ENGINEERING TRIPOS PART IIA

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Thursday 12 May 2005 9 to 10.30

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Module 3F4

DATA TRANSMISSION

*Answer not more than* ***three*** *questions.*

*All questions carry the same number of marks.*

*The* ***approximate*** *percentage of marks allocated to each part of a question is indicated in the right margin.*

*There are no attachments.*

**You may not start to read the questions printed on the subsequent pages of this question paper until instructed that you may do so by the Invigilator.**

(TURN OVER

1 (a) Give reasons for the use of line coding in a baseband digital communication system. [25%]

(b) A pulse amplitude modulated (PAM) communication system transmits data in the form of a weighted impulse train

$$x(t) = \sum_{n=-\infty}^{\infty} a_n \delta(t - nT_s) \ ,$$

where $a_n$ are the line-coded symbols and $T_s$ is the symbol period. A polar line coding scheme with levels of $+1$ V and $-1$ V is used to generate the binary symbols $a_n$. The probability of the binary data source generating a zero (i.e., $a_n = -1$ V ) is $0.4$ but the bits are otherwise random. Determine an expression for and sketch the power spectrum of $x(t)$. [50%]

(c) Prior to transmission the weighted impulses are passed through a filter with the impulse response given in Fig. 1.

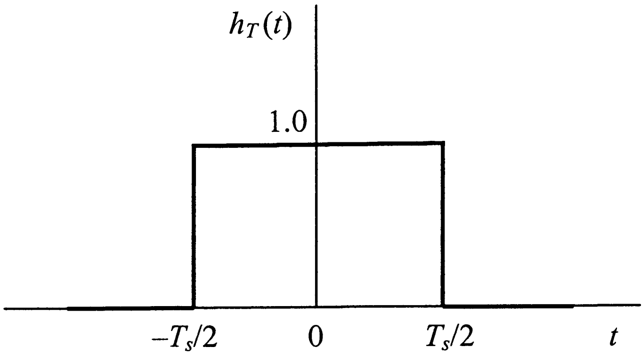

Fig. 1

Determine the power spectrum of the transmitted signal and sketch the result. [25%]

2 (a) Explain the purpose of an equaliser in a baseband digital communication system. Describe the function of a zero-forcing (ZF) equaliser, stating its principle of operation and the problem, which arises owing to its design criteria. How does the minimum mean squared error (MMSE) equaliser overcome this problem? [30%]

(b) The $z$ transform of a single received pulse is given by

$$p(z) = 0.8 - 0.6\,z^{-1} + 0.1\,z^{-2} \ .$$

Design an Infinite Impulse Response (IIR) equaliser for this pulse using the zero-forcing criterion. Draw an appropriate block diagram including the coefficient values. Why in practice are Finite Impulse Response (FIR) designs preferred over IIR designs? [30%]

(c) Redesign the IIR equaliser in (b) as a 3-tap FIR design.

For a binary unipolar transmission scheme having the pulse response in (b), determine the Bit Error Rate (BER) with and without the 3-tap FIR equaliser if the channel noise is white, Gaussian, with a standard deviation of 0.05 V and a mean of 0 V . [40%]

Note the Gaussian error integral function:

$$Q(x) \approx \frac{e^{-x^2/2}}{1.64x + \sqrt{0.76x^2 + 4}}$$

3 (a) Figure 2 shows the block diagram of an optimum demodulator for binary phase-shift keyed (BPSK) signals. Briefly explain the functions of each part of the system and the meanings of the symbols, and relate the system to the equation for the signal at the detector for bit $k$ in an optimum demodulator:

$$y(k) = G \int_{kT_b}^{(k+1)T_b} Re[r(t)\, g(t - kT_b)\, e^{-j\phi_0}]\, dt \ .$$

[25%]

(b) Figure 3 shows the block diagram of a *Quadrature Demodulator* for converting a real modulated signal into real and imaginary components, $i(t)$ and $q(t)$, of the modulating phasor $r(t)$, where $\omega_C$ is the carrier frequency. If $r(t) = [u(t) + jv(t)]\, e^{j\phi_0}$, derive expressions for $i(t)$ and $q(t)$ in terms of $u(t)$ and $v(t)$, when the two oscillator inputs to the quadrature demodulator have a phase offset $\phi_1$, as shown in Fig. 3. [25%]

