1. Small-Scale Fading

(a) The -90 dBm threshold occurs in the linear scale at $1 \times 10^{-9}$ millWatts.

$$\frac{1}{P_{av}} \int_{0}^{1 \times 10^{-9}} \exp \left( -\frac{p}{P_{av}} \right) \, dp = 1 - \exp \left( -\frac{1 \times 10^{-9}}{P_{av}} \right) = .01$$

implying that $P_{av}$ is -70 dBm.

(b) You could use three separate antennas in a space diversity scheme. If they were separated by enough space, the total probability of simultaneous fade for all three channels is $1 \times 10^{-6}$.

2. Antenna Arrays: Place 4 elements along the x-axis, separated by $\lambda/2$ and with a linear phase taper of $\pi/3$. The maximum occurs when the denominator is minimized such that $\cos \phi = -1/3$ or $\phi = 109.5^\circ$ and $250.5^\circ$.

3. Propagation Modeling:

(a) With 1 tree, 1 outer wall, and two inner walls, the Seidel-Rappaport model results in a received power of -68.7 dBm.

(b) The same received power in part (a) would be predicted by the path loss exponent model for $n = 4.59$.

4. Antenna Types:

1. V-Dipole  
2. Open Waveguide  
3. Vivaldi Antenna  
4. Yagi-Uda Array  
5. Uniform Linear Array  
6. Pyramidal Horn  
7. Log-Periodic  
8. Uniform Planar Array

5. Helical Design: Design equations mandate:

$$G_{peak} = 15N \frac{C^2 S}{\lambda^3} \geq 12.6 \quad \text{HPBW} = \frac{52 \lambda^{3/2}}{C \sqrt{NS}} \geq 20^\circ \quad \text{AR} \geq \frac{2N}{2N + 1} \geq 1.35 \quad \alpha = \tan^{-1}(S/C) = 13^\circ$$

Thus, $C = \lambda = 6 \text{ cm}$, $S = 1.3 \text{ cm}$, $N$ must be at least 30 to achieve the beamwidth criterion. With this many turns, the AR will only be 0.07 dB – near-perfect circular polarization.