RADIO WAVE PROPAGATION FORMULAE

In free space the magnetic component of an Electro-Magnetic wave is closely related to the electric component, from which one obtains the radiation power density S of the EM wave. This is measured as the electrical power (watts) passing through a plane one metre square, facing the direction of the wave. This relation is given by the equation

$$S = \frac{E^2}{120\pi} \, watts / m^2 \qquad ...(1)$$

where 120π is the intrinsic impedance of free space - approximately equal to 377ohms.

An antenna of an aperture A collects a power P (watts)

$$P = A \bullet S \;\; Watts \qquad ...(2)$$

The gain G and aperture A of antennas are related by the equation

$$G = \frac{4\pi}{\lambda^2} A \qquad ...(3)$$

Power density S at a receiver of the radiation from a transmitter of power source P_t at a distance d will be

$$S = \frac{P_t}{4\pi d^2} \;\; \text{Watts/m}^2 \qquad ...(4)$$

If the transmitter has a directivity gain G_t in the direction of the receiver, the received signal increases to:

$$S = \frac{P_t G_t}{4\pi d^2} \;\; \text{Watts/m}^2 \qquad ...(5)$$

Free space propagation loss factor L which arises due to the dispersion of wave energy as the wavelength λ reduces (ie frequency increases) is given by:

$$L = \left(\frac{4\pi d}{\lambda} \right)^2 \qquad ...(6)$$

The free space field E from transmitted power source P_t with an antenna gain G_t at a distance d in metres from the transmitter antenna is given as:

$$E = \frac{\sqrt{30 \bullet P_t \bullet G_t}}{d} \quad \text{Volts/metre} \qquad \ldots(7)$$

The field strength E is related to power density S by the equation:

$$E = \sqrt{Z_0 S} \ \text{Volts/metre} \qquad \ldots(8)$$

or

$$S = \frac{E^2}{Z_0} \ \text{Watts/m}^2 \qquad \ldots(9)$$

where Z_0 is the free space impedance of 120π.

The power P_r absorbed by a receiving in a field of power density S by antenna with an aperture A is given by:

$$P_r = S \bullet A \ \text{Watts} \qquad \ldots(10)$$

where

$$A = \frac{\lambda^2 G_r}{4\pi} \ \text{Metres}^2 \qquad \ldots(11)$$

therefore by substitution:

$$P_r = \left(\frac{\lambda}{4\pi d}\right)^2 \bullet P_t G_t G_r \ \text{Watts} \qquad \ldots(12)$$

The free space path attenuation between isotropic antennas is given by the formula:

$$L_{dB} = 22 + 20\log\left(\frac{d}{\lambda}\right) \qquad \ldots(13)$$

or

$$L_{dB} = 32 + 20\log f_{MHz} + 20\log d_{km} \qquad \ldots(14)$$

Some useful propagation formulae

The free space field in the plane of a λ/2 dipole transmitting power P_t at a distance d metres is given by:

$$E = \frac{7.02\sqrt{P}}{d} \text{ Volts/metre} \qquad ...(15)$$

The input voltage e to a matched receiver fed by a λ/2 dipole antenna is given by:

$$e = \frac{E\lambda}{2\pi} \text{ Volts} \qquad ...(16)$$

The free space path loss L_{sB} in dB between two λ/2 dipoles is:

$$L_{dB} = 18 + 20\log\frac{d}{\lambda} \text{ dB} \qquad ...(17)$$

To convert from field strength in μV/m to μV across a 50Ω dipole:

$$e_{uv} = \frac{39E}{f_{MHz}} \qquad ...(18)$$

To convert between field strength F_s dBμV/m and power in dBW across a 50Ω dipole:

$$Fs_{dBuV/m} = 105 + P_{dBW} + 20\log f_{MHz} \qquad ...(19)$$

or

$$P_{dBW} = Fs_{dBuv/m} - 20\log f_{MHz} - 105 \qquad ...(20)$$

Approximate free space path loss between two dipole antennas over distance is given by:

$$L_{P\,dB} = 20\log f_{MHz} + 20\log d_{km} + 28.1 \text{ dB} \qquad ...(21)$$

Notes:

1. A ½ wavelength dipole has an effective height of 0.64l and a gain of 1.65 = 2.15dB with respect to an isotropic source. Capture area is $0.13\lambda^2$.
2. A short dipole has an effective height of 0.5l and a gain of about 1.5 = 1.76dB with respect to an isotropic source. Capture area is $0.12\lambda^2$.