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ANTENNAS IN SATELLITE COMMUNICATION

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ABSTRACT: The antenna is the most visible part of the satellite communication system. The antenna transmits and receive the modulated carrier signal at the radio frequency (RF) portion of the electromagnetic spectrum. For satellite communication the frequencies range from about 0.3GHz(VHF) to30GHz and beyond these frequencies represent microwaves with wavelength on the order of one meter down to below one centimetre. High frequencies and the corresponding small wavelength permit the use of antennas having practical dimension for commercial use. This article summarizes the basic properties of antennas used in satellite communication and derives several fundamental relations used in antenna design and RF link analysis.

I. INTRODUCTION

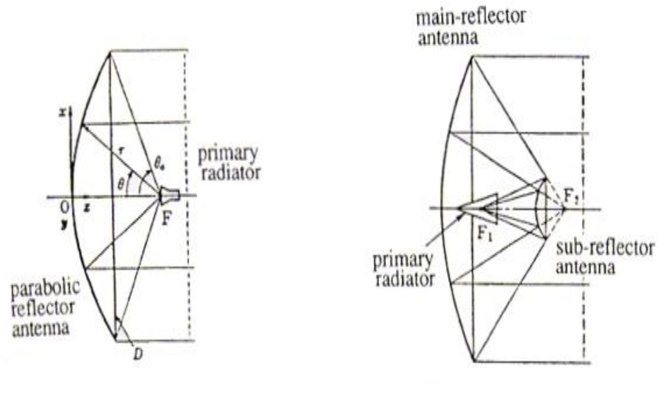
A communication satellite is an artificial satellite that relays and amplifies radio telecommunication signals via transponders, it creates communication between a source transmitter and receiver at different location on earth. Communication satellite are used for television, telephone, radio, internet and military application. The antenna is the most visible part of satellite communication system.The antenna transmits and receive the modulated carrier signal at the radio frequency (RF) portion of the electromagnetic spectrum. For satellite communication the frequencies range from about 0.3GHz(VHF) to 30GHz and beyond these frequencies represent microwave with wavelength on the order of 1m down to below 1cm.High frequencies and the corresponding small wavelength permit the use of antennas having practical dimension for commercial use. This article summarizes the basic properties of antennas used in satellite communication and derives several fundamental relations used in antenna designed RF link analysis.

II. HISTORY OF ELECTROMAGNETIC ANTENNA

The quantitative steady of electricity and magnetism began with the scientific research of the French physicist Charles Augustin Coulomb. In 1787 Coulomb proposed a law of force for charges that like Sir Isaac Newton's law of gravitation varied inversely as the square of the distance. Using a sensitive torsion balance he demonstrated its validity experimentally for forces of both repulsion and attraction. At the beginning of the nineteenth century the electrochemical cell was invented by Alessandro Volta, professor of natural philosophy at the University of Pavia in Italy. The cell created an electromotive force which made the production of continuous current possible. Then in 1820 at the University of Copenhagen, Hans Christian Oersted made the momentous discovery that an electric current in a wire could deflect a magnetic needle. Subsequently in 1831 the British scientist Michael Faraday demonstrated the reciprocal effect in which a moving magnet in the vicinity of coil of wire produce d an electric current. This phenomenon together with Oersted's experiment with the magnetic needle led Faraday to conceive the notion of a magnetic field. A field produced by a current in a wire interacted with a magnet. Faradays field concept implied that charges and currents interacted directly and locally with electromagnetic field which although produced by charges and currents has an identity of its own. The Scottish physics James Clarke Maxwell established the mathematical theory of electromagnetism based on physical concept of Faraday. Maxwell restated the laws of Coulomb, Ampere and Faraday in terms of Faraday's electric and magnetic fields. Maxwell thus unified the theories of electricity and magnetism. Furthermore Maxwell made the profound observation that his set of equations thus modified, predicted the existence of electromagnetic waves. Using the values of known experimental constants obtained solely from the measurements of charges and currents Maxwell deduced that speed of propagation was equal to speed of light. In 1888,Hertz set up standing electromagnetic waves using an oscillator and spark detector of his own design and made independent measurement of their frequency and wavelength. He found that then product was indeed the speed of light. He also verified that there waves behaved according to all the laws of reflection, refraction and polarization that applied to visible light. After learning of Hertz experiment through a magazine article, the young Italian engineer Gueglielmo Marconi constructed the first transmitter for wireless telegraphy in 1895.Within 2 yrs. he used this new invention to communicate with ships at sea Transmission over long distance was made possible by the reflection of radio waves due to Ionosphere. For their contribution to wireless telegraphy, Marconi and Braun were awarded the Nobel Prize in physics in 1909. Stimulated by the invention of radar during world war II, considerable research and development in radio communication at microwave frequency and centimetre wavelength was conducted in decade of 1940.The MIT radiation laboratory was a leading centre for research on microwave antenna theory and design. The basic formulation of the radio transmission formula was developed by Harald.T.Frissat the bell laboratories and published in 1946.This equation expressed the radiation from an antenna in terms of power flow per unit area, instead of giving the field strength in volts per meter, and is the foundation of the RF link equation used by satellite communication engineers today.

