Subject Name Solutions

4341102 – Winter 2024

Semester 1 Study Material

Detailed Solutions and Explanations

Question 1(a) [3 marks]

Define Continuous time Signal and Discrete time Signal with Wave form.

Solution

Table 1: Comparison of Signal Types

Signal Type	Definition	Waveform Example
Continuous time Signal	Signal defined for all time instants with continuous values	Smooth, unbroken curve
Discrete time Signal	Signal defined only at specific time instants with samples	Series of distinct points

Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph TD
    subgraph Continuous
        A[Continuous Time Signal] {-{-}{} B["x(t)"]}
        B {-{-}{} C[Defined for all t]}
    end
    subgraph Discrete
        D[Discrete Time Signal] {-{-}{} E["x(n)"]}
        E {-{-}{} F[Defined for integer n]}
    end
{Highlighting}
{Shaded}
```

- **Amplitude continuity**: In continuous signals, amplitude can take any value, while discrete signals have specific amplitude values
- **Mathematical notation**: Continuous signals use x(t), discrete signals use x[n] or x(n)

Mnemonic

"CoSiDi" - **Co**ntinuous **Si**gnals flow like rivers, **Di**screte signals are like stepping stones

Question 1(b) [4 marks]

Explain periodic and aperiodic signal.

Solution

Table 2: Periodic vs. Aperiodic Signals

Property	Periodic Signal	Aperiodic Signal
Definition	Repeats exactly after fixed time interval	Does not repeat or has infinite period

Mathematical Expression	x(t) = x(t + nT) for all t	x(t) $\neq x(t+T) for any T$
Energy/Power	Infinite energy, finite power	Finite energy, zero average power
Examples	Sine waves, square waves	Single pulse, damped sinusoid

Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph TD
    subgraph Periodic
        A["x(t) = x(t+T)"] {-{-}{} B[Repeats exactly]}
        B {-{-}{} C[Fundamental period T]}
    end
    subgraph Aperiodic
        D["x(t)  x(t+T)"] {-{-}{} E[Never repeats exactly]}
        E {-{-}{} F[No fundamental period]}
    end
{Highlighting}
{Shaded}
```

- **Spectral property**: Periodic signals have discrete frequency components, aperiodic have continuous spectrum
- **Fourier analysis**: Periodic signals use Fourier series, aperiodic use Fourier transform

Mnemonic

"PART" - **P**eriodic signals **A**lways **R**epeat in **T**ime

Question 1(c) [7 marks]

Explain block diagram of digital communication system.

Solution

Diagram: Digital Communication System

```
flowchart LR
    A[Source] {-{-} B[Source Encoder]}
    B {-{-} C[Channel Encoder]}
    C {-{-} D[Digital Modulator]}
    D {-{-} E[Channel]}
    E {-{-} F[Digital Demodulator]}
    F {-{-} G[Channel Decoder]}
    G {-{-} H[Source Decoder]}
    H {-{-} I[Destination]}
```

Table 3: Functions of Digital Communication System Blocks

Block	Function	Example
Source	Generates message to be transmitted	Microphone, Keyboard
Source Encoder	Removes redundancy, compresses data	Huffman coding, JPEG
Channel Encoder	Adds controlled redundancy for error detection/correction	Hamming codes, CRC
Digital Modulator	Converts digital data to analog signals	ASK, FSK, PSK
Channel	Medium that carries the signal	Wired, Wireless, Optical fiber
Digital Demodulator	Converts received signal back to digital	ASK, FSK, PSK demodulators
Channel Decoder	Detects/corrects errors using added redundancy	Error correction circuits
Source Decoder	Reconstructs original message	Data decompression

- **Advantage**: Noise immunity, secure transmission, multiplexing capability, integration with digital systems
- **Key processes**: Sampling, quantization, coding, modulation/demodulation

Mnemonic

"SECMCDS" - **S**ource **E**ncodes, **C**hannel codes, **M**odulates, **C**hannel, **D**emodulates, **S**ink receives

Question 1(c) OR [7 marks]

Explain singularity functions.

Solution

Table 4: Common Singularity Functions

Function	Mathematical Definition	Properties	Applications
Unit Step	u(t) = 1 for t $\geq 0, 0 fort < 0$	Discontinuous at t=0	Switch-on signals, Heaviside function
Unit Impulse	(t) $= \infty fort = 0, 0 elsewhere, (t)dt = 1$	Infinitely tall, zero-width	Impulse response, sampling
Unit Ramp	r(t) = t · u(t)	Continuous but not differentiable at t=0	Linear time functions
Unit Parabola	p(t) = (t$^2/2)u(t)$	Second integral of unit impulse	Acceleration to position

Diagram:

```
\^{}
|
|                    Unit Step
|
|
+{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-} t}
|
\^{                    /}
|                  /
|                 / Unit Ramp
|        /
|              /
+{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}/{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-} t}
|            /
\^{}
|            .
|             Unit Impulse
|              { t}
|            {}
```

- **Integration relationship**: Each function is the integral of the previous one
- **Mathematical toolkit**: Used to analyze complex systems by breaking into simpler components

Mnemonic

"SIPR" - **S**tep **I**mpulse **P**arable **R**amp - functions ordered by increasing order of integration

Question 2(a) [3 marks]

A signal carries 10 bit/signal elements. If 100 signal elements sent per second. Find the bit rate.

