ANTENNA VIRTUAL SLIDE RULE CALCULATORS

A guide to using Antenna Virtual Slide Rule Calculators

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Contents

Antenna Virtual Slide Rules

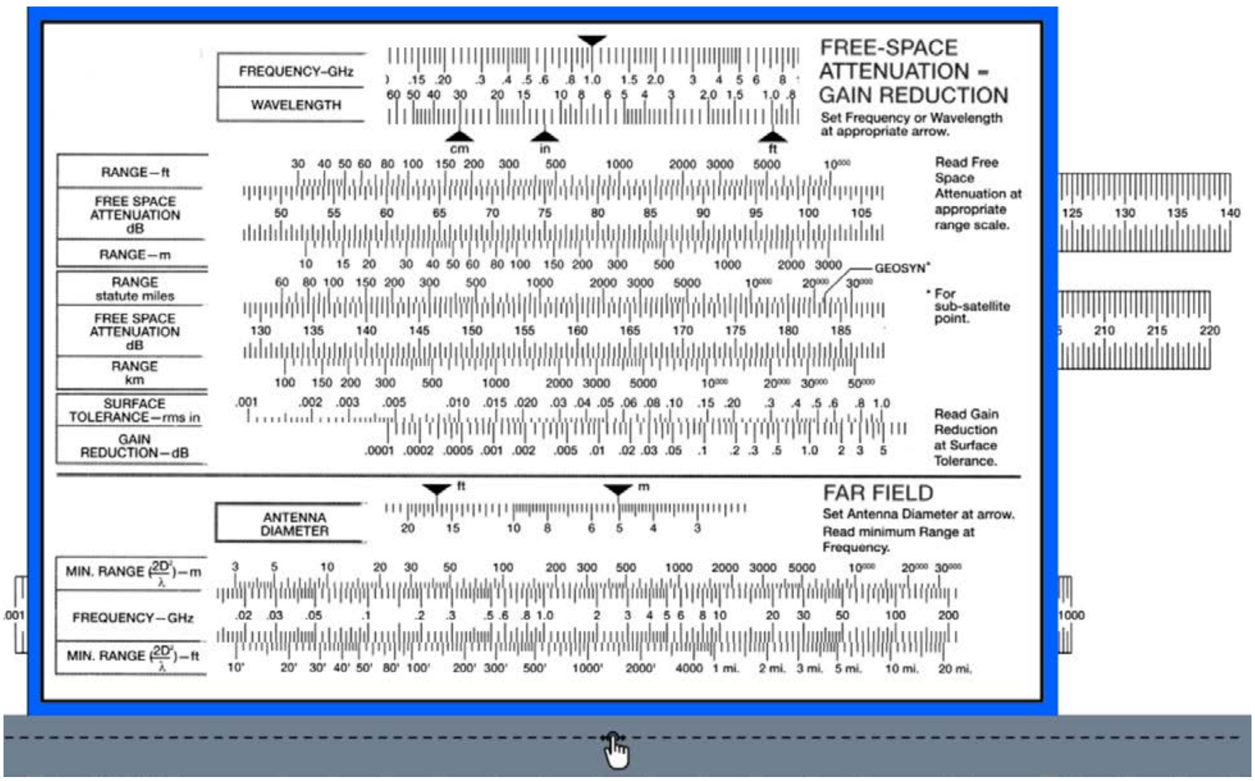
These slide rules help you compute radiation characteristics, space losses and many other parameters when using parabolic antennas for radio command and telemetry links.

To “set” the rulers, put your mouse cursor over the small hand or dotted line and drag left and right to set the indices to your desired values. Some rulers move in tandem with the ruler being dragged, similar to the physical "slide rule" type of antenna calculators.

Read the desired values from other indices after setting the rulers.

