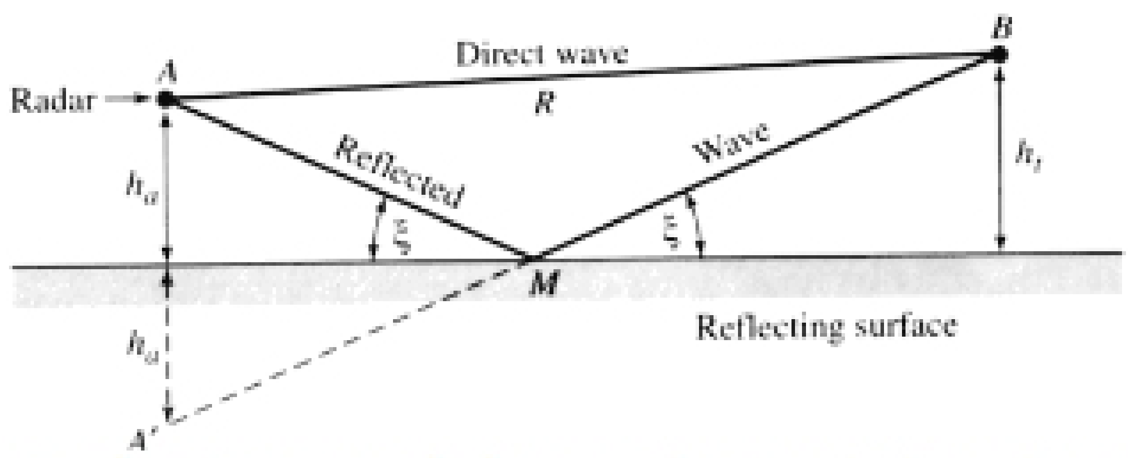
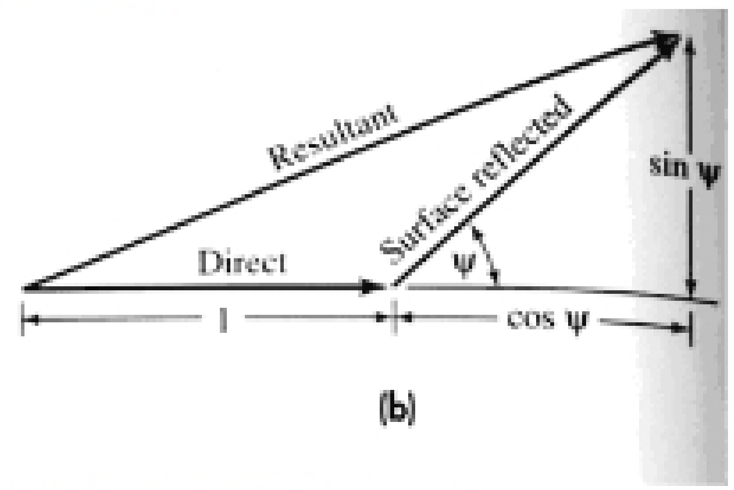
# Propagation of Radar Waves

- Forward scattering (reflection) from the surface of the earth enhances the energy at some elevations and decreases it at other.
- Refraction (bending).
- Ducting (trapping), a severe form of refraction that can extend radar range.
- Diffraction
- Attenuation
- External Noise
- Backscatter, clutter

**Forward Scattering.** Assumptions: Flat-earth model, (almost) total reflection ($\Gamma$ ~-1), path length almost equal so that differences in amplitude between reflected and direct wave is negligible, horizontal polarization, grazing angle is small.




The received power relative to what would have been received in free space is

$$P_\eta = 16\sin^4\left(\frac{2\pi h_a h_t}{\lambda R}\right)$$

Modified radar equation for point targets (we can do the same for distributed targets):

