

# EE431 Noise Homework

(not to be handed in)

Feb. 9, 2013

**Noise homework problems** (temperature is 300 kelvins unless otherwise specified). You are given all the needed information. Check your math or method if you think you need more information. Answers are not provided at the end.

- 1 What is the electronic bandwidth and noise bandwidth of a low-pass filter made from a 1,200 ohm resistor and a 0.15 uF capacitor?
- 2 What is the noise voltage delivered to a matched load from a 50 ohm resistor at 300 K over an electrical bandwidth of 60 MHz?
- 3 What is the noise power delivered to a matched load for the circuit in problem 2? How much would the noise power increase if the resistance of both source and load were increased to 500 ohms?
- 4 One of the instructor's oscilloscopes that has an electrical bandwidth of 100 MHz and an input resistance of 1 Meg-ohm shunted by 22 pF shows a displayed noise level of 200 uV peak-peak when nothing is connected to the input. How much of the total noise does the 1 Meg-ohm resistance contribute (hint: be careful about the bandwidth)?

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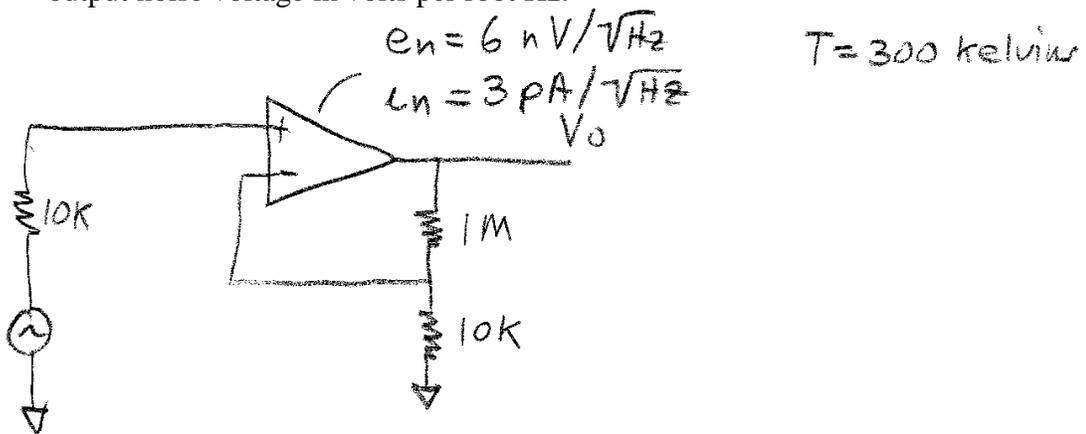
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- 5 The advertisement of a spectrum analyzer indicates that with an electrical bandwidth of 100 kHz (because of high filtering, take the noise bandwidth to be 110 kHz) the displayed noise floor is -135 dBm at room temperature. What is your opinion of this specification? Justify your answer with calculations.
- 6 The amplifier in a circuit with a non-inverting gain of 100 has an input referred noise voltage of 12 nV per root Hz. What is the output noise voltage over a 15 kHz noise bandwidth?
- 7 What is the smallest signal level in dBm that can be detected with a signal to noise ratio of 10 using a 1 kHz noise bandwidth.

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- 8 Perform a noise analysis of the circuit in the following figure to determine the output noise voltage in volts per root Hz.



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- 9 If a signal source is cooled from 300 kelvins down to 200 kelvins by what factor is the noise voltage reduced?
- 10 What is the effective temperature of a signal source if the noise voltage is 20 dB above that at room temperature (300 kelvins)? This is known as the noise temperature and is a common term used in ultra-low noise design. Note: This problem uses but is not directly part of the course material but is useful to be aware of as you may encounter this someday. See the supplemental notes on the course website about amplifier noise metrics for information on working this problem – it is a simple calculation.

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### Answers:

1.  $F_c = 1/(6.28 * 1200 * 0.15E-6) = 885 \text{ Hz}$ .  $F_n = 1.57 * 885 = \mathbf{1.39 \text{ kHz}}$ .
2.  $e_n = \sqrt{(4 * 1.38E-23 * 300 * 60E6 * 1.57 * 50)/2} = \mathbf{4.4 \text{ uVrms}}$ . The division by 2 is from voltage division.
3.  $\text{Power} = 4.4\text{uV}^2 / 50 = \mathbf{390 \text{ fW}} - \mathbf{\text{also} = \text{kTB}}$ . Power stays the same.
4.  $F_c = 1/(6.28 * 1E6 * 22E-12) = 7.24 \text{ kHz}$ .  $F_n = 1.57 * 7.24 \text{ kHz} = 11.3 \text{ kHz}$ .  $e_n = \sqrt{(4 * 1.38E-23 * 300 * 11300 * 1E6)} = \mathbf{13.7 \text{ uVrms}} == \mathbf{82 \text{ uVpp}}$  (Amplifier noise makes up the rest)
5.  $P_n = 1.38E-23 * 300 * 110,000 = 455 \text{ aW} = \mathbf{-123 \text{ dBm}}$ . The specification is impossible as it implies lower noise than the laws of physics – -135 dBm is 12 dB below the noise floor. Because spectrum analyzers typically have a 25 dB noise figure the true noise floor on the display in this situation would be around -98 dBm. Because of the non-rms method of detection the displayed noise floor is in error by a few dB so the noise floor display is a bit complicated – refer to Agilent application notes on spectrum analyzers.
6.  $12 \text{ nV} * 100 * \sqrt{15000} = \mathbf{147 \text{ uVrms}}$ .
7.  $P_n = 1.38E-23 * 300 * 3000 = 12.4 \text{ aW}$ . For 10 S/N =  $\mathbf{124 \text{ aW} = -129 \text{ dBm}}$ .
8. RI -> 1.3uVrms, RS -> 1.3 uVrms, RF -> 128.7 nVrms  
IN- -> 3.0 uVrms, IN+ -> 3.0 uVrms, Vn -> 606 nVrms  
**Total = 4.7 uVrms**
9.  $\sqrt{200/300} = 0.8165$  for a factor of **1.22** or 1.8 dB. This illustrates that cooling has little effect unless it is substantial. A reduction to 75 K would reduce the noise voltage by a factor of 2.0. A reduction to 0.3 K (hard to do!) would reduce the noise voltage by a factor of 10. In a more real example the device being cooled might have a temperature much higher than room temperature. Then cooling it down to 70 K can make a substantial reduction in noise.
10. Note that 20 dB more power is a factor of 100 – bandwidth is the same and vanishes from the calculation since we are taking a ratio of powers.  
 $\sqrt{(4 * k * T * B)} / \sqrt{(4 * k * 300 * B)} = 100$  so  $T = \mathbf{30,000 \text{ K}}$ . The effective noise temperature of a device is often a huge number such as this. For receiving signals from deep space probes great effort is made to reduce the noise temperature to low double digits.