An Example …

Here is a step by step example using the Free Space Attenuation (also referred to as Free Space Loss) and Gain Reduction rulers:



1. Set the frequency at 1 GHz by lining **1.0** with the topmost "arrow" (the black triangle at the top of the picture above).
2. The wavelength @ 1 GHz can be read directly at the arrows below the frequency. The computed wavelength read off the scale is **30cm / 11.8 in / 0.98 ft.**
3. The free space loss (attenuation) at 1 GHz at different distances (ranges) can be read from the rulers below the wavelength by reading the value which lines up

with the distance of interest. At a range of **1000m** (1 km), the loss is **92.4 dB** as read off the scale above the 1000m value. At a geostationary range (~**22,300** miles or 35,786 km directly below the satellite), the loss is **183.5 dB** as read off the scale.

4. If the antenna has a surface tolerance of **0.020"** RMS, the gain reduction of the antenna is ~ **0.0019 dB** as read off the other scales.

Note: Many of the rulers are logarithmic, and some are linear, so great care must be taken to set and read the appropriate values!

Beamwidth

An antenna's beamwidth is commonly understood to mean the half-power beamwidth, which is the angle between the two directions in which the directive gain of the main radiation lobe is one half the maximum value.

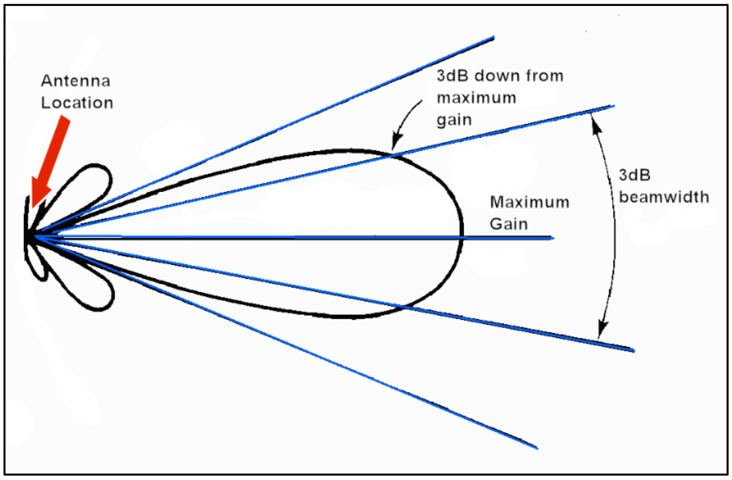
$$\theta = \frac{21}{fD}$$

where

θ = half power beamwidth in degrees ("3dB beamwidth")

f = frequency in GHz

D = diameter in m



Example antenna pattern – antenna is located at the left and is directing its beam to the right

Wavelength

Wavelength is a measure between successive crests of an electromagnetic wave and is related to the speed of light as follows:

$$\lambda = \frac{29.98}{f}$$

where

λ = wavelength in cm

f = frequency in GHz

Note that $2.998\text{x}10^8\ \frac{\text{m}}{\text{s}}$ is the speed of light in a vacuum

Gain

Antenna gain is a property describing an antennas ability to direct transmitted power in a specific direction. Gain also refers to the antenna's ability to receive energy selectively from a desired direction. Gain for a circular rimmed parabolic dish can be calculated by:

$$G = 20.4 + 20\log(f) + 20\log(D) + 10\log(\eta)$$

where

G = Gain in dBi

f = frequency in GHz

D = diameter in m

η = antenna efficiency (expressed as a decimal; e.g. 0.5 = 50%)

Efficiency

Efficiency is a measure of losses internal to the antenna, such as power losses in conductors and dielectric materials. Efficiency is the ratio of the total power radiated divided by the net power accepted by the antenna from a transmitter. Excluded from efficiency calculations are the losses due to power reflected back to the transmitter due to impedance mismatch (see VSWR). Overall gain, or "realized gain" is important to systems engineers, because it reveals how much signal will be available at the input to a receiver for a given field strength. Typical values for efficiency are 0.55 - 0.75.

