Antenna Basic

1. What is an antenna?

An **antenna** (or **aerial**) is an electrical device which converts electric power into radio waves, and vice versa. It is usually used with a radio transmitter or radio receiver. In transmission, a radio transmitter supplies an electric current oscillating at radio frequency (i.e. a high frequency alternating current (AC)) to the antenna's terminals, and the antenna radiates the energy from the current as electromagnetic waves (radio waves). In reception, an antenna intercepts some of the power of an electromagnetic wave in order to produce a tiny voltage at its terminals, that is applied to a receiver to be amplified.

Antennas are essential components of all equipment that uses radio. They are used in systems such as radio broadcasting, broadcast television, two-way radio, communications receivers, radar, cell phones, and satellite communications, as well as other devices such as garage door openers, wireless microphones, Bluetooth-enabled devices, wireless computer networks, baby monitors, and RFID tags on merchandise.

Typically an antenna consists of an arrangement of metallic conductors (elements), electrically connected (often through a transmission line) to the receiver or transmitter. An oscillating current of electrons forced through the antenna by a transmitter will create an oscillating magnetic field around the antenna elements, while the charge of the electrons also creates an oscillating electric field along the elements. These time-varying fields radiate away from the antenna into space as a moving transverse electromagnetic field wave.

Conversely, during reception, the oscillating electric and magnetic fields of an incoming radio wave exert force on the electrons in the antenna elements, causing them to move back and forth, creating oscillating currents in the antenna.

Antennas can be designed to transmit and receive radio waves in all horizontal directions equally (omnidirectional antennas), or preferentially in a particular direction (directional or high gain antennas). In the latter case, an antenna may also include additional elements or surfaces with no electrical connection to the transmitter or receiver, such as parasitic elements, parabolic reflectors or horns, which serve to direct the radio waves into a beam or other desired radiation pattern.The origin of antenna:

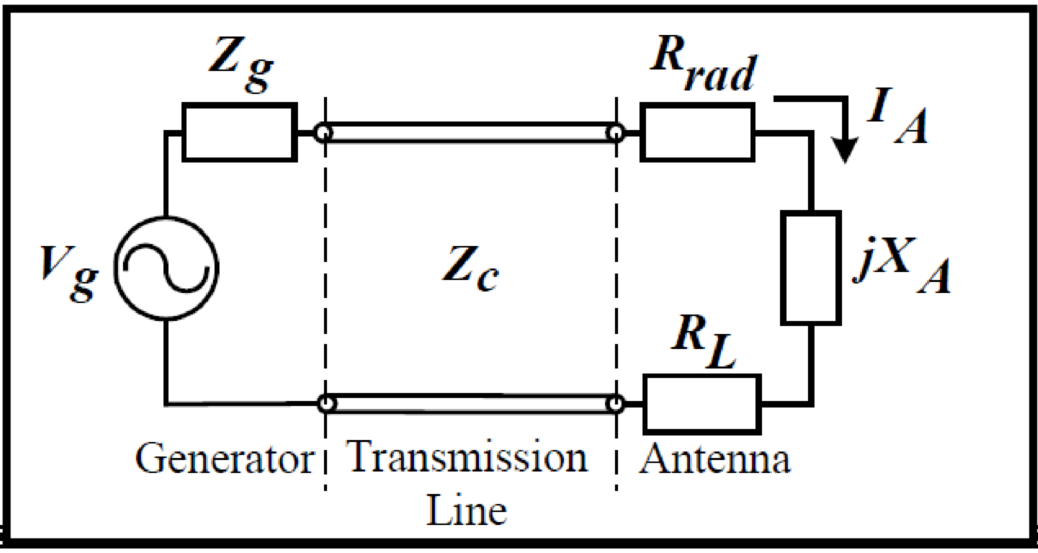
The first experiments that involved the coupling of electricity and magnetism and showed a definitive relationship was that done by Faraday somewhere around the 1830s. He slid a magnetic around the coils of a wire attached to a galvanometer. In moving the magnet, he was in effect creating a time-varying magnetic field, which as a result (from Maxwell's Equations), must have had a time-varying electric field. The coil acted as a loop antenna (a small loop antenna often used as receiver having low resistance and high reactance) and received the electromagnetic radiation, which was received (detected) by the galvanometer - the work of an antenna. Just think about when TV or television first came on to the market. All that was out there for communication in the home was the radio. There wasn't even antennas needed before television. After television came the antenna market. People wanted their TV to have the best picture. Next came more channels which meant more directions for TV signal. That's when the rotor came into place to rotate the antenna system. Then to even make television better we put TV's in several rooms. To keep the picture quality good at all locations came amplification of the antenna system. e first antennas were built in 1888 by German physicist Heinrich Hertz in his pioneering experiments to prove the existence of electromagnetic waves predicted by the theory of James Clerk Maxwell. Hertz placed dipole antennas at the focal point of parabolic reflectors for both transmitting and receiving.

