Lecture 1
Some Introductory Concepts

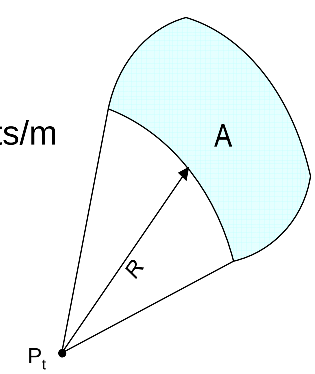
EE533-08

1

Isotropic Radiator

- Power is radiated equally in all directions
- F= flux density in Watts/m^2
- Also use Field strength, F_s= Volts/m

$$F = \frac{P_t}{4\pi R^2}\frac{Watts}{m^2}$$



2

Isotropic Radiator

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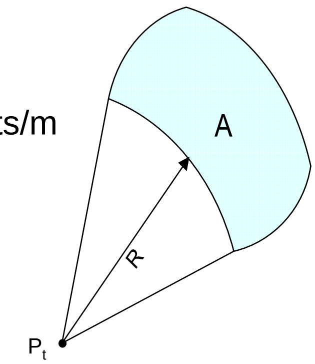

$$F = \frac{P_t}{4\pi R^2} \frac{Watts}{m^2}$$

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Flux Density and Field Strength

$$F = \frac{P_t}{4\pi R^2} \frac{Watts}{m^2}$$

$$Z_o = \sqrt{\frac{\mu}{\varepsilon}} = \sqrt{\frac{\mu_o}{\varepsilon_o}} = 120\pi = 377\Omega$$

$$F_s = \sqrt{F \bullet Z_o} = \sqrt{\frac{P_t 120\pi}{R^2 4\pi}} = \sqrt{\frac{30P_t}{R^2}} \frac{Volts}{meter}$$

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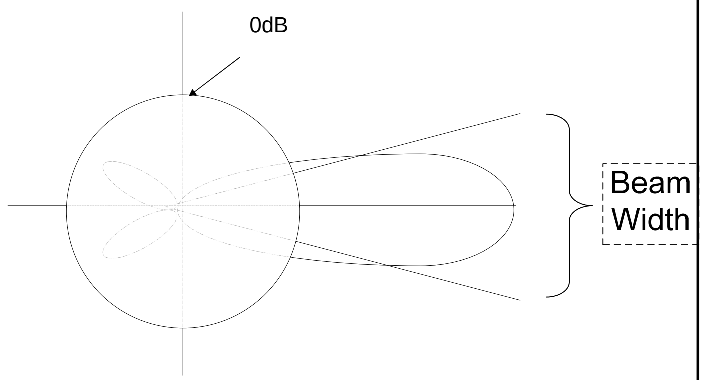
Real Antenna – Not Isotropic
Polar Plot of Normalized F



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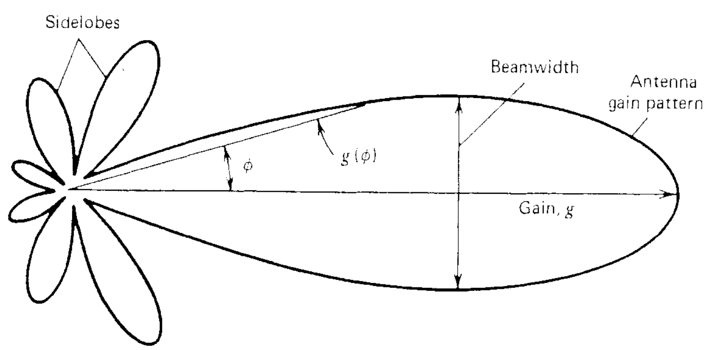

Figure 3.11. Antenna planar gain function $g(\phi)$.

