ANTENNAS

HISTORY OF ANTENNAS

Marconi's first experiments with transmitting electromagnetic waves in 1901, antennas have found several important applications over the entire radio frequency range and, numerous designs of antennas now exist. Antennas are an integral part of our everyday lives, used for a multitude of purposes. An antenna is used to either transmit or receive electromagnetic waves and it serves as a transducer converting guided waves into free space waves in the transmitting mode or vice versa in the receiving mode. All antennas operate on the same basic principles of electromagnetic theory formulated by James Clark Maxwell. Maxwell put forth his unified theory of electricity and magnetism in 1873 (1) in his famous book, *A Treatise on Electricity and Magnetism,* incorporating all previously known results on electricity and magnetism and expressing these mathematically through what we refer to as Maxwell's equations which hold over the entire electromagnetic spectrum. His theory was met with much skepticism and it wasn't until 1886 that Heinrich Hertz (2), considered the father of radio, was able to validate this theory with his experiments. The first radio system, at a wavelength of 4 m, consisted of a $\lambda/2$ dipole (transmitting antenna) and a resonant loop (receiving antenna) as shown in Fig. 1 (3). By turning on the induction coil, sparks were induced across the

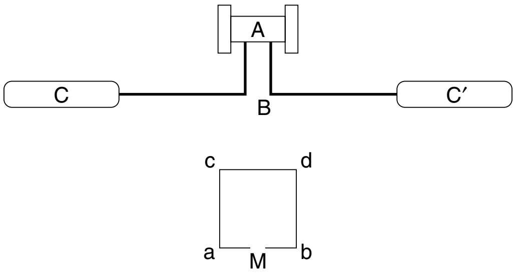

Figure 1. Heinrich Hertz's radio system.

gap A which were detected across the gap B of the receiving antenna.

Almost a decade later, Guglielmo Marconi, in 1901, was able to receive signals across the Atlantic in St. Johns, Newfoundland, sent from a station he had built in Poldhu, Cornwall, England. Marconi's transmitting antenna was a fan antenna with 50 vertical wires supported by two 6 m guyed wooden poles. The receiving antenna was a 200 m wire pulled up with a kite (3). For many years since Marconi's experiment, antennas operated at low frequencies, up to the ultra high frequency (UHF) region and were primarily wire type antennas. The need for radar during World War II launched antenna design into a new era and opened up the entire radio frequency spectrum for their use. Since the 1950s many new antenna types such as reflector, aperture, and horn antennas came into use, most of them operating in the microwave region. Their applications range from communications to astronomy to various deep space applications. These antennas have been discussed in several books and some of these have been included in Ref. 4–26. A good explanation of how an antenna radiates is given in Refs. 20 and 23. To understand how the antenna radiates, consider a pulse of electric charge moving along a straight conductor. A static electric charge or a charge moving with a uniform velocity does not radiate. However, when charges are accelerated along the conductor and decelerated upon reflection from its end, radiated fields are produced along the wire and at each end (20,21). The Institute of Electrical and Electronic Engineers (IEEE) standard definitions of terms for antennas (24) and Balanis (25) provide a good source of definitions and explanations of the fundamental parameters associated with antennas.

TYPES OF ANTENNAS

Elaborate antennas or antenna systems require careful design and a thorough understanding of the radiation mechanism involved. The selection of the type of antenna to be used is determined by electrical and mechanical constraints and operating costs. The electrical parameters of the antenna are the frequency of operation, gain, polarization, radiation pattern, impedance, and so on. The mechanical parameters of importance are the size, weight, reliability, manufacturing process, and so on. In addition, the environment under which the antenna is to be used also needs to be taken into consideration for example, the effects of temperature, rain, and wind vibrations. Antennas are shielded from the environment through the use of radomes whose presence is taken into account while designing the antenna.

Antennas can be classified broadly into the following categories: wire antennas, reflector antennas, lens antennas, traveling wave antennas, frequency independent antennas, horn antennas, and conformal antennas. In addition, antennas are very often used in array configurations to improve upon the characteristics of an individual antenna element.

Wire Antennas

Wire antennas were among the first type of antennas used and are the most familiar type to the layman. These antennas can be linear or in the form of closed loops. The thin linear dipole is used extensively and the half-wavelength dipole has a radiation resistance of 73 Ω, very close to the 75 Ω characteristic impedance of feed lines such as the coaxial cable. It has an omnidirectional pattern as shown in Fig. 2 with a half power beamwidth of 78°. Detailed discussions on dipole antennas of different lengths can be found in Ref. 25.

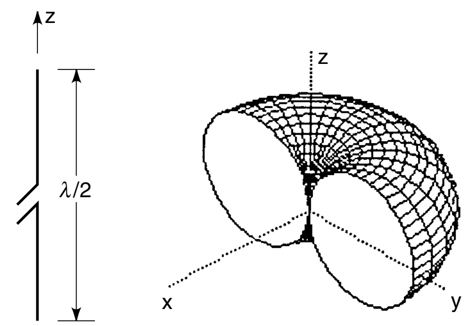

Figure 2. A half wavelength dipole and its radiation pattern.