Definition and antenna circuit theory description

The antenna is the transition between a guiding device (transmission line, waveguide) and free space (or another usually unbounded medium). Its main purpose is ***to convert the energy of a guided wave into the energy of a free-space wave (or vice versa) as efficiently as possible, while in the same time the radiated power has a certain desired pattern of distribution in space***.

The antenna is a critical component in a communication system. A good design of the antenna can relax system requirements and improve its overall performance.

a) Transmission-line Thevenin equivalent circuit of a radiating (transmitting) system.



V_g - voltage-source generator (transmitter)

Z_g - impedance of the generator (transmitter)

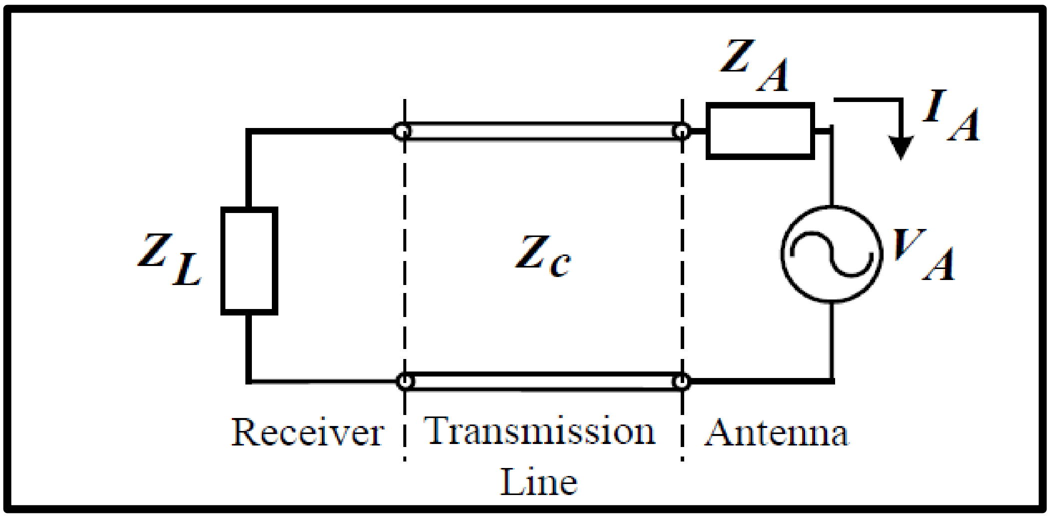
R_{rad} - radiation resistance (related to the radiated power $P_{rad} = I_A^2 \cdot R_{rad}$)

R_L - loss resistance (related to conduction and dielectric losses);

jX_A - antenna reactance.

Antenna impedance: $Z_A = (R_{rad} + R_L) + jX_A$

b) Transmission-line Thevenin equivalent circuit of a receiving antenna system.