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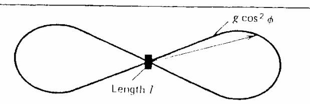
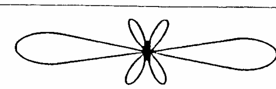
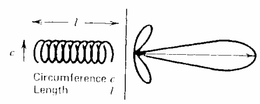
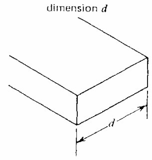
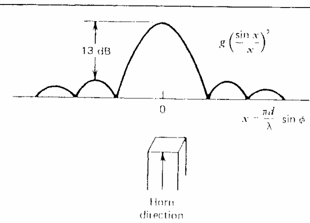
Antenna type	Pattern	Gain g	Half-power beamwidth
Short dipole $l \ll \lambda$		1.5	90°
Long dipole $l \gg \lambda$ $l = \lambda/2$		1.5 1.64	47° 78°
Helix		$15\left[\frac{cl}{\lambda^2}\right]$	$52°\left[\frac{\lambda}{c\sqrt{l}}\right]$
		$\frac{4\pi d^2}{\lambda^2}$	$\frac{0.88\lambda}{d}$ rad

Figure 3.12. Common antenna characteristics.

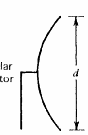
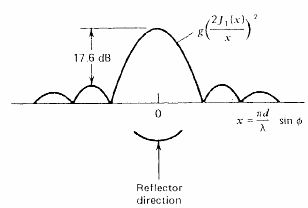
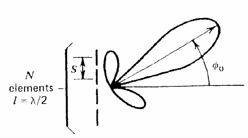
		$\left[\frac{\pi d}{\lambda}\right]^2$	$\frac{1.02\lambda}{d}$ rad
Phased array, phase difference $= \frac{2\pi s}{\lambda} \cos \theta_0$		$\left[\frac{N\pi s}{1.4\lambda}\right]^2$	$50°\left[\frac{\lambda}{Ns}\right]$ $\theta_0 = 0$

Figure 3.12 (continued)

From the polar Plot.

$$\frac{F(\theta,\phi)}{F_{isotropic}} = G_t$$ the gain over isotropic

$$G(\theta,\phi) = \frac{P(\theta,\phi)}{\frac{P_o}{4\pi \text{ steradians}}}$$

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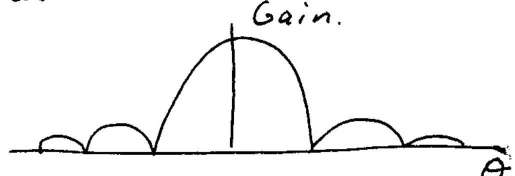
Linear Plot



for a fixed ϕ

EIRP → Effective Isotropic Radiated Power

$EIRP \triangleq P_t G_t$ watts/m^2

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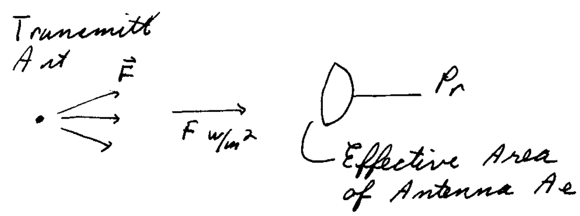
Field Strength with directional Antenna:

$$F = \frac{P_t G_t}{4\pi R^2} \quad w/m^2$$

Receive Antenna



P_r = Flux density × Receive Ant Area.

$P_r = F \cdot A_e$

For a parabolic dish

$A = \pi R^2$

due to spill-over $A_e = n_a A$

$n_a \Rightarrow$ aperature Effeciency

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Combining:

$$P_r = \frac{P_t G_t A_e}{4\pi R^2} \quad \text{watts}$$

$\Rightarrow$ it can be shown that

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

think of this as the number of wavelengths the area of the antenna intersects

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given A_e & λ we know the gain

$$A_e = \frac{G_r \lambda^2}{4\pi} \qquad P_r = \frac{P_t G_t G_r}{4\pi R^2} \frac{\lambda^2}{4\pi}$$

$$P_r = \frac{P_t G_t G_r}{\left(\frac{4\pi R}{\lambda}\right)^2}$$

free space path loss:

$$\underline{L_p \triangleq \left(\frac{4\pi R}{\lambda}\right)^2}$$

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$$P_r = \frac{P_t G_t G_r}{L_p}$$

usually written in dB.

