Answers to Mid-Semester Examination Part 1

Date: 29/09/2021, Duration: 1 Hour, Max. Marks: 60, Instructors: Prof. Deepak Ghodgaonkar and Prof. Abhishek Jindal

Answer all questions. Use of Scientific Calculator is allowed. Text Editor and Equation Editor are required. There is no need to use Diagrams/Figures in your answers. Limit answers of each question in 15 lines (or 250 words) or less. Closed Books and Closed Notes Examination in Online Proctored Mode.

1. (a) When communications moved from analog to digital, 3 pairs of functional blocks are introduced in the basic digital communication system. What are these 3 pairs of functional blocks? (4 marks)

   Source encoder (0.5 Mark)
   Source decoder (0.5 Mark)
   Channel encoder (1 Mark)
   Channel decoder (1 Mark)
   Modulator (0.5 Mark)
   Demodulator or Detector (0.5 Mark)

   (b) Explain 6 main advantages of digital communications as compared with analog communications. (12 marks)

I. **Robustness to channel noise and interference**. Digital signals can withstand channel noise and distortion much better than analog signal as long as noise (or S/N ratio) is **within certain limits**. (2 marks)

II. **Efficient regeneration of coded signals or binary signal** along the transmission path. Locate **repeater stations at short enough distances** to detect signal pulses before noise accumulate. (2 marks)

III. **More efficient than analog to exchange SNR and bandwidth**. Increase channel bandwidth for improved SNR. (2 marks)

IV. **Easier and more efficient to multiplex several digital signals by using TDM.** (2 marks)

V. **Digital signals can be coded to yield extremely low error rates, high fidelity and for privacy. Secure communication by encryption of data.** (2 marks)

VI. **Digital hardware implementation is flexible** and permit use of VLSI circuits, digital switching and microprocessors. (2 marks)

(c) These advantages of digital communications are achieved at the cost of increased channel bandwidth and increased system complexity. Explain how these two issues are overcome. (4 marks)

Increased channel bandwidth is achieved by use of **satellite communications**, **fiber-optic communications and sophisticated data compression techniques**. (2 marks)

Increased system complexities are overcome by **VLSI technology** and modulations techniques such as **delta modulation**. (2 marks)

2. (a) Message signals are assumed to be band-limited to W Hertz. Explain sampling theorem for strictly band-limited signals. What is the Nyquist sampling rate? (10 marks)

(i) Signals of **finite energy** are completely described by samples separated by $\left(\frac{1}{2\,W}\right)$ seconds. (4 marks)

(ii) Signals may be completely recovered by samples taken at the rate of **2W samples per second**. (4 marks)

(iii) Nyquist sampling rate = **2W samples per second**. (2 marks)

(b) Aliasing is produced in the information signals because they are not strictly band-limited. To overcome the effect of sampling, explain 2 corrective measures implemented for sampling of information signals. (6 marks)

(i) Before sampling, use **low-pass anti-aliasing filter**. (3 marks)

(ii) Sample at the rate **slightly higher than Nyquist rate**. (3 marks)

(d) What are types of analog pulse modulation and digital pulse modulation? What is the main difference between analog pulse modulation and digital pulse modulation? (4 marks)

Types of analog pulse modulation = **PAM** (0.5 marks), **PDM** or **PWM** (0.5 marks) and **PPM** ((0.5 marks). Types of digital pulse modulation is **PCM** (0.5 marks).

In analog pulse modulation Information is transmitted at **discrete times in analog form (1 mark)**. In digital pulse modulation, information is transmitted by **sequence of coded pulses or binary pulses**. (1 marks)

3. (a) Why binary codes are used in encoding of quantized samples in PCM? (4 marks)

Signals can **withstand** relatedly **high level of noise** by using binary codes. (2 marks)

Signals are **easy regenerate**. (2 marks)

(b) What are line codes? Name 5 types of line codes. (4 marks)

Line codes are **electrical representation** of **binary data streams**. (1.5 marks)
Unipolar NRZ signaling (0.5 mark)
Polar NRZ signaling (0.5 mark)
Unipolar RZ signaling (0.5 marks)
Bipolar RZ signaling (0.5 marks)
Split-phase signaling or Manchester Coding (0.5 marks)

