THE UNIVERSITY OF ADELAIDE
AUSTRALIA

# EXAMINATION FOR THE DEGREE OF B.E.

## Semester 1 June 2007

## 101902 COMMUNICATIONS IV (ELEC ENG 4035)

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| Official Reading Time: | 10 mins |
| Writing Time: | 120 mins |
| Total Duration: | 130 mins |

**Instructions:**

- This is a closed book examination.
- Attempt **ALL FOUR** questions.
- All questions carry equal marks; part marks are given in brackets where appropriate.
- **Explanations are expected where requested, and marks will be given for these.**
- Begin each answer on a new page.
- Examination materials must not be removed from the examination room.
- **ANSWERS TO QUESTIONS SHOULD BE EXPRESSED CLEARLY AND WRITTEN LEGIBLY. THESE ASPECTS OF PRESENTATION WILL BE TAKEN INTO ACCOUNT IN ASSESSMENT.**

**Materials:**

- One Blue Book
- The use of calculators is permitted, this equipment to be supplied by the candidate. No pre-recorded material nor calculator instruction book is permitted, and equipment with remote communication links will be barred from the examination room.

**Attachments:**

- Fourier Transform Sheet
- Table of the Q Function
- Communications IV Data Sheet

**DO NOT COMMENCE WRITING UNTIL INSTRUCTED TO DO SO**

**Total number of pages (including attachments) = 11**

*Question 1 begins on page 2*

**Question 1** **20 marks total**

**1a)** A message signal $m_1(t) = 20\text{sinc}^2(200t)$ is to be communicated via analog modulation onto a carrier with amplitude $A = 100$ and carrier frequency $f_c = 100$ kHz.

(i) Calculate the spectrum (Fourier transform) $M_1(f)$ of $m_1(t)$ and sketch it, showing clearly the magnitudes of the various components, and the frequency scales. **(4 marks)**

(ii) Suppose that the modulation is to be amplitude modulation with transmitted carrier (AM), i.e. the modulated signal is $v_1(t) = A(1 + am_1(t))\cos(2\pi f_c t)$, where the modulation index is $a = 1$.

Calculate the spectrum (Fourier transform) $V_1(f)$ of $v_1(t)$ and sketch it, showing clearly the magnitudes of the various components, and the frequency scales. **(4 marks)**

(iii) Suppose that the modulation is to be double sideband suppressed carrier (DSBSC), i.e. the modulated signal is $v_2(t) = Am_1(t)\cos(2\pi f_c t)$.

Describe the differences between the spectrum of $v_2(t)$ and the spectrum of $v_1(t)$ you calculated in part (ii). You are not required to sketch the spectrum of $v_2(t)$ or calculate a mathematical expression for $V_2(f)$. **(2 marks)**

**1b)** A message signal $m_2(t) = 10\text{sinc}(1000t)$ is to be communicated via single sideband suppressed carrier (SSBSC) analogue modulation onto a carrier with amplitude $A = 100$ and carrier frequency $f_c = 100$ kHz, i.e. the modulated signal is

$$v_3(t) = 100\left\{m_2(t)\cos(2\pi f_c t) - \hat{m}_2(t)\sin(2\pi f_c t)\right\}.$$

(i) Calculate an expression for the spectrum (Fourier transform) of the Hilbert transform of $m_2(t)$, i.e. find $\hat{M}_2(f)$. You are not required to sketch the spectrum of $\hat{M}_2(f)$. **(2 marks)**

(ii) Using your expression for $\hat{M}_2(f)$ from part (i), and the inverse Fourier transform, calculate an expression for the Hilbert transform of $m_2(t)$, i.e. find $\hat{m}_2(t)$.

**(2 marks)**

**1c)** A noise signal $n(t)$ is a stationary white random process with power spectral density $S_{nn}(f) = \alpha$. This signal is applied at the input of a low-pass filter to produce an output signal $y(t)$. The filter has impulse response

$$h(t) = e^{-\beta t}u(t), \quad \beta > 0.$$

(i) Calculate the transfer function $H(f)$ of the filter and hence calculate an expression for the power spectral density $S_{yy}(f)$ of the output of the filter in terms of $\alpha, \beta$ and $f$.

**(3 marks)**

(ii) If the power spectral density is $S_{nn}(f) = \alpha = 3 \times 10^{-3}$ V$^2$/Hz, $\beta = 2$, and the mean square value of $y(t)$ is $\langle y_o^2(t)\rangle = 1.5$ V, find the noise bandwidth $B_n$ of the filter.

**(3 marks)**

*Question 2 follows on page 3*

**Question 2** **20 marks total**

**2a)** Different analogue modulation schemes can be compared in terms of a number of properties, such as:

- transmission bandwidth;
- total transmit power;
- output signal-to-noise ratio ($\mathrm{SNR_O}$);
- the type of signal to be transmitted;
- receiver complexity.

For each of the following three analogue amplitude modulation techniques, state <u>with brief reasoning</u>, which of the above five properties you consider to be the main **advantage**, <u>relative</u> to the other two techniques, and which is the main **disadvantage** <u>relative</u> to the other two techniques.

(i) Amplitude modulation (AM).

(ii) Double sideband suppressed carrier (DSBSC) modulation.