$$P_{r\,dBw} = P_{t\,dBm} + G_{t\,dB} + G_{r\,dB} - L_p\,dB.$$

$$L_p\,dB = 20\,\mathrm{Log}\left(\frac{4\pi R}{\lambda}\right)$$

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$$L_p\,dB = 20\,\mathrm{Log}\left(\frac{4\pi R f}{c}\right)$$

$$= 20\,\mathrm{Log}\left(\frac{4\pi}{c}\right) + 20\,\mathrm{Log}\,R + 20\,\mathrm{Log}\,f$$

for f in GHz, R in Km

$$L_p\,dB = 92.4 + 20\,\mathrm{Log}\left(f_{GHz}\right) + 20\,\mathrm{Log}\left(R_{Km}\right)$$

Notice: $P_{r\,dBw} = EIRP_{dBw} + G_{r\,dB} - L_p\,dB$

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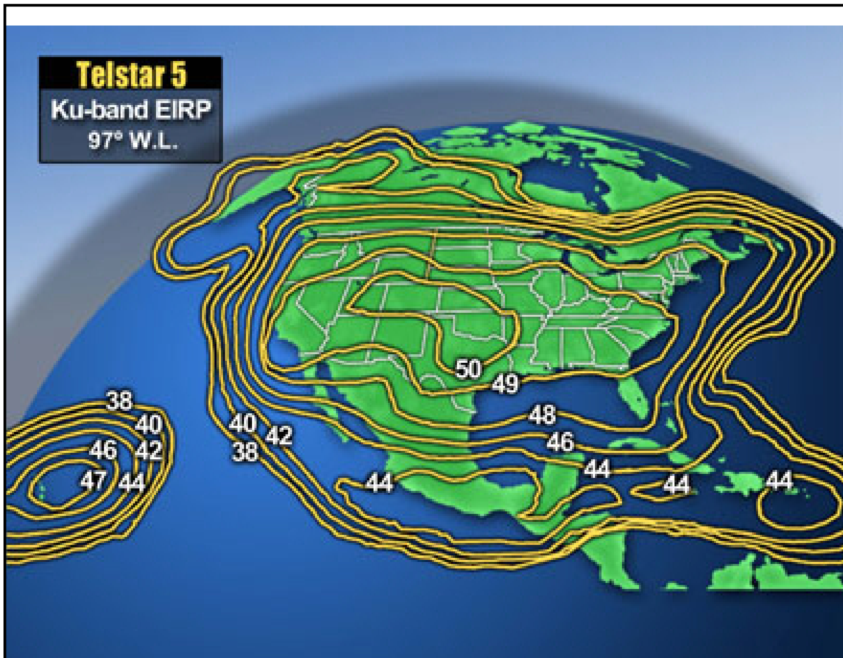
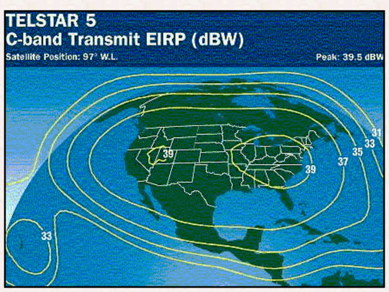
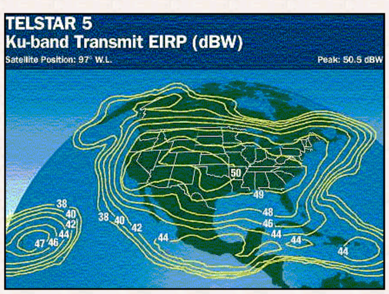


(to Western Hemisphere, Eastern Hemisphere, Footprints by Dish Size)

TELSTAR 5 (w. hemi or size list)





Telstar 5 (at 97.0W)

Dish sizes are minimum for 'Top Grade' reception
(25deg LNB for C-Band, 0.8dB LNB for Ku-Band)