Loop antennas can have several different shapes such as circular, square, and rectangular. Electrically small loops are those whose overall wire extent is less than one-tenth of a wavelength. Electrically large loops have circumferences that are of the order of a wavelength. An electrically small circular or square loop antenna can be treated as an infinitesimal magnetic dipole with its axis perpendicular to the plane of the loop. Various configurations of polygonal loop antennas have been investigated (27) in the ferrite loop, where a ferrite core is placed in the loop antenna to increase its efficiency. Loop antennas are inefficient with high ohmic losses and often are used as receivers and as probes for field measurements. The radiation pattern of small loop antennas has a null perpendicular to the plane of the loop and a maximum along the plane of the loop. An electrically large antenna has the maximum radiation perpendicular to the plane of the loop and is regarded as the equivalent to the half wavelength dipole.

Dipole and loop antennas find applications in the low to medium frequency ranges. They have wide beamwidths and their behavior is greatly affected by nearby obstacles or structures. These antennas are often placed over a ground plane. The spacing above the ground plane determines the effect the ground plane has on the radiation pattern and the increase in the directivity (21).

Thick dipoles are used to improve the narrow bandwidth of thin dipole antennas. Examples of these are the cylindrical dipole, the folded dipole, and the biconical antennas. The use of a sleeve around the input region and the arms of the dipole also results in broader bandwidths.

Reflector Antennas

Since World War II, when reflector antennas gained prominence due to their use with radar systems, these antennas have played an important role in the field of communications. Love (28) has published a collection of papers on reflector antennas. Reflector antennas have a variety of geometrical shapes and require careful design and a full characterization of the feed system. Silver (5) presents the technique for analysis based on aperture theory and physical optics. Other methods such as the geometrical theory of diffraction (GTD) and the fast Fourier transform (FFT) along with various optimization techniques (29) are now used for a more accurate design of these antennas.

The plane reflector is the simplest type of a reflector and can be used to control the overall system radiation characteristics (21). The corner reflector has been investigated by Kraus (30) and the 90° corner reflector is found to be the most effective. The feeds for corner reflectors are generally dipoles placed parallel to the vertex. These antennas can be analyzed in a rather straightforward manner using the method of images. Among curved reflectors, the paraboloid is the most commonly used. The paraboloid reflector shown in Fig. 3 is formed by rotating a parabolic reflector about its axis. The reflector transforms a spherical wave radiated from a feed at its focus into a plane wave.

To avoid blockage caused by the feed placed at the focal point in a front fed system, the feed is often off-set from the axis (31). The Cassegrain reflector is a dual reflector system using a paraboloid as the primary and a hyperboloid as the secondary reflector with a feed along the axis of the paraboloid.

The Gregorian dual reflector antenna uses an ellipse as the subreflector. The aperture efficiency in a Cassegrain antenna can be improved by modifying the reflector surfaces (28). Most paraboloidal reflectors use horn antennas (conical or pyramidal) for their feeds. With a paraboloidal reflector, beam scanning by feed displacement is limited. A spherical reflector provides greater scanning but requires more elaborate feed design since it fails to focus an incident plane to a point. Spherical reflectors can suffer from a loss in aperture and increased minor lobes due to blockage by the feed.

Figure 3. A parabolic reflector antenna with its feed. (Courtesy, NASA Lewis Center)

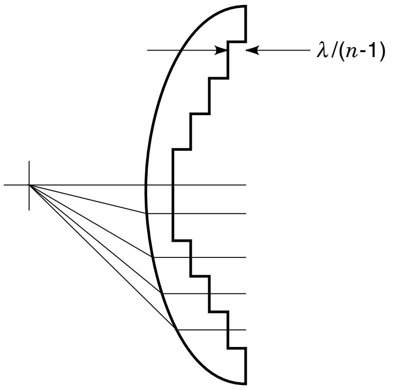

Figure 4. Zoned lens.

Lens Antennas

At larger wavelengths, reflectors become impractical due to the necessity of having large feed structures and tolerance requirements. At low frequencies, the lens antenna is prohibitively heavy. Both lens antennas and parabolic reflectors use free space as a feed network to excite a large aperture. The feed of a lens remains out of the aperture and thus eliminates aperture blockage and high side lobe levels. Dielectric lens antennas are similar to optical lenses and the aperture of the antenna is equal to the projection of the rim shape. Lenses are divided into two categories: single-surface and dual-surface. In the single-surface lens refraction occurs only at one surface. The other surface is an equiphase surface of the incident or emergent wave and the waves pass through normal to the surface without refraction. Single-surface lenses convert either cylindrical or spherical waves to plane waves. In a dual-surface lens, refraction occurs at both lens surfaces. The far field is determined by diffraction from the aperture. Dual-surface lenses allow more control of the pattern characteristics. Both surfaces are used for focusing and the second surface can be used to control the amplitude distribution in the aperture plane. These simple lenses are many wavelengths thick if their focal length and aperture are large compared to a wavelength. The surface of the lens can be zoned by removing multiples of wavelengths from the thickness. The zoning can be done either in the refracting or non-refracting surface as shown in Fig. 4. The zoned lens is frequency sensitive and can give rise to shadowing losses at the transition regions (5).