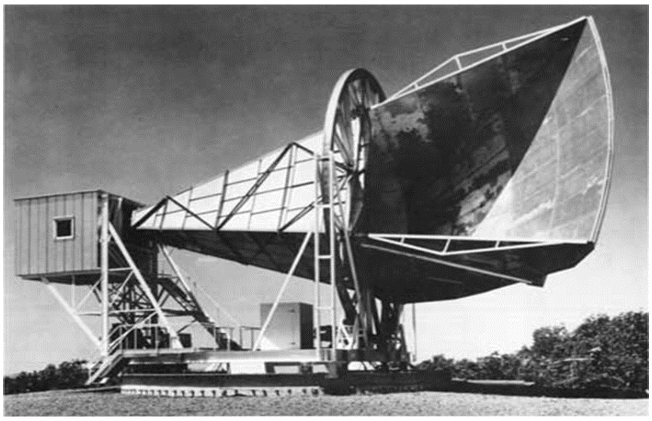
III. TYPES OF ANTENNAS

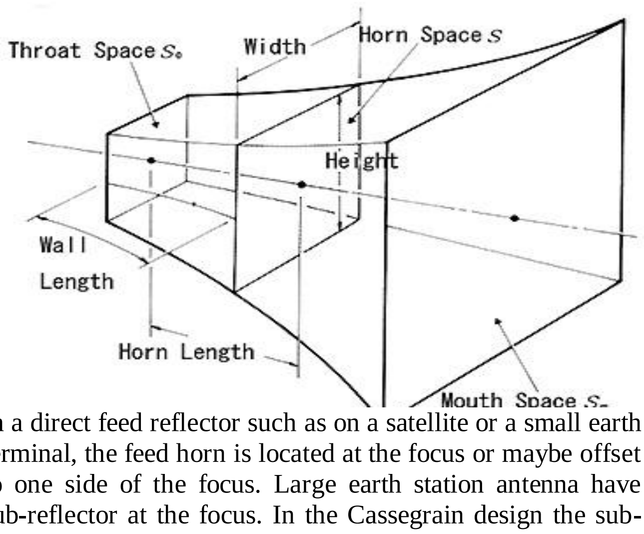
A variety of antenna types are used in satellite communication. The most widely used narrow beam antennas are reflector antennas. The shape is generally a paraboloid of revolution



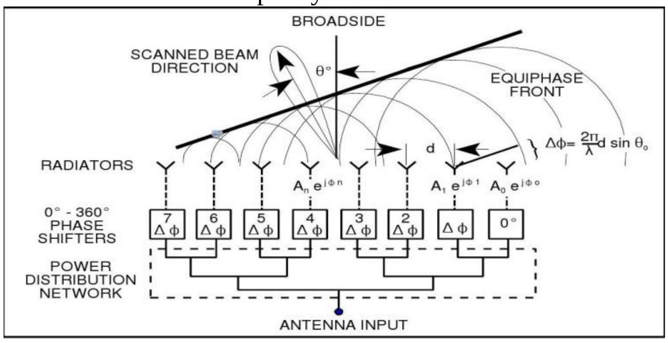
(a) Parabolic reflector antenna (b) Cassegrain antenna

For full earth coverage from a geostationary satellite a horn antenna is used. Horns are used as feed for reflector antennas.





In a direct feed reflector such as on a satellite or a small earth terminal, the feed horn is located at the focus or maybe offset to one side of the focus. Large earth station antenna have sub-reflector at the focus. In the Cassegrain design the sub-reflector is convex with hyperboloidal surface, while in Gregorian design it is concave with an ellipsoidal surface. The sub-reflector permits the antenna optics to be located near the base of antenna .This configuration reduces losses because the length of the wavelength between the transmitter or receiver and antenna feed is reduced. The system noise temperature is also reduced because the receiver looks at the cold sky instead of warm earth. In addition the mechanical stability is improved resulting in higher point accuracy. Phased array antenna may be used to produce multiple beam or full electronic steering. Phased arrays are found on many geostationary satellite such as Iridium globalstar and ICO satellites for mobile telephony.