Classification of Antennas

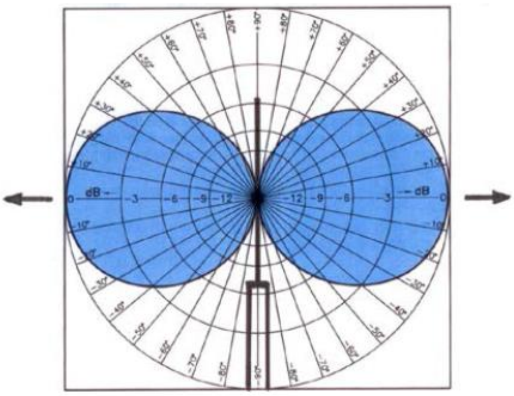
A classification of antennas can be based on:

1- Frequency and size

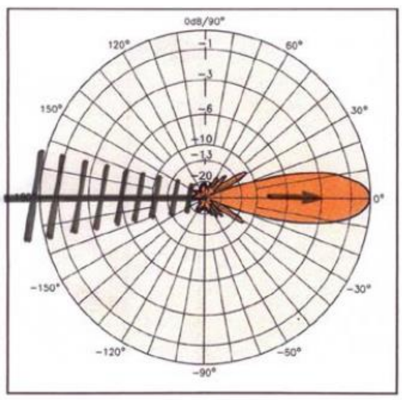
Antennas used for HF are different from the ones used for VHF, which in turn are different from antennas for microwave. The wavelength is different at different frequencies, so the antennas must be different in size to radiate signals at the correct wavelength. We are particularly interested in antennas working in the microwave range, especially in the 2.4 GHz and 5 GHz frequencies. At 2.4 GHz the wavelength is 12.5 cm, while at 5 GHz it is 6 cm.

2- Directivity

Antennas can be omnidirectional, sectorial or directive. Omnidirectional antennas radiate the same pattern all around the antenna in a complete 360 degrees 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 degrees, or as narrow as 60 degrees. Directive antennas are antennas in which the beam width 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, the horn, the helical, the patch antenna, the Parabolic Dish and many others.



Omnidirectional Antenna



Directional Antenna

3 - 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:

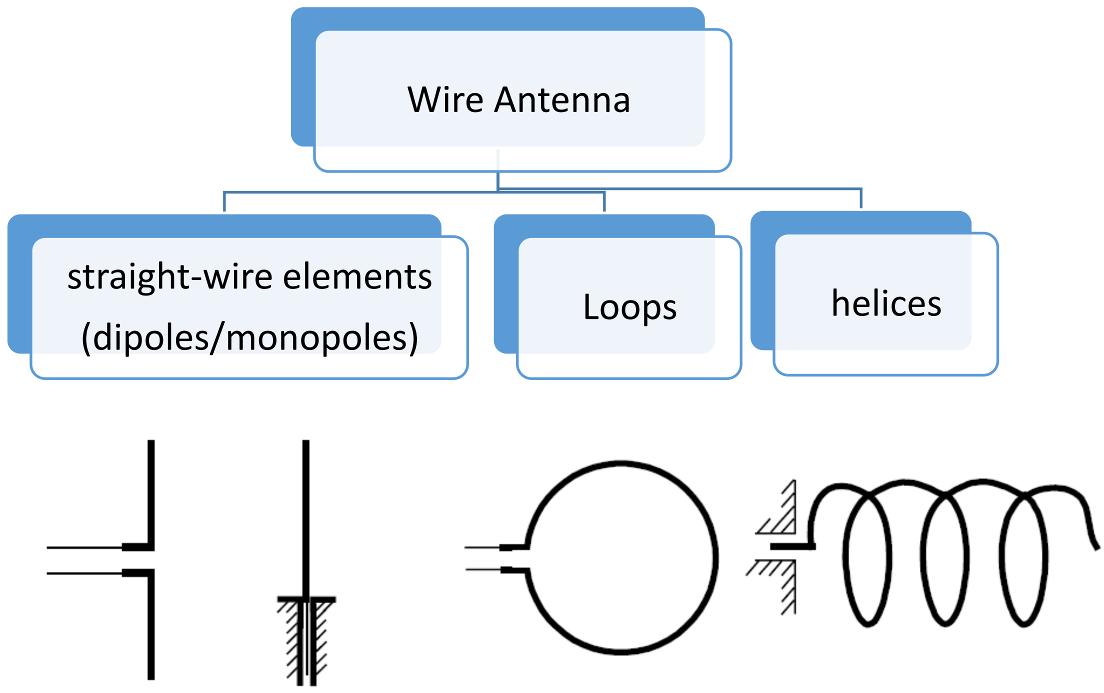
4 - Application

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.