Artificial dielectric lenses in which particles such as metal spheres, strips, disks, or rods are introduced in the dielectric have been investigated by Kock (32). The size of the particles has to be small compared to the wavelength. Metal plate lenses using spaced conducting plates are used at microwave frequencies. Since the index of refraction of a metal-plate medium depends on the ratio of the wavelength to the spacing between the plates, these lenses are frequency sensitive. The Luneberg lens is a spherically symmetric lens with an index of refraction that varies as function of the radius. A plane wave incident on this lens will be brought to a focus on the opposite side. These lens antennas can be made using a series of concentric spherical shells each with a constant dielectric.

Traveling Wave Antennas

Traveling wave antennas (33) are distinguished from other antennas by the presence of a traveling wave along the struc-

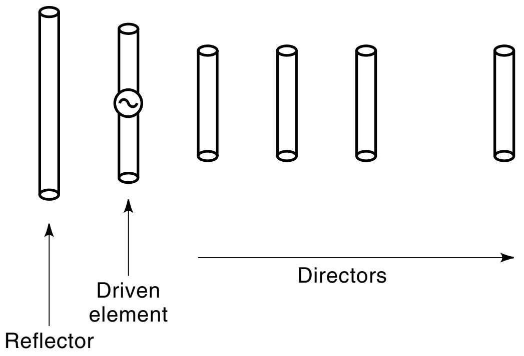

Figure 5. A Yagi–Uda antenna.

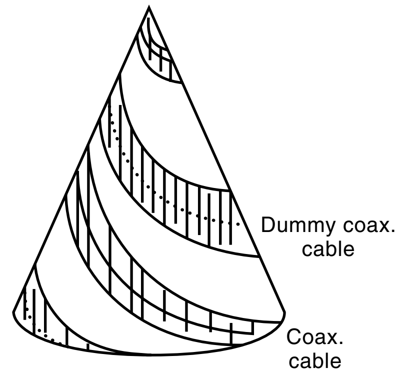

Figure 6. A two-arm balanced conical spiral antenna.

ture and by the propagation of power in a single direction. Linear wire antennas are the dominant type of traveling wave antennas. Linear wave antennas with standing wave patterns of current distributions are referred to as standing wave or resonant antennas, the amplitude of the current distribution is uniform along the source but the phase changes linearly with distance. There are in general two types of traveling wave antennas. The surface wave antenna is a slow wave structure, where the phase velocity of the wave is smaller than the velocity of light in free space. The radiation occurs from discontinuities in the structure. A leaky wave antenna is a fast wave structure, the phase velocity of the wave being greater than the velocity of light in free space. The structure radiates all its power with the fields decaying in the direction of wave travel.

A long wire antenna, many wavelengths in length, is an example of a traveling wave antenna. The Beverage antenna is a thin wire placed horizontally above a ground plane. The antenna has poor efficiency but can have good directivity and is used as a receiving antenna in the low to mid-frequency range. The V antenna is formed by using two Beverage antennas separated by an angle and fed from a balanced line. By adjusting the angle, the directivity can be increased and the side lobes can be made smaller. Terminating the legs of the V antenna in their characteristic impedances makes the wires nonresonant and greatly reduces back radiation. The rhombic antenna consists of two V antennas. The second V antenna brings the two sides together and a single terminating resistor can be used to connect the balanced lines. An inverted V over a ground plane is another configuration for a rhombic antenna.

The pattern characteristics can be controlled by varying the angle between the elements, the lengths of the elements, and the height above the ground. The helical antenna (21) is a high gain broadband end-fire antenna. It consists of a conducting wire wound in a helix. It has found applications as feeds for parabolic reflectors and for various space communications systems. A popular and practical antenna is the Yagi–Uda antenna (34,35) shown in Fig. 5. It uses an arrangement of parasitic elements around the feed element to act as reflectors and directors to produce an end-fire beam. The elements are linear dipoles with a folded dipole used as the feed. The mutual coupling between the standing wave current elements in the antenna is used to produce a traveling wave unidirectional pattern.

Frequency Independent Antennas

Frequency independent antennas or self scaling antennas were introduced in the early 1950s extending antenna bandwidths by greater than 40% (36). Ideally an antenna will be frequency independent if its shape is specified only in terms of angles. These antennas have to be truncated for practical use and the current should attenuate along the structure to a negligible value at the termination. Examples of these antennas are the bidirectional planar spiral, and the unidirectional conical spiral antenna shown in Fig. 6.

Horn Antennas

The electromagnetic horn antenna is characterized by attractive qualities such as a unidirectional pattern, high gain, and purity of polarization. Horn antennas are used as feeds for reflector and lens antennas and as a laboratory standard for other antennas. A good collection of papers on horn antennas can be found in Ref. 37. Horns can be of a rectangular or circular shape as shown in Fig. 7.

Rectangular horns, derived from a rectangular waveguide, can be pyramidal or sectoral E plane and H plane horns. The E plane sectoral horn has a flare in the direction of the E field of the dominant TE_{10} mode in the rectangular waveguide and the H plane sectoral horn has a flare in the direction of the H field. The pyramidal horn has a flare in both directions. The radiation pattern of the horn antenna can be determined from a knowledge of the aperture dimensions and the aperture field distribution. The flare angle of the horn and its dimen-

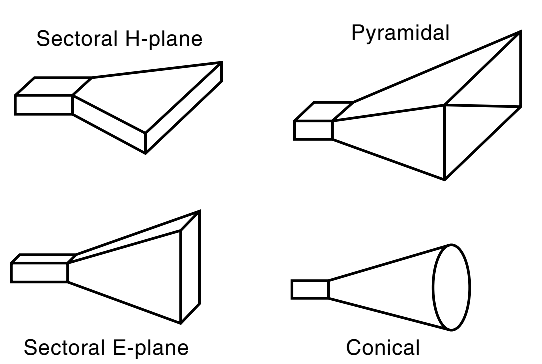

Figure 7. Examples of horn antennas.

