1. A control station uses a quarter wave monopole antenna on top of a 15' tower to control an unmanned surveillance aircraft which will be orbiting at an altitude of 3000' AGL. The station broadcasts an 800 W control signal at a frequency of 300 MHz. The receiving antenna on the aircraft has a gain of 3.0. The aircraft needs 3.3 nW of power to process the signal.

   (a) Determine the max LOS for this setup. $R_{LOS} =$ 133.5 km

   $R_{LOS,mi} = \sqrt{2(15)} + \sqrt{2(3000)}$
   $= 5.48 + 77.46 = 82.94$ mi
   $82.94 \text{ mi} \times 1.61 \text{ km/mi} = 133.5$ km

   (b) Determine the range at which the antennas have enough power to communicate R = 122.9 km

   $\lambda = c/f = 1$ m
   $G_T = 3.28$ (ideal monopole, equation sheet)
   $$R_{\text{Friis}} = \frac{\lambda}{4\pi}\sqrt{\frac{P_T G_T G_R}{P_{R,\min}}} = \frac{1}{4\pi}\sqrt{\frac{800 \cdot 3.28 \cdot 3.0}{3.3 \times 10^{-9}}}$$
   $R_{\text{Friis}} = 1.229 \times 10^5$ m $= 122.9$ km

   (c) What is the maximum distance the aircraft can be controlled by the ground station? $R_{max} =$ 122.9 km

   $R_{max} = \min(133.5, 122.9) = 122.9$ km, the smaller of (a) and (b): the power limit binds, not the line of sight.

2. A search and rescue helicopter is at 450' AGL because of clouds, while the airman they are searching for is on a 50' hill. The downed airman's survival radio transmits 6W of power at 2 MHz, with an antenna with a gain of 3. The helicopter's radio has a gain of 3.2 and requires 3 µW receive power to accurately communicate.

   (a) Will the airman be able to communicate with the helicopter at 50 km via LOS?

   $R_{LOS} =$ 64.4 km, Yes

   $R_{LOS,mi} = \sqrt{2(450)} + \sqrt{2(50)}$
   $= 30.00 + 10.00 = 40.00$ mi
   40.00 mi $\times$ 1.61 km/mi $= 64.4$ km
   64.4 km $\geqslant$ 50 km: yes, there is line of sight

   (b) Will the airman be able to communicate with the helicopter at 50 km via signal power and antenna gain?

   R = 52.3 km, Yes

   $\lambda = c/f = (3 \times 10^8)/(2 \times 10^6) = 150$ m
   The radio transmits ($G_T = 3$); the helicopter receives ($G_R = 3.2$, $P_{R,\min} = 3\ \mu$W)
   $$R_{\text{Friis}} = \frac{\lambda}{4\pi}\sqrt{\frac{P_T G_T G_R}{P_{R,\min}}} = \frac{150}{4\pi}\sqrt{\frac{6 \cdot 3 \cdot 3.2}{3 \times 10^{-6}}}$$
   $= (11.94)(4382) = 5.23 \times 10^4$ m $= 52.3$ km
   52.3 km $\geqslant$ 50 km: yes, there is enough power

   (c) What is the farthest the airman will be able to communicate?

   $R_{max} =$ 52.3 km

   The smaller of the two limits, LOS 64.4 km and power 52.3 km: $R_{max} = 52.3$ km. Power binds.

3. A HC-130 is flying a search pattern at 10,000' AGL. Your radio transmits a 4 W signal at 243.0 MHz with an antenna gain of 2.8. The HC-130 has an antenna gain of 3.0 and requires 496.8 aW of power to detect and process the signal.

(a) Determine the max LOS for this setup.

