Cem (4341107) - Problem Solver

Antigravity AI

June 4, 2026

Cem

First Edition: 2026

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To my students,
who constantly inspire me to find new analogies,
break down complex theories, and make learning
an engineered science.

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Preface

About this Book
Welcome to **Computer Networks**! This textbook is meticulously designed to serve as a comprehensive problem solver and study companion. It provides a robust and intuitive foundation in the core principles of this subject, bridging the gap between theoretical models and practical applications. A unique feature of this book is its focus on decoding complex concepts using clear, step-by-step methodologies and real-world analogies.

Target Audience
This book is intended for students and professionals looking to master the concepts of Computer Networks. Whether you are revising for exams, seeking to solidify your fundamental understanding, or looking for practical examples to clarify abstract concepts, this book has been structured to support your learning journey. It serves as an accessible guide designed to remove the fear of complex topics, replacing it with an appreciation for the underlying mechanics.

Scope and Coverage
The coverage is divided logically to follow standard academic curriculums. Each chapter focuses on key topics, breaking them down into digestible sections:

- **Theoretical Insights** – Core concepts explained intuitively.
- **Method Blocks** – Standardized, step-by-step procedures for solving specific types of problems.
- **Worked Examples** – Fully solved problems that apply the methods in practice.

We hope this resource proves invaluable in your studies and helps you achieve excellence in **Computer Networks**. Happy learning!

Acknowledgments

Writing a comprehensive book that connects the fundamental forces of Chemistry with practical engineering applications requires more than just academic knowledge—it requires a community of support. I would like to express my sincere gratitude to everyone who contributed to the realization of this project.

Specially, I extend my heartfelt gratitude to the **Department of Technical Education (DTE), Government of Gujarat**, and **Government Polytechnic, Palanpur**, for providing an environment that fosters innovation, academic rigor, and continuous professional development.

I am deeply thankful to my family for their unwavering patience and support during the countless hours spent researching, formatting, and refining these chapters.

Finally, my deepest appreciation goes to my students. Your curiosity, challenging questions, and continuous feedback are the true driving force behind the unique analogies and streamlined structure of this book. This textbook was engineered for you.

Antigravity AI

About the Author

Milav Jayeshkumar Dabgar is an engineering educator and R&D professional with over 9 years of experience in electronics hardware development, embedded systems, AI/ML, and full-stack software engineering. He currently serves as a **Lecturer (Class - II) & Innovation Leader** at Government Polytechnic, Palanpur, under the Education Department of the Government of Gujarat.

Milav holds a Master of Engineering (ME) in Communication Systems from L.D. College of Engineering and a Bachelor of Engineering (BE) in Electronics & Communication. He is also currently pursuing a **BS in Data Science and Applications from IIT Madras**, where he has completed both the **Diploma in Programming** and the **Diploma in Data Science** with distinction.

Most recently, he completed the **AICTE QIP PG Certificate Program in Deep Learning from SVNIT Surat** with a **perfect 10/10 CGPA**, topping his batch.

A dedicated mentor, Milav has guided numerous student teams in securing over **INR 45 lakhs** in innovation funding, including INR 25 lakhs from Shark Tank India and INR 20 lakhs through iHub Gujarat, resulting in two student patents. He is recognized as an **NPTEL Evangelist** and **NPTEL Discipline Star** in Computer Science, reflecting his commitment to continuous learning and academic excellence.

His technical expertise spans from embedded systems (8051, STM32, Arduino) to modern web technologies (Next.js, Python, PostgreSQL) and Data Science (TensorFlow, PyTorch). Through this textbook, he aims to simplify complex Engineering Chemistry concepts by integrating relatable, real-world analogies drawn from modern tech and engineering landscapes.

Milav is also an active content creator, running a popular **YouTube channel** (@milav.dabgar) where he shares technical tutorials and academic resources. He maintains a personal blog and resource hub at milav.in and can be reached for professional collaborations on LinkedIn.