Type of antennas

1. Single-element radiators.

A. Wire antenna

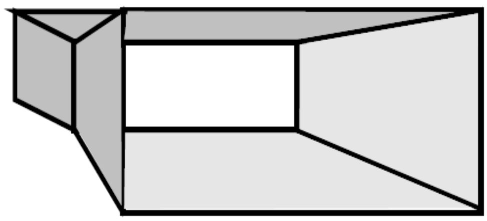


There is a variety of shapes corresponding to each group. For example, loops can be circular, square, rhombic, etc. Wire antennas are simple to make but their dimensions are commensurable with the wavelength.

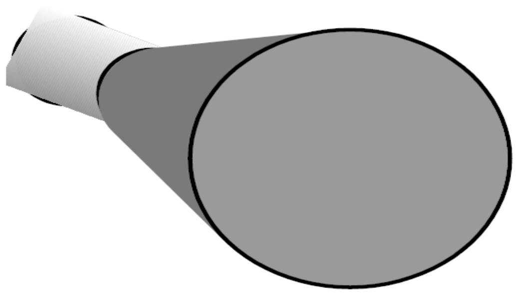
This limits the frequency range of their applicability (at most 1-2 GHz). At low frequencies, these antennas become increasingly large.

B. Aperture antennas (single element)

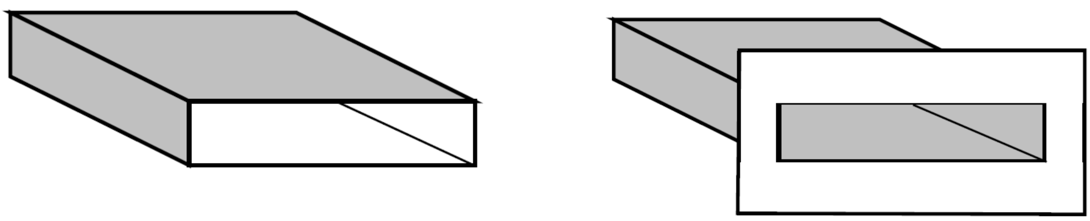
Aperture antennas were developed before and during the WW2 together with the emerging waveguide technology. Waveguide transmission lines were primarily developed to transfer high-power microwave EM signals (centimeter wavelengths), generated by powerful microwave sources such as magnetrons and klystrons. These types of antennas are preferable in the frequency range from 1 to 20 GHz. Antennas of this type are very useful for aircraft and spacecraft applications, because they can be very conveniently flush-mounted on the skin of the aircraft or spacecraft. In addition, they can be covered with a dielectric material to protect them from hazardous conditions of the environment.



