 4.20).

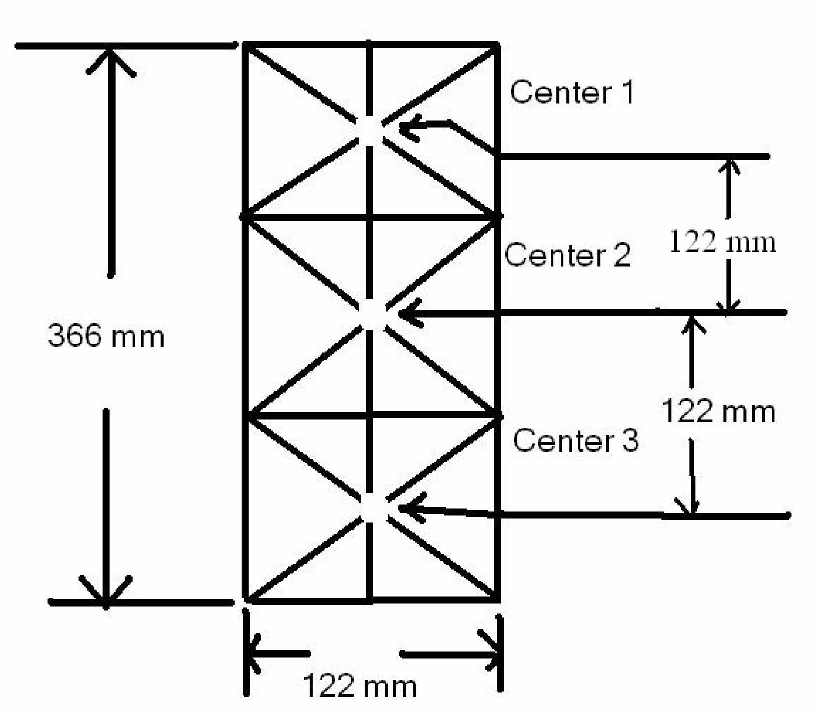


Figure 4.20 Doing centers and distance 122 mm between each other.

Insert the copper pipe into the three holes, as shown in Figure 4.20, with the notched end on the copper side of the blank PCB. The copper pipe should be protruding approx 16 mm through the hole, measured on the copper side of the PCB.

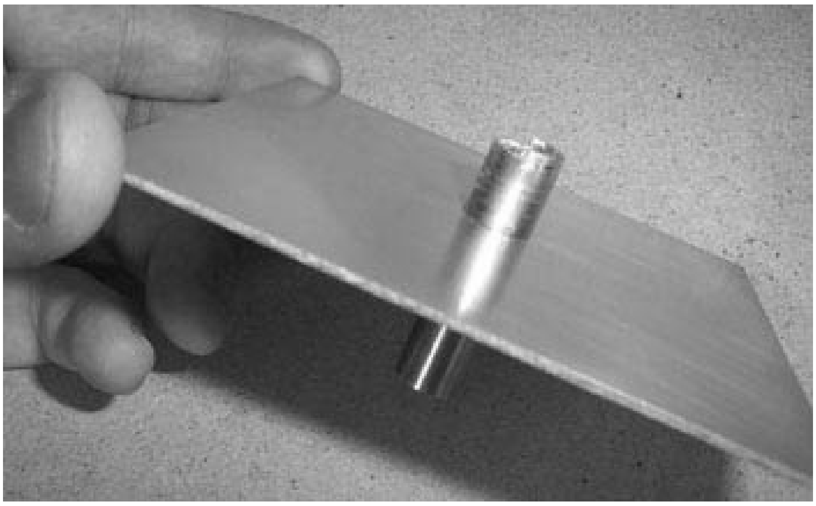


Figure 4.21 Insert the copper pipe into the PCB [10].

Solder the copper pipe to the PCB, as shown in Figure 4.21, to ensure a good physical and electrical connection.

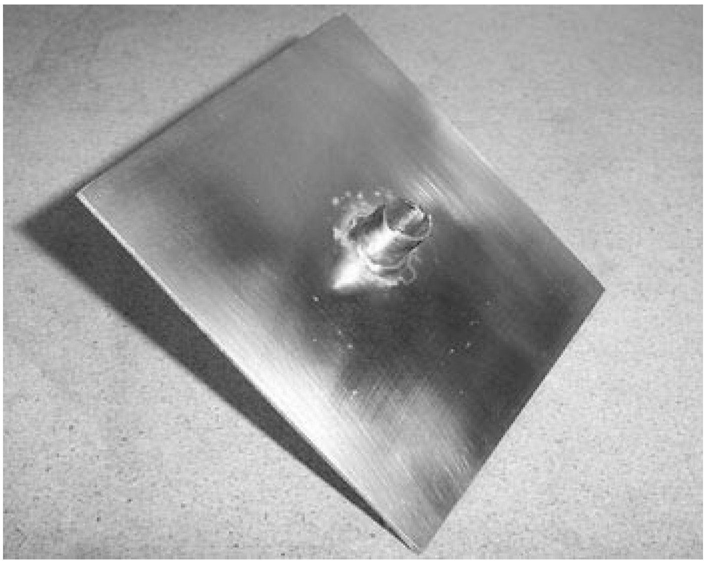


Figure 4.22 Solder the copper pipe to the PCB [10].

4.3.4 Making the Elements

The element is made from a length of copper wire, bent into the appropriate shape. Note that the length of each side should be as close to 30.5 mm as possible (measured from the centre of the copper wire to the centre of the copper wire), which is a quarter of a wavelength at 2.4 GHz measure and cut a 244 mm length the copper wire, and straighten it as shown in Figure 4.23.

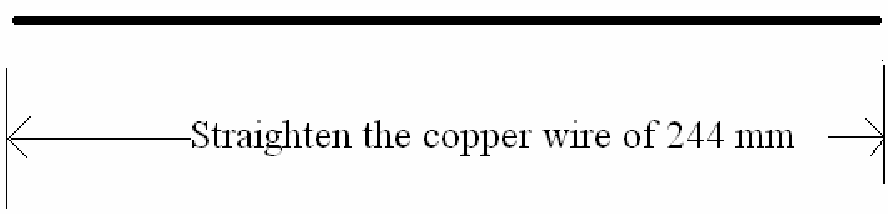


Figure 4.23 Straighten the copper wire

Measure the mid-point of the wire, and make a 90 degree bend. The bend should be quite sharp and pronounced (Figure 4.24).

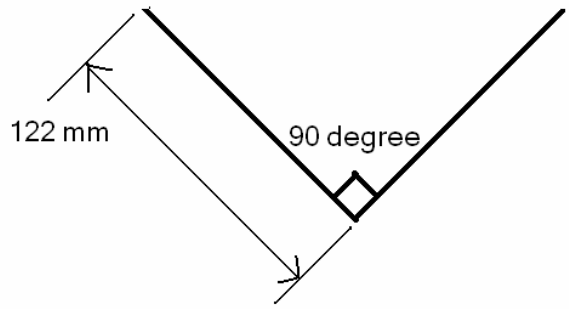


Figure 4.24 90 Degree bend

Measure the midpoints of each half, and make two more 90 degree bends in the wire, so that it looks like that shown in the Figure 4.25.

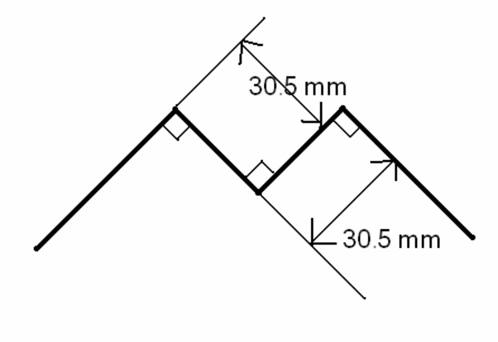


Figure 4.25 Another two bends

Once again, measure the midpoints of each section, and make some more 90 degree bends, resulting in what is shown in Figure 4.26.

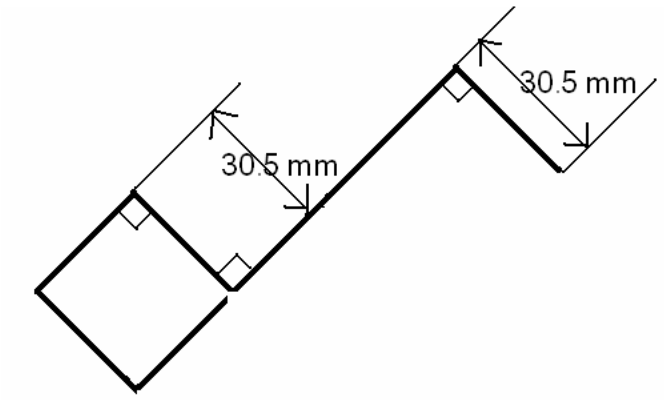


Figure 4.26 Bend it some more

Do the same to the other side, resulting in the biquad shape shown in Figure 4.27.

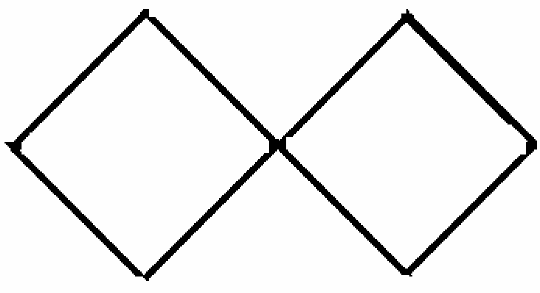


Figure 4.27 Make it symmetrical

Clean up all the bends, and ensure each side of the element is as straight as possible, and as close to 30.5mm as possible. Do more 5 shapes like Figure 4.26 and use the same steps to build them. Note that a small amount off each end may need to be trimmed of the wire to achieve what is shown in Figure 4.27.

The element must now be attached to the reflector. Note that only the two ends of the copper wire are to be attached to the copper pipe - the centre of the copper wire must not touch the copper pipe (hence the notch which was cut into the end of the copper pipe). The copper wire should be approximately 15 mm away from the reflector (Figure 4.28).

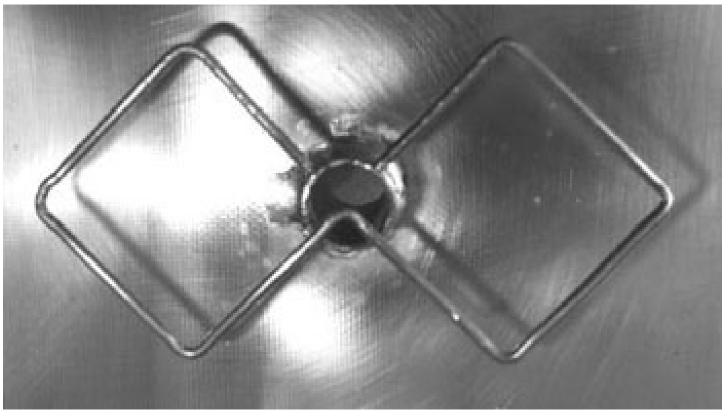


Figure 4.28 The element soldered on to the copper pipe

Strip approximately 30mm of the outer sheath from the end of the coax (Figure 4.29).