$R_{LOS} =$ 227.7 km

Your radio is on the ground, so its term is zero:
$R_{LOS,mi} = \sqrt{2(10{,}000)} + \sqrt{2(0)} = 141.42$ mi
141.42 mi $\times$ 1.61 km/mi $= 227.7$ km

(b) Determine the range at which the radio and HC-130 have enough power to communicate

R = 25,550 km

$\lambda = c/f = (3 \times 10^8)/(243.0 \times 10^6) = 1.235$ m

$$R_{\text{Friis}} = \frac{\lambda}{4\pi}\sqrt{\frac{P_T G_T G_R}{P_{R,\min}}} = \frac{1.235}{4\pi}\sqrt{\frac{4 \cdot 2.8 \cdot 3.0}{496.8 \times 10^{-18}}}$$

$= (0.09824)(2.601 \times 10^8) = 2.555 \times 10^7$ m
$= 25{,}550$ km

(c) What is the maximum distance at which your radio can communicate with the HC-130?

$R_{max} =$ 227.7 km

The smaller of the two limits, LOS 227.7 km and power 25,550 km: $R_{max} = 227.7$ km. LOS binds: the radio has power to spare, but the HC-130 must be above its horizon.

4. A reconnaissance UAS is flying over flat terrain at 800‘ AGL trying to detect the radio traffic of an insurgent group. The insurgents’ camp is on a small plateau, 25’ above the surrounding terrain. The insurgents transmit 120 W of power at 24 MHz, using an antenna with a gain of 1.5. The UAS uses an antenna with a gain of 3.0. The UAS requires 80 nW of power to detect and process the transmission.

   (a) If the UAS is 80 km away from the insurgent camp, will it be able to detect the signals?

   $R_{LOS} =$ 75.78 km, No

   $R_{LOS,mi} = \sqrt{2(800)} + \sqrt{2(25)}$
   $= 40.00 + 7.07 = 47.07$ mi
   $47.07 \text{ mi} \times 1.61 \text{ km/mi} = 75.78$ km
   75.78 km < 80 km: no. The camp is below the horizon, whatever the power.

   (b) Suppose the UAS moves within 75km. Is the signal power at the receiver adequate?

   $P_R =$ 95.0 nW, Yes

   75 km is inside the 75.78 km LOS limit of (a), so power decides.
   $\lambda = c/f = (3 \times 10^8)/(24 \times 10^6) = 12.5$ m
   $P_R = P_T G_T G_R \left(\frac{\lambda}{4\pi R}\right)^2$
   $= (120)(1.5)(3.0)\left(\frac{12.5}{4\pi(75{,}000)}\right)^2$
   $= 9.50 \times 10^{-8}$ W $= 95.0$ nW
   $95.0 \text{ nW} \geqslant 80$ nW: yes, the power is adequate

5. A KC-46 tanker at 28,000 ft MSL receives a data link from a communications satellite that is directly overhead, in orbit at an altitude of 780 km. The satellite transmits 25 W at 1.62 GHz, with an antenna gain of 120 toward the tanker. The tanker's antenna has a gain of 4.5 toward the satellite, and its receiver requires 3.5 pW of power to process the signal.

(a) What is the range between the satellite and the tanker?

R = 771.5 km

Directly overhead there is no horizon, so there is no LOS limit: the range is the difference of the two altitudes.

$h_{\text{aircraft}} = 28{,}000 \text{ ft} \times 0.305 \text{ m/ft} = 8{,}540 \text{ m}$

$R = h_{\text{sat}} - h_{\text{aircraft}} = 780{,}000 - 8{,}540$

$= 771{,}460 \text{ m} = 771.5 \text{ km}$

(b) How much power does the tanker receive, and is that enough to process the signal?

$P_R =$ 4.93 pW, Yes

$\lambda = c/f = (3 \times 10^8)/(1.62 \times 10^9) = 0.1852 \text{ m}$

The satellite transmits ($G_T = 120$); the tanker receives ($G_R = 4.5$)

$$P_R = P_T G_T G_R \left(\frac{\lambda}{4\pi R}\right)^2$$

$$= (25)(120)(4.5)\left(\frac{0.1852}{4\pi(771{,}460)}\right)^2$$

$= 4.93 \times 10^{-12} \text{ W} = 4.93 \text{ pW}$

$4.93 \text{ pW} \geqslant 3.5 \text{ pW}$: yes, the link closes