Solution

Solution:

```
Bit Rate = Number of bits per signal element \times Number of signal elements per second
Bit Rate = 10 bits/signal element \times 100 signal elements/second
Bit Rate = 1000 bits/second = 1 kbps
```

Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[Signal Elements: 100/s] {-{-}{} B[Each Element: 10 bits]}
    B {-{-}{} C[Bit Rate = 1000 bits/s]}
{Highlighting}
{Shaded}
```

- **Bit rate**: Number of bits transmitted per second (bps)
- **Signal element**: Physical manifestation of one or more bits

Mnemonic

"BEE" - **B**it rate equals **E**lements times bits per **E**lement

Question 2(b) [4 marks]

Explain Even and Odd signal.

Solution

Table 5: Even vs. Odd Signals

Property	Even Signal	Odd Signal
Definition	f(-t) = f(t)	f(-t) = -f(t)
Symmetry	Mirror symmetry about y-axis	Origin symmetry (rotational)
Fourier Series	Contains only cosine terms	Contains only sine terms
Examples	Cosine,	t

Diagram:

```
  Even Signal             Odd Signal
     \^{                       \^{}}
     |                       |
     |     .{-.               |      /}
     |    /   {              |     /}
     |{-{-}{-}/{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}       |{-}{-}{-}{-}/{-}{-}{-}{-}{-}{-}{-}{-}{-}}
     |  /       {            |   /      }
     | {                    |  /        }
     |                       | /          {}
```

- **Decomposition**: Any signal can be decomposed as sum of even and odd components
- **Even part**: f_e(t) = [f(t) + f(-t)]/2
- **Odd part**: f_o(t) = [f(t) - f(-t)]/2

Mnemonic

"ESOM" - **E**ven **S**ignals have mirror symmetry, **O**dd signals flip when **M**irrored

Question 2(c) [7 marks]

Explain the block diagram of ASK modulator and de-modulator with waveform.

Solution

ASK Modulator Diagram:

```
flowchart LR
    A[Digital Input] {-{-} B[Product Modulator]}
    C[Carrier Generator fc] {-{-} B}
    B {-{-} D[ASK Output]}
```

ASK Demodulator Diagram:

```
flowchart LR
    A[ASK Input] {-{-} B[Band{-}Pass Filter]}
    B {-{-} C[Envelope Detector]}
    C {-{-} D[Low{-}Pass Filter]}
    D {-{-} E[Comparator]}
    E {-{-} F[Digital Output]}
```

Waveform:

```
Digital Input
   \_    \_\_     \_
  | |  |  |   | |
\_\_|\_|\_\_|  |\_\_\_|\_|\_\_\_

Carrier Signal
 /{/////////}

ASK Output
     /{/    ///}
    /    {  /      }
\_\_\_/      {/        \_\_\_}
```

Table 6: ASK Modulation and Demodulation Process

Process	Function	Mathematical Representation
Modulation	Varies amplitude of carrier	s(t) = A · m(t) · cos(2 f_c · t)
Filtering	Removes noise outside band	Bandpass filter centered at f_c
Detection	Recovers envelope	Using diode and capacitor
Decision	Converts to digital	Threshold comparison

- **Binary ASK**: Carrier present for '1', absent for '0'
- **Bandwidth**: Minimum BW = bit rate, typically twice bit rate used

Mnemonic

"AMPS" - **A**SK **M**odulates carrier **P**ower (amplitude) with digital **S**ignal

Question 2(a) OR [3 marks]

A signal has a bit rate of 4000 bit/second and a baud rate of 1000 baud. How many data elements are carried by each signal element?

Solution

Solution:

```
Number of bits per signal element = Bit rate / Baud rate
Number of bits per signal element = 4000 bits/second / 1000 signal elements/second
Number of bits per signal element = 4 bits/signal element
```

Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[Bit Rate: 4000 bps] {-{-}{} C[Divide]}
    B[Baud Rate: 1000 baud] {-{-}{} C}
    C {-{-}{} D[4 bits/signal element]}
{Highlighting}
{Shaded}
```

- **Bit rate**: Data transmission speed in bits per second
- **Baud rate**: Number of signal elements (symbols) per second

Mnemonic

"BBR" - **B**its per symbol equals **B**it rate divided by **B**aud **R**ate

Question 2(b) OR [4 marks]

Discuss the various communication channels characteristics.