(c) In a practical BPSK receiver, a quadrature demodulator is used at the input of Fig. 2. Briefly explain how it can incorporate the processes in the first two blocks of Fig. 2, assuming $g(t - kT_b)$ is constant during the $k$th bit period, and why it is usually desirable that the phase offset of the oscillator $\phi_1$ correctly matches the phase offset $\phi_0$ of the incoming signal $s(t)$. [25%]

(d) Describe, with the aid of a sketch, how a *Phase-Locked Loop* can be employed to control a voltage controlled oscillator so that it generates $2\cos(\omega_C t + \phi_1)$ and $-2\sin(\omega_C t + \phi_1)$, such that $\phi_1 = \phi_0$. [25%]

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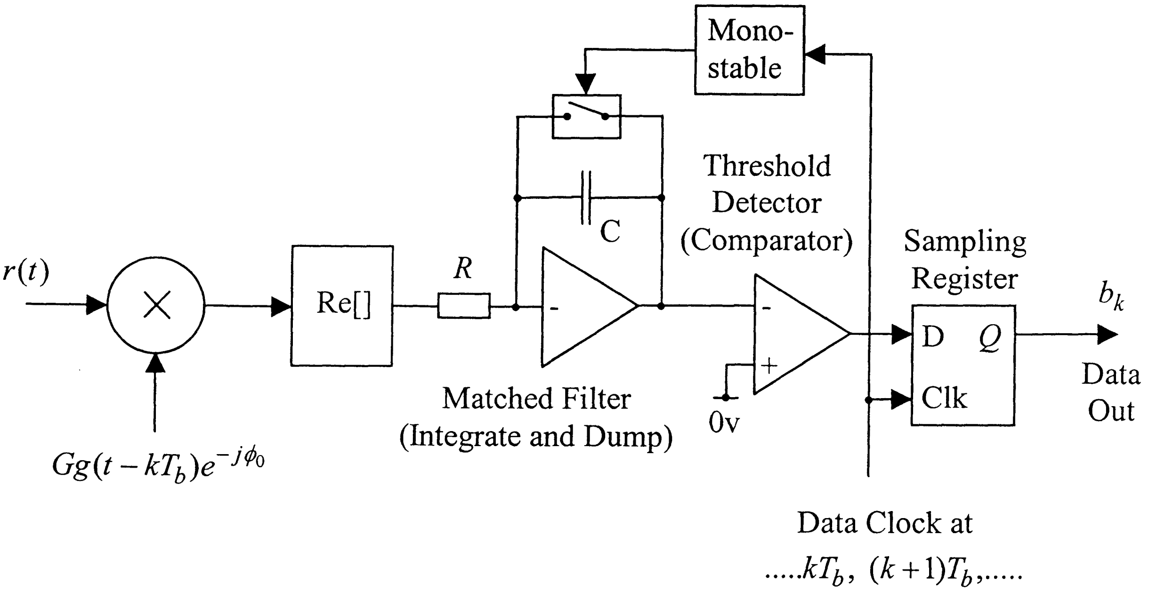