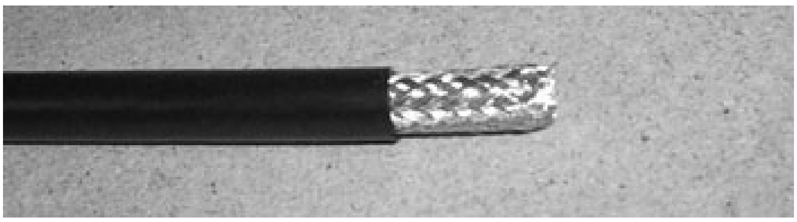


Figure 4.29 Strip the outer sheath

Fold the braid back over the outer sheath, and trim the centre conductor, so that about 4 mm is protruding, as shown in Figure 4.30.

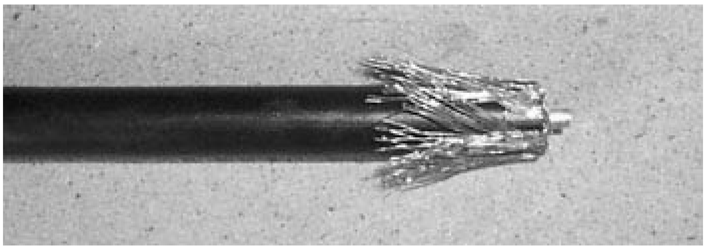


Figure 4.30 Fold the braid back, trim the centre conductor

Insert the braid into the copper pipe, so that the end of the centre conductor lines up with the extreme end of the copper pipe, and solder the centre of the element to it, ensuring the centre of the element is not in contact with the copper pipe (Figure 4.31).

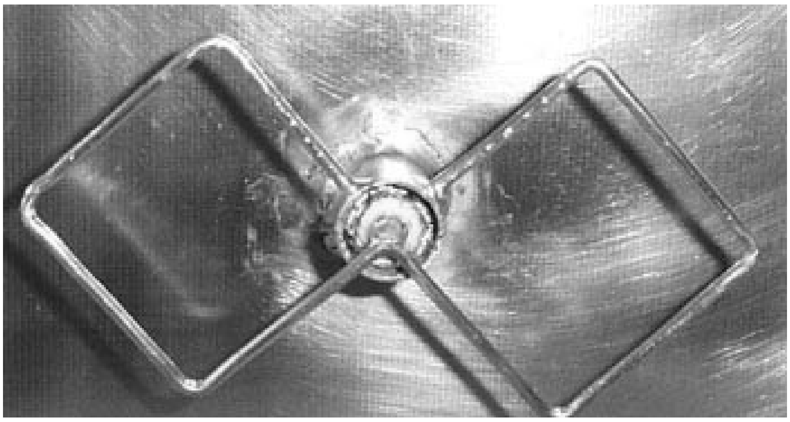
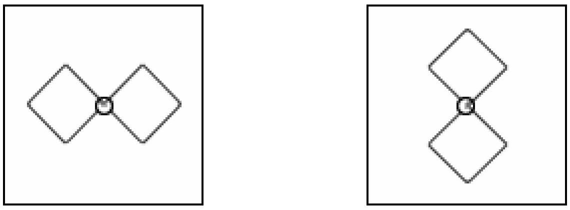


Figure 4.31 Solder the centre conductor to the element

Note that we will repeat the same steps for the previous assembling unit finishing the shape as shown in Figure 4.32.

Figure 4.32 Sector antenna completed design

Now join all the wires coming from shapes to one wire ended with SMA Connector or N-Connector. Antenna polarization is as shown in Figure 4.33. i.e. our sector antenna can operate at either horizontal or vertical polarization.



vertically polarized *horizontally polarized*

Figure 4.33 Antenna polarization

4.4 Parabolic USB Antenna

The idea here is to use the USB Wireless Card as an antenna. The signal strength enhancements were made by focusing the received signal to the USB Wireless Card.

4.4.1 The Theory

The Parabolic USB Antenna is great idea to use because one doesn't have to design new antenna, just one has to improve the normal USB Wireless card by using parabola technology. The parabola will be simplified here, in mathematics. The parabola is a conic section generated by the intersection of a right circular conical surface and a plane parallel to a generating straight line of that surface as shown Figure 4.35 below. A parabola can also be defined as the locus of points in a plane which are equidistant from a given point (the focus) and a given line (Figure 4.34).

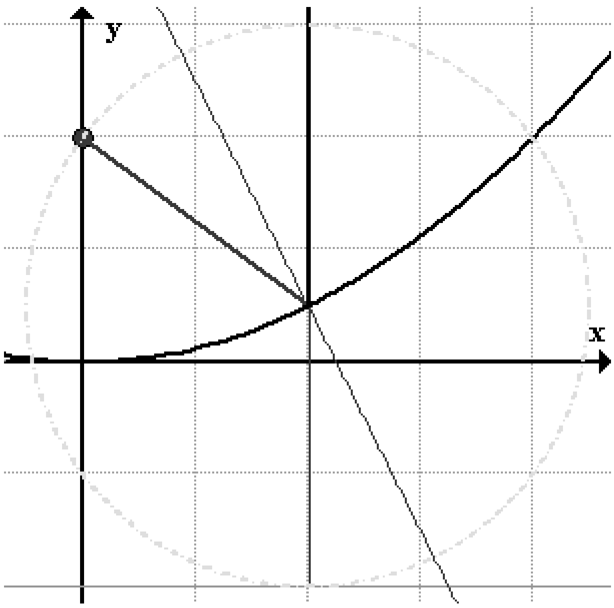


Figure 4.34 Parabola curve

A particular case arises when the plane is tangent to the conical surface. In this case, the intersection is a degenerate parabola consisting of a straight line.

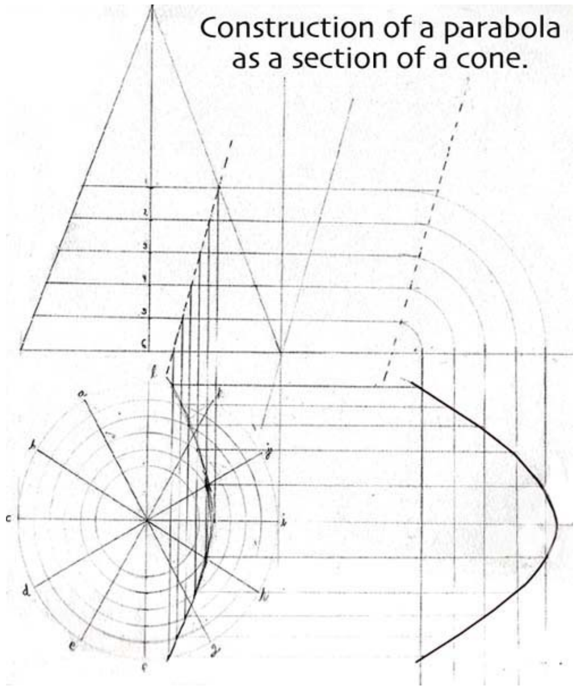


Figure 4.35 Constructions a parabola as section of cone [11].

Figure 4.36 shows the parabolic curve showing directrix (L) and focus (F). The distance from a given point P_n to the focus is always the same as the distance from P_n to a point Q_n directly below, on the directrix.

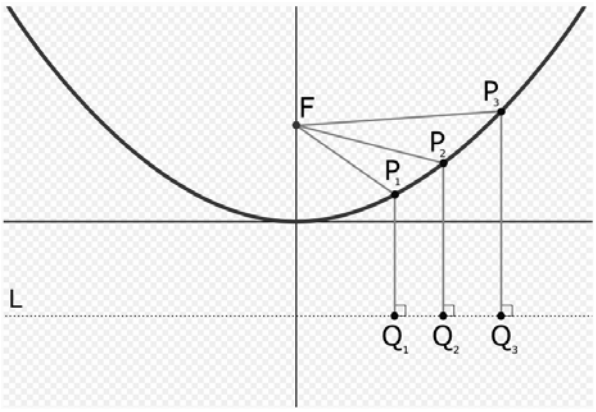


Figure 4.36 Parabolic curve showing directrix (L) and focus (F)

From Figure 4.37 we can see the Parabolic curve showing arbitrary line (L), focus (F), and vertex (V).

L is an arbitrary line perpendicular to the axis of symmetry and opposite the focus of the parabola from the vertex (i.e. farther from V than from F.) The length of any line F - P_n - Q_n is the same. This is similar to saying that a parabola is an ellipse, but with one focal point at infinity.

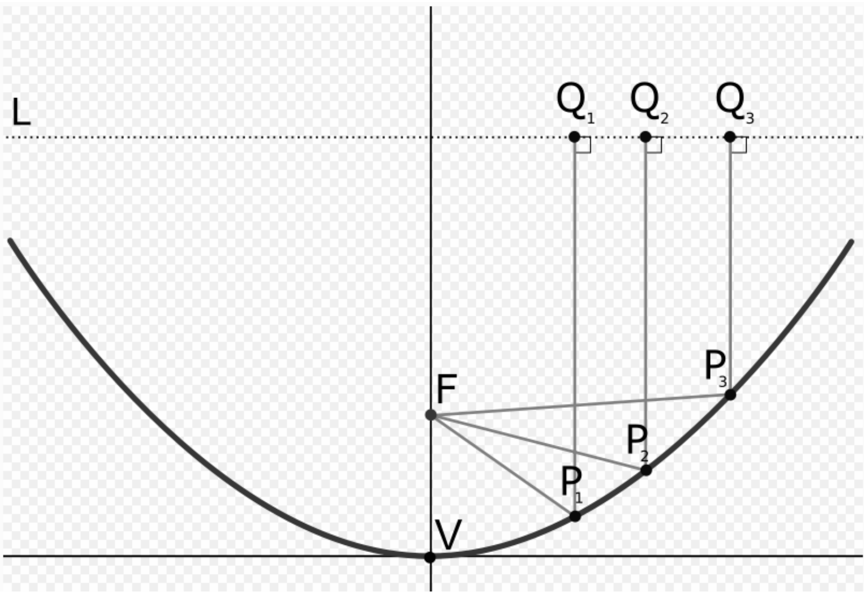


Figure 4.37 The parabolic curve showing arbitrary line (L), focus (F), and vertex (V)

The radiations of USB Wireless card such as omnidirectional antenna is shown in Figure 4.38.