C-Band (Full Transponder Analog)			Ku-Band (3/4 FEC Multiplex, Full Transponder Analog)		
EIRP (dBW)	**DTH Size (m)**	**SMATV Size (m)**	**EIRP (dBW)**	**Multiplex Channels (cm)**	**Analog Channels (cm)**
39.0	1.9	2.5	50.0	55	84
38.0	2.1	2.9	49.0	60	94
37.0	2.3	3.1	48.0	65	105
36.0	2.6	3.5	47.0	72	115
35.0	2.8	3.8	46.0	77	125
34.0	3.1	4.2	44.0	95	155
33.0	3.5	4.8	42.0	115	185
32.0	3.9	5.4	40.0	138	230
31.0	4.3	6.1	38.0	175	300

NOTE: SMATV is satellite master antenna television.

Satellite Relay
The "Bent Pipe"

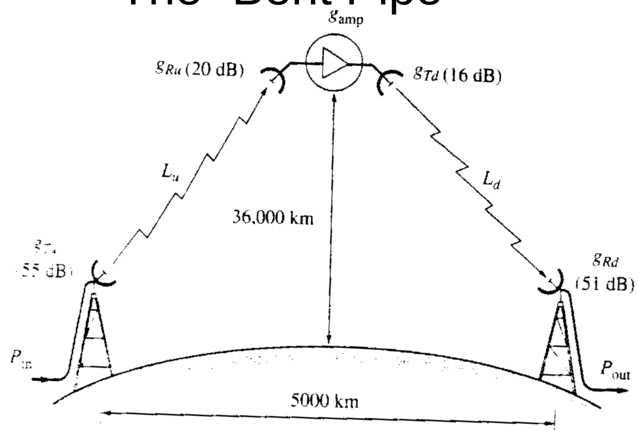


Figure 3.3–5 Satellite relay system.

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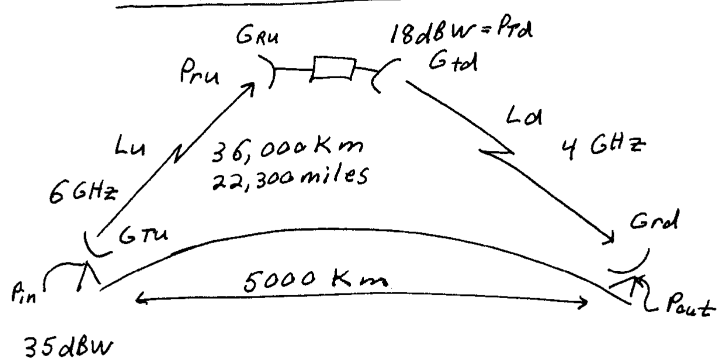
Example: Satellite Link



Uplink $L_u = 92.4 + 20\log(6) + 20\log(36{,}000)$

$L_u = 199.1 \text{ dB}$

DownLink $L_d = 92.4 + 20\log(4) + 20\log(36{,}000)$

$L_d = 195.6 \text{ dB}$

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Link Budgets:

uplink: $P_{ru} = P_t + G_{Tu} - L_p + G_{Ru}$

$P_{ru} = 35dBw + 55dB - 199.1dB + 20dB = -89dBW$

or $-59dBm$

Note: $EIRP_u = 35dBw + 55dB = 90dBw$

$= P_t + G_{TU}$

Down Link: $P_{Td} + G_{Td} - L_D + G_{rd} = P_{out}$

$P_{out} = 18dBw + 16dB - 195.6dB + 51dB = -110.6\ dBW$

$= 8.7 \times 10^{-12}$ Watts

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A Total Link Analysis includes many Factors.

Stage	Loss/Gain dB
P_t	
feedline loss	
Connector loss	
Antenna Gain	
Path Loss	
Polarization Loss	
Atmospheric Absorbcion Loss	
Rain, Clouds, Obstruction Loss	
Receive Antenna.	

Total Receive Power.

