Free-space path loss formula

Free-space path loss is [proportional](http://en.wikipedia.org/wiki/Proportionality_%28mathematics%29) to the [square](http://en.wikipedia.org/wiki/Square_%28algebra%29) of the distance between the transmitter and receiver, and also proportional to the square of the [frequency](http://en.wikipedia.org/wiki/Frequency) of the radio signal.

The equation for FSPL is

\begin{align}
  \mbox{FSPL} &= \left ( \frac{4\pi d}{\lambda} \right )^2  \\
             &= \left ( \frac{4\pi d f}{c} \right )^2
\end{align}

where:

* \ \lambdais the signal wavelength (in metres),
* \ fis the signal frequency (in [hertz](http://en.wikipedia.org/wiki/Hertz)),
* \ dis the distance from the transmitter (in metres),
* \ cis the [speed of light in a vacuum](http://en.wikipedia.org/wiki/Speed_of_light), 2.99792458 × 108 [metres per second](http://en.wikipedia.org/wiki/Metres_per_second).

This equation is only accurate in the [far field](http://en.wikipedia.org/wiki/Far_field); it does not hold close to the transmitter.

**Free-space path loss in decibels**

A convenient way to express FSPL is in terms of [dB](http://en.wikipedia.org/wiki/Decibel):

\begin{align}
\mbox{FSPL(dB)}
  &= 10\log_{10}\left(\left(\frac{4\pi}{c}df\right)^2\right) \\
  &= 20\log_{10}\left(\frac{4\pi}{c}df\right)  \\
  &= 20\log_{10}(d) + 20\log_{10}(f) + 20\log_{10}\left(\frac{4\pi}{c}\right) \\
  &= 20\log_{10}(d) + 20\log_{10}(f) - 147.56
\end{align}

where the units are as before.

For typical radio applications, it is common to find \ fmeasured in units of [MHz](http://en.wikipedia.org/wiki/MHz) and \ din km, in which case the FSPL equation becomes

\ \mbox{FSPL(dB)} = 20\log_{10}(d) + 20\log_{10}(f) + 32.44

For \ din statute miles, the constant becomes \ 36.6.

**Physical explanation**

The FSPL expression above often leads to the erroneous belief that free space [attenuates](http://en.wikipedia.org/wiki/Attenuation) an electromagnetic wave according to its frequency. This is not the case, as there is no physical mechanism that could cause this.

The expression for FSPL actually encapsulates two effects. Firstly, the spreading out of electromagnetic energy in free space is determined by the [inverse square law](http://en.wikipedia.org/wiki/Inverse_square_law), i.e.

\ S = P_t \frac{1}{4 \pi d^2} 

where:

* \ Sis the power per unit area (in [watts](http://en.wikipedia.org/wiki/Watt) per metre-squared) at distance \ d,
* \ P_tis the total power transmitted (in watts).

Note that this is not a frequency-dependent effect.

The second effect is that of the receiving antenna's [aperture](http://en.wikipedia.org/wiki/Antenna_aperture), which describes how well an antenna can pick up power from an incoming electromagnetic wave. For an isotropic antenna, this is given by

\ P_r = S \frac{\lambda^2}{4 \pi}

where \ P_ris the received power. Note that this is entirely dependent on wavelength, which is how the frequency-dependent behaviour arises.

The total loss is given by the ratio

\ \mathrm{FSPL} = \frac{P_t}{P_r}

which can be found by combining the previous two expressions.

Link budget radio systems

For a [line-of-sight](http://en.wikipedia.org/wiki/Line-of-sight_propagation) [radio](http://en.wikipedia.org/wiki/Radio) system, a link budget equation might look like this:

  P_{RX} = P_{TX} + G_{TX} - L_{TX} - L_{FS} - L_M + G_{RX} - L_{RX} \,
 

where:

*PRX* = received power (dBm)

*PTX* = transmitter output power (dBm)

*GTX* = transmitter [antenna gain](http://en.wikipedia.org/wiki/Antenna_gain) (dBi)

*LTX* = transmitter losses (coax, connectors...) (dB)

*LFS* = [free space loss](http://en.wikipedia.org/wiki/Free_space_loss) or [path loss](http://en.wikipedia.org/wiki/Path_loss) (dB)

*LM* = miscellaneous losses ([fading](http://en.wikipedia.org/wiki/Fading) margin, body loss, polarization mismatch, other losses...) (dB)

*GRX* = receiver [antenna gain](http://en.wikipedia.org/wiki/Antenna_gain) (dBi)

*LRX* = receiver losses (coax, connectors...) (dB)