(a) Pyramidal horn



(b) Conical horn



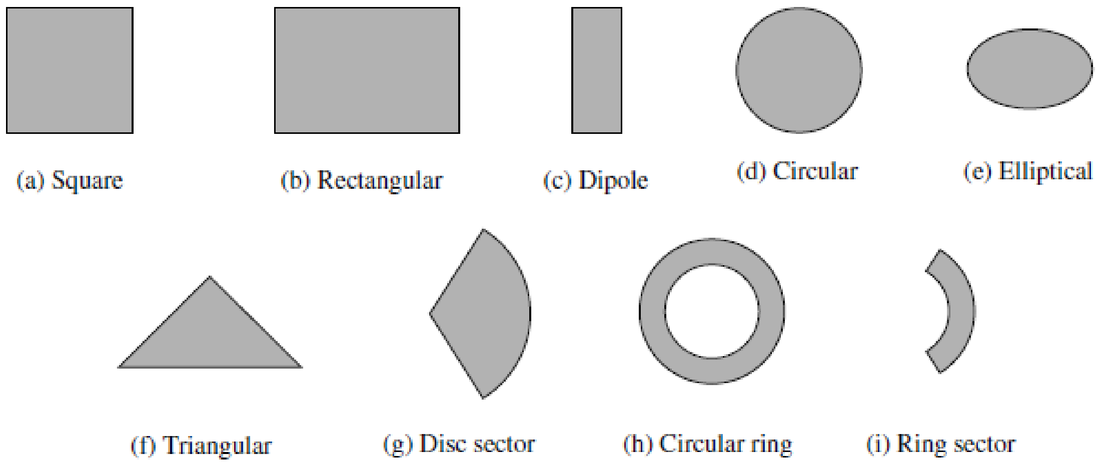
(c) Open rectangular waveguide

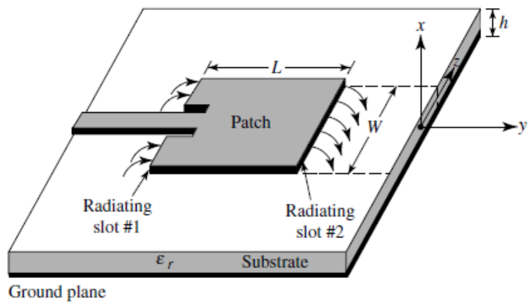
c- Printed Antenna

The patch antennas consist of a metallic patch etched on a dielectric substrate, which has a grounded metallic plane at the opposite side.

They are developed in the beginning of 1970s primarily for space borne applications. Today they are used for government and commercial applications.

The metallic patch can take many different configurations, as shown in Figure below However, the rectangular and circular patches are the most popular because of ease of analysis and fabrication, and their attractive radiation characteristics, especially low cross-polarization radiation. The microstrip antennas are low profile, comfortable to planar and nonplanar surfaces, simple and inexpensive to fabricate using modern printed-circuit technology, mechanically robust when mounted on rigid surfaces, and very versatile in terms of resonant frequency, polarization, pattern, and impedance. These antennas can be mounted on the surface of high-performance aircraft, spacecraft, satellites, missiles, cars, and even handheld mobile telephones.



