ASSIGNMENT 7
(due Thursday November 17, 2022)

1. `(30 points)` The digital output of a 1.4 GHz radio telescope gives an output with integer values, which represent the power measured at the receiver's input. For a short time the telescope gives the following values as it scans <u>uniform</u> brightness region:

time (s)	0	15	30	45	60	75	90	105	120	135
output	234	235	224	226	239	229	236	233	230	226

The measurements are done every 15 seconds because the integration time (post-detection time constant) is $\tau = 14$ s, and there is 1 s idle time needed for post-processing tasks. The system is calibrated <u>at the receiver's input</u> so that 170 integer units correspond to 2.9° K temperature (0 units correspond to 0° K temperature). The transmission line from the antenna to the receiver has 0.5 dB attenuation (e_L in dB). The antenna effective aperture is $A_{eff} = 500$ m^2 and its efficiency is $e_A = 0.98$. The receiver's bandwidth is $\Delta f = 7$ MHz.
Find: (a) the RMS noise temperature of the system at the receiver ΔT_{rms}^R in degrees Kelvin using the tabulated measurements above; (b) the minimum detectable temperature $\Delta T_{\min}$ at the antenna aperture; (c) the minimum detectable power flux density $p_{\min}$ in W/m^2, so that it produces at the antenna aperture power, which is equal to the noise power corresponding to $\Delta T_{\min}$; (d) the minimum detectable power flux density per *hertz* $p'_{\min}$ (measured in $\text{W} \times \text{m}^{-2} \times \text{Hz}^{-1}$, express also in *jansky*).
Notes:
(i) The minimum detectable temperature at the antenna $\Delta T_{\min}$ is the noise temperature at the antenna aperture, not at the receiver.
(ii) The minimum detectable power flux density $p_{\min}$ and that per *hertz* $p'_{\min}$ are evaluated at the antenna aperture. For both, assume polarization mismatch of PLF = 0.5 between the incident wave and the antenna.

2. `(35 points)` Assume that the radio telescope considered in Problem #1 is used to establish a link with a deep-space probe, with the receiver bandwidth being again $\Delta f = 7$. For a reliable link, a signal-to-noise ratio (SNR) of 3 dB is required, where the noise level at the receiver's input is equal to $\Delta T_{\min}$, calculated in Problem #1. The probe is equipped with an antenna whose gain is 36 dB and its transmitter puts out 8 W power. Assume that the probe's transmitting system is loss-free. (a) Determine the maximum distance for reliable signal reception from Pioneer 10. (b) Determine after how many days (approximately) the radio link will break down assuming that the probe travels away from Earth in a straight path with an average speed of 40,000 km/h.

3. `(10 points)` For the radio system of Problem #1, assume that the system constant is $k' = 2$ and find the system noise temperature T_{sys}^A.

4. `(25 points)` Find the system noise temperature at the antenna aperture T_{sys}^A if: (1) the sky temperature at zenith is 4° K and the antenna main beam, whose beam efficiency is $BE_M = 0.8$, is pointed at the zenith; (2) the beam efficiency of the side lobes is $BE_{SL} = 0.1$, and they "see" the horizon at temperature 150° K; (3) the beam efficiency of the back lobe is $BE_{BL} = 0.1$, and it "sees" the earth at temperature 300° K; (4) the antenna and the transmission line are at physical temperature 300° K; (5) the antenna efficiency is $e_A = 0.98$; (6) the transmission line has loss 0.5 dB; (7) the receiver has 3 amplifying stages each of 16 dB gain; (8) the 1st stage of the receiver has 50° K noise temperature, the 2nd stage noise temperature is 75° K, and that of the 3rd stage is 100° K.