ANTENNA NEAR FIELD

As noted in the sections on RF propagation and the radar equation, electromagnetic radiation expands spherically (Figure 1) and the power density at a long range (R) from the transmitting antenna is:

$$P_D = \frac{P_t G_t}{4\pi R^2}$$

[1]

When the range is large, the spherical surface of uniform power density appears flat to a receiving antenna which is very small compared to the surface of the sphere. This is why the far field wave front is considered planar and the rays approximately parallel. Also, it is apparent that at some shorter range, the spherical surface no longer appears flat, even to a very small receiving antenna.

The distances where the planer, parallel ray approximation breaks down is known as the near field. The crossover distance between near and far fields (R_{ff}) is taken to be where the phase error is 1/16 of a wavelength, or about 22.5°.

$$R_{ff} = \frac{2D^2}{\lambda}$$ where λ is the wavelength and D is the largest dimension of the transmit antenna.

[2]

If the same size antenna is used for multiple frequencies, R_{ff} will increase with increasing frequency. However, if various size antennas are used for different frequencies and each antenna is designed with D as a function of λ (λ/2 to 100λ), then R_{ff} will vary from $c/2f$ to $20000c/f$. In this case R_{ff} will decrease with increasing frequency. For example: a 10λ antenna at 3 GHZ has a D of 100 cm and corresponding R_{ff} of 20 m, while a 10λ antenna at 30 GHz has a D of 10 cm and corresponding R_{ff} of 2 m.

While the above analogy provides an image of the difference between the near and far fields, the relationship must be defined as a characteristic of the transmitting antenna.

Actual antennas, of course, are not ideal point source radiators but have physical dimensions. If the transmitting antenna placed at the origin of Figure 1 occupies distance D along the Z-axis and is boresighted along the Y-axis (φ = 90), then the geometry of point P on the sphere is represented in two dimensions by Figure 2. For convenience, the antenna is represented by a series of point sources in an array.
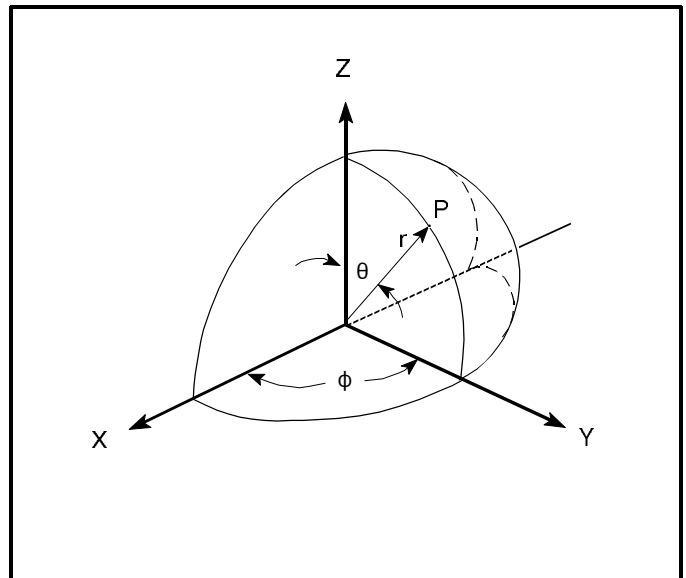

Figure 1 - Spherical Radiation to point "P" from an ideal point source.

When point P is close to the antenna, as in Figure 2, then the difference in distance of the two rays r and R taken respectively from the center of the antenna and the outer edge of the antenna varies as point P changes.

Derivation of equation [2] is given as follows: From Figure 2, the following applies:

$$r^2 = z^2 + y^2 \qquad [3]$$

$$z = r \cos \theta \qquad [4]$$

$$y = r \sin \theta \qquad \text{and} \qquad [5]$$

$$R = \sqrt{y^2+(z-z')^2} = \sqrt{y^2+z^2-2zz'+(z')^2} \qquad [6]$$

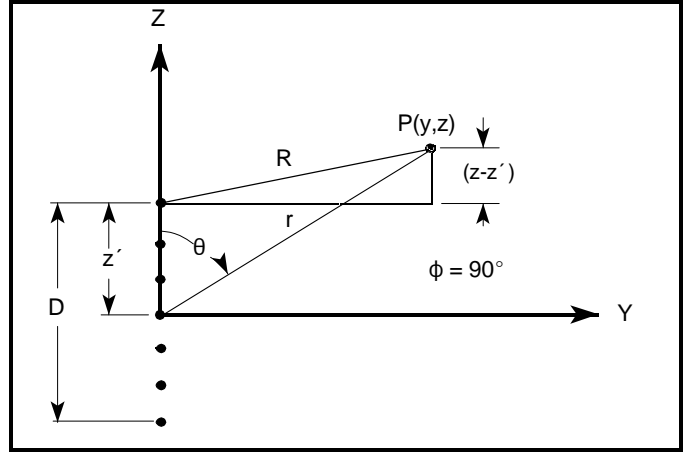**Figure 2** - Near Field Geometry of point "P" for a non-ideal radiator with dimension D.