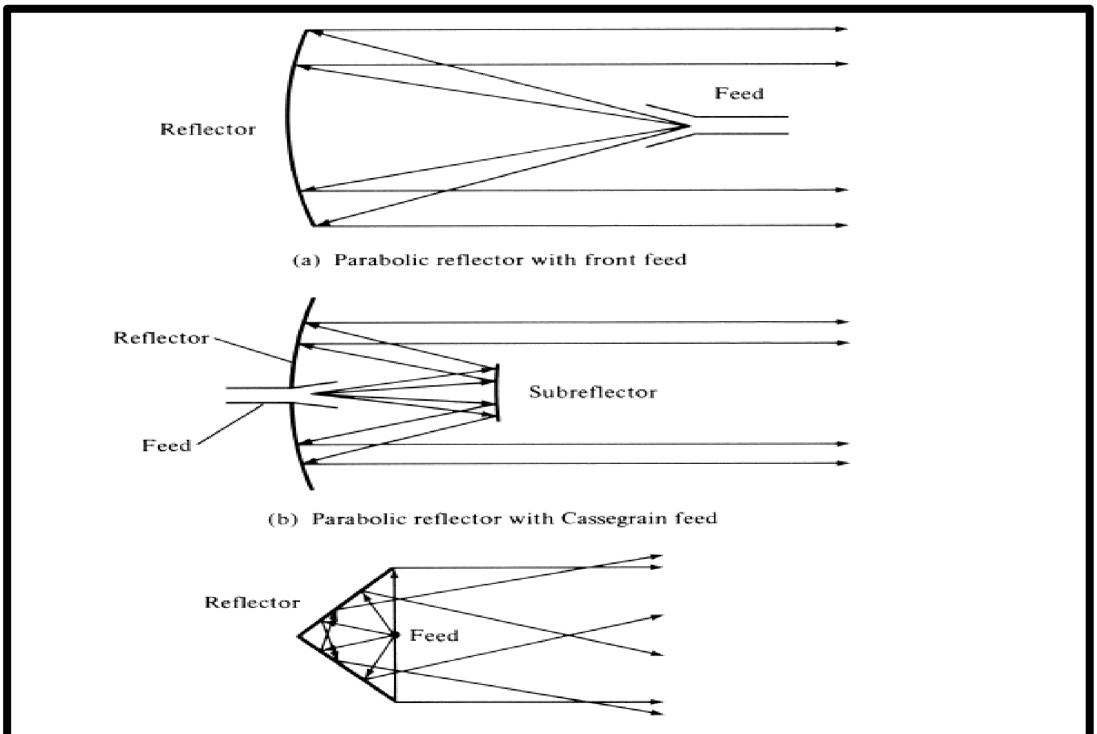


(a) Microstrip antenna

d- Reflector Antenna

The success in the exploration of outer space has resulted in the advancement of antenna theory. Because of the need to communicate over great distances, sophisticated forms of antennas had to be used in order to transmit and receive signals that had to travel millions of miles. A very common antenna form for such an application is a parabolic reflector. Antennas of this type have been built with diameters as large as 305 m. Such large dimensions are needed to achieve the high gain required to transmit or receive signals after millions of miles of travel. Another form of a reflector, although not as common as the parabolic, is the corner reflector.

A reflector is used to concentrate the EM energy in a focal point where the receiver/feed is located. Optical astronomers have long known that a parabolic cylinder mirror transforms rays from a line source on its focal line into a bundle of parallel rays. Reflectors are usually parabolic. Actually, the first use of a parabolic (cylinder) reflector was used for radio waves by Heinrich Hertz in 1888. Rarely, corner reflectors are used. Reflector antennas have very high gain and directivity. Typical applications: radio telescopes, satellite telecommunications. They are not easy to fabricate and, in their conventional technology, they are rather heavy. They are not mechanically robust.



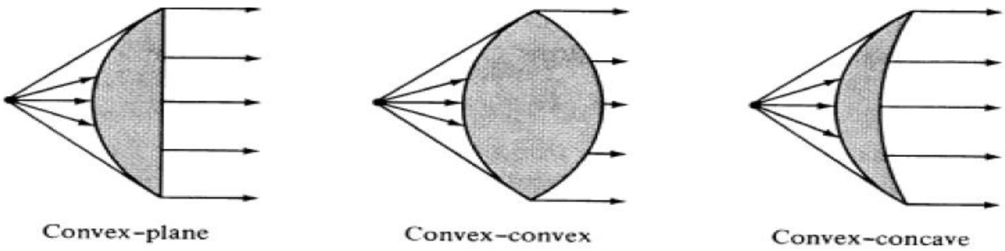
(a) Parabolic reflector with front feed

(b) Parabolic reflector with Cassegrain feed

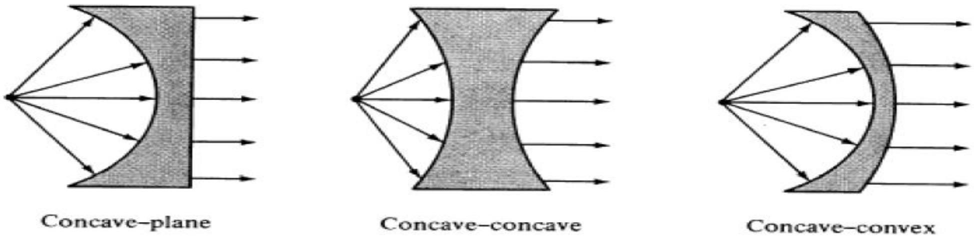
(c) Corner reflector

E. Lens antennas

Lenses play a similar role to that of reflectors in reflector antennas. They collimate divergent energy into more or less plane EM wave. Lenses are often preferred to reflectors at higher frequencies (f > 100 GHz). They are classified according to their shape and the material they are made of.



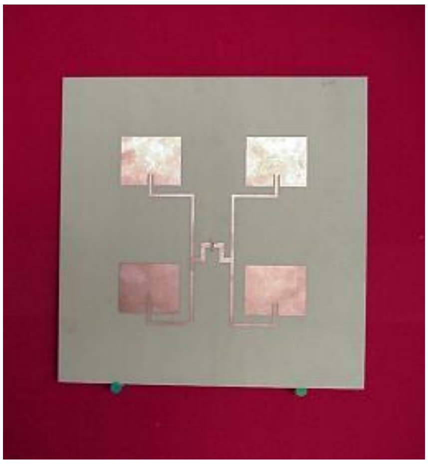
(a) Lens antennas with index of refraction $n > 1$