IV. ANTENNA PERFORMANCE PARAMETERS

A. Gain and half power beam width

The fundamental characteristic of an antenna are its gain and half power beam width. According to the reciprocity theorem the transmitting and receiving patterns of an antenna are identical at a given wavelength. The gain is a measure of how much of the input power is concentrated in particular direction it is expressed with respect to hypothetical isotropic antenna,which radiates equally in all direction.Thus in direction(θ,ϕ) the gain is

$$G(\theta,\phi)=(dp/d\varpi)\ (P_{in}/4\pi)$$

Where P_{in} is the total input power and dp is the increment of radiated output power in solid angle $d\varpi$. The gain is maximum along the bore sight direction. The bore sight gain is given in terms of the size of the antenna by the important relation.

$$G=\eta(4\pi/\lambda^2)A$$

Where λ= wavelength

η= net efficiency, for typical antenna η=0.55.

This equation determines the required antenna area for the specified gain at a given wave length. For a reflected antenna the area is simply the projected area. Thus for a circular reflector of diameter D the area is $A=\pi D^2/4$ and gain is $G=\eta(\pi D/\lambda)^2$ which can also be written as $G=\eta(\pi Df/C)^2$

Where $C=\lambda f$

The boresight gain G can be expressed in terms of the antenna beam solid angle ϖ_A that contains the total radiated power as $G=\eta*(4\pi/\varpi_A)$

Half Power beam width

The half power beam width is the angular separation between the half power points on the radiation pattern where the gain is one half the maximum value.For a reflector antenna it may be expressed as

$$HPBW=\alpha=K\lambda/D$$

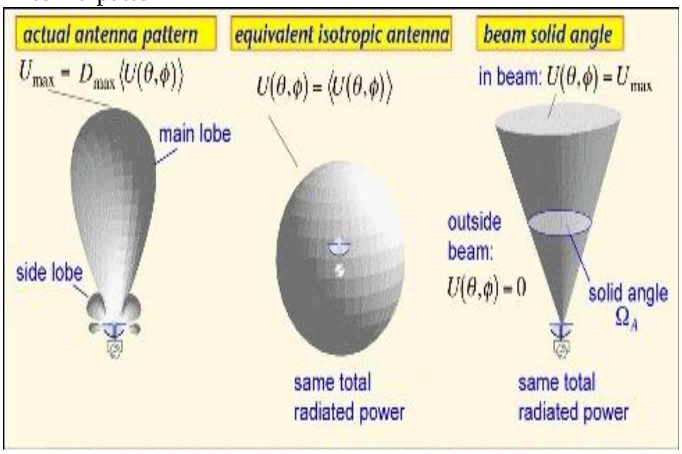
Where K is a factor that depends upon the shape of the reflector and method of illumination. For typical antenna $K=70^o$ (1.22 if α is in radians).The gain may be expressed directly in terms of the half power beam width by eliminating the factor D/λ. Thus $G=\eta(K\pi/\alpha)^2$

EIRP and G/T

For the RF link budget, the two required antenna properties are the equivalent are the equivalent isotropic radiated power(EIRP) and the figure of merit G/T.These quantities are the properties of transmit antenna and receive frequencies respectively. The equivalent isotropic radiated power is the power radiated equally in all direction that would produce a power flux density equivalent to the power flux density of the actual antenna $EIRP=GP_{in}$, where P_{in} is the input power.

Therefore EIRP is the product of antenna gain of the transmitter and the power applied to the input terminal of antenna. The figure of merit is the ratio of the antenna gain of the receiver G and the system temperature T.The System temperature is a measure of the total noise power and includes contribution from the antenna and the receiver.

Antenna pattern



Since electromagnetic energy propagates in in the form of the wave it spread out through space due to phenomenon of diffraction. Individual wave combines both constructively and destructively to form a diffraction pattern that manifests itself in the main lobe and side lobe of antenna. The antenna pattern is analogous to the "Airy rings" produced by visible light when passing through a circular aperture. There diffraction pattern where studied by Sir George Biddell Airy, Astronomer Royal of England. The diffraction pattern consist of central bright spot is produced by waves that combine constructively and is analogous to the main lobe of the antenna. The spot is bordered by a dark ring where waves combine destructively that is analogous to the first null.The surrounding bright ring are analogous to the side lobe of the antenna pattern.