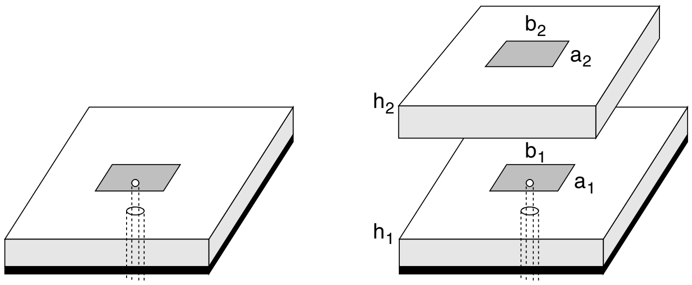

Figure 8. A coaxial fed (a) microstrip antenna and (b) stacked microstrip antenna.

sions affect the radiation pattern and its directivity. Circular horns derived from circular waveguides can be either conical, biconical, or exponentially tapered.

The need for feed systems that provide low cross polarization and edge diffraction and more symmetrical patterns led to the design of the corrugated horn (38). These horns have corrugations or grooves along the walls which present equal boundary conditions to the electric and magnetic fields when the grooves are $\lambda/4$ to $\lambda/2$ deep. The conical corrugated horn, referred to as the scalar horn, has a larger bandwidth than the small flare angle corrugated horns.

Conformal Antennas

Microstrip antennas have become a very important class of antennas since they received attention in the early 1970s. These antennas are light weight, easy to manufacture using printed circuit techniques, and are compatible with monolithic microwave integrated circuits (MMICs). In addition, an attractive property of these antennas is that they are low profile and can be mounted on surfaces, that is, they can be made to "conform" to a surface, hence they are referred to as conformal antennas. The microstrip antenna consists of a conducting patch or radiating element which can be square, rectangular, circular, or triangular etched on a grounded dielectric substrate as shown in Fig. 8.

These antennas are an excellent choice for use on aircraft and spacecraft. Microstrip antennas have been investigated extensively over the past twenty years and the two volumes published by Hall and Wood (39) provide an excellent description of various microstrip antennas, their design, and usage. Microstrip antennas are fed either using a coaxial probe, a microstrip line, proximity coupling, or through aperture coupling. A major disadvantage of these antennas is that they are poor radiators and have a very narrow frequency bandwidth. They are often used in an array environment to achieve the desired radiation characteristics. Larger frequency bandwidths are obtained by using stacked microstrip antennas.

Antenna Arrays

Antenna arrays are formed by suitably spacing radiating elements in a one or two dimensional lattice. By suitably feeding these elements with relative amplitudes and phases, these arrays produce desired directive radiation characteristics.

The arrays allow a means of increasing the electric size of the antenna without increasing the size of the individual elements. Most arrays consist of identical elements which can be dipoles, helices, large reflectors, or microstrip elements. The array has to be designed such that the radiated fields from the individual elements add constructively in the desired directions and destructively in the other directions. Arrays are generally classified as end-fire arrays that produce a beam directed along the axis of the array, or broadside arrays with the beam directed in a direction normal to the array. The beam direction can be controlled or steered using a phased array antenna in which the phase of the individual elements is varied. Frequency scanning arrays are an example where beam scanning is done by changing the frequency. Adaptive array antennas produce beams in predetermined directions. By suitably processing the received signals, the antenna can steer its beam toward the direction of the desired signal and simultaneously produce a null in the direction of an undesired signal.

APPLICATIONS AND IMPACT ON SYSTEMS

Antennas enjoy a very large range of applications, both in the military and commercial world. The most well-known applications of antennas to the average person are those associated with radio, TV, and communication systems. Today, antennas find extensive use in biomedicine, radar, remote sensing, astronomy, navigation, radio frequency identification, controlling space vehicles, collision avoidance, air traffic control, GPS, pagers, wireless telephone, wireless local area networks (LANs) etc. These applications cover a very wide range of frequencies as shown in Table 1 (2,3,40):

Antennas in Communication Systems

Antennas are one of the most critical components in a communication system since they are responsible for the proper transmission and reception of electromagnetic waves. The antenna is the first part of the system that will receive or transmit a signal. A good design can relax some of the complex system requirements involved in a communication link and increase the overall system performance.

The choice of an antenna for a specific application (cellular, satellite based, ground based, etc.), depends on the platform to be used (car, ship, building, spacecraft, etc.), the environment (sea, space, land), the frequency of operation, and the nature of the application (video, audio data, etc.). Communication systems can be broken into several different categories:

Direct (Line-of-Site) Links. A transmission link established between two highly directional antennas. The link can be between two land-based antennas (radio relays); between a tower and a mobile antenna (cellular communication); between a land-based antenna and a satellite antenna (earth-space communication); between two satellite antennas (space communication). Usually these links operate at frequencies between 1 to 25 GHz. A typical distance between two points in a high capacity, digital microwave radio relay system is about 30 miles.