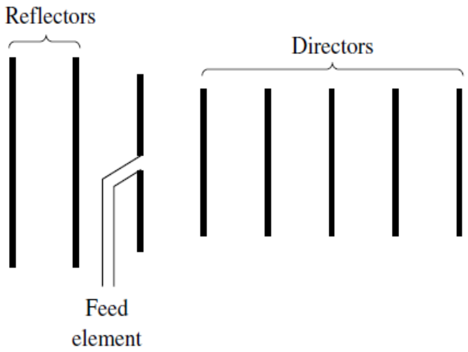


(b) Lens antennas with index of refraction $n < 1$

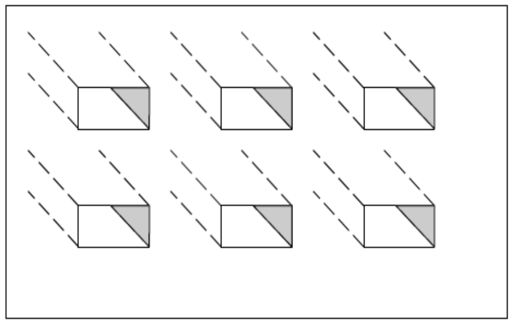
2- Antenna Arrays (1940)

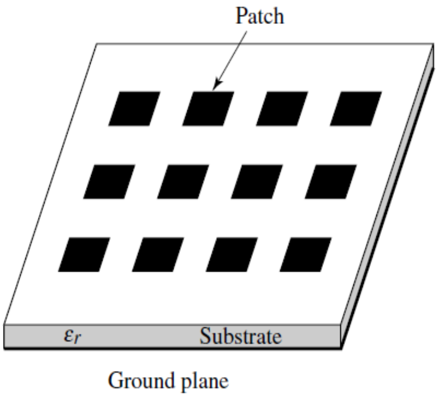
Antenna arrays consist of multiple (usually identical) radiating elements. Arranging the radiating elements in arrays allows achieving unique radiation characteristics, which cannot be obtained through a single element. The careful choice and control of the phase shift and the amplitude of the signal fed to each element allows the change of the radiation pattern electronically, i.e. electronic scanning. Such arrays are called phased arrays. The design and the analysis of antenna arrays is a subject of its own, which is also related to signal processing. Intensive research goes on nowadays, concerning smart antennas, signal processing antennas, tracking antennas, etc.



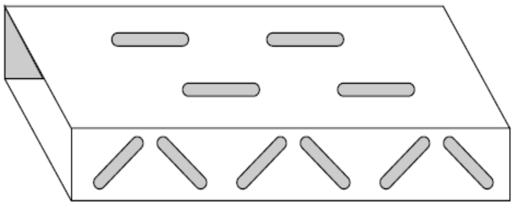


(a) Yagi-Uda array


(b) Aperture array



(c) Microstrip patch array

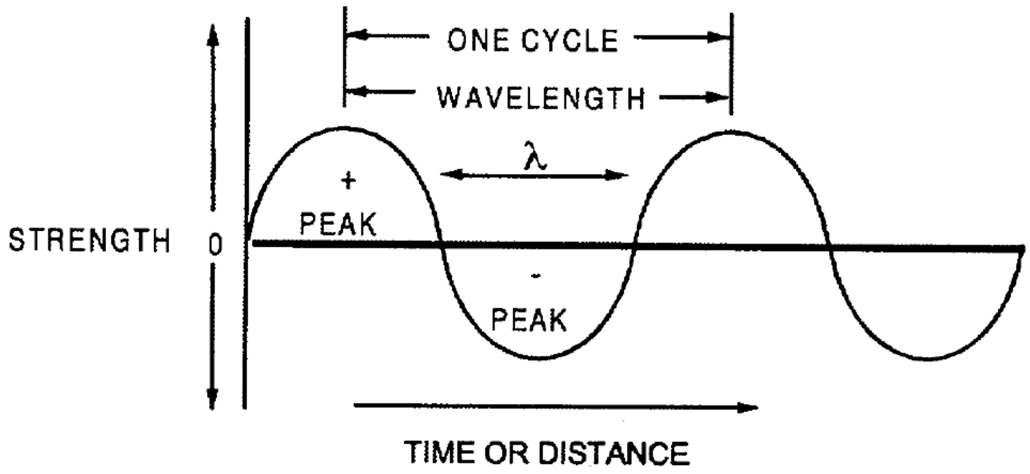

(d) Slotted-waveguide array

The mean array antenna characteristics

- increase the overall gain
- provide diversity reception
- cancel out interference from a particular set of directions
- "steer" the array so that it is most sensitive in a particular direction
- determine the direction of arrival of the incoming signals to maximize the Signal to Interference Plus Noise Ratio (SINR)