CHAPTER 1

Audio Systems

1.1 Microphone Sensitivity and Output Voltage

Methodology:

Microphone Sensitivity Calculation Microphone sensitivity is often given in millivolts per Pascal (mV/Pa) or decibels relative to 1 Volt per Pascal (dBV/Pa). To find the output voltage for a given sound pressure:

1. Identify the sensitivity of the microphone in dBV/Pa (let this be S).
2. Convert the sensitivity from dBV/Pa to V/Pa using the formula:

$$\text{Sensitivity (V/Pa)} = 10^{\frac{S}{20}}$$

3. Identify the incident sound pressure P in Pascals (Pa).
4. Calculate the output voltage V using:

$$V = P \times \text{Sensitivity (V/Pa)}$$

Worked Example:

Calculate Microphone Output Voltage A condenser microphone has a sensitivity of -40 dBV/Pa. If it is subjected to a sound pressure of 2 Pa, calculate its output voltage in millivolts.

Step 1: Identify given parameters Sensitivity $S = -40$ dBV/Pa
Sound pressure $P = 2$ Pa

Step 2: Convert sensitivity to V/Pa

$$\text{Sensitivity} = 10^{\frac{-40}{20}} = 10^{-2} = 0.01 \text{ V/Pa}$$

Step 3: Calculate output voltage

$$V = P \times \text{Sensitivity}$$

$$V = 2 \times 0.01 = 0.02 \text{ V}$$

Step 4: Convert to millivolts

$$V = 0.02 \times 1000 = 20 \text{ mV}$$

The output voltage of the microphone is 20 mV.

1.2 Loudspeaker Efficiency and Acoustic Power

Methodology:

Loudspeaker Acoustic Power Output A loudspeaker converts electrical power into acoustic power. The efficiency indicates how much electrical power is converted into sound.

1. Determine the electrical power input P_e. If given voltage V and resistance R, calculate using $P_e = \frac{V^2}{R}$.
2. Identify the efficiency η of the loudspeaker as a decimal (e.g. $5\% = 0.05$).
3. Calculate the acoustic power output P_a using the formula:

$$P_a = \eta \times P_e$$

Worked Example:

Calculate Loudspeaker Acoustic Power A moving coil loudspeaker has an impedance of $8\,\Omega$ and is driven by an amplifier providing 20 V RMS. If the efficiency of the loudspeaker is 2%, find the acoustic power generated.
Step 1: Calculate electrical power input Given $V = 20$ V and $R = 8\,\Omega$.

$$P_e = \frac{V^2}{R} = \frac{20^2}{8} = \frac{400}{8} = 50 \text{ W}$$

Step 2: Identify efficiency Efficiency $\eta = 2\% = 0.02$.
Step 3: Calculate acoustic power output

$$P_a = \eta \times P_e$$

$$P_a = 0.02 \times 50 = 1 \text{ W}$$

The acoustic power generated by the loudspeaker is 1 W.

1.3 Sound Pressure Level Distance Law

Methodology:

SPL Reduction with Distance Sound Pressure Level (SPL) decreases as the distance from the source increases. In a free field environment, the SPL drops by 6 dB for every doubling of distance.

1. Identify the initial Sound Pressure Level SPL_1 at a reference distance d_1.
2. Identify the target distance d_2.
3. Calculate the new Sound Pressure Level SPL_2 at distance d_2 using the inverse square law for sound pressure:

$$SPL_2 = SPL_1 - 20\log_{10}\left(\frac{d_2}{d_1}\right)$$

Worked Example:

Calculate SPL at a Target Distance A public address system loudspeaker produces an SPL of 100 dB at a distance of 2 meters. Calculate the SPL at a distance of 16 meters from the loudspeaker in a free field.
Step 1: Identify given parameters Initial SPL $SPL_1 = 100$ dB
Initial distance $d_1 = 2$ m
Target distance $d_2 = 16$ m

Step 2: Apply the SPL distance formula

$$SPL_2 = 100 - 20\log_{10}\left(\frac{16}{2}\right)$$

$$SPL_2 = 100 - 20\log_{10}(8)$$

Step 3: Calculate the logarithm and final SPL Since $\log_{10}(8) \approx 0.903$:

$$SPL_2 = 100 - 20(0.903) = 100 - 18.06 = 81.94 \text{ dB}$$

The SPL at 16 meters is approximately 81.94 dB.