Solution

Table 7: Communication Channel Characteristics

Characteristic	Description	Importance
Bandwidth	Range of frequencies channel can transmit	Determines maximum data rate
Noise	Unwanted signals that corrupt transmission	Affects signal quality and error rate
Attenuation	Loss of signal strength during transmission	Limits transmission distance
Distortion	Change in signal shape/timing	Causes intersymbol interference
Channel capacity	Maximum data rate with arbitrary small error	Given by Shannon's theorem

Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph TD
    A[Channel Characteristics] {-{-}{} B[Bandwidth]}
    A {-{-}{} C[Noise]}
    A {-{-}{} D[Attenuation]}
    A {-{-}{} E[Distortion]}
    A {-{-}{} F[Channel Capacity]}
    C {-{-}{} G[SNR]}
    B {-{-}{} H[Data Rate]}
    F {-{-}{} H}
{Highlighting}
{Shaded}
```

- **SNR (Signal-to-Noise Ratio)**: Ratio of signal power to noise power
- **Channel capacity**: C = B · $\log_2(1 + SNR), where B is bandwidth$

Mnemonic

"BAND-C" - **B**andwidth, **A**ttenuation, **N**oise, **D**istortion define **C**apacity

Question 2(c) OR [7 marks]

Compare ASK, FSK and PSK.

Solution

Table 8: Comparison of Digital Modulation Techniques

Parameter	ASK	FSK	PSK
Principle	Varies amplitude	Varies frequency	Varies phase
Mathematical Expression	s(t) = A · m(t) · cos(2 f_c · t)	s(t) = A · cos(2 [f_c+m(t)Δf]t)	s(t) = A · cos(2 f_c · t+m(t) ·)
Bandwidth	r_b (minimum)	2(Δf+r_b/2)	2r_b
Power Efficiency	Poor	Moderate	Good
Noise Immunity	Poor	Better	Best
Implementation Complexity	Simple	Moderate	Complex
Applications	Low-cost systems	Noise-prone environments	High-performance systems

Diagram:

```
Digital Input:
   \_    \_\_     \_
  | |  |  |   | |
\_\_|\_|\_\_|  |\_\_\_|\_|\_\_\_

ASK:
     /{/    ///}
    /    {  /      }
\_\_\_/      {/        \_\_\_}

FSK:
 /{//      ///}
/      {    /      }
        {//        //}

PSK:
 /{//////////}
/  {  /    /    /  }
    {/    /    /    }
```

- **Bit error rate**: PSK < FSK < ASK (PSK is best)
- **Complexity order**: ASK < FSK < PSK (ASK is simplest)

Mnemonic

"AFP" - **A**mplitude, **F**requency, **P**hase are modified in ASK, FSK, PSK respectively

Question 3(a) [3 marks]

Explain the working of FSK modulator with block diagram and output Waveform.

Solution

FSK Modulator Block Diagram:

```
flowchart LR
    A[Digital Input] {-{-} B[Switch Controller]}
    B {-{-} C[Oscillator 1 {-} f1]}
    B {-{-} D[Oscillator 2 {-} f2]}
    C {-{-} E[Output]}
    D {-{-} E}
```

Waveform:

```
Digital Input:
   \_    \_
  | |  | |
\_\_|\_|\_\_|\_|\_\_\_\_\_

FSK Output:
 /{//    ///}
/      {  /      }
        {/       }
        /{       /}
       /  {     /  }
```

Table 9: FSK Modulation Process

Step	Description
Digital Input	Binary data (0s and 1s)

Frequency Selection	$f_1 for bit '1', f_2 for bit '0'$
Waveform Generation	$s(t) = A \cdot \cos(2 f_1 t) for bit '1', s(t) = A cos(2 f_2 t) for bit '0'$
Output	Continuous phase frequency-shifted signal

- **Binary FSK**: Uses two frequencies $f_1 and f_2 separated by frequency deviation$
- **Advantage**: Better noise immunity than ASK

Mnemonic

"FAST" - **F**requency **A**lternates between **S**eparate **T**ones

Question 3(b) [4 marks]

Draw the PSK modulation waveform for the sequence of 1010110110.

Solution

BPSK Modulation for 1010110110:

```
Digital Input:
   \_    \_   \_\_\_   \_ \_
  | |  | | |   | | | |
\_\_| |\_\_| |\_|   |\_| | |\_\_

Carrier Signal:
 /{/////////}

BPSK Output:
 /{// /// /// /}
      {/      /      /}
      /{/// //// /}
                      {/}
```

Table 10: BPSK Mapping

Bit	Phase	Interpretation
1	0°	In-phase with carrier (positive)
0	180°	Out-of-phase with carrier (negative)

Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[Bit Stream 1010110110] {-{-}{} B[Phase Mapping]}
    B {-{-}{} C[1=0^ Phase]}
    B {-{-}{} D[0=180^ Phase]}
    C {-{-}{} E[Modulated Signal]}
    D {-{-}{} E}
{Highlighting}
{Shaded}
```

- **Phase shift**: $180° transition at each bit change$
- **Constant amplitude**: Unlike ASK, amplitude remains constant

Mnemonic

"POPI" - **Ph**ase **O**pposites for bit **P**airs represent **I**nformation

Question 3(c) [7 marks]

Draw the ASK and FSK modulation waveform for the sequence of 1100110101.

