EGT3
ENGINEERING TRIPOS PART IIA

Monday 5 May 2014   14:00 to 15:30

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.*

*Write your candidate number **not** your name on the cover sheet.*

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM
CUED approved calculator allowed
Engineering Data Book

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

1 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) Show that the power spectral density (PSD) of the signal $x(t)$ is

$$S_x(\omega) = \frac{1}{T_s} \sum_{m=-\infty}^{\infty} R(m) \, e^{jm\omega T_s}$$

where $R(m) = E[a_n \, a_{n+m}]$ and $E[.]$ is the expectation operator over n. [30%]

(b) A polar line coding scheme, with nominal signal levels of -1V and 1V, is used to generate the symbols a_n. However, owing to a fault, the symbols are transmitted with a dc shift of -0.2V with respect to the nominal levels. The probability of the binary source generating a symbol a_n, which is negative, is 0.4 but the bits are otherwise random. Determine an expression for the PSD of x and sketch it. [30%]

(c) Prior to transmission, this line coded signal $x(t)$ is passed through a filter with the following impulse response:

$$h(t) = \begin{cases} \cos \frac{\pi t}{T_s} & \text{for } \; -T_s/2 < t < T_s/2 \\ 0 & \text{elsewhere.} \end{cases}$$

Determine the PSD of the transmitted signal and sketch the result. What advantage does this pulse shape offer, compared with a rectangular pulse shape of the same duration? [40%]

2 (a) Explain with the aid of sketches the meaning of the term *intersymbol interference* (ISI). [20%]

(b) The received pulse spectrum for a particular baseband communication system is given by

$$P_r(\omega) = \begin{cases} e^{-j2\omega T}\left[1+\cos\frac{\omega}{2B}\right] & \text{if } |\omega| < 2\pi B \\ 0 & \text{otherwise} \end{cases}$$

where T is the interval between successive symbols, and $B = \frac{1}{2T}$.

(i) State Nyquist's pulse shaping criterion, and hence determine whether pulses with spectrum $P_r(\omega)$ will give rise to ISI. [20%]

(ii) Show that the corresponding time-domain pulse shape for $P_r(\omega)$ is

$$p_r(t) = \frac{2B}{1-4B^2(t-2T)^2}\ \mathrm{sinc}\,(2\pi B(t-2T))$$

where $\mathrm{sinc}(x) = \sin(x)/x$. [30%]

(iii) The received waveform is given by

$$r(t) = \sum_{k=-\infty}^{\infty} a_k\, p_r(t-kT)$$

where a_k are the data symbols. If $r(t)$ is sampled at times, $t = mT$, obtain a simplified expression for the sampled received signal. [30%]

3 (a) Explain how phasors may be used to model digital modulation schemes in which both the amplitude and phase of the transmitted signal waveform $s(t)$ are modulated by the stream of data bits b_k. [15%]

(b) Sketch constellations of phasors which represent the following types of digital modulation:

(i) Binary phase-shift keying (BPSK);

(ii) Quadrature phase-shift keying (QPSK);

(iii) 16-level phase-shift keying (16-PSK);

(iv) 16-level quadrature amplitude modulation (16-QAM). [25%]

(c) Discuss the relative merits of each of these four schemes, in terms of their bandwidth efficiency, performance in noise, and implementation complexity. [30%]

(d) In a practical wireless data transmission system, it is likely to be difficult to measure phase in an absolute way at the receiver. Why is this? What additional techniques can be used with each of the above four modulation schemes in order to overcome the problem of absolute phase uncertainty, and what performance penalty does this typically incur? [30%]

4 (a) Many modern digital communication systems employ *orthogonal frequency division multiplexing* (OFDM), combined with more basic modulation schemes. Explain what OFDM is, and discuss briefly how it can be implemented efficiently? [25%]

(b) Explain what major difficulty with high-speed digital transmission OFDM is designed to overcome, how it achieves this, and why it is virtually essential to use error correction coding with OFDM (giving *Coded OFDM*)? [25%]

(c) In a coded OFDM system, a number of digital television signals are transmitted together over a single radio carrier. The TV signals comprise three high-definition channels of 6 Mbit s^{-1} each and four standard definition channels at 2 Mbit s^{-1} each. A rate 2:3 error correction code is applied to the composite bit stream before transmission and the coded bits are modulated using 64-level quadrature amplitude modulation (64-QAM). It is necessary for the system to tolerate delays from transmission paths which differ by up to 3 km in length. Assuming the OFDM subcarriers are spaced 4 kHz apart and that 10% of them are used as pilot tones that do not carry TV data, estimate the number of subcarriers needed by this OFDM system and the radio frequency bandwidth occupied by this composite signal. [50%]

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Answers:

1. (b) $S_x(\omega) = 0.96/T_s$;
   (c) $S_y(\omega) = 0.24 T_s \left|\text{sinc}\left(\frac{\omega T_s - \pi}{2}\right) + \text{sinc}\left(\frac{\omega T_s + \pi}{2}\right)\right|^2$

2. (b) (i) ISI: yes.
   (ii) $r(mT) = \frac{1}{2T}[a_{m-3} + 2a_{m-2} + a_{m-1}]$

3. –

4. (c) 1878 carriers; 7.516 MHz plus a gap for realisable filters $\approx$ 8 MHz.