Fig. 2

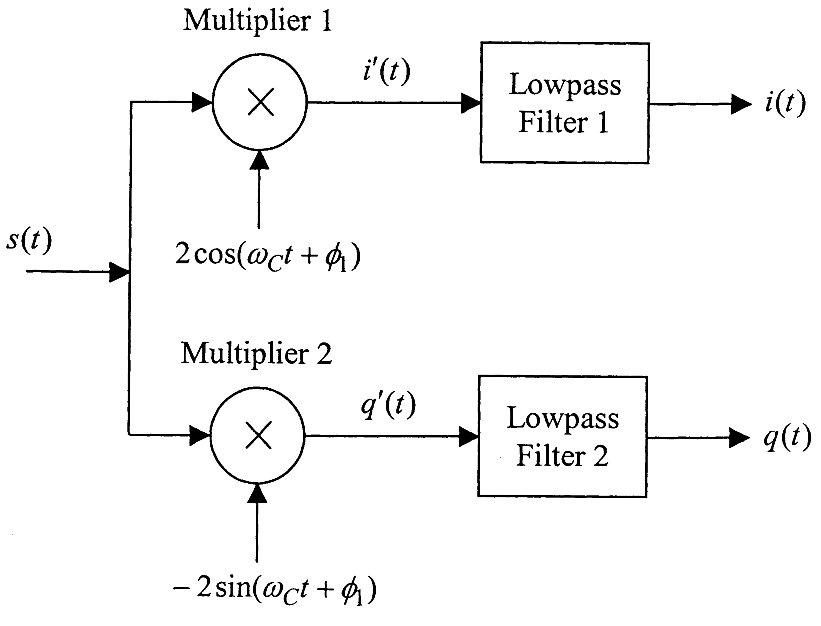

Fig. 3

(TURN OVER

4 (a) Give the main reasons why digital transmission is preferred over analogue transmission for modern systems.

Digital systems tend to require more bandwidth than their analogue counterparts. Explain how this problem can be overcome in practice. [25%]

(b) Describe a bandwidth-efficient modulation scheme in terms of its modulation states and explain why it is bandwidth efficient. [25%]

(c) Many transmission channels experience multi-path propagation conditions, in which several versions of the transmitted signal arrive at the receiver with different path delays. If the differences between the path delays are larger than the symbol period then severe inter-symbol interference can occur. Describe the method used in digital audio and digital video broadcasts to minimize the effects of such interference. [25%]

(d) Give an example of how a digital video broadcast (DVB) system with an encoded rate of 40 Mbit/s could be designed to tolerate multi-path delay differences of up to 10 μs and estimate the bandwidth of the modulated signal, stating clearly your assumptions. [25%]

**END OF PAPER**

# Engineering Triops Part 2A
# Module 3F4. Data Transmission, May 2005 - Answers

1. Generally well answered. Some candidates confused line coding with forward error correction (FEC) coding in part (a). A number of candidates made errors when calculating the power spectrum in part (b).

a) See notes.
b)

$$S_x(\omega) = \frac{0.08\pi}{T_s^2} \sum_{m=-\infty}^{\infty} \delta\left(\omega - m\frac{2\pi}{T_s}\right) + \frac{0.96}{T_s}$$

c)

$$S_y(\omega) = 0.08\pi\delta(\omega) + 0.96T_s\left|\text{sinc}\left(\frac{\omega T_s}{2}\right)\right|^2$$

2. This question was in general answered very well. In part (c) some errors were made when calculating the min eye opening and neglecting to take into account noise power enhancement with the equaliser in place.

a) See notes.
b)

$$H_E(z) = 1.25 \times \frac{1}{1 - z^{-1}a_1 - z^{-2}a_2}$$

where $a_1 = 0.75$ and $a_2 = -0.125$

c)

$$H_E(z) = b_0 + b_1 z^{-1} + b_2 z^{-2}$$

where $b_0 = 1.25$, $b_1 = 0.9375$ and $b_2 = 0.5469$

BER without equalisation = Q(1) = 0.1587

BER with equalisation = Q(4.294) = $8.78 \times 10^{-6}$

3. This question was answered very poorly. Part (a) was generally answered quite well. Given the bookwork nature of part (b) the number of errors was surprising. Relatively few candidates appreciated what was required in part (c).

a) See notes.
b)

$$i(t) = u(t)\cos(\phi_0 - \phi_1) - v(t)\sin(\phi_0 - \phi_1)$$
$$q(t) = u(t)\sin(\phi_0 - \phi_1) + v(t)\cos(\phi_0 - \phi_1)$$

c) See notes.
d) See notes.

4. This question was answered reasonably well. Most difficulties were experienced with part (d) where the assumptions made and the design rational was generally not explained very clearly.

a) See notes.
b) Use $M^2$-QAM. See notes.
c) Use OFDM. See notes.
d) For a guard band of 10μs, an FFT analysis period of 100μs and for 64-QAM. Will need approx 800 tones (allowing for additional tones for phase and amplitude references). Gives a total bandwidth of $800 \times 10\text{kHz} = 8 \times 10^6\,\text{Hz} = 8\,\text{MHz}$