1. (a) State the Nyquist sampling theorem. Explain what is meant by the *Nyquist rate* and *spectral folding*. Outline any practical considerations that arise when employing the sampling theorem.

[8 marks]

(b) An analogue speech signal is bandlimited to 7 kHz and sampled at 1.5 times the Nyquist rate and quantised to 1024 levels. What is the bit rate of the digital signal required to represent this analogue signal?

[8 marks]

(c) Explain what is meant by *companding* in the context of digitally encoding human speech. Comment on where the A-law and the μ–law for *companding* may be used.

[8 marks]

(d) Derive an expression for the signal-to-noise ratio (SNR) of a decoded pulse code modulation (PCM) signal in the presence of noise. State all assumptions used in its derivation. You may assume the following expressions for the average signal and average quantisation noise powers respectively:

$$\overline{S} = \frac{M^2 - 1}{12} q^2$$

$$\overline{N}_q = \frac{q^2}{12}$$

where q is the quantisation interval and M is the number of quantisation levels.

You may also assume the following series:

$$\sum_{n=1}^{M} n = \frac{M(M+1)}{2}$$

[9 1/3 marks]

2. (a) Explain what is meant by *multiplexing*. Describe each of the following techniques: *frequency division multiplexing (FDM), time division multiplexing (TDM),* and *code division multiplexing (CDM)*. In each case indicate where the technique might be used.

[9 marks]

(b) Compare the performance of frequency division multiple access (FDMA) and time division multiple access (TDMA) in terms of throughput and average delay. State all assumptions made in carrying out the comparison.

[9 1/3 marks]

(c) Using appropriate diagrams describe the structure of a frame and multiframe in the 30 channel PCM TDM signal. Include in your answer how synchronisation and signalling information is carried in the signal.

[9 marks]

(d) Explain what is meant by *plesiochronous operation* and *plesiochronous digital hierarchy*.

[6 marks]

3.(a) Outline some of the desirable properties that a line code for digital baseband signalling should exhibit.

[5 marks]

(b) Describe the following line codes:

(i) Polar return-to-zero (RZ)
(ii) Manchester
(iii) Alternate Mark Inversion (AMI)

In each case, sketch the line code for the input binary data sequence 11001011 and outline its advantages and disadvantages.

[12 marks]

(c) Describe how a timing clock signal may be extracted from the AMI line code.

[8 1/3 marks]

(d) Describe the HDB3 line code and briefly outline its advantages.

[8 marks]

4.(a) Explain what is meant by *attenuation* and *dispersion* in the context of digital baseband signal transmission.

[8 marks]

(b) Explain what is meant by an *amplifying repeater* and a *regenerative repeater*.

[8 marks]

(c) Compare the performance of an amplifying repeater and a regenerative repeater by deriving an expression for the average probability of error after m hops for each case. You may assume binary polar signaling in the presence of AWGN where the average probability of error P_e is given by

$$P_e = Q\left(\sqrt{\frac{2E_s}{N_0}}\right)$$

where $Q(.)$ is the complementary error function, E_s is the average symbol energy and $N_0/2$ is the average noise power spectral density.

[8 marks]

(d) Explain how intersymbol interference (ISI) can arise in the transmission of digital baseband signals over bandlimited channels.

[9 1/3 marks]