Solution

Input Bit Sequence: 1100110101
ASK Modulation:

```
Digital Input:
   \_\_    \_\_    \_  \_
  |  |  |  |  | || |
\_\_|  |\_\_|  |\_\_| ||\_|\_\_

ASK Output:
 /{///    ////  // /}
         {  /         /     }
         /\_\_\_\_\_\_\_\_\_\_\_\_\_\_      {\_}
```

FSK Modulation:

```
Digital Input:
   \_\_    \_\_    \_  \_
  |  |  |  |  | || |
\_\_|  |\_\_|  |\_\_| ||\_|\_\_

FSK Output (f1=high, f0=low):
 /{///       ////      //    }
        {      /            /      /}
         {    /            /      /  }
          {//            /            }
           Higher freq     Higher freq   Higher freq
           for 1s          for 1s        for 1s

             Lower freq      Lower freq    Lower freq
             for 0s          for 0s        for 0s
```

Table 11: Comparison for the Sequence 1100110101

Bit Position	Bit Value	ASK Representation	FSK Representation
1-2	11	Carrier present	Higher frequency
3-4	00	Carrier absent	Lower frequency
5-7	110	Carrier present/absent	Higher/lower frequency
8-10	101	Carrier present/absent/present	Higher/lower/higher frequency

- **ASK modulation**: Simple on-off keying where carrier is present for '1' and absent for '0'
- **FSK modulation**: Frequency shifts between two distinct values based on bit value

Mnemonic

"AFOP" - **A**SK switches carrier **O**n-**O**ff while **F**SK shifts between **P**airs of frequencies

Question 3(a) OR [3 marks]

Explain the working of MSK modulator with block diagram and output Waveform.

Solution

MSK Modulator Block Diagram:

```
flowchart LR
    A[Digital Input] {-{-} B[Serial to Parallel]}
    B {-{-} C[Even Bits]}
```

```
    B {-{-} D[Odd Bits]}
    C {-{-} E[Cos Modulator]}
    D {-{-} F[Sin Modulator]}
    G[90^ Phase Shifter] {-{-} F}
    H[Carrier Generator] {-{-} E}
    H {-{-} G}
    E {-{-} I[Combiner]}
    F {-{-} I}
    I {-{-} J[MSK Output]}
```

Waveform:

```
Digital Input:
   \_    \_
  | |   | |
\_\_|\_|\_\_|\_|\_\_\_\_\_

MSK Output:
  \_{-\_     \_{-}\_  }
 /   {   /    }
/     {\_/     \_}
       \_{-\_     \_{-}}
      /   {   /  }
     /     {\_/    }
```

Table 12: MSK Modulation Process

Characteristic	Description
Principle	Special case of OQPSK with sinusoidal pulse shaping
Phase Continuity	Ensures smooth phase transitions (no abrupt phase changes)
Frequency Deviation	$\pm 0.25 bit rate from carrier frequency$
Bandwidth Efficiency	Better than conventional FSK

- **Phase continuity**: Key advantage - reduces bandwidth compared to FSK
- **Constant envelope**: Resistant to non-linear amplification

Mnemonic

"MCPS" - **M**SK ensures **C**ontinuous **P**hase **S**hifts

Question 3(b) OR [4 marks]

Draw the constellation diagram of 8-PSK and 16-QAM.

Solution

8-PSK Constellation Diagram:

```
       001 * * 000
           {|/}
    010 *{-{-}{-}+{-}{-}{-}* 111}
           /|{}
       011 * * 101
           100
```

16-QAM Constellation Diagram:

```
    *   *   *   *

    *   *   *   *
```

```
  *   *   *   *

  *   *   *   *
```

Table 13: Comparison of Constellation Diagrams

Parameter	8-PSK	16-QAM
Bits per Symbol	3 bits	4 bits
Symbol Positions	8 points on circle	16 points in grid
Amplitude Levels	1 (constant)	3 (variable)
Phase Angles	8 angles ($45° apart$)	12 angles
Error Sensitivity	Moderate	Higher than 8-PSK
Spectral Efficiency	3 bits/Hz	4 bits/Hz

- **8-PSK**: Points equally spaced around circle with constant amplitude
- **16-QAM**: Points arranged in square grid with different amplitudes and phases

Mnemonic

"CEPA" - **C**onstellation points in PSK have **E**qual amplitudes but different **P**hases, QAM has both **A**mplitude and phase variations

Question 3(c) OR [7 marks]

Draw BPSK and QPSK modulation waveform for 1010101011.

