Detection of Light: Exercise 7

Set: Fri 27th Mar 2015,
Due: Fri 3rd Apr 2015

1 Heterodyne Performance [20 marks]

Suppose you would like to design a heterodyne receiver for observations at $\lambda = 240\,\mu$m, and you want it to perform better than the bolometer we designed in Ex.6 ($\eta = 0.75$). Assume the bolometer is operated through a spectral band of width 20% of the central frequency. Our heterodyne receiver includes a diode photomixer of diameter $85\,\mu$m and depletion region of width $1.5\,\mu$m, and is constructed from HgCdTe which has a dielectric constant $\kappa = 10$. The input impedance of the amplifier is $130\,\Omega$.

a Calibration observations are made of two black bodies with temperatures $T_1 = 3000\,\mathrm{K}$ and $T_2 = 200\,\mathrm{K}$, for which the receiver measures 3.7 V and 1.2 V respectively.
i) Calculate the effective noise temperature T_N of this receiver.
ii) Does this operate in the thermal or quantum limit of the heterodyne receiver?

[4 marks]

b Calculate the IF bandwidth of the receiver, assuming this is limited by the frequency response of the mixer.

[Hint: Model the mixer circuit as a simple RC circuit with finite time constant τ]

[6 marks]

c One of the noise sources which is independent of the local oscillator is the amplifier, where Johnson noise effects play an important role. Calculate the RMS amplifier noise current for our heterodyne receiver.

[3 marks]

d It can be shown that the ratio between the (S/N) of our heterodyne receiver and that of an incoherent receiver operating at the same background level, bandwidth and wavelength is given by:

$$\frac{(S/N)_{\mathrm{coh}}}{(S/N)_{\mathrm{inc}}} = \left[\left(\frac{1}{\eta}\right)\left(\frac{\Delta f_{\mathrm{IF}}}{\Delta\nu}\right)\left(\frac{h\nu}{kT_B}\right)\right]^{1/2}$$

where η is the quantum efficiency of the incoherent receiver.

Compare the relative (S/N) for the bolometer and heterodyne receiver; which one performs better under the given conditions?

[2 marks]

e i) At which bandwidth would the heterodyne receiver provide equal performance?
ii) What is the fundamental assumption under which this trade-off is valid?
iii) What spectral resolution does this correspond to, and what is the equivalent Doppler velocity (in km/s)?

[5 marks]