Expressions for a simple path loss model in free space

For relatively quick estimations of a radio signal's loss in free space one can use the following expressions.

1) Friis free space equation:

$$Pr(d) = [Pt*Gt*Gr*\lambda^2]/(4\pi)^2 *d^2 *L \qquad \text{Eqn 1.0}$$

Here:

Pr(d) is the received power ,
Gt, Gr are the transmitter and receiver antenna gains
d is the distance between the transmitter and the receiver
L is a loss factor ($L \geq 1$) of a particular system. L = 1 indicates no loss in the system hardware.

2) Antenna gain is given by:

$$G = 4\pi(Ae)/ \lambda^2 \qquad \text{Eqn 2.0}$$

Here:

Ae is the effective aperture
that is related to the physical size
of the antenna.

3) The wavelength (λ) is:

$$\lambda = c/f = 2\pi c/\omega_c \qquad \text{Eqn 3.0}$$

c = speed of light in meters/second
ω_c = carrier frequency in radians per second.

4) Path loss in dB in free space with antenna gains included is:

$$PL(dB) = 10\log[Pt/Pr] = -10\log\left[\lambda^2 /(4\pi)^2 *d^2\right] \qquad \text{Eqn 4.0}$$

These equations are valid for the far-field or the Fraunhofer region of the antenna. In this region d, the distance between the transmitter and the receiver should be:

$$dfr > 2D^2 / \lambda \qquad \text{Eqn 5.0.}$$

D = largest linear dimension of the antenna

In addition to really be in the far field we must also have:

$$dfr >> D \text{ and } dfr >> \lambda \qquad \text{Eqn 6.}$$

Obviously this model is invalid for d =0; so choose a close – in distance d0 as a reference point for received power. The reference point should be in the far – field region and smaller than the distances under consideration for the overall system. Under these assumptions the received power in free space at a distance greater than d0 is:

$$Pr(d) = Pr(d0)*\ (d0/d)^2 \qquad \text{Eqn 7.0}$$

Here $d \geq d0 \geq dfr$

Where dfr is the Fraunhofer distance.

Also large changes over many orders magnitude may be expected in received power. So use decibel calculations:

$$Pr(dBm) = 10\log(Pq) + 20\log(d0/d) \qquad \text{Eqn 8.0}$$

$d \geq d0 \geq dfr$

$Pq = Pr(d0)/0.001$Watts

The voltage at the antenna can be calculated as:

$$Vantenna = sqrt(Pr(d)*4*Rant)\ (\text{ rms}) \qquad \text{Eqn 9.0}$$

References: ARRL antenna book, Antennas: Krauss, Wireless Communications: Rappaport.