ECEG 497 **Wireless System Design** **Spring 2025**

Homework Assignment #6 – due via Moodle at 11:59 pm on Tuesday, Apr. 8, 2025

***Instructions, notes, and hints*:**

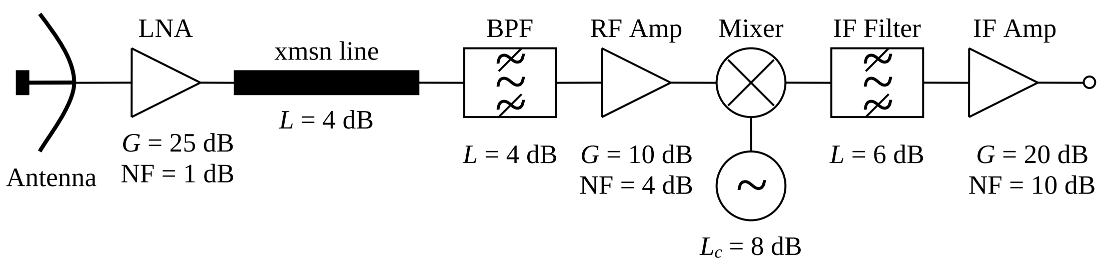
You may make reasonable assumptions and approximations to compensate for missing information, if any. Provide the details of all solutions, including important intermediate steps. You will not receive credit if you do not show your work.

It might be necessary to use reasonable approximations or assumptions to solve some of these problems, especially if critical information is missing. In those cases, your answer might differ from the posted answer by a significant margin. That's okay. If you justify any approximations that you make, you will be given full credit for such answers.

The first set of problems will be graded and the rest will not be graded. Only the graded problems must be submitted by the deadline above. Do not submit the ungraded problems.

***Graded Problems*:**

1. Find the overall standard noise figure and equivalent noise temperature of the receiver system shown below. The passband of the first filter (after the transmission line) is 9.5–10.5 GHz, and that of the IF filter is 1.10–1.11 GHz. The local oscillator tunes 8.9–9.2 GHz. There is no significant selectivity (i.e., no other narrow filters) beyond the IF amplifier. The later stages also contribute negligibly to the overall noise figure. The variable L_c represents the conversion loss of the mixer. It indicates that the power level of the output IF signal is 8 dB less than the power level of the input RF signal. The indicated noise figures in the diagram are standard and based on a temperature of 290 K.



2. Repeat the previous problem with the positions of the transmission line and the LNA interchanged. Compare the results of the previous problem to those of this problem and comment.

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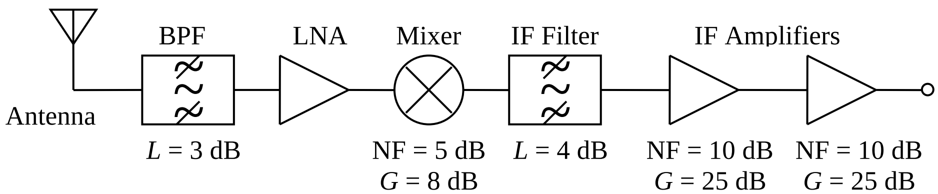
3. Suppose that a new receiver is being designed for the 2.4-2.5 GHz frequency range and is to have a system noise figure no greater than 2.0 dB. A block diagram of the receiver's front end is shown below. The input band-pass filter, IF filter, mixer, and IF amplifier circuits have been selected, and they have the indicated specifications. (The mixer uses active devices, so it has gain.) The selected LNA transistor will yield a noise figure of 0.5 dB if it is biased properly. The front-end filter's passband is 2.3–2.6 GHz, respectively, and the IF filter has a bandwidth of 20 MHz. The circuitry following the IF amplifiers contributes negligible noise. The transmission line between the antenna and the receiver's input port has negligible loss. You have been asked to find the minimum required gain of the LNA to achieve the desired system noise figure; however, you should find that it cannot be done! Explain why not, and show your work to support your answer. The indicated noise figures in the diagram are standard and based on a temperature of 290 K.