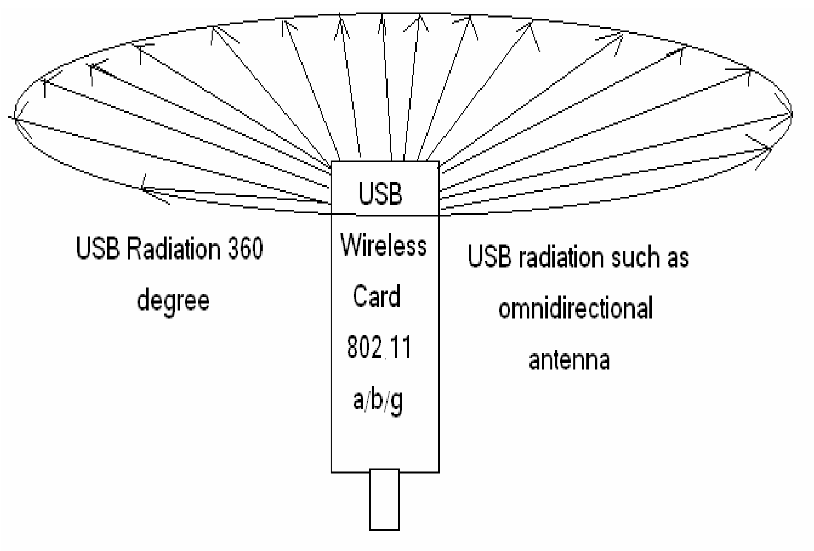


Figure 4.38 Normal USB wireless network radiation

As we know, when an omnidirectional antenna is used, the antenna performance will be decreased because energy is lost in all directions. Thus, the idea here is to collect all the signals and send them to the focal point of the parabola where the USB wireless card is placed, a shown in Figure 4.39.

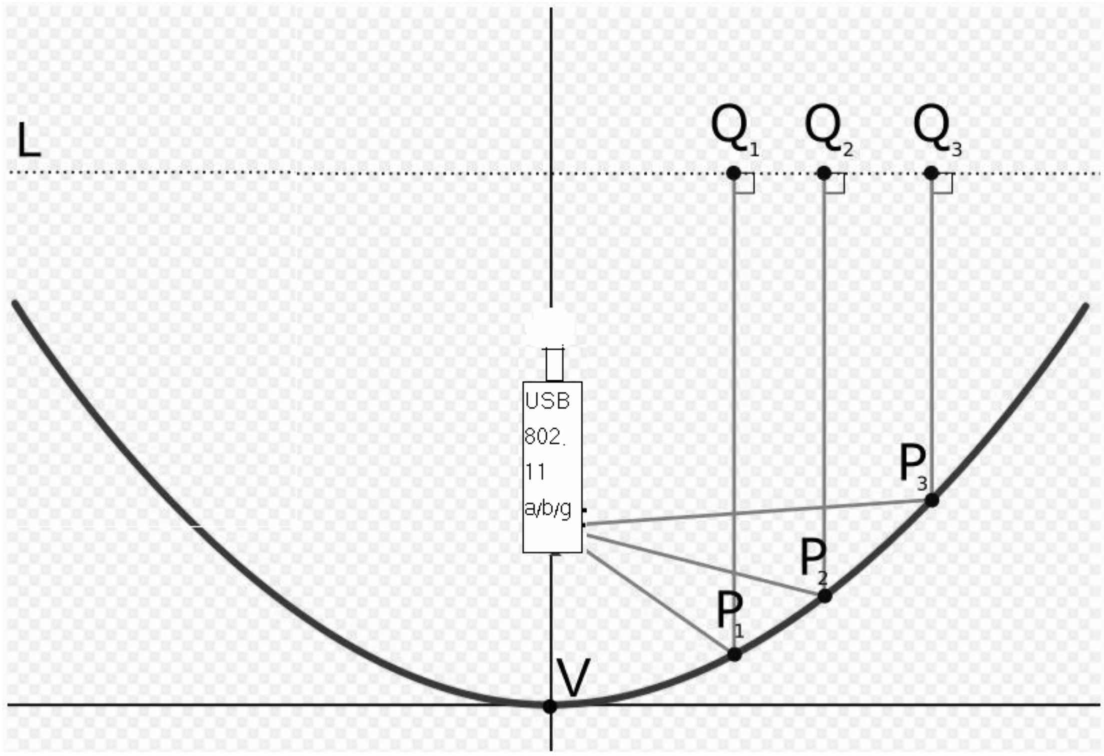


Figure 4.39 USB radiations by parabola signal technology

As can be seen from Figure 4.39, the signals from all directions will be collected and the signal strength will be increased, thus making it possible to capture signals from longer distances.

4.4.2 Parabolic USB Antenna Implementation

It is very easy to construct a parabolic USB antenna as described below in steps:

- Get a 90 cm parabolic dish.
- Get a USB Wireless card (any model will work).
- Get 5 meters USB cable extender.
- Connect the USB wireless card to the focal point for the parabolic dish as shown Figure 4.39 above.
- Connect the USB wireless card to the computer.

Figure 4.40 shows a picture of the USB parabolic antenna constructed by the author.

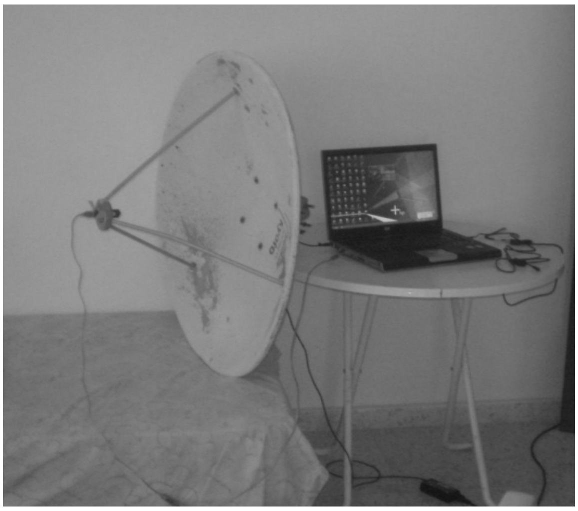


Figure 4.40 Parabolic USB antenna

Note that the gain of the antenna increases when the diameter of the parabolic antenna is increased.

The results of the parabolic USB antenna will be given in Chapter 5. In this regard we have increased the antenna gain of the USB wireless card to nearly three times. For instance the antenna gain was changed from 2 dBi to 8 dBi. This is an optimized result for the gain.

4.5 Fan Cover antenna

This antenna is based on using an old fan cover. The theory is similar to parabolic USB antenna.

4.5.1 The Theory

The theory for fan cover antenna depends on the same theory as the Parabolic USB antenna, but the difference here is that we used a fan cover as the parabolic dish. The focal point of the antenna is found by using the parabolic dish equation given in Chapter 3. One can use the 4nec program for drawing and designing a parabolic antenna (Figure 4.41).

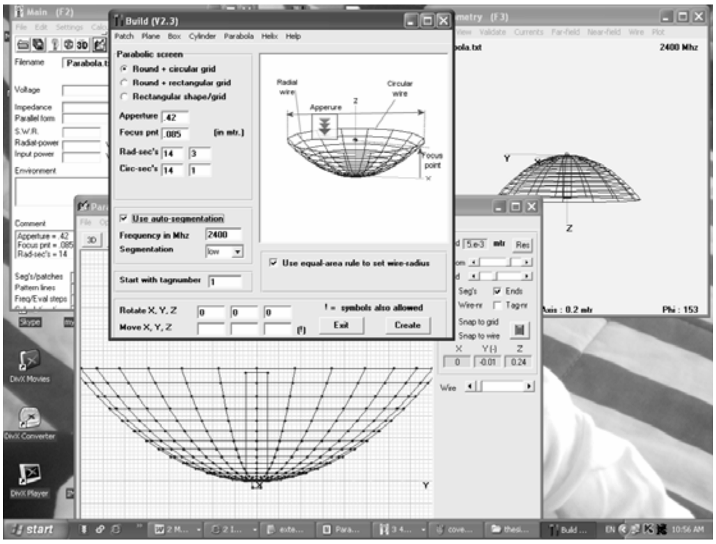


Figure 4.41 4nec program for designing an antenna

Our ideal here is saving the energy of the signal by letting the entire radiation crossing by focal point of parabolic dish.

4.5.2 Parts Required

The following parts are required for the fan cover antenna:

- Front cover of an old fan
- Empty hair gel cover
- USB wireless card 802.11 a/b/g
- Heat gun silicon

4.5.3 Implementation

The construction of the fan cover antenna is very easy and is described in steps below:

- Get the cover of an old fan
- Drill a hole in the center of fan cover
- Measure the radius and the depth to calculate the focal point using the equation given in section 3.11 or use the 4nec program to find it as shown in Figure 4.41**.** In our design for fan cover the radius is 0.42 meter and the depth is 0.085 meter, so we can find the focus point as**:**

$$f = \frac{D^2}{16d}, \qquad (3.3)$$

where f is the focal point of the dish, D is the diameter and d is the depth.

- Install the USB wireless point in the focal point as shown in Figure 4.42.

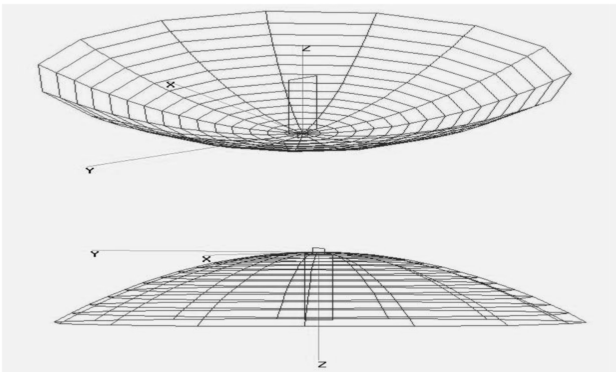


Figure 4.42 Installing the USB wireless card inside the fan cover.

- Join the USB wireless card by heat gun silicon
- Join the empty hair gel cover by heat gun silicon and cover USB wireless card to isolated form weather and water as shown in Figure 4.43.

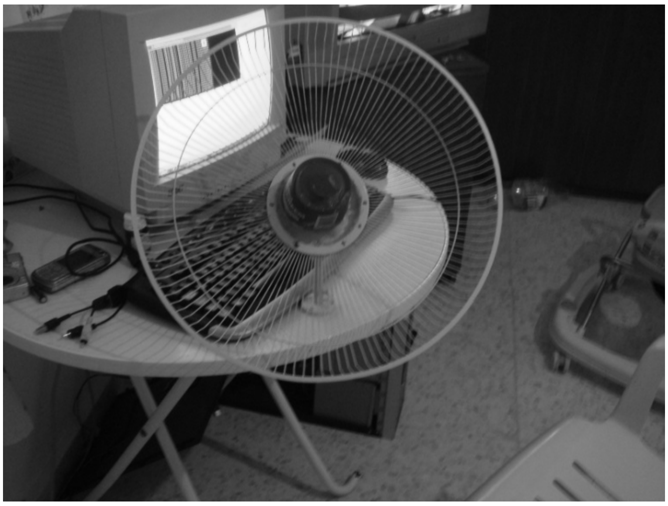


Figure 4.43 Fan cover antenna

The results obtained from the fan cover antenna were very good and are given in Chapter 5. The important point here is that it is possible to increase the gain of a wireless antenna by using equipment and tools available in our home. i.e. there is no need to purchase an expensive parabolic antenna.

4.6 RB Antenna

This is a new antenna designed and developed by the author. The RB Antenna is a waveguide antenna using a Wi-Fi 802.11 card. This antenna is based on the waveguide theory described below.