(c) Describe implementation of these 5 line codes in terms symbol 1 and symbol 0. Also, compare advantages and disadvantages of these line codes in terms of DC level, bit timing recovery and power spectra. (12 marks)

In unipolar signaling, **symbol 1** is represented by transmitting a **pulse of amplitude A** and **symbol 0** is represented by **zero amplitude pulse** or **switching off pulse.** (1 mark)
Advantage - **Simplicity in implementation as on-off signaling.** (0.5 marks)
Disadvantage - **No bit timing recovery and Wastage of power due to DC level** (0.5 marks).

In polar signaling, **symbol 1** is represented by transmitting pulse of amplitude **+A** and **symbol 0** is represented by transmitting pulse of amplitude **-A**. (1 mark)
Advantage – **Relatively easy to generate.** (0.5 marks)
Disadvantage- **Wastage of power due to DC level and No bit timing recovery** for long strings of like symbols (0.5 marks).

In unipolar RZ signaling, **symbol 1** is represented by amplitude A for half-symbol width and **symbol 0** by no pulse. (1 mark)
Advantage – Because of delta functions in power spectrum bit timing recovery is easy at the receiver. (0.5 marks).
Disadvantage - **Wastage of power due to DC level** for long strings of symbol 1. (0.5 marks).

In bipolar RZ signaling, +A and -A half-symbol pulses are alternately used for Symbol A. No pulse for symbol 0. (1 mark)
Advantage – **No DC component. Bit timing can be extracted** easily except for long strings of symbol 0. (1 mark)
Disadvantage – Special technique is required to recover bit timing information for long strings of symbol 0. (1 mark)

In split-phase signaling, **symbol 1** is realized by pulse of half-symbol width of amplitude +A and pulse of half-symbol width of amplitude -A. **Symbol 0** is realized by pulse of half-symbol width of amplitude -A and pulse of half-symbol width of amplitude +A. (1 mark)

Advantage - **No DC component. Bit timing can be extracted**. (1 mark)
Disadvantage - Requires **twice the bandwidth** compared with polar NRZ signaling. (1 mark)

ans 1(a) SNR$_o$ of a uniform quantizer

signal in range $(-m_{max}, m_{max})$ & L → total no. of quantizn levels & R → no. of bits per sample.

$$SNR_o = 3L^2 \frac{\widetilde{m^2(t)}}{m_{max}^2} \text{ or } 3(2^R)^2 \frac{\widetilde{m^2(t)}}{m_{max}^2}$$

$$= 3 \cdot 2^{2R} \frac{\widetilde{m^2(t)}}{m_{max}^2}$$

where $\widetilde{m^2(t)}$ is the power of message signal m(t) or mean square value of m(t)

(i) Derivation of the power/ mean square value of quantization noise

steps in broader sense

a) range of quantization error & its formulation is $\left(-\frac{\Delta V}{2}, \frac{\Delta V}{2}\right)$ where $\Delta V = \frac{2m_{max}}{L}$

3marks

b) assumption that error lies in the range $\left(-\frac{\Delta V}{2}, \frac{\Delta V}{2}\right)$ uniformly

3marks

mean-square quantizing error $\widetilde{q^2(t)}$ is given by

$$\widetilde{q^2(t)} = \frac{1}{\Delta V}\int_{-\Delta V/2}^{\Delta V/2} q^2 dq = \frac{m_{max}^2}{3L^2} \text{ or } \frac{m_{max}^2}{3 \cdot 2^{2R}}$$

3marks

(ii) Received signal $\hat{m}(t) = m(t) + q(t)$ — ①

(iii) with $S_o = \widetilde{m^2(t)}$, $N_q = \frac{m_{max}^2}{3L^2}$

SNRo for model in ① becomes $\frac{S_o}{N_q} = 3L^2 \frac{\widetilde{m^2(t)}}{m_{max}^2}$ or $3 \cdot 2^{2R} \frac{\widetilde{m^2(t)}}{m_{max}^2}$

3marks

In each part above allocate 0/1/2/3 based on answer given ans 1(b) (i) In order to handle -ve inputs in either of the laws, we use absolute value operator '| |' on the input x.