Beamwidths and gains of parabolic antennas of different apertures can be estimated as follows:

Aperture-Type	Beamwidth (From Aperture)	Directive gain (From Aperture)	Directive gain (From Beamwidth)	Antenna Efficiency (Aperture Illumination Efficiency)
Uniformly illuminated circular aperture-hypothetical parabola (a) 18 dB side-lobe level	$\theta = \frac{58\lambda}{a}$ $\theta = \theta_1 = \theta_2$	$g_d = \frac{15a^2}{\lambda^2}$ $g_d = \frac{9.87a^2}{\lambda^2}$	$g_d = \frac{52{,}525}{\theta^2}$ $\theta = \theta_1 = \theta_2$	100%
Uniformly illuminated rectangular aperture or linear array a, b 13 dB side-lobe level	$\theta_1 = \frac{51\lambda}{a}$ $\theta_2 = \frac{51\lambda}{b}$	$g_d = \frac{1.6ab}{\lambda^2}$	$g_d = \frac{41{,}253}{\theta_1\theta_2}$	100%
Rectangular horn a) Polarization plane: E-plane a_E 13 dB side-lobe level b) Orthogonal polarization plane: H-plane a_H 26 dB side-lobe level	$\theta_1 = \frac{56\lambda}{a_E}$ $\theta_2 = \frac{67\lambda}{a_H}$	$g_d = \frac{7.5a_E a_H}{\lambda}$	$g_d = \frac{31{,}000}{\theta_1\theta_2}$	60%
Nonuniformly illuminated circular aperture (10 dB taper)–normal parabola (a) 26 dB side-lobe level	$\theta = \frac{72\lambda}{a}$ $\theta = \theta_1 = \theta_2$	$g_d = \frac{5a^2}{\lambda^2}$	$g_d = \frac{27{,}000}{\theta^2}$ $\theta = \theta_1 = \theta_2$	50%
	$a >> \lambda$	$G_d = 10\log_{10} g_d$ dB	$G_d = 10\log_{10} g_d$ dB	

Free Space Loss

Free-space path loss is the loss in signal strength of an electromagnetic wave resulting from a line-of-sight path through free space, with no obstacles to cause reflection or diffraction. Free-space loss does not include factors such as the gain of the antennas used for transmitting or receiving, nor any losses associated with cabling or other inefficiencies.

$$L = 92.45 + 20\log(d) + 20\log(f)$$

where

L = loss in dB

f = signal frequency in GHz

d = distance from the transmitter (in km)

This equation is only accurate in the far field - it does not apply close to the transmitter.

Gain Reduction

Inaccuracies in the making of reflector panels, or degradation of the panels due to other factors, such as weathering, pitting, damage, improper painting or other physical deformations cause antenna gain reduction due to deviations from a "perfect" parabolic surface. These surface tolerances are statistically measured using a root mean square (RMS) approach, which is a good way to measure these inaccuracies due to both positive and negative deviation distances from the "perfect" surface.

In general, RMS values are calculated using the following formula:

$$x_{rms} = \sqrt{\frac{1}{n}\sum_{i=1}^{n} {x_i}^2} = \sqrt{\frac{{x_1}^2+{x_2}^2+\cdots+{x_n}^2}{n}}$$

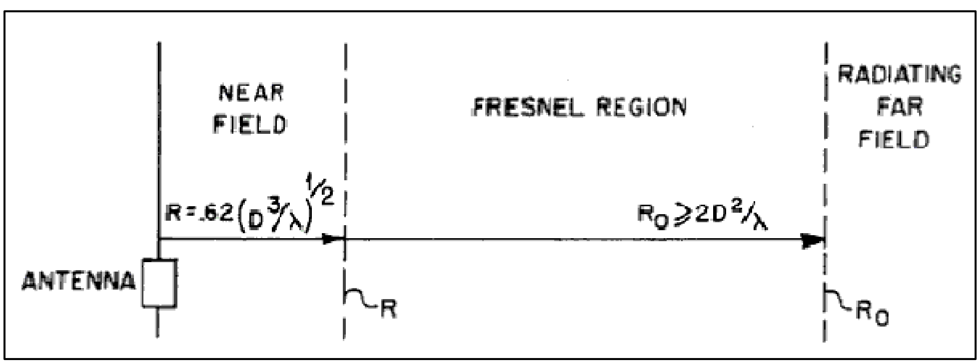
where

x_i = a specific measurement

Far Field

Antenna energy levels depend on the distance from the antenna. The near field is that part of the radiated field nearest to the antenna. Beyond the near field is the infinite far field.

