This mid-term has 6 questions worth a total of 50 points. Answer the questions in the spaces provided on the question sheets. If you run out of room for an answer, continue on the back of the page allotted to that question. Clearly indicate your derivations and circle your final answer.

Last Name: ______________________________

First Name: ______________________________

1. $\boxed{\text{10 points}}$ Short-answer questions:

1.) What type of wireless communication system/network can establish direct point-to-point links in excess of 10,000 km? (Hint: It is one of the 6 networks we discussed in L1).

satellite

2.) Name a non-cellular standard targeted as a competitor to 4G.

WiMax

3.) 802.11 can be run in two modes, one is the "infrastructure" mode, what is the other?

ad-hoc

4.) Our three-part dissection of the radio structure consists of the "antenna", "digital baseband", and...?

RF front-end

5.) Electromagnetic energy is carried over long distance through space by which particle?

photon

6.) Does a real antenna radiate equally in all directions?

no

7.) Does the spatial focusing ability of an antenna improve of degrade as its physical size is increased?

improve

8.) If you run your received signal through a high-quality electronic amplifier can you improve the SNR (at the amplifier output of course)?

no

9.) When a wireless signal curves around the edge of an object we call that...?

diffraction

10.) The random variation incurred in the large-scale received power is referred to as...?

shadowing

2. $\boxed{\text{8 points}}$ Basic antenna stuff.

(a) $\boxed{\text{2 points}}$ You want a monopole antenna for a wireless system operating at a 5-GHz carrier. How long should the antenna be (in meters)?

$$L = \frac{\lambda}{4} = \frac{c}{f \cdot 4} = \frac{3 \times 10^8}{5 \times 10^9 \cdot 4} = 0.015 \text{ m}$$

(b) $\boxed{\text{2 points}}$ A 40-cm antenna designed to operate at 10.5 GHz achieved a beamwidth of 55°. What is the beamwidth factor that you would use to describe this antenna?

$$\text{beamwidth} = k \cdot \frac{\lambda}{L}$$

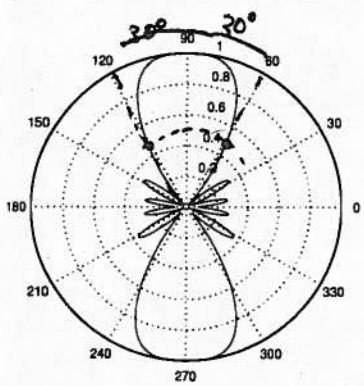
$$k = \text{beamwidth} \cdot \frac{L}{\lambda} = 55 \times \frac{40 \times 10^{-2}}{3 \times 10^8} \times 10.5 \times 10^9 = 770$$

(c) $\boxed{\text{2 points}}$ A 700-MHz antenna achieves a 11-dBi gain while exhibiting an efficiency of 0.7, what is its aperture area?

$$G = \frac{4\pi\eta A_e}{\lambda^2} = \frac{4\pi\eta A_e f^2}{c^2}$$

$$A_e = \frac{G c^2}{f^2 4\pi\eta} = \frac{10^{1.1} \cdot (3 \times 10^8)^2}{(700 \times 10^6)^2 \cdot 4 \cdot \pi \cdot 0.7} = 0.263 \text{ m}^2$$

(d) $\boxed{\text{2 points}}$ For the antenna pattern below approximate the 3-dB beamwidth (you should be able to get it within 10%).




~ 60°

3. $\boxed{\text{6 points}}$ For the questions on this page **assume** that all communications occur in free-space (i.e. don't worry about fading of any kind). Assume the wavelength for all questions on this page is 0.125 m.

(a) $\boxed{\text{3 points}}$ A transmitter with a $P_{1dB}$ of 1.7 W is attached to a matching network with a 0.5-dB loss followed by a transmission line with 3-dB loss and finally to an antenna with a gain of 3.3-dBi. What it the equivalent isotropic radiated power in Watts?

$$EIRP = \frac{P_t G_t}{L_{sys}} \qquad EIRP|_{dB} = 10 \cdot \log\left(\frac{1.7}{10^{-3}}\right) - 0.5 - 3 + 3.3$$

t line loss $\quad G_t$

$$\doteq 32.1 \text{ dBm}$$

$$EIRP = 10^{\frac{EIRP|_{dB}}{10}} \cdot 10^{-3}$$

$$\doteq 1.62 \text{ W}$$

(b) $\boxed{\text{3 points}}$ 1.5 W is actually radiated out of a transmit antenna towards an antenna with a receive gain of 2.7-dBi attached to a front-end receiver with a gain of 70-dB and a sensitivity of -50 dBm. How close can the receive antenna be to the transmit antenna in km?