$\boxed{\text{3 marks}}$

(ii) In order for output to take the sign of input, which is must, we use a signum (or sign) function as a multiplier to compander

$\boxed{\text{2.5 marks}}$

(iii) Range of output depends upon normalization.

If not done then $[-y_{max}, y_{max}]$

otherwise if normalized $[-1, 1]$

$\boxed{\text{2.5 marks}}$

If absolute value only considered then

not normalized $[0, y_{max}]$

normalized i.e divided by y_{max} $[0, 1]$

ans 2 (a)

(i) peak signal to quantizing noise ratio $= 3L^2$

$L \to$ no. of " steps.

$$SQNR = 3L^2$$

$$SQNR|_{dB} = 10\log_{10} 3 + 2\times 10\log_{10} L$$

$$= 4.77 + 20\log_{10} 2^n$$

(n:- no. of bits for each level)

$$= 4.77 + 20n\log_{10} 2 = 6n + 4.77$$

or $6.02n + 4.77$

So, $SQNR|_{dB} > 55\,dB \Rightarrow 6.02n + 4.77 > 55$

$$n > \frac{55 - 4.77}{6.02} = 8.34.$$

So $n > 8.34 \Rightarrow n = 9$

2 marks for derivation above.

$$\boxed{\begin{array}{l} \text{word-length} = 9 \quad - 2 \\ \text{no. of steps} = 2^9 = 512 \quad - 2 \end{array}}$$

(ii) Equivalent bit rate

BW = 4.2 MHz, Nyquist Sampling rate $= 2\,BW = 2\times 4.2 = 8.4$ MHz.

$f_s \geq 8.4$ MHz.

$T_s \leq \frac{1}{8.4}\times 10^{-6}\,s. = 0.119\times 10^{-6}\,s.$ or $0.119\,\mu s. \sim 0.12\,\mu s.$

8.4 Mega samples per second, with each sample represented using 9 bits, this implies

$8.4\times 10^6 \times 9$ bits/sec $= \boxed{75.6\text{ Mbps}}$.

If considering rounded f_s i.e 9 MHz (instead of 8.4)

equivalent bit-rate $= \boxed{81\text{ Mbps}}$

1 - marks for explanation (correct one)

1 - mark for final correct answer

(iii) For rectangular pulses, first null BW is

A. Unipolar NRZ
B. Polar NRZ
C. Bipolar RZ

$$B_{PCM} = n f_s = 9 \times 8.4 \times 10^6 \text{ Hz} = 75.6 \text{ MHz}.$$

$$\text{or } 9 \times 9 \times 10^6 \text{ Hz} = 81 \text{ MHz}.$$

(4) marks for correct answer & specifying that the result is for which type of waveform out of A., B. and C.

(3) marks if correct answer but wrong type of waveform, or waveform not mentioned at all.

Note:- answer will be $2 \times B_{PCM}$ above if Unipolar RZ or Manchester NRZ are used. Then also do marking as per scheme above.

Ans 2(b):-

(i) DS:- ↓ 01101010011 — 11 bits

ref bit:- 0

encoded DS:- $\boxed{0 \vdots 010011100010}$ — 12 bits (need to append ref bit before)

DS:- ↓ 01101010011

1

encoded DS:- $\boxed{1 \vdots 10110011101}$ — 12 bits

④ marks for 12 bit correct output, 2 mark for each stream above.

② marks if ref. bit is missing but encoded stream is correct.

i.e ① to be deducted for not adding ref bit

(ii) You can see that encoded streams are complement of each other: logic $1 \oplus b = \bar{b}$

$0 \oplus b = b$

↳ bit, can take value 0 or 1

So, for data stream b_1, b_2, b_3.

↓ $b_1 \; b_2 \; b_3$

0 $\; 0 \oplus b_1, \; 0 \oplus b_1 \oplus b_2, \; 0 \oplus b_1 \oplus b_2 \oplus b_3$.

