Learning Objective 4.1: I can apply the radar equation to calculate received power for a given geometry, and account for path loss and radar cross section (RCS).

Show your work. A **Documentation** line at the end is required (write **None** if you did not collaborate).

1. **Friis applied twice.** A radar operates at 10 GHz, so $\lambda = 3.0$ cm. Its target sits at $R = 3$ m.

   (a) Compute the one-way free-space path loss $(4\pi R/\lambda)^2$ in dB.

   L_{fs} =

   (b) A one-way link loses power as $1/R^2$, but a radar echo falls as $1/R^4$. Explain where the extra $1/R^2$ comes from, in one or two sentences.

   (c) The target moves from 3 m to 6 m. By how many dB does the echo power change? By how many dB would the received power on a one-way link change?

   radar:

   link:

   (d) The radar equation in dB carries the constant $10\log_{10}\left((4\pi)^3\right)$. Evaluate it.

   constant =

2. **Three shapes.** At 10 GHz ($\lambda = 3.0$ cm), compare three targets of the same size: a sphere 20 cm in diameter, a square flat plate 20 cm on a side facing the radar, and a trihedral corner reflector with 20 cm edges, viewed along its symmetry axis. Give each peak RCS in m^2 and in dBsm.

   (a) Find the sphere's peak RCS.

   $\sigma =$ ____

   (b) Find the flat plate's peak RCS.

   $\sigma =$ ____

   (c) Find the corner reflector's peak RCS.

   $\sigma =$ ____

   (d) The plate has the largest peak RCS, yet radar ranges calibrate against corner reflectors. Explain why, and state how the corner's peak RCS compares with the plate's.

3. **Noise and G/T.** A receiver at room temperature has an antenna that sees $T_A = 290$ K. At $T_0 = 290$ K the noise density is $kT_0 = -174$ dBm/Hz.

   (a) Find the thermal noise power kT_0B in a 2 kHz bandwidth.

   N =

   (b) The receiver has a 3 dB noise figure. Find its equivalent noise temperature and the system noise temperature.

   T_e =

   T_{sys} =

   (c) The receive antenna has 20 dBi of gain. Find G/T in dB/K.

   G/T =

   (d) Every PHASER element feeds a low-noise amplifier with 24 dB of gain before anything else. Explain why the first amplifier sets the noise figure of the whole receiver.

4. **The PHASER link budget.** The PHASER transmits $P_t = -16$ dBm at 10 GHz through a 6 dBi antenna and receives on its array with $G_r = 15$ dBi . The target is a trihedral corner reflector with 10 cm edges ($\sigma = -3.3$ dBsm). The receiver noise figure is 2 dB , the antenna sees 290 K, and the bandwidth is 1 MHz.

   (a) Find the echo power at $R = 5$ m.

   P_r =

   (b) Find the SNR at 5 m.

   SNR =

   (c) The detector needs an SNR of at least 13 dB . Find the maximum range.

   R_{max} =

   (d) What transmit power would extend the maximum range to 25 m, with everything else unchanged?

   P_t =

5. **Seeing a drone.** The same PHASER setup now looks for a small drone with $\sigma = -20$ dBsm , still in a 1 MHz bandwidth and with a 13 dB threshold.

   (a) Find the maximum range against the drone.

   R_{max} = [ ]

   (b) How many dB must the budget improve to detect the drone at 10 m?

   Δ = [ ]

   (c) Find the receiver bandwidth that provides the whole improvement on its own.

   B = [ ]

   (d) The same 19.4 dB could come from about 87 times the transmit power instead. State which change you would make on the PHASER and why, in two or three sentences.

Documentation: _____