Taper

The gain pattern of a reflector antenna depends on how the antenna is illuminated by feed.The variation in electric feed.The variation inelectricfeed across the antenna diameter is called the antenna Taper.The total antenna solid angle containing all the radiated power including the side lobe is

$$\varpi = \eta*(4\pi/G)=(1/\eta_a)(\lambda^2/A) =(1/\eta_a)(\lambda^2/A)$$

Where ηa is the aperture taper efficiency and $\eta*$ is the radiation efficiency associated with losses.The beam efficiency is defined as

$$\xi=\varpi_M/\varpi_A$$

Where ϖ_M is the solid angle for the main lobe.

In general maximum aperture taper efficiency occurs for a uniform distribution but maximum beam efficiency occurs for a highly tapered distribution.

Coverage Area

The gain of satellite antenna is designed to provide a specified area of coverage on the earth.The area of coverage within the half power beam width is

$$S=d^2\varpi$$

Where, d is the slant range to the centre of the footprint

ϖ is the solid angle of a cone

That intercepts the half power points,which may be expressed in terms of the angular dimension of the antenna beam.

$$\text{Thus} = k\alpha\beta$$

Where α and β are the principle plane half power beam width in radians and K is a factor that depends on the shape of the coverage area.For a square or rectangular area of coverage,K=1 while for circular or elliptical area of coverage,$K=\pi/4$.

Shaped Beam

Often the area of coverage has an irregular shape, such as one defined by the country or continent, until recently the usual practise has been to create the desired coverage pattern by means of a beam forming network. Each beam has its own feed and illuminates the full reflector area. The superposition of all the individual circular beam produces the specified shaped beam. For example the Old Galaxy 5 satellite operated by PanAmSat. The reflector diameter is 1.80m.there are two linear polarization, horizontal and verticle. in a given polarization, the Contiguous United States(CONUS) might be covered by four beams, each with half power beam width 3^o at the C-band downlink frequency of 4GHz.From geostationary orbit, The angular dimension of Conus are approximately $6^o *3^o$.For this rectangular beam pattern the maximum gain is about 31dB less with TWTA output power of 16W (12dBW),a waveguide loss of 1.5dBand an assumed beam forming network loss of 1dB,the maximum EIRP is 40.5dBW. The shaped reflector represents a new technology instead of illuminating o conventional parabolic reflector with multiple feeds in a beam forming network, there is a single feed that illuminates a reflector with an undulating shape that provides the required region of coverage. The advantages are lower spill over loss, a significant reduction in mass, lower signal losses and lower cost.

Example of Reflector Antenna sizing for European coverage

Design Parameters Requirements

- Geostationary satellite at 16o east
- European coverage
- Frequency 20\30GHz
- Minimum gain 40dB

Unknowns

- Reflector diameter
- Focal length
- Number of beams
- Feed size

Design procedure

All dimension expressed in λ=10,15mm

GdBi, peak = 3+$GdBi_{min}$→ (η=0.5), $G_{peak} = 0.5(\pi d)^2$,G_{max}= $\eta 4\pi A/\lambda^2 = \eta(\pi D/\lambda)^2$

D= $(4.10^4/\pi)^{1/2}$ = 113

$\theta_{-3dB} = 70/D = 0.62, \theta_{-3dB} = K\lambda/D$

Assume beam spacing of 0.5^o (to be adjusted later) and h=D/4, f/D = 1

$\theta = \arctan[4f(h+D)/4f^2 - (h+D)^2] - \arctan(4fh/4f^2 - h)$

Assume feed gain at reflector edge G_{feed},peak – 6dB,ϕ_{feed},-3dB = $\phi/(2)^{1/2}$

Derive feed parameter d = $60/\phi_{feed}$,-3dB

Compute scan angle θ assuming K=1

$\theta = d/[(h+d/2)^2 + (f-(h+d/2)^2)/4f]^{1/2}$

Finally check consistency with assumption of 0.5^o

V. SUMMARY

The gain of an antenna is determined by the intended area of coverage. The gain at a given wavelength is achieved by appropriately choosing the size of the antenna. The gain may also be expressed in terms of half power beamwidth. Reflected antennas are generally used to produce narrow beam for geostationary satellite and earth stations. The efficiency of antenna is optimised by the method of illumination and choice of edge taper, phased array antennas are used on many LEO and MEO satellites. New technologies includes large unfurl able antennas for producing small spot beams from geostationary orbit and shaped reflectors for creating a shaped beam with only a single feed.

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