1.4 Combining Sound Pressure Levels

Methodology:

Adding Multiple Sound Sources When two or more independent sound sources play simultaneously, their total Sound Pressure Level cannot be added algebraically (e.g. 80 dB + 80 dB $\neq$ 160 dB). They must be combined logarithmically.

1. Identify the individual SPL values: $SPL_1, SPL_2, \ldots, SPL_n$.
2. Convert each SPL into its relative acoustic power ratio:

$$\text{Ratio}_i = 10^{\frac{SPL_i}{10}}$$

3. Sum the power ratios:

$$\text{Sum} = \sum_{i=1}^{n} 10^{\frac{SPL_i}{10}}$$

4. Convert the sum back to decibels:

$$SPL_{total} = 10\log_{10}(\text{Sum})$$

Worked Example:

Calculate Total SPL of Two Speakers Two identical PA speakers are placed next to each other. Speaker A produces an SPL of 85 dB and Speaker B produces an SPL of 88 dB at the same measuring point. Calculate the total SPL.

Step 1: Identify individual SPLs $SPL_1 = 85$ dB
$SPL_2 = 88$ dB

Step 2: Convert to power ratios

$$\text{Ratio}_1 = 10^{\frac{85}{10}} = 10^{8.5} \approx 316227766$$

$$\text{Ratio}_2 = 10^{\frac{88}{10}} = 10^{8.8} \approx 630957344$$

Step 3: Sum the ratios

$$\text{Sum} = 316227766 + 630957344 = 947185110$$

Step 4: Convert sum to decibels

$$SPL_{total} = 10\log_{10}(947185110)$$

$$SPL_{total} \approx 10 \times 8.976 = 89.76 \text{ dB}$$

The total Sound Pressure Level is 89.76 dB.

1.5 Audio Amplifier Gain

Methodology:

Amplifier Power and Voltage Gain An audio amplifier increases the signal level. Gain is typically expressed in decibels (dB).

1. To calculate Voltage Gain (A_v) in dB:

$$A_v = 20\log_{10}\left(\frac{V_{out}}{V_{in}}\right)$$

2. To calculate Power Gain (A_p) in dB:

$$A_p = 10\log_{10}\left(\frac{P_{out}}{P_{in}}\right)$$

Worked Example:

Calculate Amplifier Voltage and Power Gain An audio pre-amplifier receives an input signal of 50 mV and produces an output of 2 V. The input power is 0.1 mW and the output power is 2 W. Calculate the voltage gain and power gain in decibels.

Step 1: Identify given parameters $V_{in} = 50$ mV $= 0.05$ V
$V_{out} = 2$ V
$P_{in} = 0.1$ mW $= 10^{-4}$ W
$P_{out} = 2$ W

Step 2: Calculate voltage gain in dB

$$A_v = 20\log_{10}\left(\frac{2}{0.05}\right) = 20\log_{10}(40)$$

$$A_v \approx 20 \times 1.602 = 32.04 \text{ dB}$$

Step 3: Calculate power gain in dB

$$A_p = 10\log_{10}\left(\frac{2}{10^{-4}}\right) = 10\log_{10}(20000)$$

$$A_p \approx 10 \times 4.301 = 43.01 \text{ dB}$$

The voltage gain is 32.04 dB and the power gain is 43.01 dB.

1.6 Impedance Matching in Public Address Systems

Methodology:

Impedance Matching using Transformers In PA systems, an audio matching transformer is often used to match the high output impedance of an amplifier to the low impedance of a loudspeaker for maximum power transfer.

