King's College London

UNIVERSITY OF LONDON

M.Sci. EXAMINATION

CP/4750 Image Capture and Sensor Technology

Summer 2000

Time allowed: 3 Hours

Candidates must answer THREE questions.
No credit will be given for answering further questions.

The approximate mark for each part of a question is indicated in square brackets.

You must not use your own calculator for this paper.
Where necessary, a College calculator will have been supplied.

TURN OVER WHEN INSTRUCTED

You may use the following equalities where the symbols have their usual meanings:

Boltzmann's constant $k = 1.38 \times 10^{-23}$ J K^{-1}

Electronic charge $e = 1.60 \times 10^{-19}$ C

Speed of Light $c = 3.0 \times 10^{8}$ m s^{-1}

$kT/e = 0.025$eV at 300 K

$\exp - \left(\frac{h\nu}{kT}\right) = \frac{1}{120}$ **at 300 K for 10μm radiation.**

$dI_{\nu,\Omega} = \frac{2h\nu^3 d\nu}{c^2 \exp\left(\frac{h\nu}{kT}\right) - 1}$ **in the frequency interval $d\nu$ per unit solid angle Ω**

$\sigma \times T^4 = 460 Wm^{-2}$ **is the total energy radiated by a black body of area 1 m^2 at 300 K.**

$\int_0^\infty dx/(1+x^2) = \pi/2$

Answer THREE questions

1) Briefly explain each of the following terms

   a) quantum efficiency,

   [2 marks]

   b) signal to noise ratio,

   [2 marks]

   c) noise equivalent power,

   [2 marks]

   d) the Weiner-Khintchine relationship and

   [2 marks]

   e) avalanche breakdown.

   [2 marks]

The probability $p(n,k)$ of a detector detecting n photons in a pulse of unit time interval, when the average photon arrival rate is k, is governed by the Poisson probability distribution

$$p(n,k) = \frac{(k)^n}{n!} \exp(-k).$$

Show that, for the above distribution,

$$\overline{n^2} - \overline{n}^2 = \overline{n}$$

[10 marks]

Calculate the minimum number of photons, per pulse, required to form a digital signal with a bit error rate of 10^{-9}.

[10 marks]

2) Describe, giving examples of device types, the principles of thermal detection with each of the following types of detector

   a) bolometer,

   [10 marks]

   b) pyroelectric and

   [10 marks]

   c) SPRITE.

   [10 marks]

3) Explain what is meant by an 'Ideal Photon Detector' and show that for such a detector with a bandwidth B and average signal current I, the mean squared shot noise fluctuations in the signal may be expressed as

$$\overline{i_N^2} = 2eIB.$$

[5 marks]

Describe the spectral characteristics of electromagnetic wave propagation through the atmosphere, explaining the mechanisms which give rise to attenuation and discussing any infrared spectral bands where relatively low losses occur. Explain any technological significance of these spectral bands.

[10 marks]

An artificial satellite in Earth-synchronous orbit 400 000 km above an ocean, is equipped with a 5 Watt laser which has a beam divergence of 1 milliradian. Suggest an appropriate wavelength for the laser to operate, so that a communications channel, of moderately high data rate, may be established to a submarine just beneath the ocean's surface.

[2 marks]

For this value of wavelength, calculate a maximum data rate to the submarine, such that the signal to noise ratio is better than 20 dB, given the submarine has a receiving aperture of 1 metre diameter, coupled to an ideal photon detector.

[13 marks]

4) Describe the nature of blackbody radiation and state Wien's law.

[5 marks]

Explain what is meant by the terms 'background limited detection' and 'noise equivalent temperature change' (ΔT.).

[5 marks]

Show that the Noise Equivalent Power (P) for a background limited detector system is given by

$$P = \sqrt{\frac{(2h\nu)(P_s + P_B)B}{\eta}}$$

where the symbols have their usual meanings.

[5 marks]

A thermal imaging system with angular field of view of 1 milliradian and entrance aperture size 100 cm^2, is to image an object which generates temperature fluctuations in a background radiation field received from a scene which has a blackbody temperature of 300 K. A cooled filter is incorporated in to the imaging system with peak transmittance at 10 μm at a 10% bandwidth. Calculate a value for ΔT. for the imaging system if the bandwidth required is that of a 1 MHz television channel.

[15 marks]

5) A thermal detector element with total thermal energy E at a temperature T, has a heat capacity $C = \frac{dE}{dT}$. Using the Boltzmann relationship for the probability of the detector element to have an energy E_i, show that the mean squared fluctuations in temperature are given by

$$\overline{\Delta T^2} = \frac{kT^2}{C}.$$

[10 marks]

Hint: The differential of a sum of terms is the sum of the differential of the terms e.g.

$$\left\{ \frac{dE}{dT} = \frac{1}{kT^2}\left[\frac{\sum_i E_i^2 \exp -(E_i/kT)}{\sum_i \exp -(E_i/kT)} - \left(\frac{\sum_i E_i \exp -(E_i/kT)}{\sum_i \exp -(E_i/kT)} \right)^2 \right] \right\}.$$

The detector has a thermal conductance $G = \frac{dP}{dT}$, where P is the incident thermal power, and its frequency response may be described by

$$\overline{\Delta T^2}(\omega) = \frac{A}{1 + \omega^2 \tau^2}$$

where $\tau = C/G$ is the time constant of the device and A is a constant. Show that in a low frequency regime, limited to a bandwidth B, the mean squared temperature fluctuations may also be described by

$$\overline{\Delta T^2} = \frac{4kT^2}{G} B.$$

[10 marks]

Hence show that the noise equivalent power (P) of such an idealised thermal detector of unit area is given by

$$P = 4\sqrt{\sigma k T^5 B}$$

[6 marks]

Calculate the specific detectivity of the detector (D^*) when it is at a temperature of $300K$.

[4 marks]