In many practical applications one is only interested in effects where the distance from the antenna to the target is quite significantly greater than the largest dimension of the transmitting antenna. The equations describing the fields created can be simplified by assuming a large separation and dropping all terms which provide only minor contributions to the far field. These simplified distributions have been termed the far field and usually have the properties that the angular distribution of energy does not change with distance, however the energy levels still vary with distance and time. Such an angular energy distribution is usually termed an antenna pattern.



VSWR

The Voltage Standing Wave Ratio (VSWR) is the ratio between the impedances of the feed lines and the load. In general, VSWR is a measurement of the mismatch between transmission lines. It provides a measurement of the amount of signal being reflected back from the mismatch, which is directly related to the amount of energy that is being transmitted.

For many antennas, the VSWR represents the largest component of the antenna efficiency (the rest results from ohmic losses in the antenna itself). To determine the contribution from VSWR, it is necessary to calculate the ratio of the net power to the forward power.

VSWR is defined as the ratio of maximum to minimum voltage on the transmission line and is given by:

$$VSWR = \frac{V_{max}}{V_{min}} = \frac{V_{inc} + V_{refl}}{V_{inc} - V_{refl}}$$

where

V_{max} = the maximum voltage on the transmission line (feed cable)

V_{min} = the minimum voltage on the transmission line

V_{inc} = the voltage magnitude of the incident wave

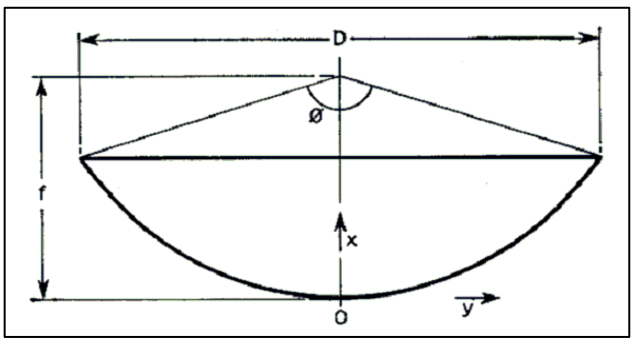
V_{refl} = the voltage magnitude of the reflected wave

Subtended Angle

A reflector with a long focal length has a relatively flat surface and a narrower subtended angle, requiring relatively large feed horns and consequently higher aperture blockages.

A reflector with a short focal length is relatively steeply curved, and has a larger subtended angle, requiring a relatively small feed horn, but it can be difficult to achieve wide beamwidths from such feed horns.

The reflector diameter (D), focal length (f) and subtended angle (Ø) can be visualized using the diagram below:



The half-subtended angle at the feed can be calculated using the following formula:

$$Half\ Subtended\ Angle = \tan^{-1}\left[\frac{8\frac{f}{D}}{16\left(\frac{f}{D}\right)^2 - 1}\right]$$

G/T

G/T is a fundamental antenna/system figure of merit, where G is the antenna gain in decibels at a particular frequency, and T is the equivalent noise temperature of the receiving system in degrees Kelvin (°K). G/T is arguably the most important measure of performance of an antenna system.

G/T is an enlightening and significant measurement because it reflects a particular antenna's receive gain while considering received thermal noise.

G/T is calculated by:

$$\frac{G}{T} = G_t - 10\log T_s$$

where

$\frac{G}{T}$ = Gain over temperature in dB/°K

G_t = Antenna gain

T_s = System temperature in °K

There are two factors that dominate antenna noise figures. These factors are:

1. The amount of noise that a feed sees as it looks out towards a target. The "hot" earth (which has a noise temperature of ~290° K) can be a significant noise contributor for satellites which look down upon the earth.
2. The noise contribution of the low noise amplifier internal circuitry is the other major source of noise. A low noise amplifier (LNA) is a special type of electronic amplifier used to amplify very weak signals captured by the antenna. It is often located very close to the antenna itself. If the LNA is located close to the antenna, then losses in the feedline become less critical. This "active antenna" arrangement is frequently used in microwave systems since coaxial cable feedline losses are significant at microwave frequencies. Using an LNA, the noise of all the subsequent stages is reduced by the gain of the LNA, and the noise of the LNA is injected directly into the received signal. Thus, it is necessary for an LNA to boost the desired signal power while adding as little noise and distortion as possible so that the retrieval of a desired signal is possible in the later stages in the system. For low noise, the amplifier needs to have a high amplification in its first stage.