1. Identify the primary impedance Z_p (amplifier output impedance).

2. Identify the secondary impedance Z_s (loudspeaker impedance).

3. Calculate the required turns ratio $\frac{N_p}{N_s}$ using the formula:

$$\frac{N_p}{N_s} = \sqrt{\frac{Z_p}{Z_s}}$$

Worked Example:

Calculate Transformer Turns Ratio A public address amplifier has an output impedance of $500\,\Omega$. It needs to drive an $8\,\Omega$ horn loudspeaker. Determine the turns ratio of the matching transformer required for maximum power transfer.

Step 1: Identify the given parameters Primary impedance $Z_p = 500\,\Omega$
Secondary impedance $Z_s = 8\,\Omega$

Step 2: Apply the turns ratio formula

$$\frac{N_p}{N_s} = \sqrt{\frac{Z_p}{Z_s}}$$

Step 3: Calculate the ratio

$$\frac{N_p}{N_s} = \sqrt{\frac{500}{8}} = \sqrt{62.5}$$

$$\frac{N_p}{N_s} \approx 7.91$$

The matching transformer must have a primary-to-secondary turns ratio of approximately 7.91 to 1.

1.7 Reverberation Time Calculation

Methodology:

Sabine Formula for Reverberation Time Reverberation time (RT_{60}) is the time required for the sound pressure level in a room to decay by 60 dB after the sound source stops. Sabine's formula provides a way to estimate this based on room volume and sound absorption.

1. Determine the volume of the room V in cubic meters (m^3).

2. Calculate the total sound absorption A in metric Sabins (m^2). This is found by multiplying the surface area S_i of each material by its absorption coefficient a_i and summing them:

$$A = S_1a_1 + S_2a_2 + \cdots + S_na_n$$

3. Calculate the reverberation time using Sabine's formula:

$$RT_{60} = \frac{0.161 \times V}{A}$$

Worked Example:

Calculate Room Reverberation Time A listening room has a volume of $1000\,m^3$. The total surface area of the walls, floor, and ceiling is $600\,m^2$. The average sound absorption coefficient of all surfaces combined is 0.2. Calculate the reverberation time of the room.

Step 1: Identify given parameters Volume $V = 1000\,m^3$
Total area $S = 600\,m^2$
Average absorption coefficient $a = 0.2$

Step 2: Calculate total absorption

$$A = S \times a = 600 \times 0.2 = 120\,m^2 \text{ metric Sabins}$$

Step 3: Apply Sabine's formula

$$RT_{60} = \frac{0.161 \times V}{A}$$

$$RT_{60} = \frac{0.161 \times 1000}{120} = \frac{161}{120} \approx 1.34 \text{ seconds}$$

The reverberation time of the room is approximately 1.34 seconds.

CHAPTER 2

Television Systems

2.1 Aspect Ratio and Viewing Distance

Methodology:

Aspect Ratio and Screen Dimensions The aspect ratio defines the proportional relationship between the width and height of the television screen.

1. **Aspect Ratio** (a):
$$a = \frac{W}{H}$$
where W is the screen width and H is the screen height. Standard aspect ratios are 4:3 (traditional) and 16:9 (widescreen).

2. **Diagonal Length** (d): Using the Pythagorean theorem, the diagonal of the screen is:
$$d = \sqrt{W^2 + H^2}$$

3. **Optimal Viewing Distance** (D): The optimal distance to view the screen without observing individual scanning lines is generally considered to be:
$$D = c \times H$$
where c is typically between 3 and 6 depending on the standard (e.g. $c = 6$ for standard definition).

Worked Example:

Screen Dimensions Calculation Calculate the exact width and height of a 55-inch television screen (measured diagonally) that has an aspect ratio of 16:9.
Solution:

1. **Set up the aspect ratio equations**: Given $a = \frac{16}{9}$, we can express the width W in terms of height H:
$$W = \frac{16}{9}H$$

2. **Use the diagonal formula**: The diagonal $d = 55$ inches.
$$d^2 = W^2 + H^2$$
$$55^2 = \left(\frac{16}{9}H\right)^2 + H^2$$

3. **Solve for height** H:
$$3025 = \frac{256}{81}H^2 + H^2 = \left(\frac{256}{81} + \frac{81}{81}\right)H^2 = \frac{337}{81}H^2$$

$$H^2 = \frac{3025 \times 81}{337} \approx 727.08$$

$$H \approx \sqrt{727.08} \approx 26.96 \text{ inches}$$

4. **Solve for width W**:

$$W = \frac{16}{9} \times 26.96 \approx 47.93 \text{ inches}$$

The screen is approximately 47.93 inches wide and 26.96 inches high.