Solution

Input Bit Sequence: 1010101011
BPSK Modulation:

```
Digital Input:
   \_ \_ \_ \_ \_ \_ \_ \_
  | | | | | | | | | |
\_\_| |\_| |\_| |\_| |\_| |\_\_

BPSK Output:
 /{// /// /// /// /}
     {/     /     /     /}
     /{/// //// ////}
```

QPSK Modulation (Grouping bits: 10,10,10,10,11):

```
Grouped Bits:
   10    10    10    10    11

I{-channel (odd bits):}
   \_     \_     \_     \_     \_
  | |   | |   | |   | |   | |
\_\_| |\_\_\_| |\_\_\_| |\_\_\_| |\_\_\_| |\_\_

Q{-channel (even bits):}
    \_     \_     \_     \_
   | |   | |   | |   | |    |
\_\_\_| |\_\_\_| |\_\_\_| |\_\_\_| |\_\_\_\_|

QPSK Output:
 /{  /  /  /  /}
/  {/  /  /  /  }
    Phase    Phase   Different
    00       00      phase for 11
```

Table 14: BPSK vs. QPSK for 1010101011

Characteristic	BPSK	QPSK
Bits per symbol	1	2
Number of symbols	10	5
Symbol rate	Same as bit rate	Half of bit rate
Bandwidth efficiency	1 bit/Hz	2 bits/Hz
Phase states	2 $(0°, 180°)$	4 $(45°, 135°, 225°, 315°)$

- **BPSK**: Each bit causes a potential $180° phaseshift$
- **QPSK**: Processes two bits at once, uses four phase states

Mnemonic

"BQSE" - **B**PSK takes **1** bit while **Q**PSK takes **2** bits, doubling **S**pectral **E**fficiency

Question 4(a) [3 marks]

Encode the data using Shanon Fano code for below probability sequence. P = { 0.30, 0.25, 0.20, 0.12, 0.08, 0.05}

Solution

Table 15: Shannon-Fano Coding Process

Symbol	Probability	Division Steps	Shannon-Fano Code
A	0.30	Top Group	0
B	0.25	Top Group	10
C	0.20	Bottom Group	110
D	0.12	Bottom Group	1110
E	0.08	Bottom Group	1111 0
F	0.05	Bottom Group	1111 1

Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph TD
    A[Symbols] {-{-}{} B[A:0.30, B:0.25, C:0.20, D:0.12, E:0.08, F:0.05]}
    B {-{-}{} C[A:0.30, B:0.25]}
    B {-{-}{} D[C:0.20, D:0.12, E:0.08, F:0.05]}
    C {-{-}{} E[A:0.30]}
    C {-{-}{} F[B:0.25]}
    D {-{-}{} G[C:0.20, D:0.12]}
    D {-{-}{} H[E:0.08, F:0.05]}
    G {-{-}{} I[C:0.20]}
    G {-{-}{} J[D:0.12]}
    H {-{-}{} K[E:0.08]}
    H {-{-}{} L[F:0.05]}
    E {-{-}{} M[Code: 0]}
    F {-{-}{} N[Code: 10]}
    I {-{-}{} O[Code: 110]}
    J {-{-}{} P[Code: 1110]}
    K {-{-}{} Q[Code: 11110]}
    L {-{-}{} R[Code: 11111]}
{Highlighting}
{Shaded}
```

- **Shannon-Fano algorithm**: Recursively divide symbols into two groups with nearly equal probabilities
- **Code efficiency**: Not always optimal but generally good compression

Mnemonic

"SPDF" - **S**plit **P**robabilities and assign **D**igits based on **F**requency

Question 4(b) [4 marks]

Explain Hamming code.

Solution

Table 16: Hamming Code Properties

Property	Description
Type	Linear error-correcting code
Error Detection	Can detect up to 2 bit errors
Error Correction	Can correct single bit errors
Parity Bits (r)	For n data bits: 2^r $\geq n + r + 1$
Code Structure	Systematic: message bits + parity bits
Positions of Parity Bits	Powers of 2: positions 1, 2, 4, 8, 16...

Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[Hamming Code] {-{-}{} B[Parity Bits]}
    A {-{-}{} C[Data Bits]}
    B {-{-}{} D[Position 1]}
    B {-{-}{} E[Position 2]}
    B {-{-}{} F[Position 4]}
    B {-{-}{} G[Position 8]}
    A {-{-}{} H["Example: Hamming(7,4)"]}
    H {-{-}{} I[4 data bits + 3 parity bits]}
{Highlighting}
{Shaded}
```

- **Encoding**: Calculate parity bits to ensure specific bit positions have even/odd parity
- **Decoding**: Calculate syndrome to determine error position

Mnemonic

"PSEC" - **P**arity bits in **P**ower of 2 positions **S**ystematically **E**nable error **C**orrection

Question 4(c) [7 marks]

Compare TDMA and FDMA.