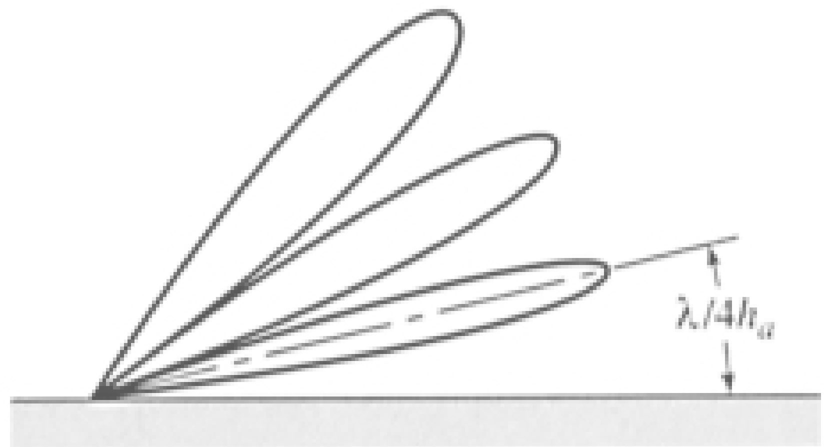
$$P_r = \frac{G^2\lambda^2 P_t \sigma}{64\pi^3 R^4} \times 16\sin^4\left(\frac{2\pi h_a h_t}{\lambda R}\right)$$

Maxima (16 times free-space power) and minima (null) occur when

$$\frac{4h_a h_t}{\lambda R} = 2n+1 \text{ maxima}$$

$$\frac{2h_a h_t}{\lambda R} = 2n \text{ minima}$$

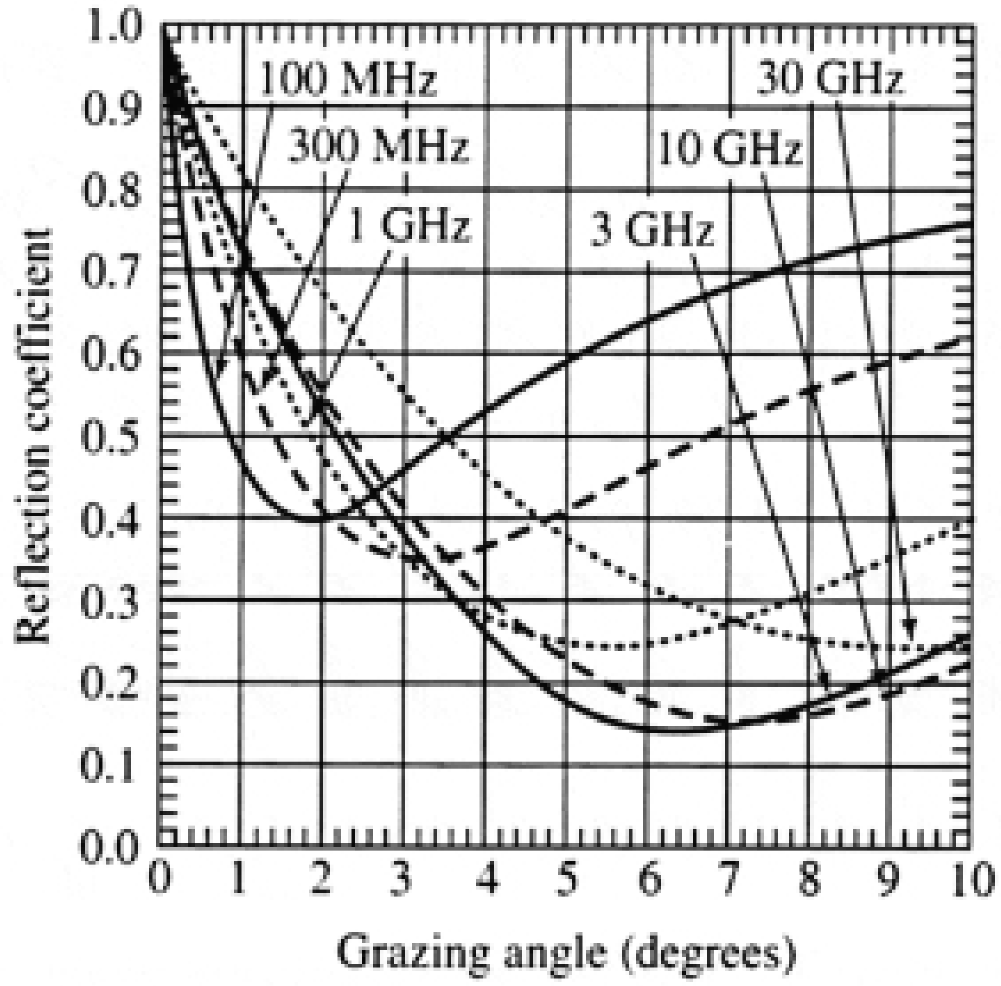
This leads to "lobing" of the received energy:




For small arguments of the sine (region below the peak of the first lobe):

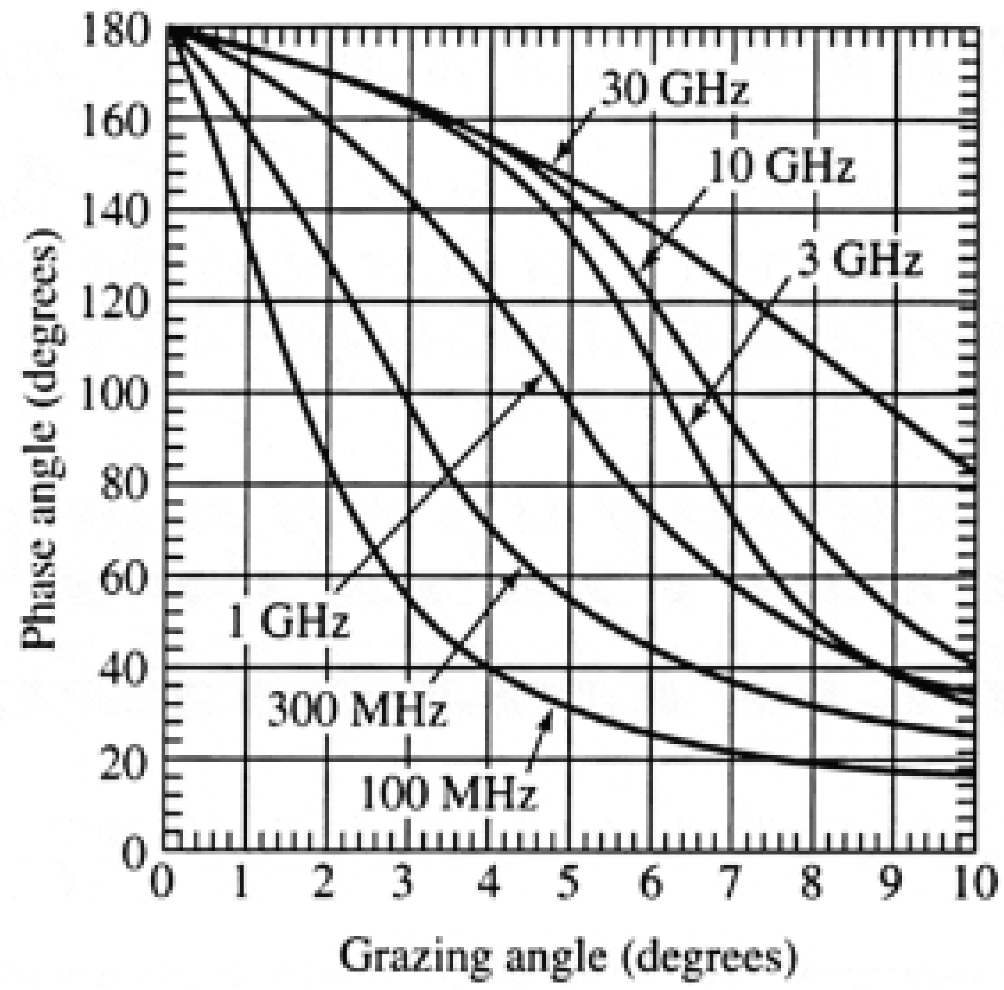
$$P_r =\approx \frac{4\pi P_t G^2 \sigma (h_a h_t)^4}{\lambda^2 R^8}$$