2.2 Scanning Frequencies

Methodology:

Horizontal and Vertical Scanning Frequencies Television pictures are formed by scanning an electron beam across the screen. To prevent flicker, interlaced scanning is used, dividing a single frame into two fields (odd and even).

1. **Frame Frequency (f_p)**: The number of complete pictures (frames) transmitted per second.
2. **Field Frequency (f_v)**: The number of fields scanned per second. Since there are 2 fields per frame:

$$f_v = 2 \times f_p$$

3. **Total Lines (Z)**: Total number of horizontal scanning lines per frame.
4. **Horizontal Scanning Frequency (f_h)**: The number of horizontal lines scanned per second.

$$f_h = Z \times f_p$$

5. **Time Period of One Line (H)**:

$$H = \frac{1}{f_h}$$

Worked Example:

Scanning Frequency of PAL System The standard PAL television system uses interlaced scanning with 625 lines per frame and 50 fields per second. Calculate the frame frequency, horizontal scanning frequency, and the time required to scan one complete line.

Solution:

1. **Determine the frame frequency**: Given field frequency $f_v = 50$ Hz and interlaced scanning (2 fields per frame):

$$f_p = \frac{f_v}{2} = \frac{50}{2} = 25 \text{ frames/second}$$

2. **Calculate the horizontal scanning frequency**: Total lines $Z = 625$.

$$f_h = Z \times f_p = 625 \times 25 = 15625 \text{ Hz}$$

3. **Calculate the time to scan one line (H)**:

$$H = \frac{1}{f_h} = \frac{1}{15625} \text{ seconds}$$

$$H = 64\ \mu\text{s}$$

The horizontal scanning frequency is 15625 Hz, and the line time is 64 μs.

2.3 Resolution and Pixels

Methodology:

Vertical and Horizontal Resolution Resolution indicates the capability of the TV system to display fine details. Not all scanning lines are visible due to the retrace (blanking) period.

1. **Active Lines (N_a):**

$$N_a = Z \times (1 - k_v)$$

where k_v is the fraction of total time spent in vertical blanking.

2. **Vertical Resolution (R_v):** The actual number of distinguishable horizontal lines.

$$R_v = N_a \times K$$

where K is the Kell factor (a typical value is approximately 0.7).

3. **Horizontal Resolution (R_h):** The number of distinguishable elements along a horizontal line. For a square pixel assumption matching the vertical resolution density:

$$R_h = R_v \times a = N_a \times K \times a$$

where a is the aspect ratio (W/H).

4. **Total Picture Elements (Pixels) per Frame (N_p):**

$$N_p = R_v \times R_h$$

Worked Example:

Resolution and Total Pixels Calculation A television system has 525 total scanning lines, a vertical blanking period of 8% of the total frame time, an aspect ratio of 4:3, and a Kell factor of 0.7. Find the vertical resolution, horizontal resolution, and the total number of visible pixels per frame.

Solution:

1. **Calculate the number of active lines (N_a):** $Z = 525$, $k_v = 0.08$ (8%).

$$N_a = 525 \times (1 - 0.08) = 525 \times 0.92 = 483 \text{ lines}$$

2. **Calculate the vertical resolution (R_v):** $K = 0.7$.

$$R_v = N_a \times K = 483 \times 0.7 \approx 338 \text{ lines}$$

3. **Calculate the horizontal resolution (R_h):** $a = 4/3$.

$$R_h = R_v \times a = 338 \times \frac{4}{3} \approx 451 \text{ elements}$$

4. **Calculate total visible pixels (N_p):**

$$N_p = R_v \times R_h = 338 \times 451 \approx 152438 \text{ pixels}$$

The vertical resolution is 338, horizontal resolution is 451, and there are approximately 152,438 visible pixels.