A full Link Budget will also include a noise analysis

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Factors affecting Free Space Loss

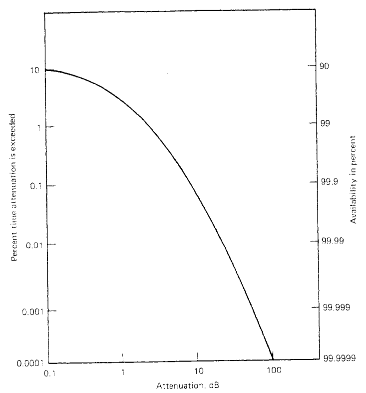

Figure 3.23. Percent time abscissa is exceeded (f = 10 GHz).

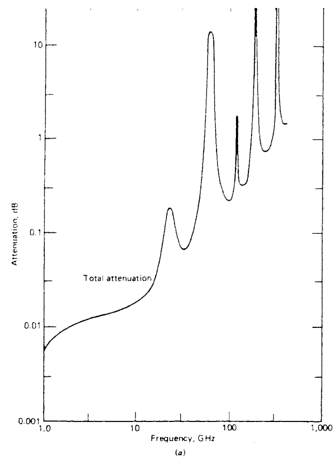

Figure 3.21. Atmospheric attenuation due to absorption: (a) horizontal path at sea le

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Factors affecting Free Space Loss

CARRIER PROPAGATION CHANNELS 117

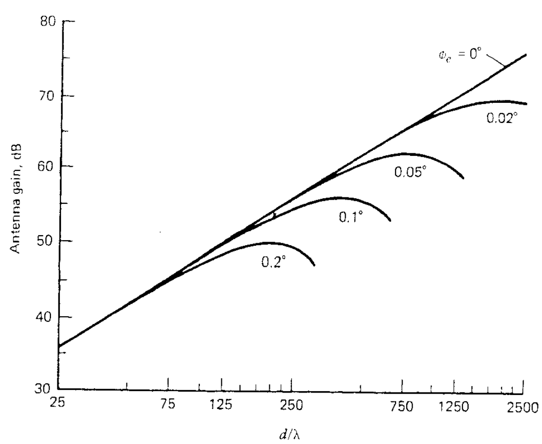

Figure 3.17. Antenna gain versus d/λ. The pointing error is denoted by ϕ_e.

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Factors affecting Free Space Loss

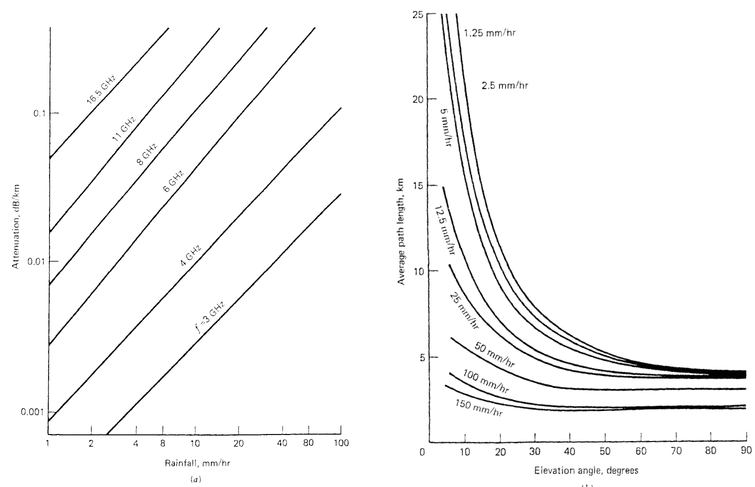

Figure 3.22. (*a*) Rainfall attenuation versus rainfall rate and frequency.