Wind Force

A parabolic dish becomes a sail in the wind and tremendous forces can be imposed on the supporting structure and foundation. Wind forces grow proportionally to the square of the reflector diameter, while an antenna's overturning moment grows in rough proportion of the cube of the diameter. Overturning moments are the sum of all forces acting on the antenna and are generally referenced to the antenna mounting point(s). In the illustration below, the overturning moment is referenced to the base of the antenna. In general:

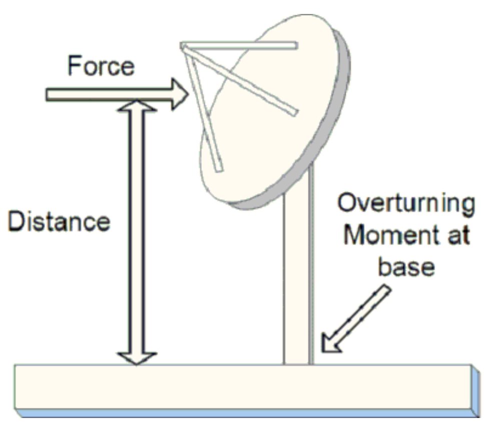
$$Overturning\ Moment = D \times F$$

where

$Overturning\ Moment$ = force at a point of rotation

D = distance from the point at which the force is applied

F = magnitude of the forces (wind, gravity and any other forces)



Actual wind forces applied to the antenna are dependent on the antenna shape and structure, azimuth and elevation angles and wind direction and turbulence. Forces are distributed unevenly rather than occurring at a single discrete point as shown in the simplified diagram above.

The shape and orientation of the antenna is quantified by specifying antenna drag and lift coefficients. Antennas usually have a large drag coefficient and a smaller lift coefficient.

In general:

$$F = A \times P \times C_d$$

where

F = force in pounds

A = surface area (sq ft)

P = wind pressure (pounds per sq ft)

C_d = drag coefficient: typically 2.0 for flat plates, 1.2 for tubing, somewhere in between for parabolic reflectors

Also keep in mind that the lower the air temperature, the denser the air, thus the higher the force for a given wind speed.

Illumination Level

Illumination level can be calculated as follows:

$$W = EIRP - 163.3 - L_{add} \qquad \left(\frac{dbW}{m^2}\ at\ edge\ of\ earth\right)$$

$$W = EIRP - 169.5 - 20\log\left[\sin\frac{\alpha}{2}\right] - L_{add} \qquad \left(\frac{dbW}{m^2}\ satellite - to - satellite\right)$$

where

W = illumination level in $\frac{dBW}{m^2}$

$EIRP$ = effective isotropic radiated power in dBW

L_{add} = Additional losses in dB

α = longitudinal separation of satellites in degrees

EIRP

The Effective Isotropic Radiated Power (EIRP) is the apparent power transmitted towards a receiver assuming that the signal is radiated equally in all directions (i.e. as a spherical wave emanating from a point source)