Substituting [3] and [4] into [6]
$$R = \sqrt{r^2+[-2(r\ \cos\ \theta)z'+(z')^2]} \qquad [7]$$

which puts point P into spherical coordinates.

Equation [7] can be expanded by the binomial theorem which for the first three terms, reduces to:

$$R = r - z'\ \cos\ \theta + \frac{(z')^2\sin^2\ \theta}{2r} + \ .... \qquad [8]$$

In the parallel ray approximation for far field calculations (Figure 3) the third term of [8] is neglected.

The distance where the far field begins (R_{ff}) (or where the near field ends) is the value of r when the error in R due to neglecting the third term of equation [8], equals 1/16 of a wavelength.

R_{ff} is usually calculated on boresight, so $\theta = 90°$ and the second term of equation [8] equals zero (Cos 90° = 0), therefore from Figure 3, where D is the antenna dimension, R_{ff} is found by equating the third term of [8] to 1/16 wavelength.

$$\frac{(z')^2\ \sin^2\ \theta}{2R_{ff}} = \frac{\lambda}{16}$$

$Sin\ \theta = Sin\ 90 = 1\ and\ z' = D/2$ so:
$$\frac{\left(\dfrac{D}{2}\right)^2}{2R_{ff}} = \frac{\lambda}{16}$$

$$R_{ff} = \frac{16(D/2)^2}{2\lambda} = \frac{2D^2}{\lambda} \qquad [9]$$

Equation [9] is the standard calculation of far field given in all references.

Besides [9] some general rules of thumb for far field conditions are:
$$r \gg D \quad \text{or} \quad r \gg \lambda$$

If the sphere and point P are a very great distance from the antenna, then the rays are very nearly parallel and this difference is small as in Figure 3.
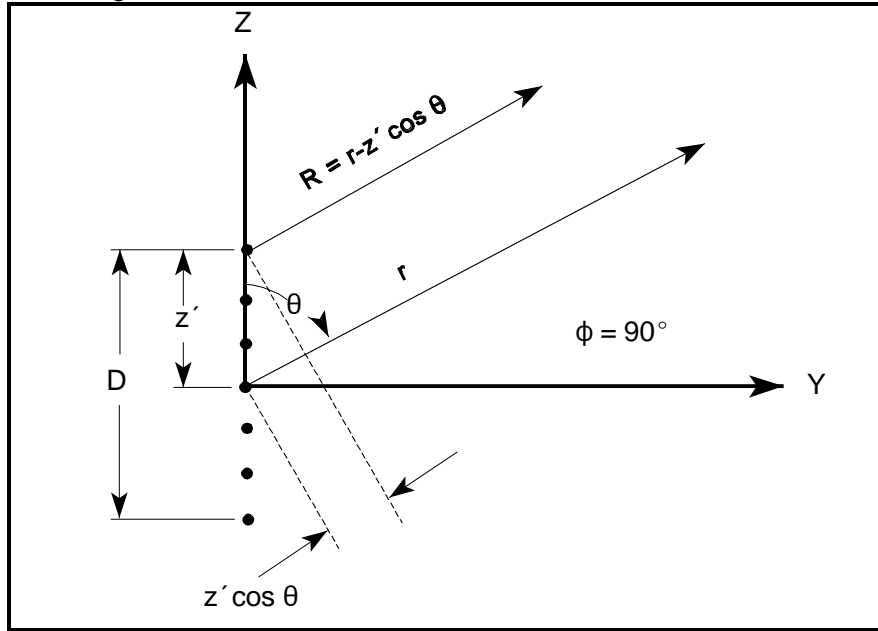

Figure 3 - Far Field Parallel Ray Approximation for Calculations.

The power density within the near field varies as a function of the type of aperture illumination and is less than would be calculated by equation [1]. Thus, in the antenna near field there is stored energy. (The complex radiation field equations have imaginary terms indicating reactive power.) Figure 4 shows normalized power density for three different illuminations.

Curve A is for reference only and shows how power density would vary if it were calculated using equation [1].

Curve B shows power density variations on axis for an antenna aperture with a cosine amplitude distribution. This is typical of a horn antenna in the H-plane.

Curve C shows power density variations on axis for a uniformly illuminated antenna aperture or for a line source. This is typical of a horn antenna in the E-plane.

Curve D shows power density variations on axis for an antenna aperture with a tapered illumination. Generally the edge illumination is approximately -10 dB from the center illumination and is typical of a parabolic dish antenna.

Point E - For radiation safety purposes, a general rule of thumb for tapered illumination is that the maximum safe level of 10 mW/cm^2 (~200 V/m) is reached in the near field if the level at R_{ff} reaches 0.242 mW/cm^2 as can be verified by computing the power density at point E in Figure 4. (10 mW/cm^2 at point E extrapolates to 0.242 mW/cm^2 [16 dB lower] at R=R_{ff}, or Y axis value =1). Figure 1 in Section 3-6 depicts more precise values for radiation hazard exposure.