Satellites and Wireless Communications. Antennas on orbiting satellites are used to provide communications between various locations around the earth. In general, most telecommunication satellites are placed in a geostationary orbit

Table 1. Frequency Bands and General Usage

Band Designation	Frequency Range	Usage
Very low frequencies (VLF)	3–30 kHz	Long distance telegraphy, navigation. Antennas are physically large but electrically small. Propagation is accomplished using earth's surface and the ionosphere. Vertically polarized wave
Low frequency (LF)	30–300 kHz	Aeronautical navigation services, long distance communications, radio broadcasting. Vertical polarization
Medium frequency (MF)	300–3000 kHz	Regional broadcasting and communication links, AM radio
High frequency (HF)	3–30 MHz	Communications, broadcasting, surveillance, CB radio (26.965–27.225 MHz). Ionospheric propagation. Vertical and horizontal propagation
Very high frequency (VHF)	30–300 MHz	Surveillance, TV broadcasting (54–72 MHz), (76–88 MHz), and (174–216 MHz), FM radio (88–108 MHz). Wind profilers
Ultra high frequency (UHF)	300–1000 MHz	Cellular communications, surveillance TV (470–890 MHz)
L	1–2 GHz	Long range surveillance, remote sensing
S	2–4 GHz	Weather, traffic control, tracking, hyperthermia
C	4–8 GHz	Weather detection, long range tracking
X	8–12 GHz	Satellite communications, missile guidance, mapping
Ku	12–18 GHz	Satellite communications, altimetry, high resolution mapping
K	18–27 GHz	Very high resolution mapping
Ka	27–40 GHz	Airport surveillance
Submillimeter waves		Experimental stage

(GEO), about 22,235 miles above the earth as shown in Fig. 9. There are also some satellites at lower earth orbits (LEOs) that are used for wireless communications. Modern satellites have several receiving and transmitting antennas which can offer services such as video, audio, data transmission, and telephone in areas that are not hard-wired. Moreover, direct-TV is now possible through the use of a small 18-inch reflector antenna with 30 million users in the U.S. today (41,42).

Satellite antennas for telecommunications are used either to form a large area-of-coverage beam for broadcasting or spot beams (small area-of-coverage) for point-to-point communications. Also, multibeam antennas are used to link mobile and fixed users that cannot be linked economically via radio, land-based relays (43–46).

The impact of antennas on satellite technology continues to grow. For example, very small aperture terminal dishes (VSAT) at Ku band that can transmit any combination of voice, data, and video using satellite networking, have become valuable tools for several small and large companies. Most satellites operate at the L, S, or Ku band, but increasing demand for mobile telephony and high speed interactive data exchange is pushing the antenna and satellite technology into higher operational frequencies (47). Future satellites will be equipped with antennas at both the Ku and the Ka bands. This will lead to greater bandwidth availability. For example, the ETS-VI (A Japanese satellite comparable to NASA's TDRS), carries five antennas: an S-band phased array, a 0.4 m reflector for 43/38 GHz, for up and down links, an 0.8 m reflector for 26/33 GHz, a 3.5 m reflector for 20 GHz, and a 2.5 m reflector for 30 GHz and 6/4 GHz. Figure 10 shows a few typical antennas used on satellites. It is expected that millions of households, worldwide, will have access to dual Ku/Ka band dishes in the twenty-first century. These households will be able to enjoy hundreds of TV channels from around the world. Moreover, low cost access to high speed, voice, data, and video communications will be available to more customers (48).

Personal/Mobile Communication Systems. The vehicular antennas used with mobile satellite communications constitute the weak link of the system. If the antenna has high gain, then tracking of the satellite becomes necessary. If the vehicle antenna has low gain, the capacity of the communication system link is diminished. Moreover, hand-held telephone units require ingenious design due to lack of "real estate" on the portable device.

There is more emphasis now in enhancing antenna technologies for wireless communications, especially in cellular communications, which will enhance the link performance and reduce the undesirable visual impact of antenna towers. Techniques that utilize "smart" antennas, fixed multiple beams, and neural networks are now being utilized to increase the capacity of mobile communication systems, whether it is land-based or satellite-based (49). It is anticipated that in the twenty-first century the "wire" will no longer dictate where we must go to use the telephone, fax, e-mail, or run a computer. This will lead to the design of more compact and more sophisticated antennas.

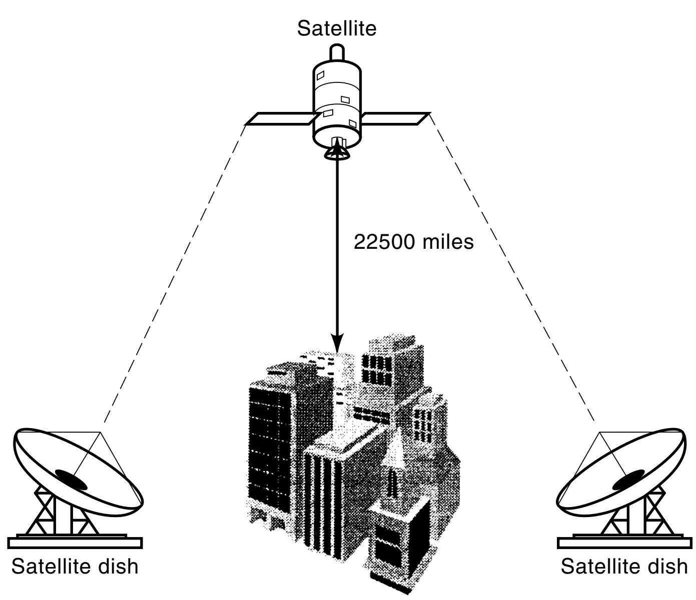

Figure 9. A satellite communication system.