EIRP is calculated as follows:

$$EIRP = G + 10\log P$$

where

$EIRP$ = EIRP in dBW

G = gain of the transmitting antenna in dBi

P = amplifier power in Watts

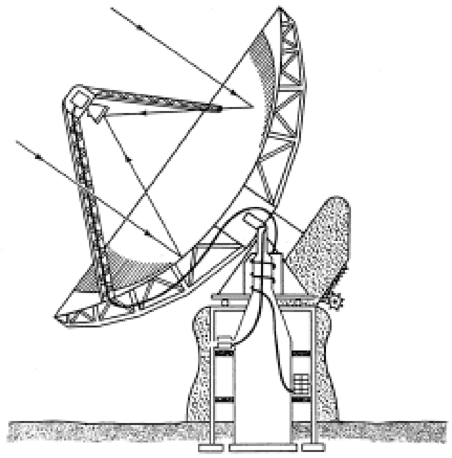
Parabolic Antenna Notes

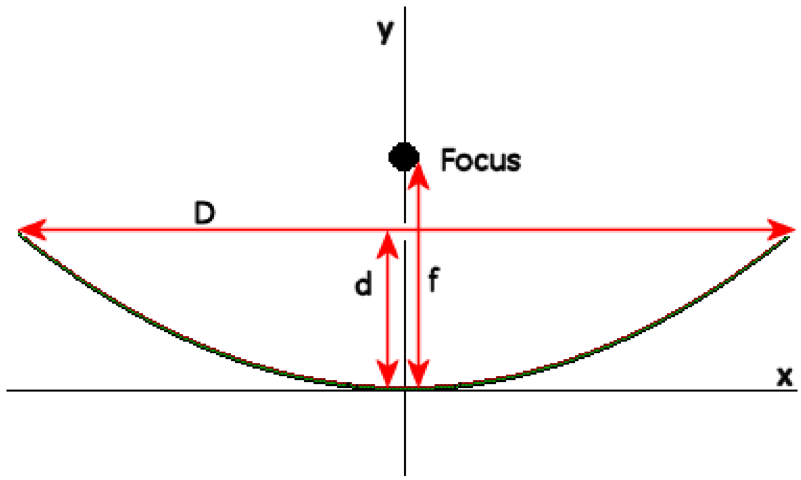
An example of a parabolic antenna with a secondary (or sub) reflector

Parabolic antennas are high gain reflector antennas frequently used for radio frequency communications. The relatively short wavelength of electromagnetic energy at relatively high frequencies allows reasonably sized reflectors to exhibit highly directional gains for both receiving and transmitting. A typical parabolic antenna consists of a parabolic reflector surface illuminated by a small feed antenna (see photo above).

The reflector surface is generally metal formed into a paraboloid of revolution and is usually truncated in a circular rim that forms the diameter of the antenna. This paraboloid possesses a distinct focal point by virtue of having the reflective property of parabolas in that a point source at the focus produces a parallel beam aligned with the axis of revolution.

The focusing point of parabolic antenna can be illustrated by examining the picture below. The prime focus is the point at which the incoming energy is reflected and directed to a common point (the focus).





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

where

f = focal point

D = diameter

d = depth

A small feed antenna can be placed at the reflector focus as in the graphic above. In a Cassegrain antenna, a subreflector is used to direct the energy into the parabolic reflector from a feed antenna located away from the primary focal point.

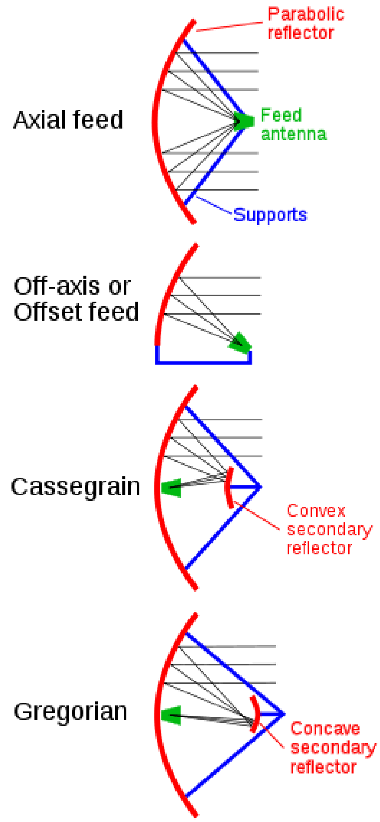
The feed antenna is connected to the associated radio frequency (RF) transmitting or receiving equipment by means of a coaxial cable transmission line, RF over optical fiber or hollow waveguide.