4.6.1 The Waveguide Theory

A waveguide is a circular, elliptical or rectangular metal tube or pipe through which electromagnetic waves are propagated in microwave and RF communications. The wave passing through the medium is forced to follow the path determined by the physical structure of the guide.

The two-wire transmission line used in conventional circuits is inefficient for transferring electromagnetic energy at microwave frequencies. At these frequencies, energy escapes by radiation because the fields are not confined in all directions, as illustrated in Figure 4.44. Coaxial lines are more efficient than two-wire lines for transferring electromagnetic energy because the fields are completely confined by the conductors, as illustrated in Figure 4.44.

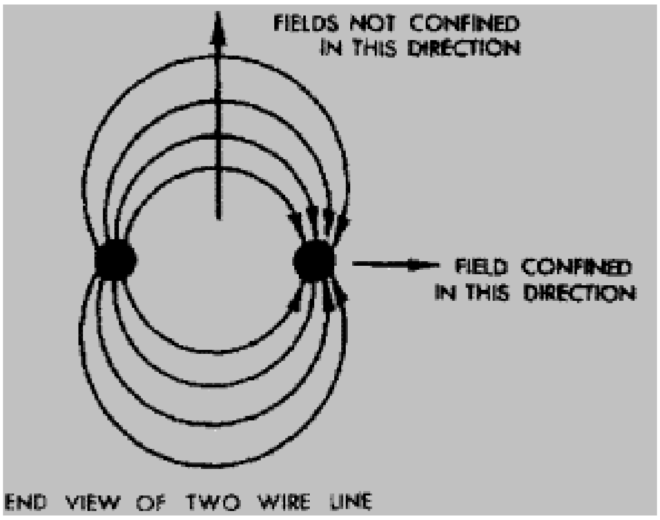


Figure 4.44 Fields confined in two directions only [12].

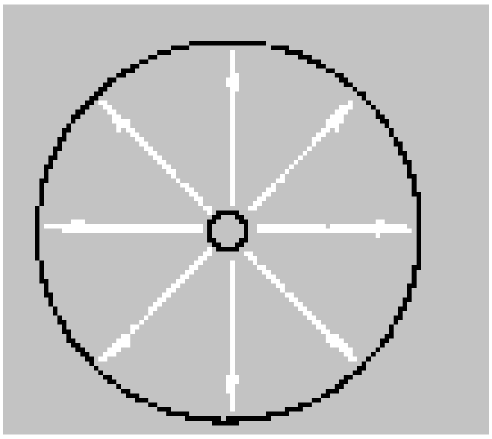


Figure 4.45 Fields confined in all directions [12].

Waveguides are the most efficient way to transfer electromagnetic energy. Waveguides are essentially coaxial lines without center conductors. They are constructed from conductive material and may be rectangular, circular, or elliptical in shape, as shown in Figure 4.46.

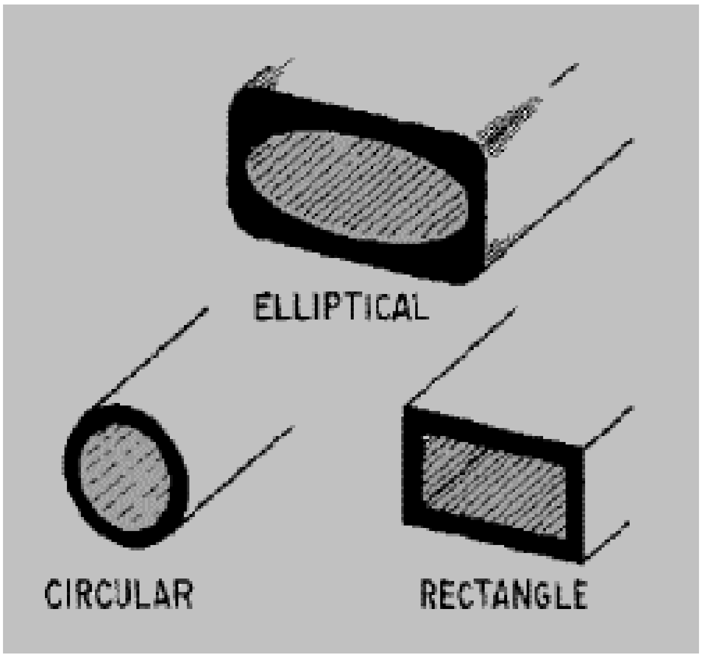


Figure 4.46 Waveguide shapes [12].

4.6.2 Waveguide Advantages

Waveguides have several advantages over two-wire and coaxial transmission lines. For example, the large surface area of waveguides greatly reduces copper (I^2R) losses. Two-wire transmission lines have large copper losses because they have a relatively small surface area. The surface area of the outer conductor of a coaxial cable is large, but the surface area of the inner conductor is relatively small. At microwave frequencies, the current-carrying area of the inner conductor is restricted to a very small layer at the surface of the conductor by an action called skin effect.

Skin effect tends to increase the effective resistance of the conductor. Although energy transfer in coaxial cable is caused by electromagnetic field motion, the magnitude of the field is limited by the size of the current-carrying area of the inner conductor. The small size of the center conductor is even further reduced by skin effect and energy transmission by coaxial cable becomes less efficient than by waveguides. Dielectric losses are also lower in waveguides than in two-wire and coaxial transmission lines. Dielectric losses in two-wire and coaxial lines are caused by the heating of the insulation between the conductors. The insulation behaves as the dielectric of a capacitor formed by the two wires of the transmission line. A voltage potential across the two wires causes heating of the dielectric and results in a power loss. In practical applications, the actual breakdown of the insulation between the conductors of a transmission line is more frequently a problem than is the dielectric loss.

This breakdown is usually caused by stationary voltage spikes or nodes which are caused by standing waves. Standing waves are stationary and occur when part of the energy traveling down the line is reflected by an impedance mismatch with the load. The voltage potential of the standing waves at the points of greatest magnitude can become large enough to break down the insulation between transmission line conductors.

The dielectric in waveguides is air, which has a much lower dielectric loss than conventional insulating materials. However, waveguides are also subject to dielectric breakdown caused by standing waves. Standing waves in waveguides cause arcing which decreases the efficiency of energy transfer and can severely damage the waveguide. Also since the electromagnetic fields are completely contained within the waveguide, radiation losses are kept very low. Power-handling capability is another advantage of waveguides. Waveguides can handle more power than coaxial lines of the same size because power-handling capability is directly related to the distance between conductors. Figure 4.47 illustrates the greater distance between conductors in a waveguide.

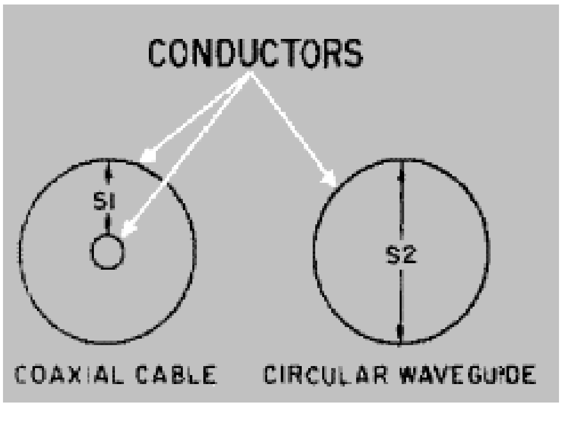


Figure 4.47 Comparison of spacing in coaxial cable and a circular waveguide [12].

In view of the advantages of waveguides, you would think that waveguides should be the only type of transmission lines used. However, waveguides have certain disadvantages that make them practical for use only at microwave frequencies.

4.6.3 Waveguide Disadvantages

Physical size is the primary lower-frequency limitation of waveguides. The width of a waveguide must be approximately a half wavelength at the frequency of the wave to be transported. For example, a waveguide for use at 1 megahertz would be about 500 feet wide. This makes the use of waveguides at frequencies below 1000 megahertz increasingly impractical but its note effecting in our antenna design because we are using high frequency more than 2.2 GHz.

The lower frequency range of any system using waveguides is limited by the physical dimensions of the waveguides. Waveguides are difficult to install because of their rigid, hollow-pipe shape. Special couplings at the joints are required to assure proper operation. Also, the inside surfaces of waveguides are often plated with silver or gold to reduce skin effect losses. These requirements increase the costs and decrease the practicality of waveguide systems at any other than microwave frequencies.

4.6.4 RB Antenna Theory

The disadvantages of waveguides do not affect our design since in our design the copper radiator is replaced and also a higher frequency is used. The waveguides are essentially coaxial lines without center conductors. They are constructed from conductive material and may be rectangular, circular, or elliptical in shape as shown in Figure 4.46. The idea here is we will try to develop horn antenna but without having disadvantage when using waveguide theory.

The RB antenna uses a horn antenna with circular or cylindrical shape as in Figure 4.48.

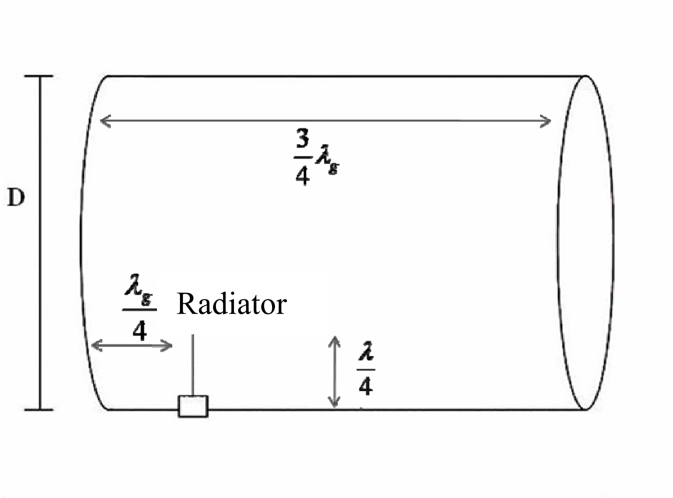


Figure 4.48 Circular or cylinder waveguide

The important point is how we can find the way to develop this antenna and also clear waveguide disadvantages and may be gain some extra performance. As shown in Figure 4.49, in the antenna developed by the author, a USB wireless card is used as the radiator.

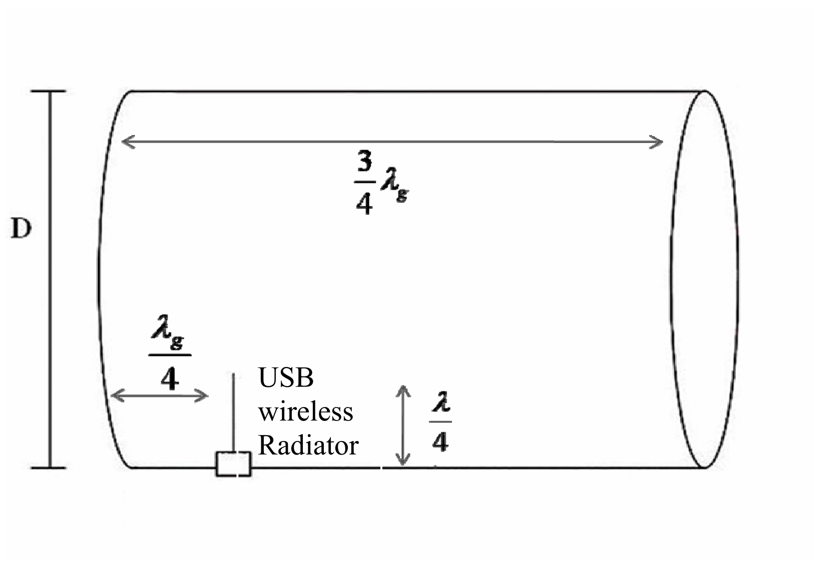


Figure 4.49 The USB wireless card radiator

It is known that a typical horn antenna has gain more than 10 dBi as shown in Figure 4.50.