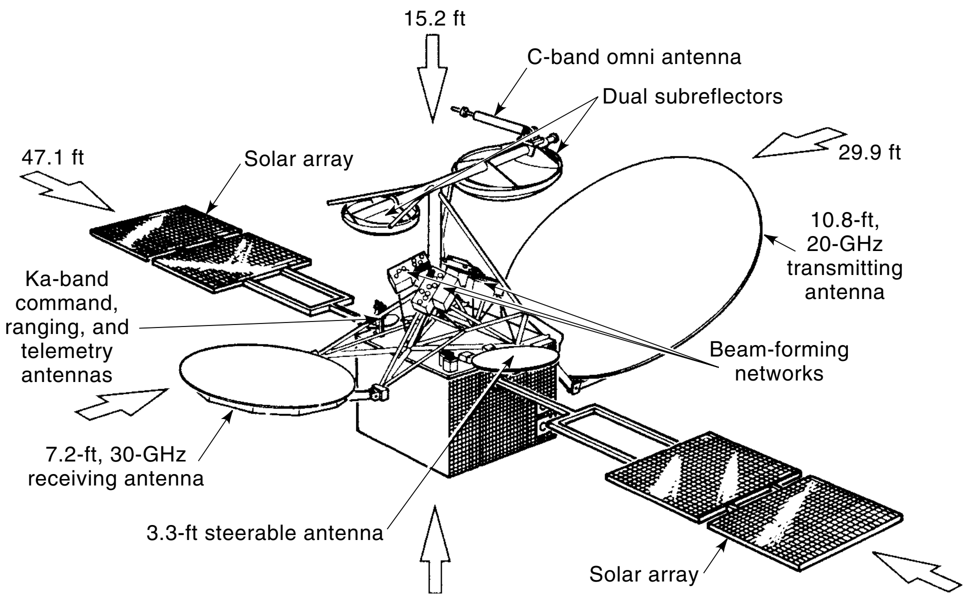

Figure 10. Typical antennas on a satellite. (Courtesy, NASA Lewis Center)

Antennas for Biomedical Applications

In many biological applications the antenna operates under very different conditions than the more traditional free-space, far-field counterparts. Near fields and mutual interaction with the body dominate. Also, the antenna radiates in a lossy environment rather than free space. Several antennas, from microstrip antenna to phased arrays, operating at various frequencies, have been developed to couple electromagnetic energy in or out of the body. Most medical applications can be classified into two groups (50): (1) therapeutic and (2) informational. Examples of therapeutic applications are hyperthermia for cancer therapy, enhancement of bone and wound healing, nerve simulation, neural prosthesis, microwave angioplasty, treatment of prostatic hyperlastia, and cardiac ablation. Examples of informational applications are tumor detection using microwave radiometry, imaging using microwave tomography, measurement of lung water content, and dosimetry.

Therapeutic applications are further classified as invasive and noninvasive. Both applications require different types of antennas and different restrictions on their design. In the noninvasive applications (not penetrating the body), antennas are used to generate an electromagnetic field to heat some tissue. Antennas such as helical-coils, ring capacitors, dielectrically loaded waveguides, and microstrip radiators are attractive because of their compactness. Phased arrays are also used to provide focusing and increase the depth of penetration. The designer has to choose the right frequency, size of the antenna, and the spot size that the beam has to cover in the body. The depth of penetration, since the medium of propagation is lossy, is determined by the total power applied or available to the antenna. Invasive applications require some kind of implantation in the tissue. Many single antennas and phased or nonphased arrays have been extensively used for treating certain tumors. A coaxial cable with an extended center conductor is a typical implanted antenna. This type of antenna has also been used in arteries to soften arterial plaque and enlarge the lumen of narrowed arteries.

Antennas have also been used to stimulate certain nerves in the human body. As the technology advances in the areas of materials and in the design of more compact antennas, more antenna applications will be found in the areas of biology and medicine.

Radio Astronomy Applications

Another field where antennas have made a significant impact is the field of astronomy. A *radio telescope* is an antenna system that astronomers use to detect radio frequency (RF) radiation emitted from extraterrestrial sources. Since radio wavelengths are much longer than those in the visible region, radio telescopes make use of very large antennas to obtain the resolution of optical telescopes. Today, the most powerful radio telescope is located in the Plains of San Augustin, near Sorocco, N.M. It is made of an array of 27 parabolic antennas, each about 25 m in diameter. Its collecting area is equivalent to a 130-m antenna. This antenna is used by over 500 astronomers to study the solar system, the Milky Way Galaxy, and extraterrestrial systems. Puerto Rico is the site of the world's largest single-antenna radio telescope. It uses a 300-m spherical reflector consisting of perforated aluminum panels. These panels are used to focus the received radio waves on movable antennas placed about 168 meters above the reflector surface. The movable antennas allow the astronomer to track a celestial object in various directions in the sky.