Other parabolic antenna types include off-center, Gregorian and Cassegrain types. In the offset type, the feed element is still located at the focal point, which because of the angles utilized, is usually located below the reflector so that the feed element and support do not interfere with the main beam. This also allows for easier maintenance of the feed, but is usually only found in smaller antennas.

The Gregorian and Cassegrain types, generically referred to as "dual optics" antennas, utilize a secondary reflector allowing for better control over the collimated beam as well as allowing the antenna feed system to be more compact. These antennas are usually much larger where prime focus and off-set construction are not practical. The feed element is usually located in a feed horn which protrudes out from the main reflector. This setup is used when the feed element is bulky or heavy such as when it contains a preamplifier or even the actual receiver or transmitter.

Parabolic antenna theory closely follows optics theory, so a Gregorian antenna can be identified by the fact that it uses a concave subreflector, while a Cassegrain antenna uses a convex subreflector.

Parabolic antennas can have different feed and reflector arrangements, physical supports and transmitting and receiving components. These components are typically arranged as follows:



A parabolic antenna with a circular aperture gives the following approximation for the maximum gain:

$$G \cong \frac{\pi^2 D^2}{\lambda^2}$$

where:

G = power gain over isotropic

D = reflector diameter in same units as wavelength

λ = wavelength in same units as diameter

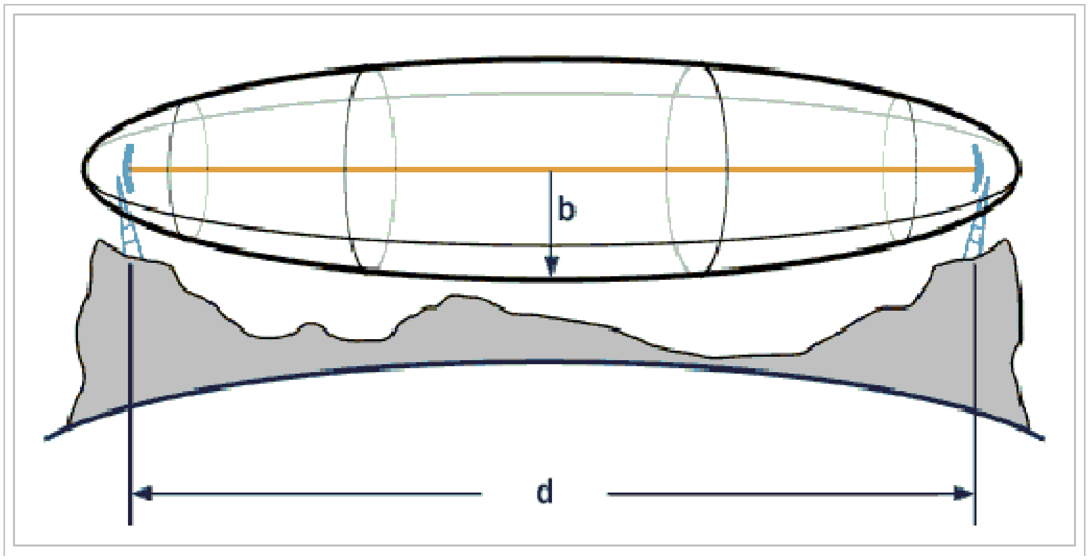
Practical considerations of antenna effective area and sidelobe suppression reduce the actual gain obtained to between 35 and 55 percent of this theoretical value.

The reflector surface can be solid, mesh or wire and can be either circular or somewhat rectangular depending on the radiation pattern of the feeding element. Solid antennas have more ideal characteristics but can be challenging to implement in practice because of weight and **wind** loads. Mesh and wire types weigh less, are easier to construct and have nearly ideal characteristics if the holes/gaps are kept under 1/10 of the wavelength.

Note that an antenna, by itself, is NOT an amplifier. The shaped antenna surface(s) simply reflect and direct electromagnetic energy in various ways.