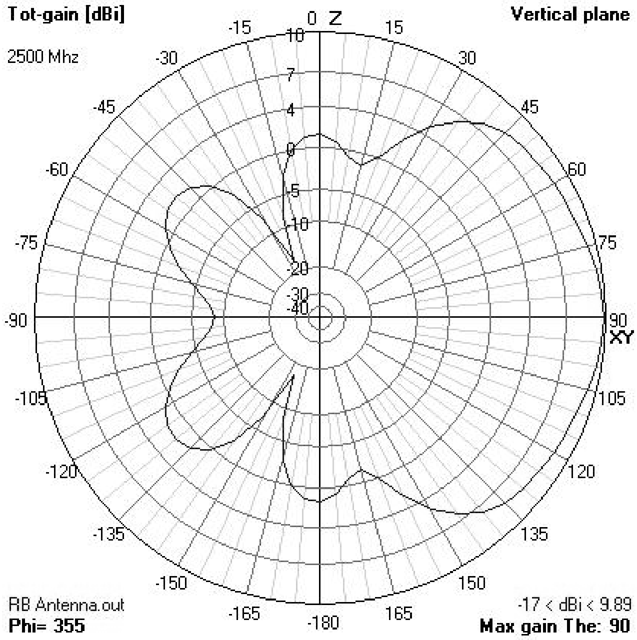


Figure 4.50 Horn antennas gain

From Figure 4.50 it is clear that the horn antenna has excellent performance with a gain of 10 dBi. Here, the aim of the author was to get a large gain improvement by using a combination of a horn antenna and a wireless card. The idea is to concentrate all the received signals at a point. i.e. at the wireless card. As an example, imagine we throw a stone into a lake, what happens is that we see a lot of waves in all directions (Figure 4.51)

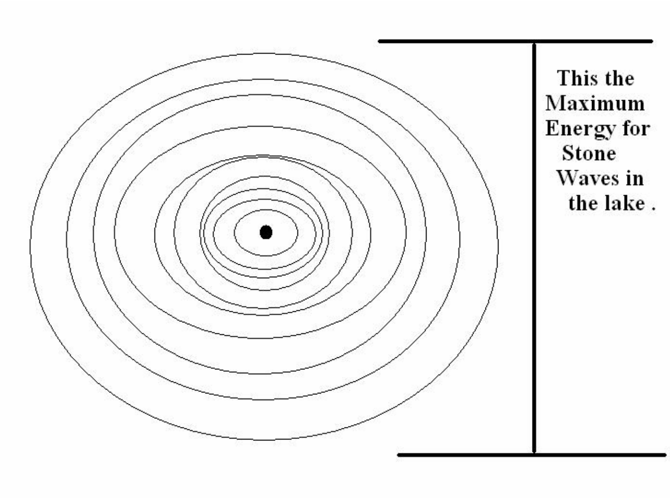


Figure 4.51 Waves radiation in the lake

Figure 4.51 shows that the energy of the waves was lost because the wave radiation was in all directions. Imagine if we can concentrate all the signals in a specific direction, then we can collect signals from longer distances, because the waves shape like carves. Thus we can stretch these curves to lines as shown in Figure 4.52.

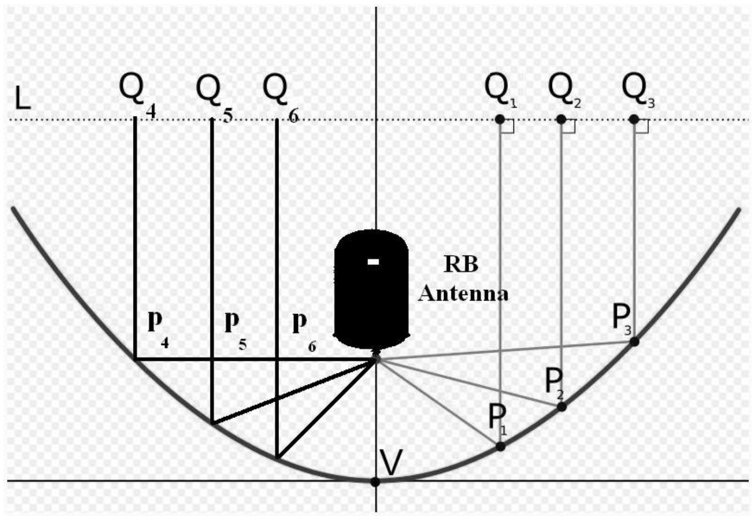


Figure 4.52 Parabola signal

4.6.5 Calculation and Implementation

The wireless networks operate at 2.4 GHz with some countries having only 11 channels, and some countries having 13 channels. The author aimed to design for 13 channels so that the antenna is universal. i.e. it can be used anywhere in the world.

Table 4.1 shows the channel frequencies, ranging from 2.4000 GHz to 2.4835 GHz From Figure 4.49, we have to calculate λ in air and λ guide. Calculating λ in air by applying Equations (4.1) and (4.2)

$$\lambda_{air} = \frac{3\times10^{8}}{2441\times10^{6}} = 124mm$$

Now we have to calculate the guide wavelength (λ_G) as:

$$\lambda_G = \frac{\lambda}{\sqrt{1 - \frac{\lambda^2}{2.910 D^2}}}, \tag{4.3}$$

where D is the diameter of the cylinder shape and λ is wavelength in air condition.

We used a mushroom tin for cylinder shape with diameter 100 mm and length 128 mm. Using Equation (4.3) we obtain

$$\lambda_G = \frac{0.1244}{\sqrt{1 - \frac{(0.1244)^2}{2.910(100)^2}}} = 0.1788$$

Calculation of λ_G is of much concern to us since it is used for our design in Figure 4.49. Hence we may calculate λ_G for every segment as follows:

$\frac{3}{4}\lambda_G$ = 134 mm

$\frac{1}{4}\lambda_G$ = 44 mm

$\frac{1}{4}\lambda$ = 31 mm

D=Diameter = 100 mm

After doing the calculations, RB antenna can be built as follows:

4.6.7 Parts Required

- USB wireless card IEEE 802.11 b/g
- Mushroom tin or a similar shape material. The size of the chosen material must be compatible with the above calculations.
- 5 meters USB cable extender.
- Heat gun silicon

- 90 cm or more dish feeder

4.6.8 Construction & Assembly

The RB antenna construction is easy to build. Figure 4.53 shows the shape of the antenna with the design parameters.

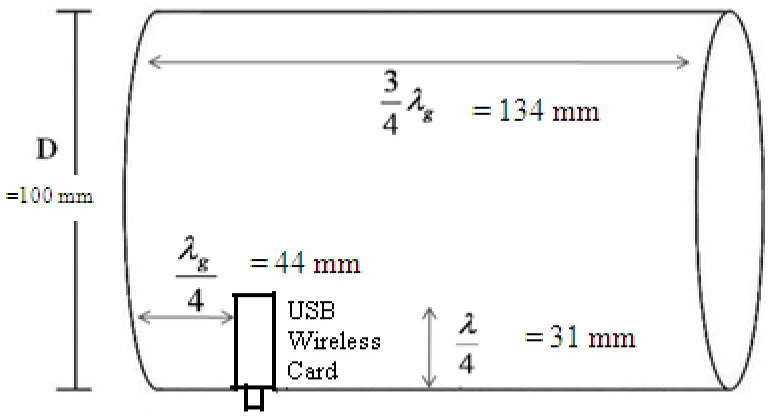


Figure 4.53 RB Antenna dimensions

- Remove the upper part of the can as shown in Figure 4.54.

Figure 4.54 Mushroom tin upper part removed

- With the ruler, measure 44 mm from the bottom of the can and draw a point. Be careful to measure from the inner side of the bottom. Use a punch (or a small drill bit or a Phillips screwdriver) and a hammer to mark the point. This makes it easier to precisely drill the hole. Be careful not to change the shape of the can doing this by inserting a small block of wood or other object in the can before tapping it.

- Drill a hole, it is will be enough to holding the size of the USB wireless card, measure 31 mm from the upper part of the USB wireless card.
- Put the 31 mm from upper part of USB dongle you measured inside the mushroom tin.
- Fix the USB wireless card inside the mushroom tin by heat gun silicon
- Put the RB antenna in the middle of the focus point for dish feeder

The final antenna is shown in Figure 4.55.

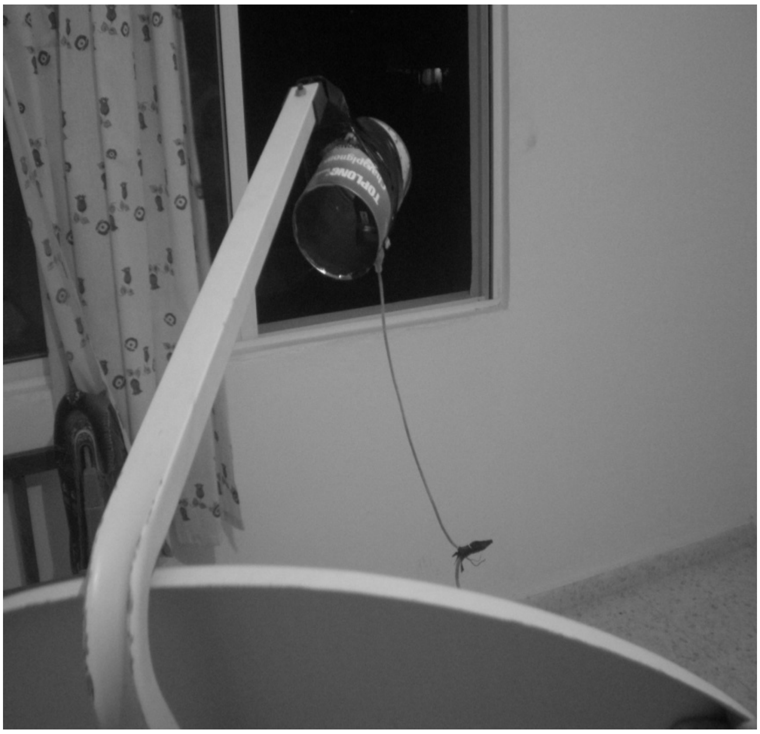


Figure 4.55 RB Antenna ready to use with dish feeder

CHAPTER FIVE

TESTS AND RESULTS

5.1 Overview

The author has tested the new design for an antenna consisting of the USB wireless card and waveguide antenna for the sake of making an improvement of the gain. The design has been extended by introducing the parabolic dish to this setup. This chapter describes the tests carried out and gives the results.