4. Below the VHF range (i.e., below 30 MHz or so), anthropogenic noise is usually the more important limiting factor in a communication system than the internally generated noise in the receiver circuitry. Using Equation (4.30) of the textbook (Ellingson, 2016) with the appropriate model parameters listed in Table 4.2 as a starting point, determine the maximum system noise figure that a receiver located in a typical quiet rural area can have such that the internally generated receiver noise is no worse than that from the surrounding environment at the following frequencies. Fig. 4.7 in the textbook plots Equation (4.30) for the four sets of parameters given in Table 4.2, but the equation is easier to use. Assume that a "low-gain omnidirectional antenna at ground level" is used, as specified in the textbook.

- **a.** 1070 kHz (AM broadcast station WKOK in Sunbury, PA)
- **b.** 10 MHz (time standard station WWV)
- **c.** 28 MHz (bottom of amateur radio 10-meter band)

Ungraded Problems:

The following problems will not be graded. However, you should attempt to solve them on your own and then check the solutions. Try not to give up too quickly if you struggle to solve any of them. Move on to a different problem and then come back to the difficult one after a few hours.

1. Find the actual power level P_N of the internally generated noise at the output port of an amplifier that has a gain of 20 dB and a noise figure of 11 dB. Express the power level in the dBm unit. The amplifier is used in a receiver system with an operational bandwidth of 50 kHz. Assume a standard temperature of 290 K.

2. Calculate the difference in decibels between the antenna temperature associated with the "quiet rural" model of anthropogenic noise and that associated with galactic noise at 10 MHz. Repeat the calculation for the case of the "city" model compared to galactic noise.

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3. One of the challenges with image rejection mixers like the one shown below is the amplitude and phase mismatch between the two paths through the mixer. Either type of mismatch will cause the image signal not to be completely canceled. The two parts of this problem consider separately the impacts of amplitude and phase mismatches.

a. Suppose that there is a 1.2 dB amplitude mismatch between the upper and lower signal paths but that the phase shifts along each path are exactly equal. The result is that the phase-shifted and frequency-translated desired (RF) and image signals at node v_e each have an amplitude of A_e = 1.00 mV, and the corresponding signals at node v_f each have an amplitude of A_f = 1.15 mV. (It is unlikely that the RF and image amplitudes would be equal. They are assumed equal here to highlight the effect of amplitude mismatch.) Find the ratio of the image amplitude at the output of the summing junction to that of the RF amplitude expressed in dB. The downconverted components at the summing junction can be expressed as

$$v_{out}(t) = v_e(t) + v_f(t) = \frac{1}{2}\left[A_e \cos(\omega_o t - \omega_1 t) + A_e \cos(\omega_2 t - \omega_o t - 90°)\right]$$
$$+\frac{1}{2}\left[A_f \cos(\omega_o t - \omega_1 t) + A_f \cos(\omega_2 t - \omega_o t + 90°)\right]$$

b. Now suppose that there is a 2.2° phase mismatch between the upper and lower signal paths in the mixer shown below but that the amplitude changes along each path are exactly equal. The result is that the output of the mixer can be expressed as

$$v_{out}(t) = v_e(t) + v_f(t) = \frac{1}{2}\left[A_e \cos(\omega_o t - \omega_1 t) + A_e \cos(\omega_2 t - \omega_o t - 90°)\right]$$
$$+\frac{1}{2}\left[A_f \cos(\omega_o t - \omega_1 t + 2.2°) + A_f \cos(\omega_2 t - \omega_o t + 92.2°)\right],$$

where the signal component amplitudes are equal (i.e., $A_e = A_f$). Find the ratio of the downconverted image signal strength at the output of the summing junction relative to that of the downconverted RF signal expressed in dB.