Antennas have also been used in constructing a different type of a radio telescope, called *radio interferometer.* It consists of two or more separate antennas that are capable of receiving radio waves simultaneously but are connected to one receiver. The radio waves reach the spaced antennas at different times. The idea is to use information from the two antennas (interference) to measure the distance or angular position of an object with a very high degree of accuracy.

Radar Applications

Modern airplanes, both civilian and military, have several antennas on board used for altimetry, speed measurement, collision avoidance, communications, weather detection, naviga-

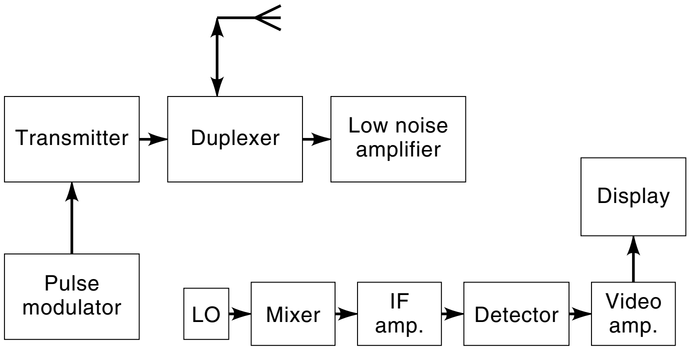

Figure 11. A basic radar system.

tion, and a variety of other functions (40,51–53). Each function requires a certain type of antenna. It is the antenna that makes the operation of a radar system feasible. Figure 11 shows a block diagram of a basic radar system.

Scientists in 1930 observed that electromagnetic waves emitted by a radio source were reflected back by aircrafts (echoes). These echoes could be detected by electronic equipment. In 1937, the first radar system, used in Britain for direction finding of enemy guns, operated around 20 MHz to 30 MHz. Since then, several technological developments have emerged in the area of radar antennas. The desire to operate at various frequencies led to the development of several, very versatile and sophisticated antennas. Radar antennas can be ground-based, mobile, satellite-based, or placed on any aircraft or spacecraft. The space shuttle orbiter, for example, has 23 antennas. Among these, four C-band antennas are used for altimetry, two to receive and two to transmit. There are also six L-band antennas and 3 C-band antennas used for navigation purposes.

Today, radar antennas are used for coastal surveillance, air traffic control, weather prediction, surface detection (ground penetrating radar), mine detection, tracking, air-defense, speed-detection (traffic radar), burglar alarms, missile guidance, mapping of the surface of the earth, reconnaissance, and other uses.

In general, radar antennas are designed as part of a very complex system that includes high power klystrons, traveling wave tubes, solid state devices, integrated circuits, computers, signal processing, and a myriad of mechanical parts. The requirements on the radar antennas vary depending on the application (continuous wave, pulses radar, Doppler, etc.) and the platform of operation. For example, the 23 antennas on the space shuttle orbiter must have a useful life of 100,000 operational hours over a ten-year period or about 100 orbital missions. These antennas are required to operate at temperatures from −150 °F to 350 °F during re-entry. The antennas also have to withstand a lot of pressure and a direct lightning strike. The antenna designer will have to meet all of these constraints along with the standard antenna problems of polarization, scan rates, frequency agility, etc.

Impact of Antennas in Remote Sensing

Remote sensing is a radar application where antennas such as horns, reflectors, phased arrays, and synthetic apertures are used from an airplane or a satellite to infer the physical properties of planetary atmosphere and surface or take images of objects.

There are two types of remote sensing: active and passive (radiometry) and both are in wide use. In the active case a signal is transmitted and the reflected energy, intercepted by the radar as shown in Figure 12, is used to determine several characteristics of the illuminated object such as temperature, wind, shape, etc. In the passive case the antenna detects the amount of microwave energy radiated by thermal radiation from the objects on the earth. Radiometers are used to measure the thermal radiation of the ground surface and/or atmospheric condition (13,54–56).

Most antennas associated with remote sensing are downward-looking, whose radiation patterns possess small, close-in sidelobes. Remote sensing antennas require a very careful design to achieve high beam efficiency, low antenna losses, low sidelobes, and good polarization properties. Ohmic losses in the antenna is perhaps the most critical parameter since it can modify the apparent temperature observed by the radiometer system.

The degree of resolution of a remote map depends on the ability of the antenna system to separate closely space objects in range and azimuth. To increase the azimuth resolution a technique called “synthetic aperture” is employed. Basically, as an aircraft flies over a target the antenna transmits pulses assuming the value of a single radiating element in a long array. Each time a pulse is transmitted, the antenna, due to the aircraft’s motion, is further along the flight path. By storing and adding up the returned signals from many pulses, the single antenna element acts as the equivalent of a very large antenna, hundreds of feet long. Using this approach, an antenna system can produce maps approaching the quality of good aerial photographs. This synthetic aperture antenna becomes a “radio camera” that can yield excellent remote imagery. Figure 13 depicts a reflectivity map of the earth taken by NASA’s scatterometer.