Solution

Table 17: Comparison of TDMA and FDMA

Parameter	TDMA	FDMA
Basic Principle	Divides time into slots	Divides frequency into channels
Resource Allocation	Each user gets full bandwidth for short time	Each user gets narrow bandwidth for entire time
Guard Time/Band	Requires guard time between slots	Requires guard bands between channels
Synchronization	Critical (timing-dependent)	Not required (frequency separation)
Efficiency	Better for bursty data	Better for continuous data
Interference	Less susceptible to interference	More susceptible to adjacent channel interference
Hardware Complexity	Complex (needs buffering, synchronization)	Simpler (fixed filters)
Power Consumption	Lower (transmitter on only during time slot)	Higher (continuous transmission)
Capacity	Easily expanded by adding time slots	Limited by available spectrum
Applications	GSM, DECT cordless phones	Analog cellular, satellite systems

Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph TD
    subgraph TDMA
        A[Time Slots] {-{-}{} A1[User 1]}
        A {-{-}{} A2[User 2]}
        A {-{-}{} A3[User 3]}
        A {-{-}{} A4[Guard Time]}
    end
    subgraph FDMA
        B[Frequency Bands] {-{-}{} B1[User 1]}
        B {-{-}{} B2[User 2]}
        B {-{-}{} B3[User 3]}
        B {-{-}{} B4[Guard Bands]}
    end
{Highlighting}
{Shaded}
```

- **System flexibility**: TDMA can dynamically allocate slots, FDMA is fixed allocation
- **Implementation**: TDMA requires digital technology, FDMA works with analog/digital

Mnemonic

"TIME-FREQ" - **T**DMA splits **I**ntervals of ti**ME**, **F**DMA splits **R**anges of fr**EQ**uency

Question 4(a) OR [3 marks]

Encode the data using Huffman code for below probability sequence. P = { 0.4, 0.19, 0.16, 0.15, 0.1}

Solution

Table 18: Huffman Coding Process

Symbol	Probability	Huffman Code
A	0.40	0
B	0.19	10
C	0.16	110
D	0.15	111
E	0.10	110

Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    Z[Root: 1.0] {-{-}{} A[A: 0.4]}
    Z {-{-}{} Y[0.6]}
    Y {-{-}{} B[B: 0.19]}
    Y {-{-}{} X[0.41]}
    X {-{-}{} C[C: 0.16]}
    X {-{-}{} W[0.25]}
    W {-{-}{} D[D: 0.15]}
    W {-{-}{} E[E: 0.1]}
    A {-{-} 0 {-}{-}{} AA[Code: 0]}
    B {-{-} 1 {-}{-}{} BB[Code: 10]}
    C {-{-} 0 {-}{-}{} CC[Code: 110]}
    D {-{-} 0 {-}{-}{} DD[Code: 1110]}
    E {-{-} 1 {-}{-}{} EE[Code: 1111]}
{Highlighting}
{Shaded}
```

- **Huffman algorithm**: Build a binary tree from bottom up, starting with least probable symbols
- **Optimality**: Produces minimal average code length

Mnemonic

"HUMP" - **H**uffman creates shorter codes for **H**igher **P**robabilities

Question 4(b) OR [4 marks]

Define Channel Capacity in terms of SNR and its importance in communication.

Solution

Shannon's Channel Capacity Formula:

```
C = B \times log_{2}(1 + SNR)
```

Where: -
C = Channel capacity in bits per second -
B = Bandwidth in Hz -
SNR = Signal-to-Noise Ratio

Table 19: Channel Capacity Characteristics

Aspect	Description	Importance
Definition	Maximum error-free data rate possible	Sets fundamental limits
SNR Dependence	Logarithmically increases with SNR	Shows diminishing returns of power
Bandwidth Dependence	Linearly increases with bandwidth	Shows value of spectrum
Theoretical Bound	Can't exceed Shannon limit with any coding	Guides system design

Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[Channel Capacity] {-{-}{} B[Bandwidth B]}
    A {-{-}{} C[Signal{-}to{-}Noise Ratio]}
    B {-{-}{} D["C = B  log_{2}(1 + SNR)"]}
    C {-{-}{} D}
    D {-{-}{} E[Theoretical Maximum]}
    E {-{-}{} F[Error{-}free Communication]}
{Highlighting}
{Shaded}
```

- **Shannon-Hartley theorem**: Establishes theoretical maximum data transfer rate
- **Error probability**: Can be made arbitrarily small if data rate < channel capacity

Mnemonic

"SNRB" - **S**hannon capacity depends on **N**oise ratio and **B**andwidth

Question 4(c) OR [7 marks]

Explain FDMA Technique in detail.

Solution

FDMA (Frequency Division Multiple Access)

Table 20: FDMA System Characteristics

Aspect	Description	Significance
Basic Principle	Divides available spectrum into channels	Enables multiple simultaneous users
Channel Allocation	Fixed frequency bands per user	Simplifies hardware design
Guard Bands	Frequency separation between channels	Prevents adjacent channel interference
Duplexing	Often paired with FDD (separate Tx/Rx bands)	Enables simultaneous two-way communication
Bandwidth Utilization	Each channel has fixed bandwidth	Potentially inefficient for bursty data
Intermodulation	Products of multiple carriers	Requires careful power amplifier design

Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph TD
    A[Available Spectrum] {-{-}{} B[Guard Band]}
    A {-{-}{} C[User 1 Channel]}
    A {-{-}{} D[Guard Band]}
    A {-{-}{} E[User 2 Channel]}
    A {-{-}{} F[Guard Band]}
    A {-{-}{} G[User 3 Channel]}
    A {-{-}{} H[Guard Band]}
    A {-{-}{} I[User 4 Channel]}
{Highlighting}
{Shaded}
```

