MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Department of Electrical Engineering and Computer Science

Receivers, Antennas, and Signals – 6.661

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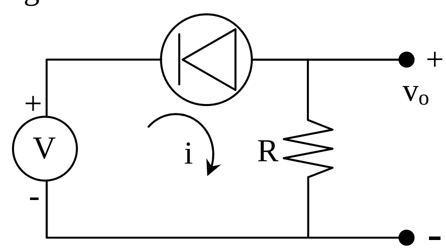
Problem Set No. 5 Due: 3/13/03

Problem 5.1

A fully back-biased photodiode (p-n junction) has a DC dark current i_o that is temperature sensitive and an energy gap E_g.

a) Do the photo-excitations that control i_o occur primarily in the n-type, p-type, or junction region? Explain briefly. Hint: see Figure 2.4-7 in the course notes.

b) This thermal current i_o introduces shot noise v_{shot} (rms) across the load resistor R which adds to the Johnson noise v_J from the resistor R. In order for this shot noise v_{shot} to equal v_J from R, what should R be?



c) To within a constant multiplier, approximately how does the dark current i_0 vary with junction temperature T? Assume that T is near room temperature so that $kT << E_g$, and that the energy level distribution (states per volt) is uniform in the valence and conduction bands.

Problem 5.2

a) For what kinds of detection problems would photodiodes generally perform better than avalanch photodiodes with $x \cong 0.3$? Explain briefly, using simple inequalities if appropriate.

b) Repeat (a), but comparing PT's and PMT's to PD's and APD's. The system cost and complexity of these devices generally increase in the order: PD, APD, PT, and PMT. Refrigeration costs can exceed the device cost unless very low device power and cooling is involved.

Problem 5.3

Photodetectors emit a current pulse of A coulombs for every detected photon, and these pulses are poisson distributed in time. Two hypothetical photodetectors are being compared. Each produces a current of I_o amperes when exposed to a standard calibration light source. For detector (1) $A = A_o$, while detector (2) randomly has $A = 2A_o/3$ half the time and $A = 4A_o/3$ the other half of the time. What is the ratio of the rms shot noise voltages v_s associated with these two photodetectors?

Problem 5.4

How many photons per second do we need to receive in order to have a CNR of 20 dB in an optical superheterodyne receiving voice signals of bandwidth 3 kHz?

a) Assume the dark count D is zero.

b) Assume $D = 10^5$ counts/sec.

Problem 5.5

A certain square bolometer 1 mm on a side has responsivity S = 40, T_o = 5K, diode physical temperature T = 22K, and a 1-ma operating current. Its thermal conductivity to the 18K cold bath is $G_t = 10^{-7}$. The output circuit has 1-second boxcar integration and an effective bandwidth B of 0.5 Hz.

a) What is the nominal resistance R of the bolometer under these conditions? Hint: the equilibrium heat flow to the bath equals the I^2R power dissipated.

b) What is the nominal rms Johnson noise n_J across the output terminals? Hint: The bias resistor contribution should be negligible.

c) What is the bolometer NEP (W/Hz) due to Johnson noise only?

d) What is the contribution to bolometer NEP from phonon noise?

e) What is the contribution to NEP from photon noise assuming infinite bandwidth and 2π solid angle?

f) What one or two bolometer parameters might we change first to improve its total effective NEP? Discuss briefly.

Problem 5.6

A certain communications system between Mars and Earth uses 3-cm radiation and antennas on Earth and Mars having antenna gains of 70 dB and 50 dB, respectively. Our receiver system temperature T_s is 20K and our transmitter power P_T at Mars is 10 watts. How much bandwidth B (Hz) can we transmit while still achieving SNR = 20 dB at the Earth receiver when Mars is 10^{11} meters away?