**Notice the $R^8$ dependence**.



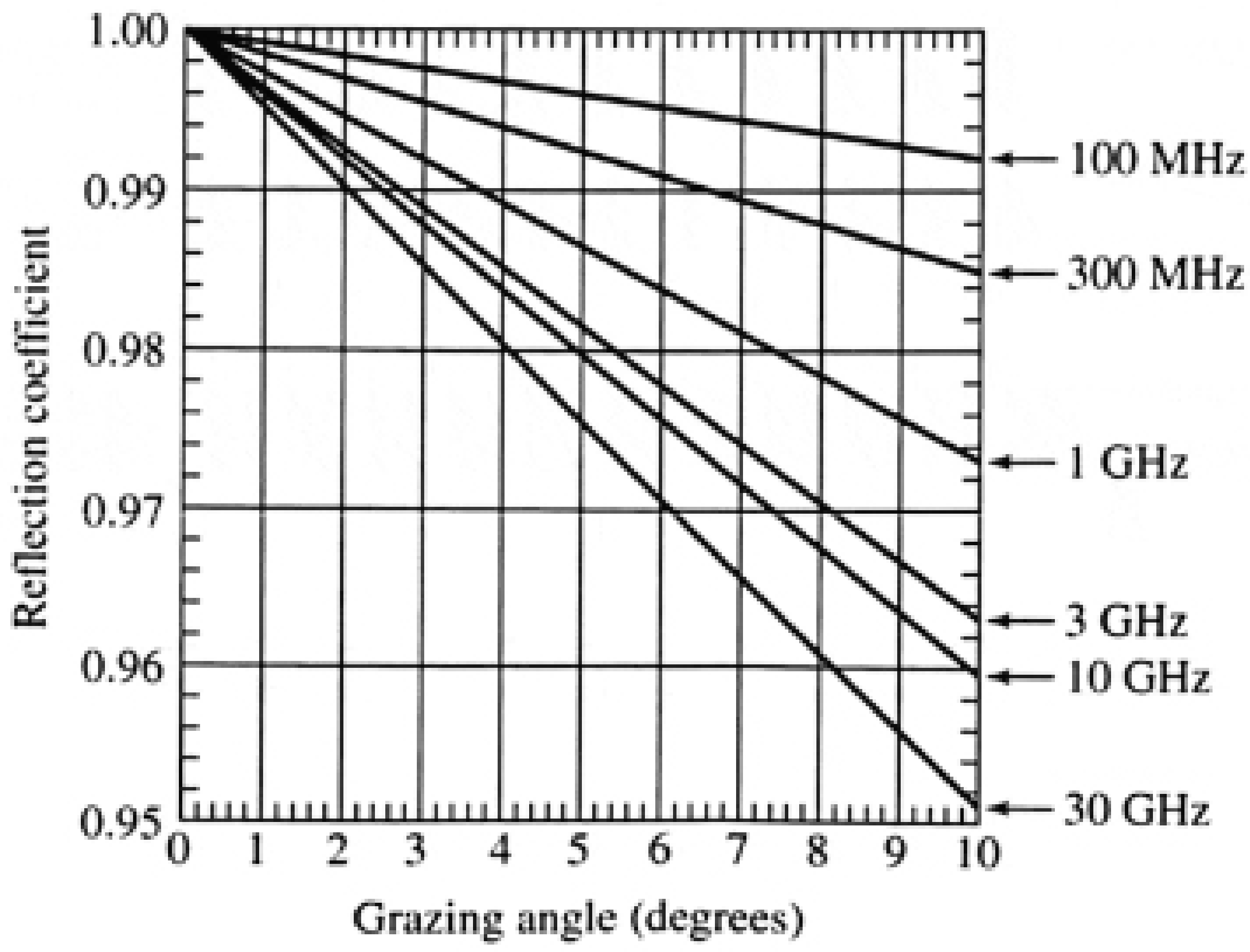
Reflection coefficient
Grazing angle (degrees)
100 MHz
300 MHz
1 GHz
3 GHz
10 GHz
30 GHz
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0 1 2 3 4 5 6 7 8 9 10


(a)



Phase angle (degrees)
Grazing angle (degrees)
30 GHz
10 GHz
3 GHz
1 GHz
300 MHz
100 MHz
180
160
140
120
100
80
60
40
20
0
0 1 2 3 4 5 6 7 8 9 10


(b)



Reflection coefficient
Grazing angle (degrees)
100 MHz
300 MHz
1 GHz
3 GHz
10 GHz
30 GHz
1.00
0.99
0.98
0.97
0.96
0.95
0 1 2 3 4 5 6 7 8 9 10


(c)