Free-Space Propagation

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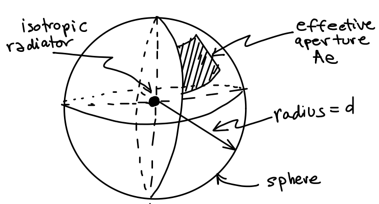
Time-varying electromagnetic fields propagate through free space and can be used for wireless communication. Frequencies between 3 kHz and 3 THz can be used.

Although free space is lossless, the power density of the field transmitted from an antenna decreases as the square of the distance (for a line of sight or "LOS" link).

Consider an isotropic source (one that transmits equally in all directions) at the center of a sphere of radius d transmitting power P_T and a receiving antenna of area A_e that collects all of the power "shining" on it:



Since the transmit power is equally distributed over the surface of the sphere (of area $= 4\pi d^2$), the ratio of the received power to transmitted power is:

$$\frac{P_R}{P_T} = \frac{A_e}{4\pi d^2}$$

Rather than effective aperture, it's more practical to measure another antenna parameter called gain which is the effective aperture normalized by the wavelength (see below):

$$G = \frac{4\pi A_e}{\lambda^2}$$

Exercise 1: For some types of antennas, such as reflectors, the effective aperture is closely approximated by the physical area of the antenna. What are the approximate effective aperture and gain of a 1-m diameter Ku-band (≈ 15 GHz) satellite dish?

Friis Equation

Substituting for A_e we get the Friis equation:

$$P_R = P_T G_T G_R \left(\frac{\lambda}{4\pi d}\right)^2$$

where P_R and P_T are the received and transmitted powers, G_R is the gain of the receive antenna, λ is the wavelength and d is the distance from transmitter to receiver. The term G_T can be used to account for a non-isotropic transmit antenna that increases the transmit power by a factor (gain) G_T in the direction of the receiver compared to an isotropic radiator.

This equation only applies at distances that are in the "far field" which means there must be many wavelengths and antenna dimensions between the antennas.

Exercise 2: A point-to-point link uses a transmit power of 1 Watt, transmit and receive antennas with gains of 20dB and operates at 3 GHz. How much power is received by a receiver 300m away?

Loss vs Frequency

Antenna gain and effective area are clearly related and we expect both to vary proportionately. It can be shown (but not here) that the relationship is given by the equation above:

$$G = \frac{4\pi A_e}{\lambda^2}$$

Note that the antenna gain increases as the square of the frequency. This means that for a given antenna size (area) the antenna becomes more directional as the frequency increases. Conversely, for a given antenna gain the effective area (power collected) decreases with the square of the frequency.

This is the reason that the propagation "loss" given by the last factor of Friis equation above appears to increase as the square of the frequency.

However, it's important to understand that the reason the propagation loss appear to increase with frequency is simply because, for an antenna with a fixed gain, the effective aperture decreases as the frequency increases. Propagation loss is ***not*** a result of power being absorbed by the medium through which the signal is propagating.

Exercise 3: If we kept the *effective aperture* constant at one end of a link (transmitter or receiver), how would the path loss change as a function of frequency? What if we kept it constant at both ends? Is this a feasible approach for mobile systems?

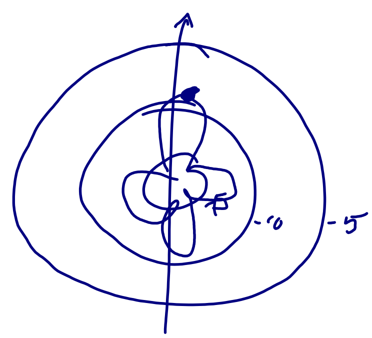
Directivity and Gain

Real antennas transmit different amounts of power in different directions. The *directivity* of an antenna is the ratio of the maximum power density U_m to the average power density U_0:

$$D = \frac{U_m}{U_0}$$

However, measuring directivity requires measuring the power density in all directions in order to compute the average. A more practical measurement is the *gain* of an antenna which is the ratio of the maximum power density to the power density of a lossless reference antenna U_r, typically an ideal (lossless) isotropic radiator:

$$G = \frac{U_m}{U_r}$$



The ratio of gain to directivity:

$$k = \frac{G}{D} = \frac{U_0}{U_r}$$

is the antenna's *efficiency*, the ratio of the average radiated power of the real antenna to the average radiated power of an ideal isotropic source.

Antenna gain, like most quantities in communications is usually specified in dB. If the reference antenna is an ideal (lossless) isotropic antenna the units are specified as dBi.

Reciprocity

The gain, directivity or effective area of an antenna is the same whether it is transmitting or receiving.