(iii) Single sideband suppressed carrier (SSBSC) modulation. **(6 marks)**

**2b)** In a broadcast communication system the transmitted power of the <u>carrier</u> is 85 kW, the channel attenuation is 70 dB, the noise power spectral density is $S_{nn}(f) = N_o/2$ with $N_o = 2 \times 10^{-10}$ W/Hz and the normalised baseband message signal $m(t)$ has a bandwidth of 12 kHz, $|m(t)| \leq 1$ and a mean square value $\langle m^2(t) \rangle = 0.2$.

(i) If the modulation used is amplitude modulation (AM) with a modulation index $a = 0.95$, calculate the following for a receiver with bandwidth equal to that of the signal:

- the bandwidth of the signal;
- the predetection signal-to-noise ratio ($\mathrm{SNR_P}$) in decibels;
- the output signal-to-noise ratio ($\mathrm{SNR_O}$) in decibels. **(5 marks)**

(ii) Briefly discuss the difference in the values you calculated for $\mathrm{SNR_P}$ and $\mathrm{SNR_O}$ for the AM system in (ii), and why one is larger than the other. **(2 marks)**

(iii) If the modulation used is frequency modulation (FM) with peak frequency deviation 80 kHz, calculate the following for a receiver with a bandwidth given by Carson's rule:

- the (approximate) bandwidth of the signal;
- the predetection signal-to-noise ratio ($\mathrm{SNR_P}$) in decibels;
- the output signal-to-noise ratio ($\mathrm{SNR_O}$) in decibels. **(5 marks)**

(iv) What is the maximum channel attenuation (in decibels) allowed if the FM system in (iii) is to be above threshold? **(2 marks)**

*Question 3 follows on page 4*

**Question 3** **20 marks total**

**3a)**

(i) State three facts that any given two-dimensional signal constellation diagram indicates about a digital modulation scheme. **(3 marks)**

(ii) A 16QAM digital modulation system consists of $M = 16$ symbols. If the system can transmit 19200 bits per second, determine the minimum bandwidth required for transmission. **(2 marks)**

(iii) A BPSK (Binary Phase Shift Keyed) system is used to transmit data at a rate of 9600 bits per second. For an average received power $P = 6.00 \times 10^{-7}$ W and additive white Gaussian noise, with power spectral density with $N_o = 1.5625 \times 10^{-11}$ W/Hz, determine the probability of error for a matched filter receiver. **(3 marks)**

**3b)**

(i) Briefly state and describe two factors that are important when choosing the shape of a pulse for the transmission of digital data in a bandlimited communications system.

**(2 marks)**

(ii) An 'eye diagram' can provide an indication of the Inter-Symbol Interference (ISI) properties of a pulse shape. Briefly describe what the width of the 'eye' in an eye diagram indicates, and what the height of the 'eye' in an eye diagram indicates. **(2 marks)**

**3c)** A voice band telephone channel passes frequencies in the range $300$ Hz to $3300$ Hz. It is desired to design a modem using Nyquist pulses and which is capable of transmitting digital data at a symbol rate of 2400 symbols per second and a data rate of 4800 bits per second.

(i) Select an appropriate QAM (Quadrature Amplitude Modulation) signal constellation, a suitable sub-carrier frequency (i.e. in the range 300-3300 Hz) and an appropriate roll-off factor $\rho$ for Nyquist pulses, assuming the whole frequency band is utilised. **(5 marks)**

(ii) Sketch the spectrum of the transmitted signal, showing clearly the carrier frequency and the frequencies where the Nyquist roll-off begins and ends. **(3 marks)**

*Question 4 follows on page 5*

**Question 4** **20 marks total**

**4a)** A source $X$ has five symbols, with an alphabet $\{A, B, C, D, E\}$ with corresponding probabilities $\{0.2, 0.15, 0.05, 0.1, 0.5\}$.

(i) Calculate the source entropy $H(x)$ and explain what this means. **(2 marks)**

(ii) Calculate the entropy of a uniformly distributed source that also has five symbols, and comment on how this compares with the entropy you calculated for the source in part (i).

**(2 marks)**

(iii) Design a binary Huffman code for this source and calculate its average code length and its efficiency. **(4 marks)**

(iv) Explain why it is possible to uniquely decipher a Huffman code. **(2 marks)**

**4b)** Suppose that data transmitted in a digital communications system utilising BPSK modulation is corrupted by additive white Gaussian noise (this is the combined noise from the the channel and the receiver). The transmitted data utilises a (15,11) Hamming block code to achieve error correction, and to hence reduce the probability of bit errors after decoding at the receiver.

(i) Explain the difference between the terms 'channel bit rate' and 'message bit rate,' and why one may be larger than the other. **(1 mark)**

(ii) If the bandwidth available for communication is 1 MHz, what is the maximum channel bit rate, the message bit rate, and the code rate for this system? **(2 mark)**

(iii) How many errors can the Hamming code correct in each block of 15? **(1 mark)**

(iv) Suppose the communications channel is such that $\frac{2E_b}{N_o} = 12.5$ dB, where $E_b$ is the energy per transmitted message bit and $N_o/2$ is the power spectral density of additive white Gaussian noise. Calculate the probability that any given bit in a block is in error, $P_b$, and also the probability that $0$ errors occur in the block, and that $1$ error occurs in the block.

**(4 marks)**

(v) Using your value for $P_b$ from part (iv), calculate the bit error probability after error correction. **(2 marks)**

END OF QUESTIONS

DATA SHEETS FOLLOW ON PAGES 6 - 11

# Tables etc

# Tables etc

# Tables etc

# Tables etc

# Tables etc

# Tables etc

END OF EXAMINATION PAPER