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Plane Earth Loss- LOS

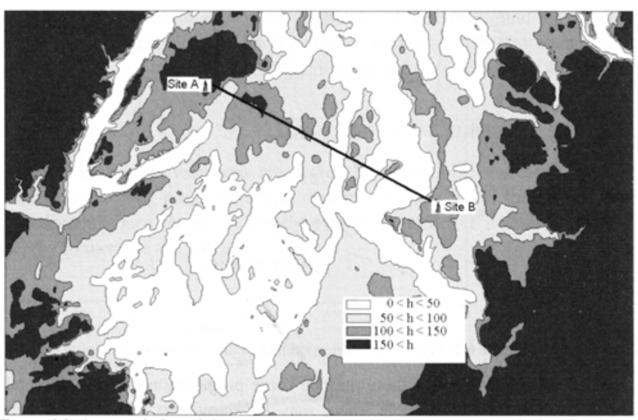

Figure 6.1: A great circle path between two antenna sites; contours are marked with heights in metres above mean sea level. Data is for the Seattle area using the USGS 3 and 1 arcsecond digital terrain models translated into Vertical Mapper format

- When the wave interacts with the ground or some other obstruction we no longer have free space propagation to the receiver

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Plane Earth Loss-LOS

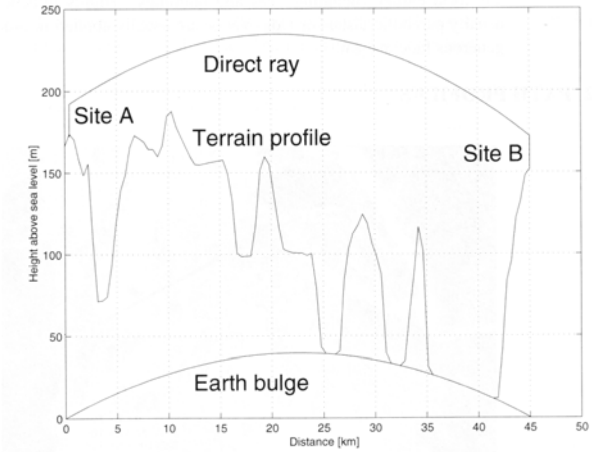

Figure 6.2: Path profile corresponding to the path shown in Figure 6.1

- When the wave interacts with the ground or some other obstruction we no longer have free space propagation to the receiver

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Plane Earth Loss- Fresnel Diffraction

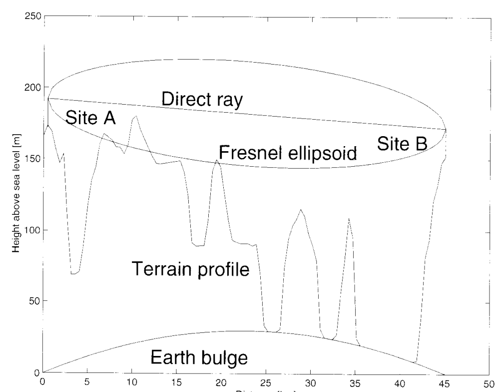

Figure 6.7: Path profile as Figure 6.2 but with Earth radius corrected to account for atmospheric refractive index gradient. The Fresnel ellipsoid represents $0.6 \times$ the first Fresnel zone at 900 MHz

- Non-LOS communication involves an additional loss due to Diffraction

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Earth Bulge

http://www.cisco.com/univercd/cc/td/doc/product/wireless/bbfw/ptop/p2pspg02/spg02ch2.htm#xtocid19

Earth Bulge

When planning for paths longer than seven miles, the curvature of the earth might become a factor in path planning and require that the antenna be located higher off the ground. The additional antenna height needed can be calculated using the following formula:

$$H = \frac{D^2}{8}$$

where
H = Height of earth bulge (in feet)
D = Distance between antennas (in miles)

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Earth Bulge with Fresnel Diffraction

http://www.cisco.com/univercd/cc/td/doc/product/wireless/bbfw/ptop/p2pspg02/spg02ch2.htm#xtocid19

Minimum Antenna Height

The minimum antenna height at each end of the link for paths longer than seven miles (for smooth terrain without obstructions) is the height of the First Fresnel Zone plus the additional height required to clear the earth bulge. The formula would be:

$$H = 43.3\sqrt{\frac{D}{4F}} + \frac{D^2}{8}$$

where
H = Height of the antenna (in feet)
D = Distance between antennas (in miles)
F = Frequency in GHz