$$P_r = \frac{P_t \cdot G_t \cdot G_r}{(4\pi d/\lambda)^2} \qquad P_t G_t = 1.5$$

$$d = \sqrt{\frac{P_t G_t G_r \lambda^2}{(4\pi)^2 P_r}}$$

$$= \sqrt{\frac{\overset{P_t G_t}{1.5} \cdot \overset{G_r}{10^{0.27}} \times \overset{\lambda}{(0.125)^2}}{(4\pi)^2 \underbrace{10^{-5} \times 10^{-3}}_{P_r}}}$$

$$= 166 \text{ m}$$

$$\boxed{d = 0.166 \text{ km}}$$

4. $\boxed{\text{10 points}}$ Unless otherwise stated assume that the reference temperature for the questions on this page is 290 K.

(a) $\boxed{\text{3 points}}$ A receive antenna with $T_{ant} = 210$ K operates over a bandwidth of 250 MHz. What is the minimum power that we need to deliver to this antenna in dBm if we require a SNR of 11-dB?

$$P_{ni}\big|_{dBm} = 10\log\left(\frac{kTB}{10^{-3}}\right) = 10\log\left(\frac{1.38\times10^{-23}\cdot 210\cdot 250\times10^{6}}{10^{-3}}\right) = -91.4d$$

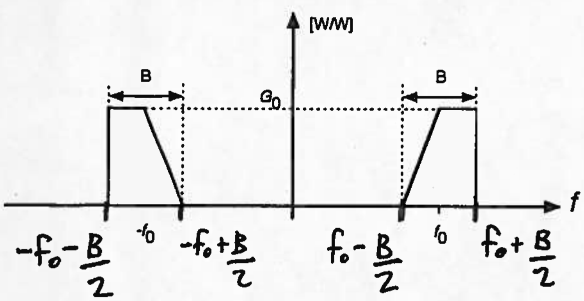
$$P_{si}\big|_{dBm} = P_{ni}\big|_{dBm} + \underbrace{SNR}_{11} = \boxed{-80.4\ dBm}$$

(b) $\boxed{\text{2 points}}$ For an amplifier with noise figure $NF = 5$ dB and a power gain of 22 dB what is the noise power spectral density at the output of the amplifier? Give the absolute quantity (i.e. not dB) and **show your units.**

$$S = \frac{k\cdot T\cdot F\cdot G}{2} = \frac{(1.38\times10^{-23})(290)(10^{0.5})(10^{2.2})}{2}$$

$$= 1\times10^{-18}\ \frac{W}{Hz} \quad \text{or} \quad J$$

(c) $\boxed{\text{5 points}}$ For an amplifier with $G(f)$ indicated below where $G_0 = 1250$ W/W, $B = 38$ MHz and $f_0 = 2.4$ GHz what is the equivalent noise bandwidth in MHz?




$$G_0 N_0 B_N = \frac{N_0}{2}\int_{-\infty}^{\infty} G(f)\,df$$

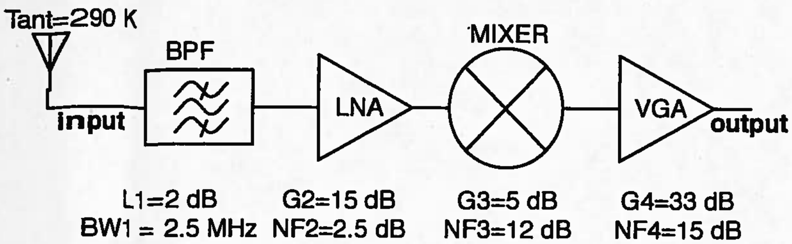
$$= \frac{N_0}{2}\times 2\times\left[\frac{G_0\times B/2}{2} + G_0\times\frac{B}{2}\right]$$

$$= N_0\times G_0\left[\frac{B}{4} + \frac{B}{2}\right]$$

$$G_0 N_0 B_N = N_0\times G_0\times\frac{3B}{4}$$

$$B_N = \frac{3B}{4} = \frac{3\times38}{4} = 28.5\ MHz$$

5. $\boxed{\text{6 points}}$ For the receiver shown below find...