$\boxed{0 \quad b_1 \quad b_1 \oplus b_2 \quad b_1 \oplus b_2 \oplus b_3}$

↓ $b_1 \; b_2 \; b_3$

1 $\; 1 \oplus b_1, \; 1 \oplus b_1 \oplus b_2, \; 1 \oplus b_1 \oplus b_2 \oplus b_3$.

$\boxed{1 \quad \bar{b_1} \quad \overline{b_1 \oplus b_2} \quad \overline{b_1 \oplus b_2 \oplus b_3}}$

② for confirming seq. are complement.

② for logic

Ans 3 (a) 5 signals each of BW 240 Hz

sampling rate $= 240\times2 + \frac{20}{100}\times240\times2$

$= 240\times2\,[1+0.2] = 240\times2\times1.2$

$= 576$ Hz.

$\boxed{\text{(2) marks for correct answer}}$

Suppose the PCM encoder uses n-bit for encoding i.e. 2^n levels for quantization, then within a time span of $1/576$ seconds, we must put $5n$ bits

So, a frame is $5n$ bits long + 0.5% extra bits for synchronizn.

$= 5n\left(1+\frac{0.5}{100}\right) = n\left(5+\frac{0.5}{20}\right)$

$= n\times5.025$

so, frame length $= 5.025n$ bits

$\boxed{\text{(3) marks for correct answer}}$

~~(2) If 0.5% not considered.~~

→ If someone has assumed a particular value of n such as 8, then put $n=8$ above, find the answer. If correct, full marks.

$5.025n$ bits in $1/576$ seconds.

or $\frac{1}{576}$ s → $5.025n$

1 s → $576\times5.025n$ bits/s.

$= 2894.4\,n$ bits/s. (2.5)

or $2895n$ bits/sec.

minimum BW reqd. to Tx a data stream of R bits/sec is R/2 Hz

our date rate is 2894.4 n bps.

so BW reqd. $= \frac{2894.4n}{2} = 1447.2n$ Hz

or 1447.5n Hz if 2894.4 is ≃ 2895

2.5 marks.

Ans 3b :- Nothing has been said about the predictor -s at Tx & RX i.e, they may be same or different.

If same then,

Start with $n=1$, & assume both the predictors share the same first value i.e $\hat{m}[1]$. Then

$$d[1] = m[1] - \hat{m}[1] \quad -① \qquad \text{At Tx, this happens}$$

$$dq[1] = d[1] + q[1]$$

At RX, input to prediction filter, denoted as $m_R[n]$ can be written for $n=1$ as,

$$m_R[1] = dq[1] + \hat{m}[1] = \hat{m}[1] + d[1] + q[1]$$

5 marks

$$\text{from ①} = m[1] + q[1]$$

so the input to rx predictor for $n=1$ is not $m[1]$ rather $m[1] + q[1]$, which can be denoted as $m_q[1]$. This continues & we observe that both predictors work on different inputs.

case 2 is when predictors are different & can be individually optimized.

in this case, $m_R[n] = \hat{m}_R[n] + dq[n]$

$$= \hat{m}_R[n] + d[n] + q[n]$$

5 marks

$$= \hat{m}_R[n] + m[n] - \hat{m}[n] + q[n]$$

$$m_R[n] = m[n] + \boxed{\hat{m}_R[n] + q[n] - \hat{m}[n]}$$

This shows that for both predictors to work on same output $\hat{m}_R[n] + q[n] = \hat{m}[n]$

otherwise they work on different inputs

Also for this to happen either $q[n]$ needs to be sent to RX, or somehow it is to be used at TX.

Lastly, even if for all n, predictor output is same at TX & RX i.e, $\hat{m}_R[n] = \hat{m}[n]$, then

$$m_R[n] = dq[n] + \hat{m}_R[n] = dq[n] + \hat{m}[n]$$

4 marks

$$= \hat{m}[n] + d[n] + q[n]$$

$$= m[n] + q[n]$$

so, predictor still works on different input.

If the student has done one of the case above, give marks as written there. If all cases are done give full marks i.e, 10. Otherwise for subcases i.e., 1+2 or 2+3, or 1+3 give 10, 9, 9 respectively