5.2 Parabolic USB Antenna

In this kind of antenna a normal wireless card is connected to the computer via the USB Port. The wireless USB card was placed in the middle of focus point of the parabolic dish as shown in Figure 5.1.

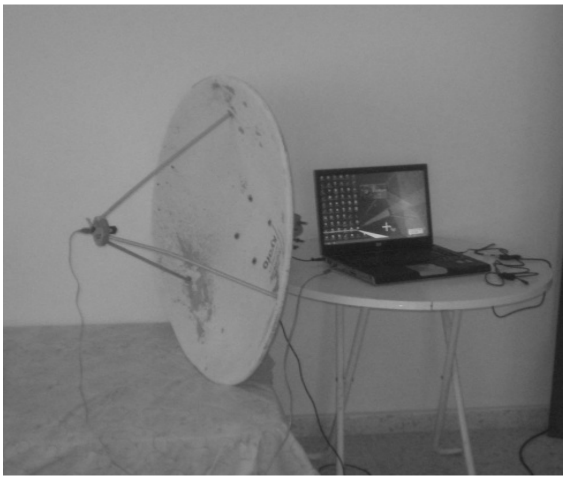


Figure 5.1 USB wireless card with parabolic dish

It was found that adding the parabolic dish for USB wireless card, the gain has increased from 2 *dBi to* 9 *dBi.* Furthermore, in doing the site survey for wireless network, a lot of base stations for wireless networks was found. The SSID would have not been available whenever the parabolic dish has not existed.

The author tried to make connection with wireless networks. For example, an attempt was made to connect to the Extend wireless network system. Extend is an internet service provider company operating in Northern Cyprus. Network Stumbler program was used by the author to measure the gains and the Signal to Noise Ratio (SNR) of the connected networks. The signal level from the Extend site without the antenna was -88 dBm. With the antenna, the signal level increases to -75 dBm. As can be seen in Figures 5.2-5.4, there has been a gain improvement of over 6 dBi when the antenna designed by the author was used.

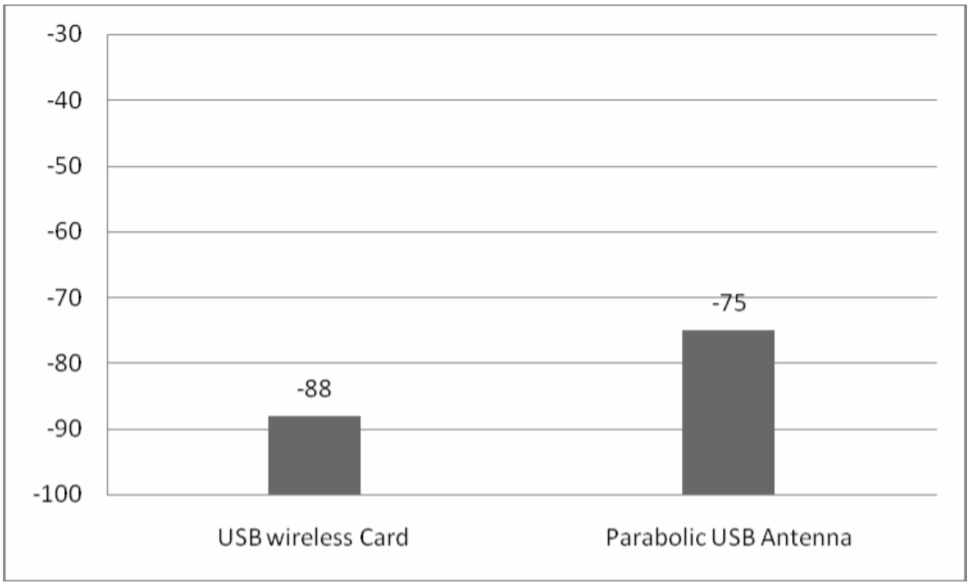


Figure 5.2 SNR graph of parabolic USB antenna

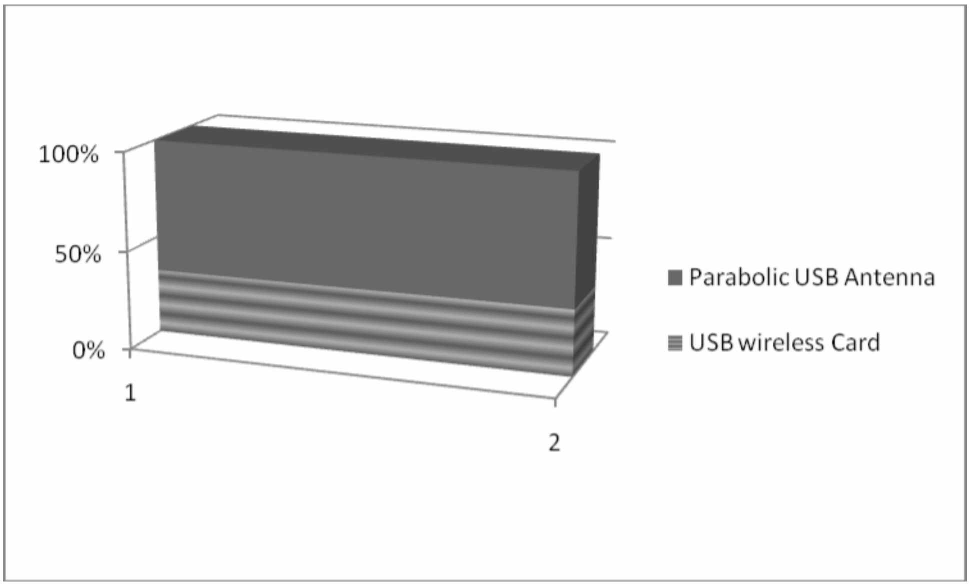


Figure 5.3 Efficiency graph of parabolic USB antenna

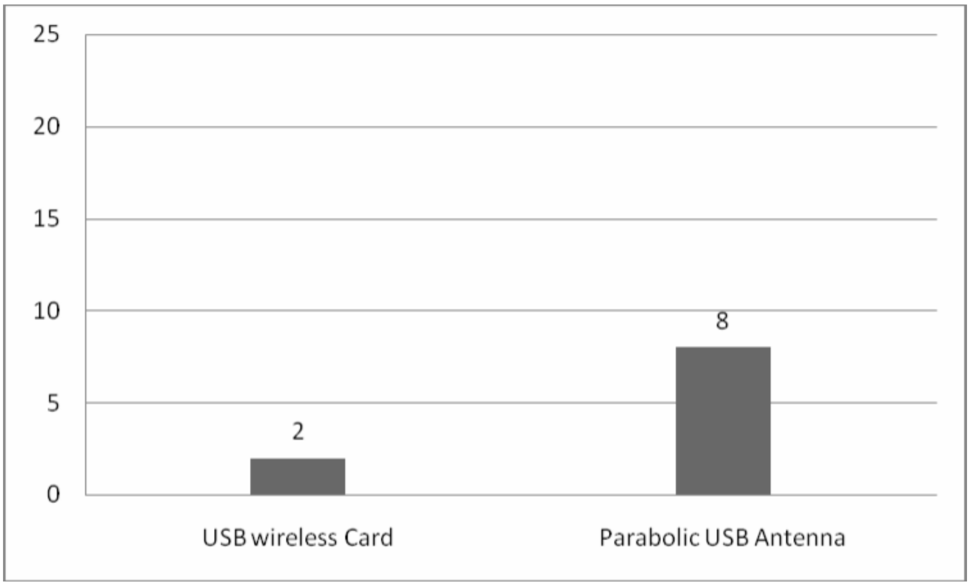


Figure 5.4 Gain graph of parabolic USB antenna

5.3 Fan Cover Antenna

Fan cover antenna is similar to parabolic USB antenna. The gain has increased by only 5 dBi, from 2 dBi to 7 dBi. We also improved the signal strength from -88 dBm to -79 dBm (Figures 5.5 - 5.7).