Fresnel Zones

A Fresnel zone is one of a number of concentric ellipsoids of revolution which define volumes in the radiation pattern of an antenna aperture. Fresnel zones result from diffraction by the aperture. The cross section of the 1^{st} Fresnel zone is circular. Subsequent Fresnel zones are annular in cross section and concentric with the first. One needs to minimize the effect of the out of phase signals by removing obstacles from the RF line of sight to maximize signal strength. The strongest signals are on the direct line between transmitter and receiver and always lie in the $1^{\mathbf{st}}$ Fresnel Zone.



Fresnel zones: d is the distance between the transmitter and the receiver, b is the radius of a specific zone

The n^{th} Fresnel zone radius is calculated as follows:

$$F_n = \sqrt{\frac{n\lambda d_1 d_2}{d_1 + d_2}}$$

where

F_n = The n^{th} Fresnel Zone radius in meters

d_1 = The distance of P (any selected point in a link) from one end in meters

d_2 = The distance of P from the other end in meters

λ = The wavelength of the transmitted signal in meters

The cross section radius of the first Fresnel zone is the highest in the center of the RF line of sight which can be calculated as:

$$r = 72.05\sqrt{\frac{D}{4f}}$$

where

r = radius in feet

D = total distance in miles

f = frequency GHz

Or (equivalently):

$$r = 17.32\sqrt{\frac{D}{4f}}$$

where

r = radius in meters

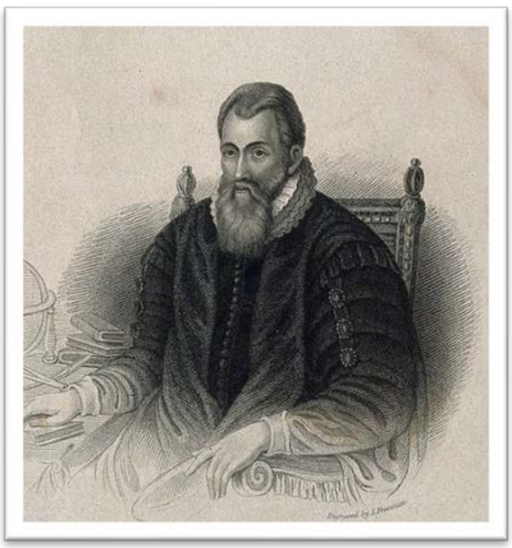
D = total distance in kilometers

f = frequency GHz

Logarithmic Slide Rule History

This software makes extensive use of log-log and log-linear slide rules. These rules make calculation of various parameters quick and fairly accurate.

Logarithmic scales are not very new ...



John Napier (1550 – 1617), Stipple engraving by S. Freeman

In 1614, John Napier discovered the logarithm which made it possible to perform multiplications and divisions by addition and subtraction:

$$a \times b = 10^{\log a + \log b}$$

$$\frac{a}{b} = 10^{\log a - \log b}$$

This was a great time saver but there was still quite a lot of work required. The mathematician had to look up two logs, add them together and then look for the number whose log was the sum. Edmund Gunter soon reduced the effort by drawing a number line in which the positions of numbers were proportional to their logs.

The scale started at one because the log of one is zero. Two numbers could be multiplied by measuring the distance from the beginning of the scale to one factor with a pair of dividers, then moving them to start at the other factor and reading the number at the combined distance.

Soon afterwards, William Oughtred simplified things further by taking two Gunter's lines and sliding them relative to each other thus eliminating the dividers.

In the years that followed, other people refined Oughtred's design into a sliding bar held in place between two other bars. Circular slide rules and cylindrical/spiral slide rules also appeared quickly. The cursor appeared on the earliest circular models but appeared much later on straight versions. By the late 17th century, the slide rule was a common instrument with many variations. It remained the tool of choice for many for the next three hundred years.

See more at http://www.hpmuseum.org

Notes

The calculations largely apply to parabolic antenna systems and are not meant to be used for official or precise calculations. Some calculations, such as free space loss, are not specific to the type of antenna being used.

Credits

JavaScript: *DHTML API, Drag & Drop for Images and Layers*, Walter Zorn - http://www.walterzorn.de/en/dragdrop/dragdrop_e.htm

www.tgtechsolutions.net/antcalc/antcalc.html