2.4 Video Signal Bandwidth

Methodology:

Video Bandwidth Calculation The maximum video frequency (bandwidth) is determined by the rate at which picture elements are scanned. Since one cycle of the maximum frequency video signal corresponds to two adjacent picture elements (one black and one white):

1. **Active Line Time (t_a)**:
$$t_a = H \times (1 - k_h) = \frac{1 - k_h}{f_h}$$
where k_h is the fraction of total line time spent in horizontal blanking.

2. **Maximum Signal Frequency (f_{max})**: The highest frequency is generated when the beam scans alternating black and white elements. The number of elements per line is R_h.
$$f_{max} = \frac{\text{Elements per line}}{2 \times \text{Active line time}} = \frac{R_h}{2 \times t_a}$$

3. **Bandwidth (BW)**: Substituting the formulas for R_h and t_a:
$$BW = f_{max} = \frac{a \times Z \times (1 - k_v) \times K \times f_h}{2 \times (1 - k_h)}$$

Worked Example:

Bandwidth of a Standard TV System Calculate the bandwidth required for a TV system with 625 lines, 25 frames per second, aspect ratio 4:3, Kell factor 0.69, vertical blanking of 8%, and horizontal blanking of 18%.

Solution:

1. **Determine necessary parameters**: $Z = 625$, $f_p = 25$ Hz, $a = \frac{4}{3}$, $K = 0.69$, $k_v = 0.08$, $k_h = 0.18$.

2. **Calculate horizontal scanning frequency (f_h)**:
$$f_h = Z \times f_p = 625 \times 25 = 15625 \text{ Hz}$$

3. **Calculate vertical resolution (R_v)**:
$$R_v = Z \times (1 - k_v) \times K = 625 \times 0.92 \times 0.69 = 396.75$$

4. **Calculate horizontal resolution (R_h)**:
$$R_h = R_v \times a = 396.75 \times \frac{4}{3} = 529$$

5. **Calculate active line time (t_a)**:
$$t_a = \frac{1 - k_h}{f_h} = \frac{1 - 0.18}{15625} = \frac{0.82}{15625} \approx 52.48 \times 10^{-6} \text{ seconds}$$

6. **Calculate maximum video frequency (BW)**:
$$BW = \frac{R_h}{2 \times t_a} = \frac{529}{2 \times 52.48 \times 10^{-6}} \approx 5.04 \times 10^6 \text{ Hz} = 5.04 \text{ MHz}$$

The required video bandwidth is approximately 5.04 MHz.

2.5 Color Video Signals

Methodology:

Luminance and Color Difference Signals In color television, images are captured using Red (R), Green (G), and Blue (B) primary colors. To maintain compatibility with monochrome TVs and conserve bandwidth, these are encoded into a luminance (brightness) signal and chrominance (color) signals.

1. **Luminance Signal (Y)**: Based on the human eye's spectral sensitivity to the primary colors:

$$Y = 0.30R + 0.59G + 0.11B$$

2. **Color Difference Signals (U and V)**: These signals carry the color information (chrominance) without redundant brightness information.

$$U = B - Y$$

$$V = R - Y$$

Note: The green color difference signal $(G - Y)$ is not transmitted because it can be recovered at the receiver from Y, U, and V.

3. **Recovering Green**: By rearranging the luminance equation:

$$(G - Y) = -0.51(R - Y) - 0.19(B - Y)$$

Worked Example:

Signal Values for Pure Colors Calculate the values of the Luminance signal (Y) and the color difference signals (U and V) for a camera scanning a pure green object (where R = 0, G = 1, B = 0).
Solution:

1. **Calculate the Luminance signal (Y)**: Substitute R=0, G=1, and B=0 into the luminance equation:

$$Y = 0.30(0) + 0.59(1) + 0.11(0)$$

$$Y = 0.59$$

2. **Calculate the U signal (B - Y)**:

$$U = B - Y = 0 - 0.59 = -0.59$$

3. **Calculate the V signal (R - Y)**:

$$V = R - Y = 0 - 0.59 = -0.59$$

For a pure green object, $Y = 0.59$, $U = -0.59$, and $V = -0.59$.