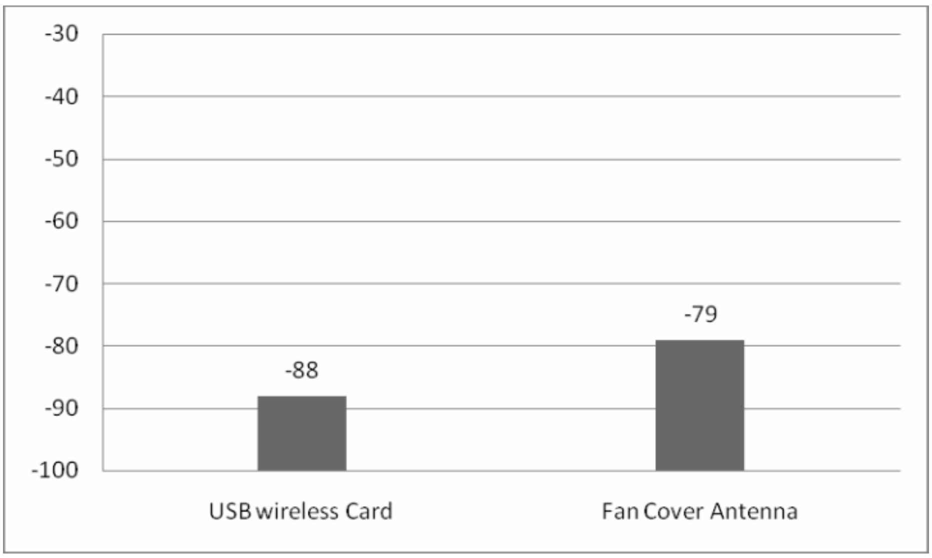


Figure 5.5 SNR graph of fan cover antenna

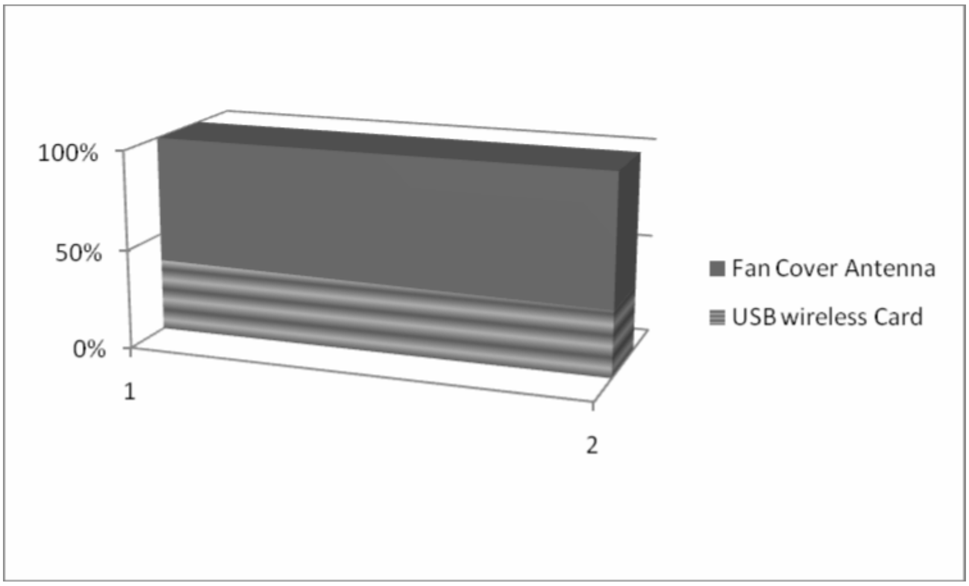


Figure 5.6 Efficiency graph of fan cover antenna

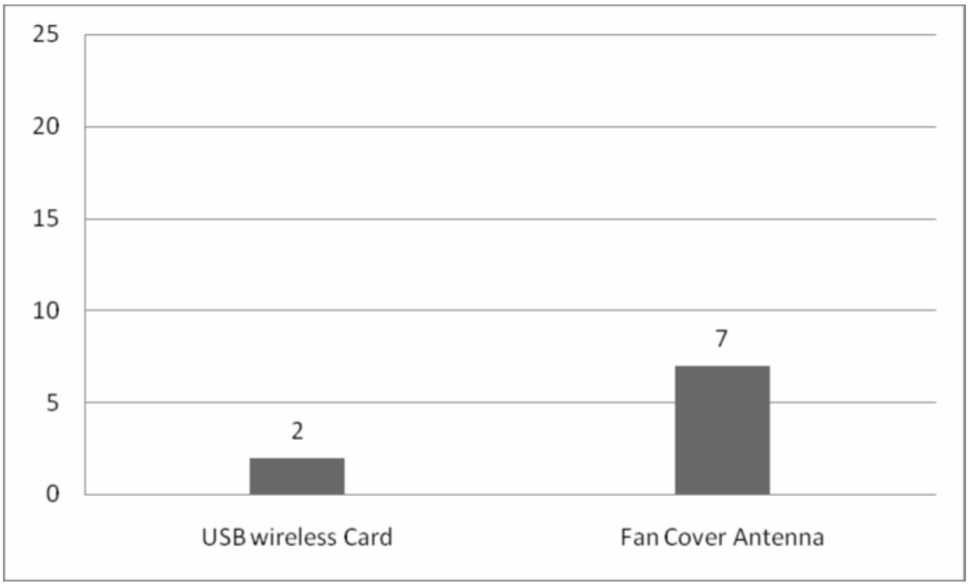


Figure 5.7 Gain graph of fan cover antenna

5.4 Sector Antenna

The Sector antenna is normally used for base stations of wireless networks. One can use it as client mode but it is not efficient to use, because the design was made to hold a lot of data traffic with 120 degrees, as shown in Figure 5.8.

Figure 5.8 Sector antenna

The gain is 10 *dBi.* We improved the signal strength from -88 dBm to -75 dBm as seen in Figures 5.9 to 5.11.

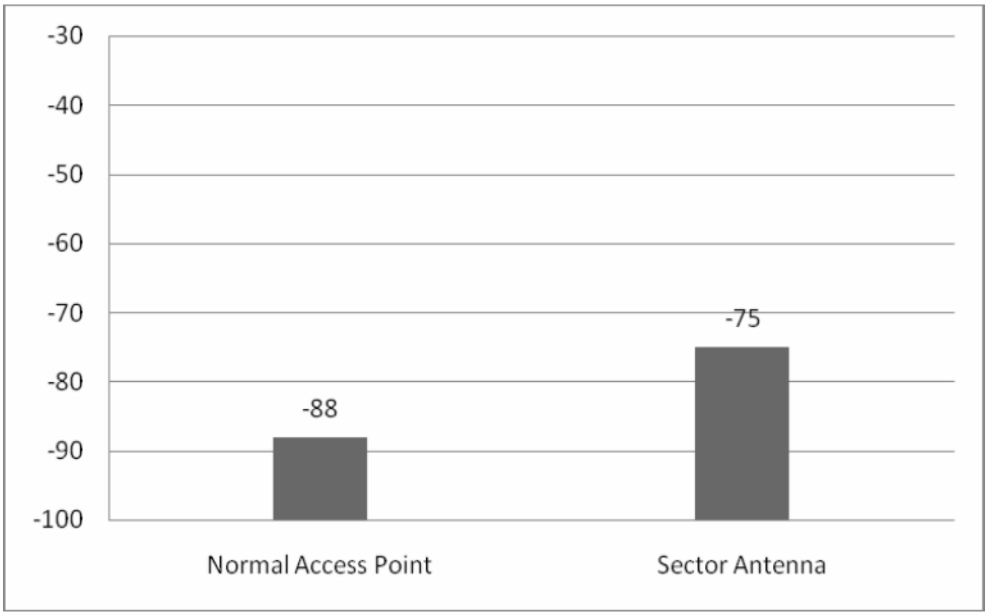


Figure 5.9 SNR graph of sector antenna

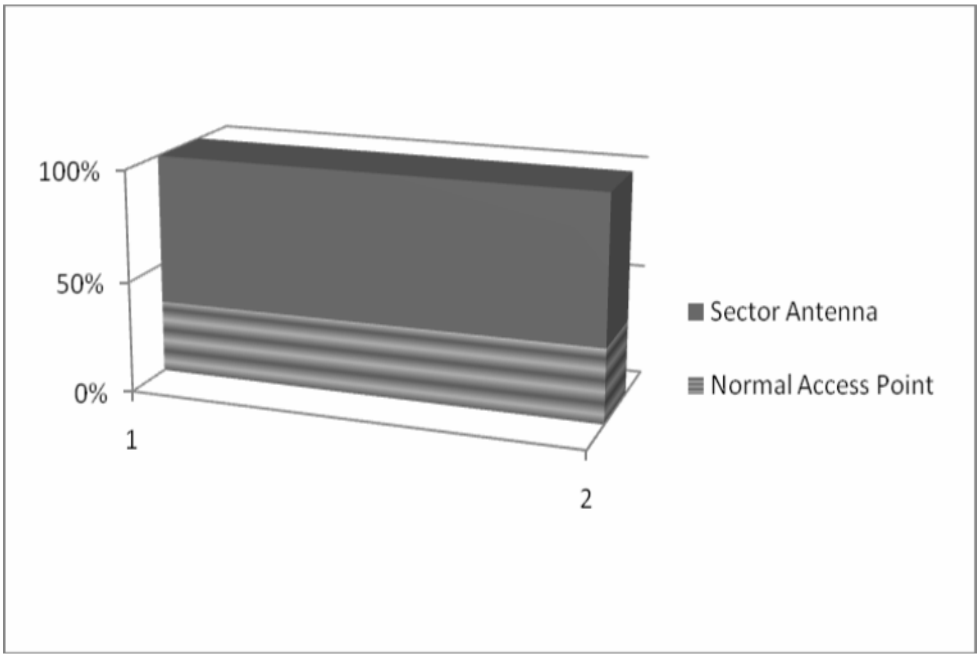


Figure 5.10 Efficiency graph of sector antenna

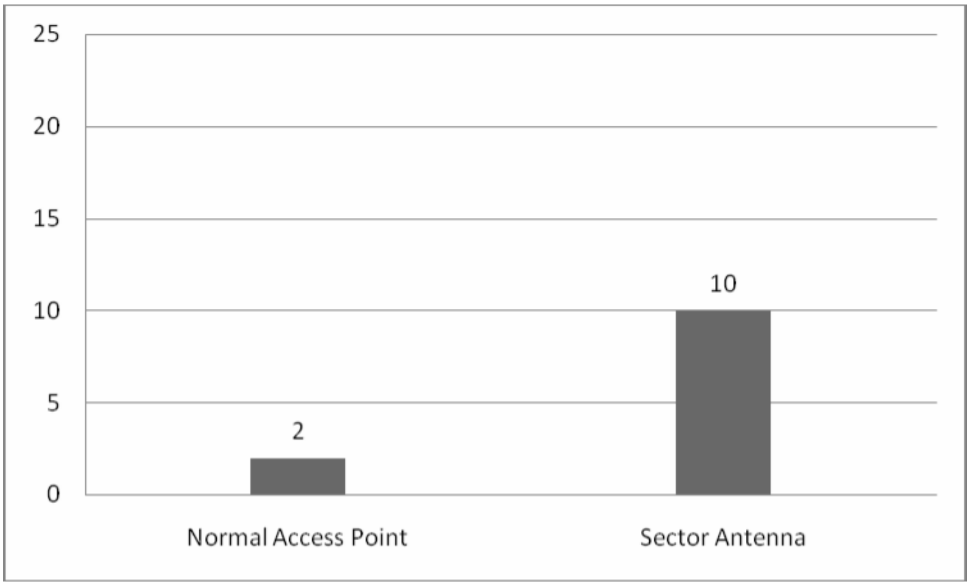


Figure 5.11 Gain graph of sector antenna

5.5 RB Antenna

The RB Antenna can be used as a Point to Point Connection or Client connection as shown in Figure 5.12.

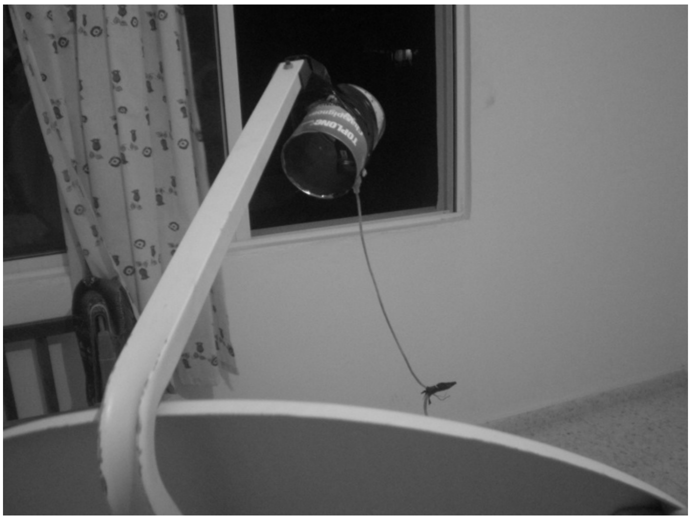


Figure 5.12 RB antenna in focus point of parabolic dish

The gain of normal USB Wireless Card is around 2 or 3 dBi. The gain has increased from $2\ dBi\ to\ 10\ dBi.$ It is found that adding the parabolic dish for RB antenna, the gain has improved from $10\ dBi\ to\ 20\ dBi.$ We also improved the signal strength from -88 dBm to -70 dBm by using RB antenna. When we are using the parabolic dish, the signal strength has improved from -70 dBm to -64 dBm as seen in Figures 5.13 to 5.15.