(a) $\boxed{\text{2 points}}$ ... the total power gain in dB from the antenna to the "output" node.

$$G_T = -2 + 15 + 5 + 33 = 51$$

(b) $\boxed{\text{4 points}}$ ... the total noise power referred to the input (i.e. just after the antenna and accounting for the electronics) in dBm.

$$L_1 = 10^{\frac{L1|dB}{10}} \qquad G_2 = 10^{\frac{G2|dB}{10}} \qquad G_3 = 10^{\frac{G3|dB}{10}} \qquad G_4 = 10^{\frac{G4|dB}{10}}$$

$$F_2 = 10^{\frac{NF2|dB}{10}} \qquad F_3 = 10^{\frac{NF3|dB}{10}} \qquad F_4 = 10^{\frac{NF4|dB}{10}}$$

$$F_T = L_1 + L_1(F_2-1) + \frac{L_1}{G_2}(F_3-1) + \frac{L_1(F_4-1)}{G_2 G_3}$$

$$= 4.05$$

$$P_{ni}|_{dBm} = 10\log\left(\frac{kTBF_T}{10^{-3}}\right)$$

$$= 10\log\left(\frac{1.38\times10^{-23} \times 290 \times 2.5\times10^{6} \cdot F_T}{10^{-3}}\right)$$

$$= \boxed{-104\,dBm} \qquad (4.05\times10^{-14}\,W)$$

6. $\boxed{\text{10 points}}$ Realistic channels. Part (c) is on the next page.

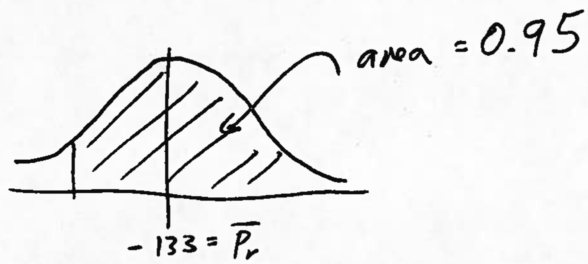
(a) $\boxed{\text{3 points}}$ You design a radio able to communicate up to 20-km in free space. Now someone tells you that you have 10-dB more system-loss than you expected and that your path-loss coefficient is actually 6.2. What is the expected communication distance of your system now?

$$P_r = \frac{P_t'}{d_1^2} = \frac{P_t'}{d_2^{6.2} \cdot L_{sys}}$$

$$\frac{d_2^{6.2}}{d_1^2} = \frac{1}{L_{sys}}$$

$$d_2 = \left(\frac{d_1^2}{10}\right)^{\frac{1}{6.2}} = \left(\frac{20^2}{10}\right)^{\frac{1}{6.2}} = \boxed{1.81\ km}$$

(b) $\boxed{\text{4 points}}$ Assume a large-scale fading scenario with a path variance of 13-dB and a path-loss exponent of 4.6. If the average received power is -133 dBm what must be the mobile sensitivity in dBm to achieve at least 95% reception in the cell?




$$0.95 = Q\left(\frac{p_r - \bar{P}_r}{\sigma_{path}}\right)$$

$$0.05 = Q\left(\frac{\bar{P}_r - p_r}{\sigma_{path}}\right)$$

from table $Q(x) = 0.05 \Rightarrow x$ is between 1.6 & 1.7

say $\sim 1.65$

$$\therefore \frac{\bar{P}_r - p_r}{\sigma_{path}} = 1.65$$

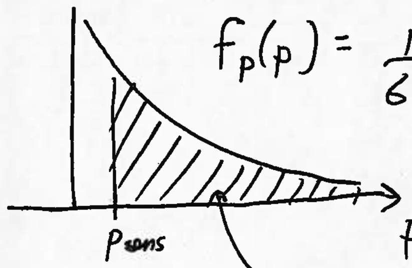
$$-p_r = 1.65 \cdot \sigma_{path} - \bar{P}_r$$

$$p_r = -1.65 \times 13 - 133 = \boxed{-154.5\ dBm}$$

the needed mobile sensitivity

(c) 3 points A Rayleigh channel has an average received power of -133 dBm. What is the mobile sensitivity in dBm needed to achieve 95% reception in the immediate vicinity of the phone?

$$f_p(p) = \frac{1}{\sigma^2} e^{-\frac{p}{\sigma^2}}$$




← Rayleigh power distribution

$$Pr[p_r > p_{sense}] = 0.95$$

← probability of being able to sense 95% of the possible received power levels

$$0.95 = \int_{p_{sense}}^{\infty} \frac{1}{\sigma^2} e^{-\frac{p}{\sigma^2}} dp$$

$$\sigma^2 = 10^{-13.3} \times 10^{-3} = 5.01 \times 10^{-17}\ W$$

$$0.95 = -e^{-\frac{p}{\sigma^2}} \Big|_{p_{sense}}^{\infty}$$

$$0.95 = 0 - \left(-e^{-\frac{p_{sense}}{\sigma^2}}\right)$$

$$0.95 = e^{-\frac{p_{sense}}{\sigma^2}}$$

$$p_{sense} = -\sigma^2 \ln(0.95) = 2.5708 \times 10^{-18}\ W$$

$$\boxed{p_{sense}\big|_{dBm} = -146\ dBm}$$