FDMA Implementation:

```
   \^{}
   |
 F |  +{-{-}{-}{-}{-}+  +{-}{-}{-}{-}{-}+  +{-}{-}{-}{-}{-}+  +{-}{-}{-}{-}{-}+}
 r |  |User1|  |User2|  |User3|  |User4|
 e |  |     |  |     |  |     |  |     |
 q |  |     |  |     |  |     |  |     |
   |  +{-{-}{-}{-}{-}+  +{-}{-}{-}{-}{-}+  +{-}{-}{-}{-}{-}+  +{-}{-}{-}{-}{-}+}
   |
   |   Guard    Guard    Guard
   |   Band     Band     Band
   +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{
                    Time
```

- **Implementation**: Relatively simple using bandpass filters
- **Advantages**: No synchronization required, continuous transmission
- **Disadvantages**: Spectrum inefficiency, limited flexibility

Mnemonic

"FDMA-CIGS" - **F**requency **D**ivision creates **M**ultiple **A**ccess through **C**hannels with **I**ndividual **G**uard band **S**eparation

Question 5(a) [3 marks]

Explain TDMA Access technique.

Solution

TDMA (Time Division Multiple Access)

Table 21: TDMA Key Characteristics

Characteristic	Description
Basic Principle	Divides time into frames and slots
Resource Sharing	Each user assigned specific time slot
Guard Time	Small time separation between slots
Frame Structure	Multiple slots form a complete frame
Synchronization	Timing reference required for all users

Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph TD
    A[TDMA Frame] {-{-}{} B[Slot 1 {-} User 1]}
    A {-{-}{} C[Slot 2 {-} User 2]}
    A {-{-}{} D[Slot 3 {-} User 3]}
    A {-{-}{} E[Slot 4 {-} User 4]}
    A {-{-}{} F[Slot 5 {-} User 5]}
    A {-{-}{} G[Slot 6 {-} User 6]}
{Highlighting}
{Shaded}
```

- **Digital implementation**: Requires ADC/DAC for analog signals
- **Burst transmission**: Users transmit only during assigned slots

Mnemonic

"TIME" - **T**ime slots **I**ndividually **M**anaged for **E**ach user

Question 5(b) [4 marks]

Explain E1 Career system.

Solution

E1 Carrier System

Table 22: E1 Carrier System Specifications

Parameter	Specification	Details
Total Bit Rate	2.048 Mbps	European standard
Number of Channels	32 time slots (0-31)	30 voice + 2 control
Voice Channels	Time slots 1-15, 17-31	Each 64 kbps
Signaling Channel	Time slot 16	For channel signaling
Frame Alignment	Time slot 0	Synchronization
Frame Duration	125 s	8000 frames per second
Sampling Rate	8 kHz	Follows Nyquist theorem

Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph TD
    A[E1 Frame {- 2.048 Mbps] {-}{-}{} B[TS0: Framing]}
    A {-{-}{} C[TS1{-}15: Voice Channels]}
    A {-{-}{} D[TS16: Signaling]}
    A {-{-}{} E[TS17{-}31: Voice Channels]}
    B {-{-}{} F[Frame Alignment Signal]}
    D {-{-}{} G[Channel Associated Signaling]}
{Highlighting}
{Shaded}
```

- **Multiplexing technique**: TDM (Time Division Multiplexing)
- **PCM encoding**: 8-bit samples at 8 kHz sampling rate

Mnemonic

"E132" - **E1** has **32** time slots with **2**.048 Mbps

Question 5(c) [7 marks]

Explain block diagram of Digital telephone exchange, elements of hardware sub systems.

Solution

Digital Telephone Exchange Block Diagram

```
flowchart TD
    A[Digital Telephone Exchange] {-{-} B[DLU: Digital Line Unit]}
    A {-{-} C[LTG: Line/Trunk Group]}
    A {-{-} D[SN: Switching Network]}
    A {-{-} E[CP: Central Processor]}
    B {-{-} F[Interface to Subscribers]}
    C {-{-} G[Interface to Trunks]}
    D {-{-} H[Digital Switching]}
    E {-{-} I[System Control]}
```

Table 23: Hardware Subsystems of Digital Telephone Exchange

Subsystem	Function	Key Components
DLU (Digital Line Unit)	Interface between subscriber lines and exchange	Line cards, CODEC, SLIC, PCM conversion
LTG (Line/Trunk Group)	Handles trunk lines, interfaces with other exchanges	Trunk cards, signaling units, echo cancellers
SN (Switching Network)	Routes calls between ports, provides connectivity	Time/space switches, connection memory, control logic
CP (Central Processor)	Controls overall system operation	Main processor, memory, operating system, databases
Peripherals	Supporting functions	Power supply, alarm systems, maintenance terminals

Hardware Elements Details:

- **DLU**: Converts analog voice to 64 kbps PCM, handles line signaling
- **LTG**: Manages E1/T1 trunks, implements protocols like SS7
- **SN**: Typically time-division switching fabric, non-blocking architecture
- **CP**: Call processing, billing, maintenance, administrative functions

Mnemonic

"DLSC" - **D**LU connects subscribers, **L**TG connects trunks, **S**N switches calls, **C**P controls everything

Question 5(a) OR [3 marks]

Compare TDM and FDM.