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Tower Height

Line of Sight Distance Between Antenna Towers	Height of Tower to Avoid Flat Earth Curvature	Tower Height Required Over Tallest Obstacle In Line-of-Sight to Provide 60% Fresnel Zone Clearance	
		2.4GHz 802.11b/g (Fresnel Zone Radius = 39 Feet)	5.8 GHz 802.11a (Fresnel Zone Radius = 25 Feet)
8 Miles	10 feet	33	25
10 Miles	15 feet	38	30
12 Miles	20 feet	43	35
14 Miles	25 feet	48	40
16 Miles	30 feet	53	45
18 Miles	40 feet	63	55
20 Miles	50 feet	73	65
22 Miles	60 feet	83	75
24 Miles	70 feet	93	85
26 Miles	80 feet	103	95
28 Miles	100 feet	123	115
32 Miles	125 feet	148	140

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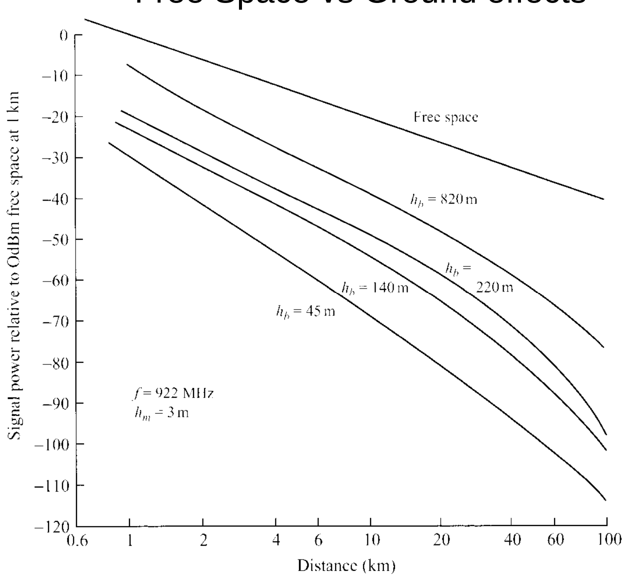
Free Space vs Ground effects



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Plane Earth Loss

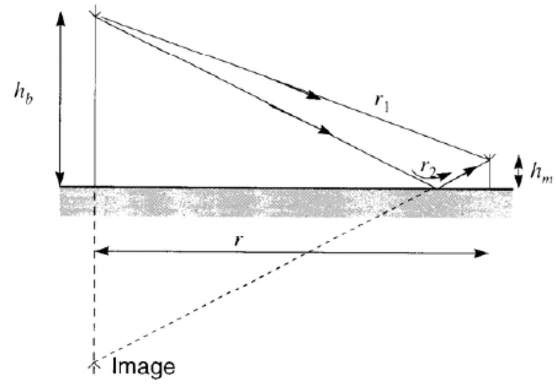

Figure 5.5: Physical situation for plane earth loss

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Plane Earth Loss

$$r_1 = \sqrt{(h_b - h_m)^2 + r^2}$$
$$r_2 = \sqrt{(h_b + h_m)^2 + r^2}$$

$$(r_2 - r_1) = r\left[\sqrt{\left(\frac{h_b + h_m}{r}\right)^2 + 1} - \sqrt{\left(\frac{h_b - h_m}{r}\right)^2 + 1}\right]$$

$$(1 + x)^n \approx 1 + nx$$

$$(r_2 - r_1) \approx \frac{2h_m h_b}{r}$$

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Plane Earth Loss

The overall amplitude of the result (electric or magnetic field strength) is then

$$A_{\text{total}} = A_{\text{direct}} + A_{\text{reflected}} = A_{\text{direct}} \left| 1 + R \exp\left(jk \frac{2h_m h_b}{r} \right) \right| \tag{5.28}$$

where k is the free space wavenumber.

$$\frac{P_r}{P_{\text{direct}}} = \left(\frac{A_{\text{total}}}{A_{\text{direct}}} \right)^2 = \left| 1 + R \exp\left(jk \frac{2h_m h_b}{r} \right) \right|^2 \tag{5.29}$$

where P_r is the received power.