Today, antennas are used in remote sensing applications for both the military and civilian sectors. For example, in the 1960s the US used remote sensing imaging from satellite and airplanes to track missile activities over Cuba. In the 1970s, remote sensing provided NASA with needed maps of the lunar surface before the Apollo landing. Also in July 1972, NASA launched the first earth resource technology satellite (ERTS-1). This satellite provided data about crops, minerals, soils, urban growth, and other earth features. This program

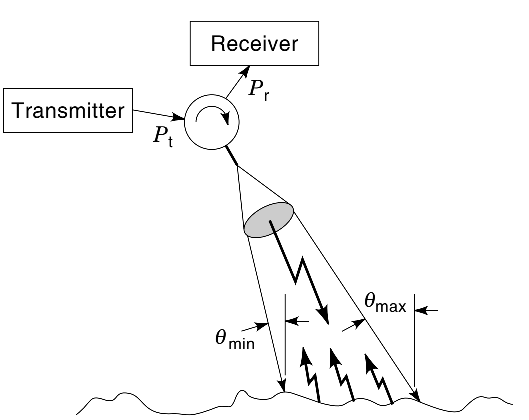

Figure 12. Active remote sensing (microwave scatterometer).

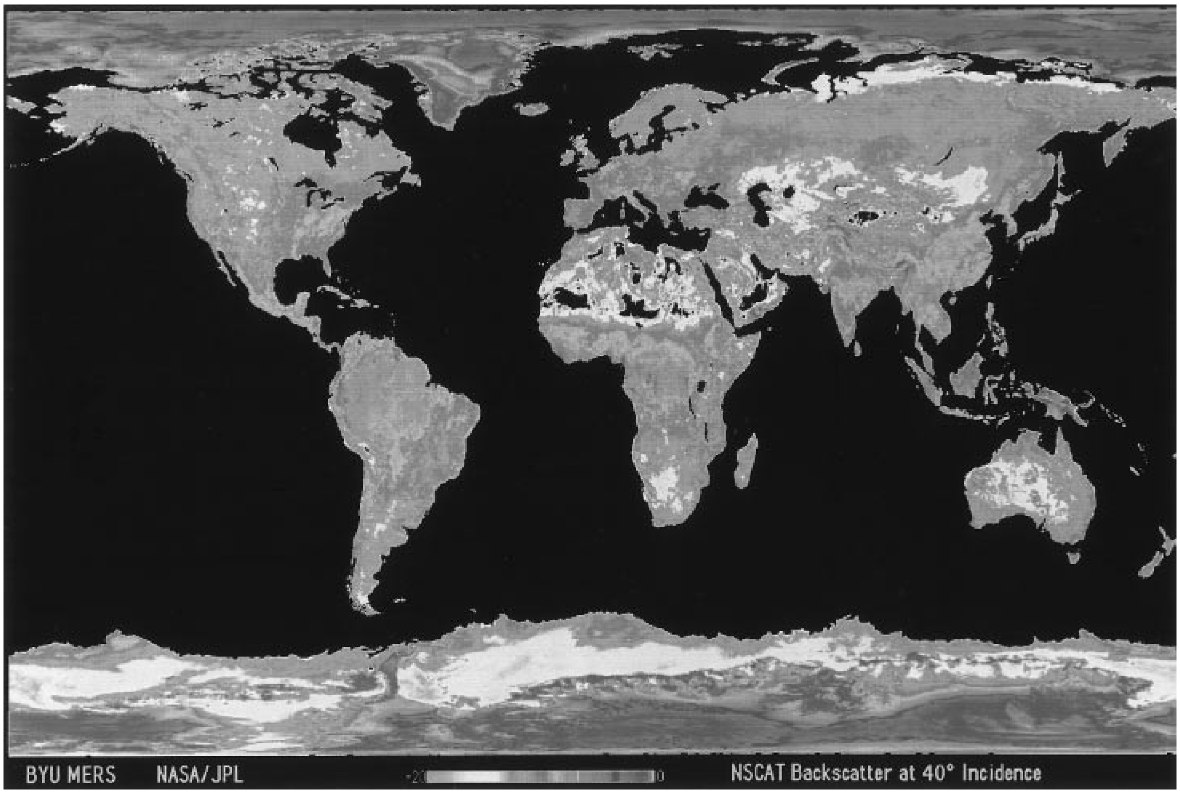

Figure 13. A reflectivity map of the earth taken by NASA's Scatterometer. (Courtesy, NASA/JPL)

still continues its original success using the new series of satellites called the Landsats. In 1985, British scientists noted the ozone depletion over Antarctica. In 1986, US and French satellites sensed the Chernobyl nuclear reactor explosion that occurred in Ukraine. Landsat images from 1975 to 1986 proved to be very instrumental in determining the deforestation of the earth, especially in Brazil. In 1992, hurricane Andrew, the most costly natural disaster in the history of the United States, with winds of 160 miles per hour, was detected on time by very high resolution radar on satellites. Because of the ability to detect the hurricane from a distance, on time, through sophisticated antennas and imagery, the casualties from this hurricane were low. In 1993, during the flooding of the Mississippi River, antenna images were used to assist in emergency planning, and locating threatened areas (56). In 1997, NASA, using antennas, managed to receive signals from Mars and have the entire world observe the pathfinder maneuver itself through the rocky Martian terrain.

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