Solution

Table 24: Comparison of TDM and FDM

Parameter	TDM	FDM
Domain Division	Time	Frequency
Channel Separation	Guard time	Guard bands
Multiplexing Process	Sequential time slots	Parallel frequency bands
Implementation	Digital (primarily)	Analog or digital

Crosstalk	Generally less	More susceptible
Synchronization	Critical	Not required

Diagram:

```
TDM:
  Time {-{-}}
  +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}+}
  | Channel 1 | Ch 2 | Ch 3 | Ch 1 |...
  +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}+}

FDM:
  \^{}
  |   +{-{-}{-}{-}{-}+}
F |   | Ch3 |
r |   +{-{-}{-}{-}{-}+}
e |   | Ch2 |
q |   +{-{-}{-}{-}{-}+}
  |   | Ch1 |
  |   +{-{-}{-}{-}{-}+}
  +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}}
        Time
```

- **Bandwidth utilization**: TDM more efficient for digital, FDM better for analog
- **System complexity**: TDM requires precise timing, FDM needs precise filters

Mnemonic

"TFDS" - **T**ime and **F**requency **D**ivision **S**ystems divide different domains

Question 5(b) OR [4 marks]

Discuss T1 Multiplexing hierarchy.

Solution

Table 25: T1 Multiplexing Hierarchy

Level	Designation	Data Rate	Number of Voice Channels	Multiplexing
T1	DS1	1.544 Mbps	24	24 DS0 (64 kbps)
T2	DS2	6.312 Mbps	96	4 DS1
T3	DS3	44.736 Mbps	672	7 DS2
T4	DS4	274.176 Mbps	4032	6 DS3

Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[Individual Voice Channels {- DS0 64 kbps] {-}{-}{} B[T1/DS1 {-} 1.544 Mbps]}
    B {-{-}{} C[T2/DS2 {-} 6.312 Mbps]}
    C {-{-}{} D[T3/DS3 {-} 44.736 Mbps]}
    D {-{-}{} E[T4/DS4 {-} 274.176 Mbps]}
{Highlighting}
{Shaded}
```

T1 Frame Structure:

```
T1 Frame (193 bits):
  F  Ch1  Ch2  ...  Ch24  F  Ch1  ...
  |  |    |         |     |
  |  8    8         8     |
  |  bits bits      bits  |
  |                       |
  Framing bit (1 bit)     Next frame
```

- **T1 frame format**: 193 bits (24 channels $\times 8 bits + 1 framingbit$)
- **Frame duration**: 125 s (8000 frames per second)

Mnemonic

"T-QUAD" - **T**1, T2, T3, T4 form a **QUAD**ruple hierarchy of multiplexing levels

Question 5(c) OR [7 marks]

List Features, Characteristics, Advantages and Disadvantages of IoT.

Solution

Table 26: Internet of Things (IoT) Overview

Category	Key Points
Features	Device connectivity, Sensor integration, Automated control, Data analytics, Remote monitoring
Characteristics	Low power consumption, Small form factor, Wireless communication, Real-time data processing, Scalability
Advantages	Improved efficiency, Data-driven decisions, Remote management, Predictive maintenance, Resource optimization
Disadvantages	Security vulnerabilities, Privacy concerns, Interoperability issues, Implementation complexity, Power constraints

Features of IoT:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph TD
    A[IoT Features] {-{-}{} B[Connectivity]}
    A {-{-}{} C[Intelligence]}
    A {-{-}{} D[Sensing]}
    A {-{-}{} E[Automation]}
    A {-{-}{} F[Cloud Integration]}
    A {-{-}{} G[Data Analytics]}
{Highlighting}
{Shaded}
```

Advantages & Disadvantages:

```
Advantages                    Disadvantages
+{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+      +{-}{-}{-}{-}{-}{-}{-}{-}{-}{-
|   Automation        |      |   Security risks      |
|   Enhanced data     |      |   Privacy concerns    |
|   Remote control    |      |   Complex setup       |
|   Cost reduction    |      |   High initial cost   |
|   Quality of life   |      |   Battery life        |
|   Resource savings  |      |   Compatibility       |
+{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+      +{-}{-}{-}{-}{-}{-}{-}{-}{-}{-
```

Characteristics Details:

- **Interconnectivity**: Anything can be connected to global information & communication infrastructure
- **Things-related services**: IoT provides thing-related services like privacy protection
- **Heterogeneity**: Devices based on different hardware/software platforms
- **Dynamic changes**: Device state changes dynamically (connecting/disconnecting, sleeping/waking)
- **Enormous scale**: Number of devices requiring management exceeds traditional internet connected devices

Mnemonic

"CASED" - **C**onnectivity, **A**utomation, **S**ensing, **E**fficiency, **D**ata analytics - key IoT features