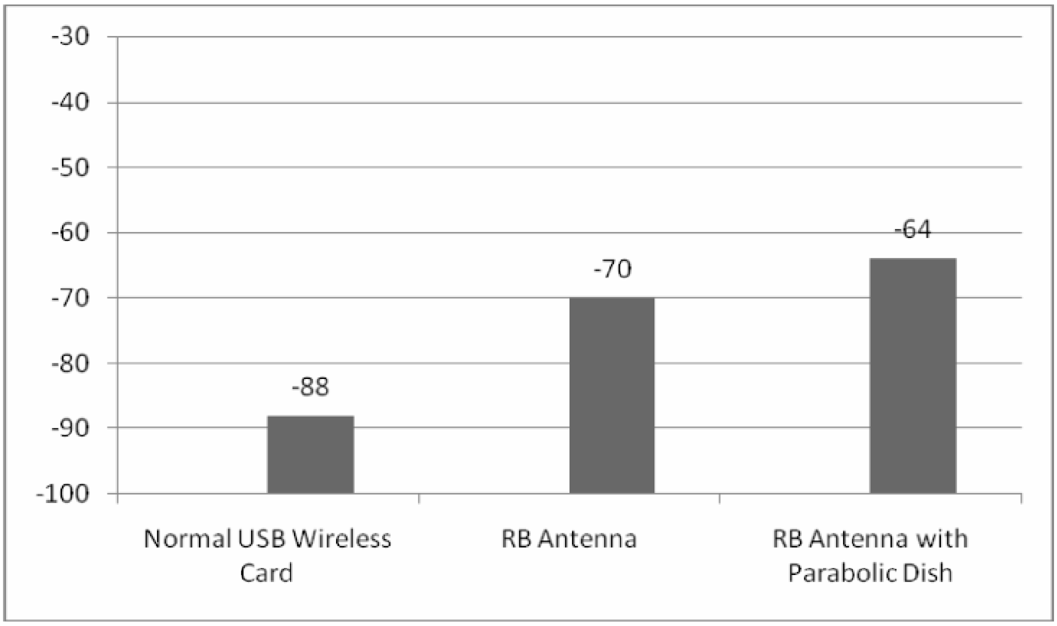


Figure 5.13 SNR graph of RB antenna

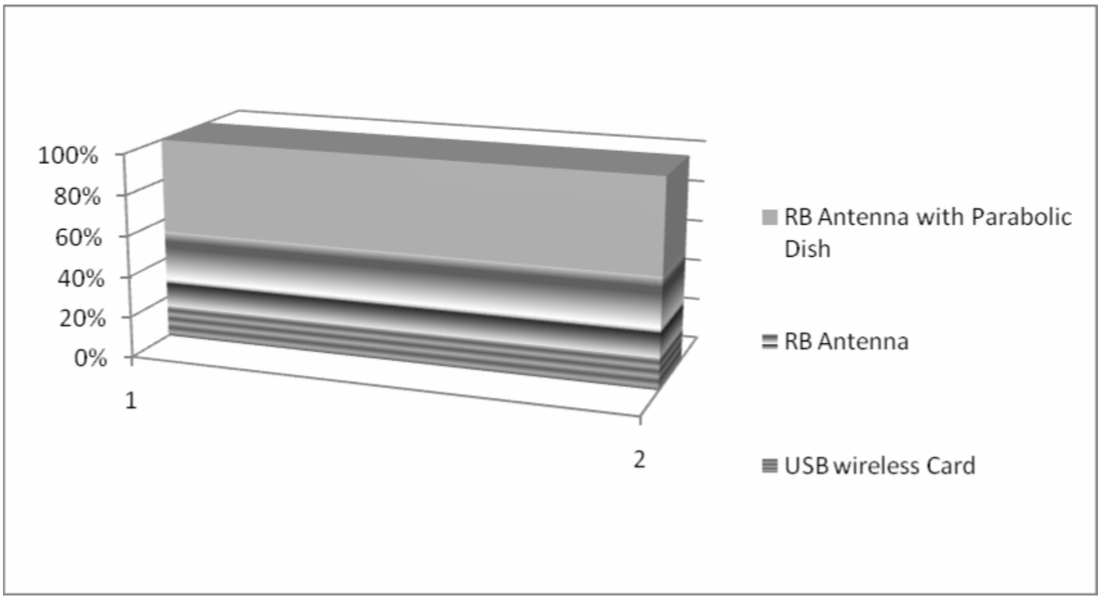


Figure 5.14 Efficiency of RB antenna

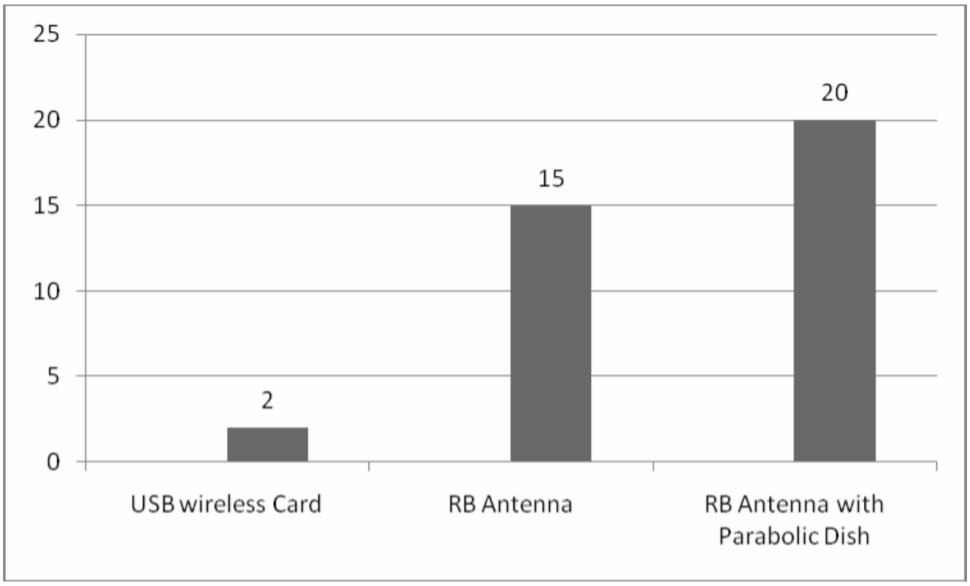


Figure 5.15 Gain graph of RB antenna

5.6 Comparing Antennas

Figures 5.16 and 5.17 show the results for each antenna. One can see from these figures that improvements have been made in antenna gains. Results show that the RB antenna with parabolic dish was by far the superior of all the antennas designed by the author.

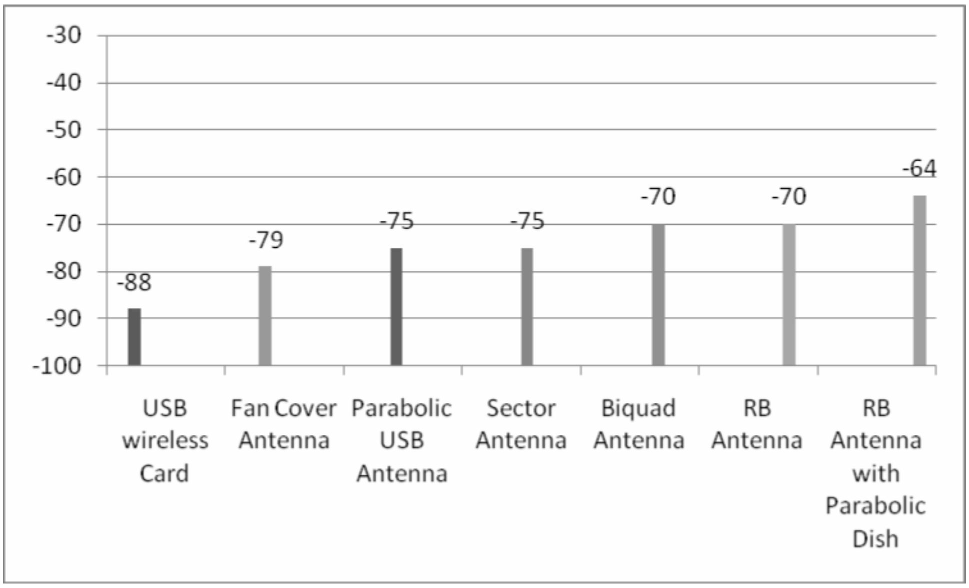


Figure 5.16 SNR for each antenna

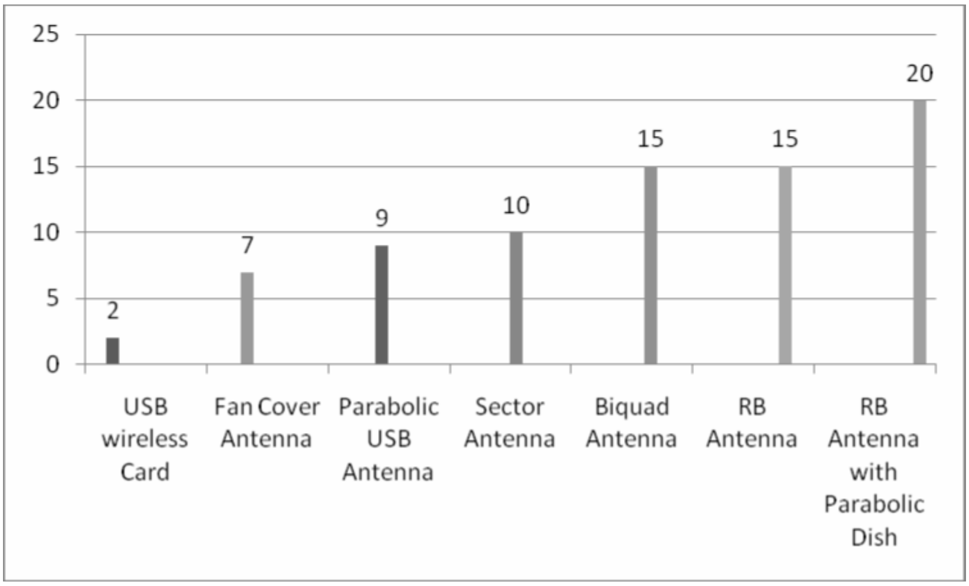


Figure 5.17 The gain for each antenna

CONCLUSION

This thesis has described the design and construction of two new types of antennas for the wireless LAN systems namely the Parabolic USB Antenna, and the RB Antenna. A wireless network card is used in both designs as the active device.

The theory is based on collecting all the signals at a point where the network card is placed. This has the effect of amplifying small signals at far away distances, thus extending the range of the antenna. For the parabolic antenna the wireless network card is placed at the focal point of the parabola where all the signals concentrate.

RB antenna was based on the principle of using a horn type antenna, collecting all the signals at the radiator point and hence extending the range of the antenna.

The results show that a much higher gain is achieved when the RB Antenna is used. One of the biggest advantages of this type of antenna is that it is very cheap, costing around $35, and it is relatively easy to construct. The RB antenna has given over 10 dBi gain which is enough to extend the network range to several kilometers.

The antennas designed also have some disadvantages. Firstly, the parabolic antenna will only work in line-of-sight conditions where both the transmitter and the receiver must see each other. Another disadvantage is that the distance between the antenna and the computer can not be greater than about 10 meters. This is because the maximum length of a USB cable is specified as 10 meters.

It can be concluded that the antennas designed by the author can be used to communicate to wireless networks which are at line-of-sight of each other and which can be many kilometers or more away from each other.

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