RADIO WAVES

Radio waves propagate (travel) much like surface water waves. They travel near the Earth's surface and also radiate skyward at various angles to the Earth's surface. As the radio waves travel, their energy spreads over an ever-increasing surface area. A typical radio wave has two components, a crest (top portion) and a trough (bottom portion). These components travel outward from the transmitter, one after the other, at a consistent velocity (speed). The distance between successive wave crests is called a wavelength and is commonly rep- resented by the Greek lowercase lambda (λ)



Frequency

Radio waves transmit radio and television (TV) signals. They have wavelengths that range from less than a centimeter to tens or even hundreds of meters. Frequency modulated (FM) radio waves are shorter than amplitude modulated (AM) radio waves. A radio wave's frequency equals the number of complete cycles that occur in 1 second. The longer the cycle time, the longer the wavelength and the lower the frequency. The shorter the cycle time, the shorter the wavelength and the higher the frequency.

Frequency is measured and stated in hertz (Hz). A radio wave frequency is very high. It is generally measured and stated in thousands of hertz (kilohertz [kHz]), in millions of hertz (megahertz [MHz]), or sometimes in billions of hertz (gigahertz [GHz])

1 Hz= 1cycle per second

1 kHz = 1thousand cycles per second

1 MH = 1million cycles per seconds

1 GHz= 1 billion cycles per second

Wireless vs. cable communication systems

There are two broad categories of communication systems: those that utilize transmission lines as interconnections (*cable systems*), and those that use EM radiation with an antenna at both the transmitting and the receiving end (*wireless systems*).

In areas of high density of population, the cable systems are economically preferable, especially when broadband communication is in place. Even for narrow-band communication, such as voice telephony and low-data-rate digital transmission, it is much simpler and cheaper to build wire networks with twisted-pair cables, when many users are to be interconnected. These lines are not suitable at higher frequencies because of the higher losses and dispersion. At higher frequency carriers, carrying broadband signals (TV transmission and high data rate digital transmission), coaxial cables are commonly used. The loss is around 4-5 dB/km. The least distortion and losses are offered by the optical-fiber transmission lines, which operate at three different wavelengths: 850 nm (≅ 2.3 dB/km), 1300 nm (≅ 0.25 dB/km) and 155 nm (≅ 0.25 dB/km). They are more expensive though and the respective transmitting/receiving equipment is costly. Transmission lines provide a measure of security and noise-suppression (coaxial, optical-fiber), but they are not the best option in many cases (long distance, wide spreading over large areas, low frequency dispersion).

A fundamental feature of all transmission lines is the exponential increase of loss power. This makes it rather obvious why wireless systems are preferred for long-range communications, and in scarcely populated areas. In most wireless channels, the radiated power per unit area decreases as the inverse square of the distance *r* between the transmitting and the receiving point.

Frequency Band

HF is used primarily for long-range communications. An HF signal is reflected by the outermost portion of the atmosphere, the ionosphere. VHF is used for short-range communications. To use VHF, it is necessary to be able to visualize a direct line of sight (LOS) between the transmitter and receiver. This limits UHF to distances that are not much greater than the distance to the horizon, assuming that there are no massive obstructions in the LOS. When the LOS path exists and VHF transmission is possible, VHF is always preferred to HF because a VHF signal can be made to follow a much narrower and more direct path to the receiver. UHF is a third type of transmission. UHF transmission is like VHF in that both follow the direct or LOS path. But with the proper antenna, UHF transmission can be made to follow an even narrower path to the receiver than VHF.

Each frequency band has unique characteristics. The ranges shown in table 1-1 are for normal operating conditions (i.e., proper siting and antenna orientation and correct operating procedures). Ranges will change according to the condition of the propagation medium and the transmitter output power.