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Plane Earth Loss

The direct path is itself subject to free space loss, so it can be expressed in terms of the transmitted power as

$$P_{direct} = P_T \left(\frac{\lambda}{4\pi r} \right)^2 \tag{5.30}$$

so the path loss can be expressed as

$$\frac{P_r}{P_T} = \left(\frac{\lambda}{4\pi r} \right)^2 \left| 1 + R \exp\left(jk \frac{2h_m h_b}{r} \right) \right|^2 \tag{5.31}$$

$$\frac{P_r}{P_T} = 2 \left(\frac{\lambda}{4\pi r} \right)^2 \left[1 - \cos\left(k \frac{2h_m h_b}{r} \right) \right]$$

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Plane Earth Loss

$$\frac{P_r}{P_T} \approx \left(\frac{\lambda}{4\pi r} k \frac{2h_m h_b}{r}\right)^2 \approx \frac{h_m^2 h_b^2}{r^4}$$

Expressing this in decibels:

$$L_{\mathrm{PEL}} = 40\log r - 20\log h_m - 20\log h_b$$

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Plane Earth Loss

Example 5.5

Calculate the maximum range of the communication system in Example 5.1, assuming $h_m = 1.5$ m, $h_b = 30$ m, $f = 900$ MHz and that propagation takes place over a plane earth. How does this range change if the base station antenna height is doubled?

Solution

Assuming that the range is large enough to use the simple form of the plane earth model (5.34), then

$$\log r = \frac{L_{\mathrm{PEL}} + 20\log h_m + 20\log h_b}{40} = \frac{148.3 + 3.5 + 29.5}{40} \approx 4.53$$

Hence r = 34 km, a substantial reduction from the free space case described in Example 5.4. If the antenna height is doubled, the range may be increased by a factor of $\sqrt{2}$ for the same propagation loss. Hence r = 48 km.

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Empirical Path Loss

Table 2.1 *Empirical power drop-off values*

City	n_1	n_2	$d_b(m.)$
London	1.7–2.1	2–7	200–300
Melbourne	1.5–2.5	3–5	150
Orlando	1.3	3.5	90

$$g(d) = d^{-n_1}(1+\frac{d}{d_b})^{-n_2}$$

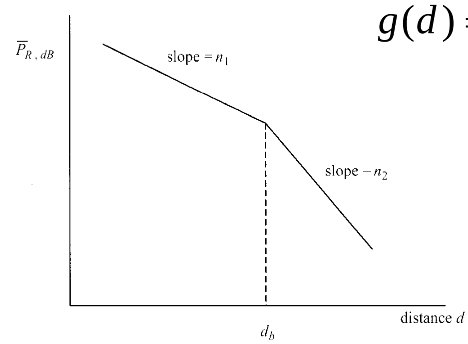

Figure 2.2 Two-slope received signal model, wireless communication

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Mobile Signal

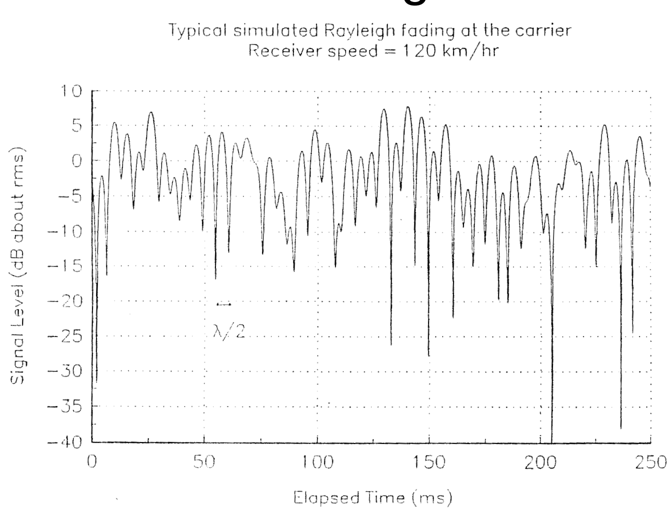

Figure 5.15 A typical Rayleigh fading envelope at 900 MHz [from [Fun93] © IEEE].

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