Point F - Far Field Point. At distances closer to the source than this point (near field), the power density from any given antenna is less than that predicted using Curve A. At farther distances, (far field) power densities from all types of antennas are the same.
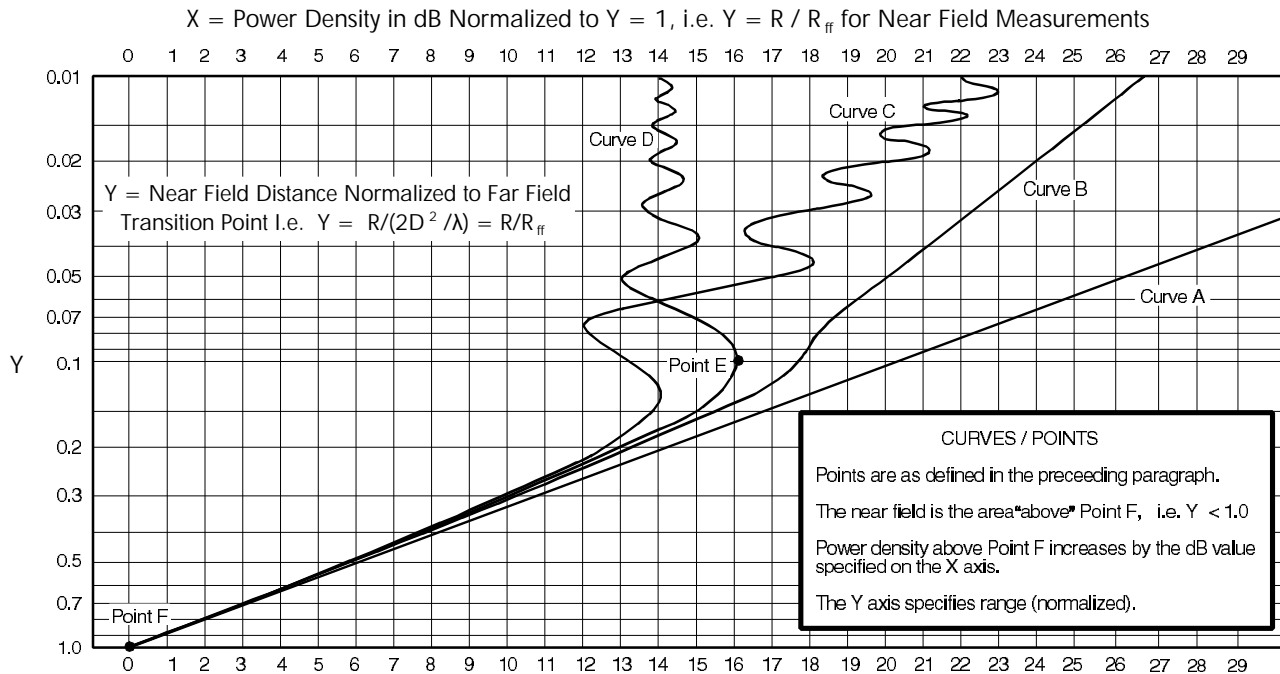
Figure 4 - Antenna Near-Field On-Axis Power Density (Normalized)
For Various Aperture Illuminations

FOR FAR FIELD MEASUREMENTS:

ONE WAY SIGNAL STRENGTH (S)	
S ↓ **6 dB** (1/4 pwr)	S decreases by **6 dB** when the distance doubles	**2R** ↑ **R**
6 dB (4x pwr) ↑ **S**	S increases by **6 dB** when the distance is half	**R** ↓ **0.5 R**

TWO WAY SIGNAL STRENGTH (S)	
S ↓ **12 dB** (1/16 pwr)	S decreases by **12 dB** when the distance doubles	**2R** ↑ **R**
12 dB (16x pwr) ↑ **S**	S increases by **12 dB** when the distance is half	**R** ↓ **0.5 R**

When free space measurements are performed at a known distance from a source, it is often necessary to know if the measurements are being performed in the far field. As can be seen from Curve A on Figure 4, if the distance is halved (going from 1.0 to 0.5 on the Y axis), the power density will increase by 6 dB (going from 0 to 6 dB on the X axis). Each reduction in range by ½ results in further 6 dB increases. As previously mentioned, Curve A is drawn for reference only in the near field region, since at distances less than R$_{ff}$ the power density increases less than 6 dB when the range is halved. In the far field, all curves converge and Equation [1] applies.

When a measurement is made in free space, a good check to ensure that is was performed in the far field is to repeat the measurement at twice the distance. The power should decrease by exactly 6 dB. A common error is to use 3 dB (the half power point) for comparison. Conversely, the power measurement can be repeated at half the distance, in which case you would look for a 6 dB increase, however the conclusion is not as sure, because the first measurement could have been made in the far field, and the second could have been made in the near field.