Worked Example:

Composite Color Signal Calculations An object being scanned by a color TV camera produces output voltages: $R = 0.8$ V, $G = 0.4$ V, and $B = 0.2$ V. Calculate the transmitted Luminance signal Y and the unweighted color difference signals U and V.
Solution:

1. **Calculate Luminance (Y)**:

$$Y = 0.30R + 0.59G + 0.11B$$

$$Y = 0.30(0.8) + 0.59(0.4) + 0.11(0.2)$$

$$Y = 0.24 + 0.236 + 0.022 = 0.498 \text{ V}$$

2. **Calculate U signal**:
$$U = B - Y = 0.2 - 0.498 = -0.298 \text{ V}$$

3. **Calculate V signal**:
$$V = R - Y = 0.8 - 0.498 = 0.302 \text{ V}$$

The transmitted signals are $Y = 0.498$ V, $U = -0.298$ V, and $V = 0.302$ V.

CHAPTER 3

Domestic Appliances

This chapter focuses on the computational aspects of various domestic appliances. Key calculations involve power consumption, energy efficiency, heating times, and cooling loads.

3.1 Energy Consumption and Operating Cost

Methodology:

Energy Consumption and Cost Calculation The electrical energy consumed by any domestic appliance is determined by its power rating and the duration of its active usage.

1. Energy Consumed (E):

$$E = P \times t$$

Where: E = Energy consumed in Watt-hours (Wh) or Kilowatt-hours (kWh) P = Power rating of the appliance in Watts (W) or Kilowatts (kW) t = Operating time in hours (h)
To convert Wh to standard electrical units (kWh):

$$\text{Units (kWh)} = \frac{\text{Energy in Wh}}{1000}$$

2. Operating Cost:

$$\text{Total Cost} = \text{Units consumed (kWh)} \times \text{Rate per Unit}$$

Worked Example:

Calculate the monthly cost of operating a water heater A 2000 W electric water heater is used for 2 hours daily. Calculate the total energy consumed in a month (30 days) and the monthly operating cost if the electricity rate is Rs 7 per unit.

Solution:

1. **Identify Given Data:** Power $P = 2000$ W $= 2$ kW
   Daily operating time $t = 2$ hours
   Number of days $= 30$
   Rate $=$ Rs 7 / kWh

2. **Calculate Daily Energy Consumption:**

$$E_{\text{daily}} = P \times t = 2\text{ kW} \times 2\text{ hours} = 4\text{ kWh (units)}$$

3. **Calculate Monthly Energy Consumption:**

$$E_{\text{monthly}} = 4\text{ kWh/day} \times 30\text{ days} = 120\text{ kWh}$$

4. **Calculate Monthly Cost:**

$$\text{Cost} = E_{\text{monthly}} \times \text{Rate} = 120 \times 7 = \text{Rs } 840$$

3.2 Microwave Oven Heating Calculations

Methodology:

Microwave Heating Time and Energy The required time to heat a substance in a microwave oven depends on the substance's mass, its specific heat capacity, and the desired temperature change alongside the oven's output power and efficiency.

1. Heat Energy Required (Q):

$$Q = m \times c \times \Delta T$$

Where: Q = Heat energy required in Joules (J)
m = Mass of the substance in kilograms (kg)
c = Specific heat capacity of the substance (for water $c \approx 4184$ J/(kg $\cdot^\circ$ C))
ΔT = Change in temperature in $^\circ C$ ($T_{\text{final}} - T_{\text{initial}}$)

2. Output Power Required (P_{out}):

$$P_{\text{out}} = \frac{Q}{t}$$

Where: P_{out} = Microwave output power in Watts (W)
t = Heating time in seconds (s)

3. Efficiency (η):

$$\eta = \frac{P_{\text{out}}}{P_{\text{in}}} \times 100\%$$

Where P_{in} is the electrical power consumed by the microwave from the grid.

Worked Example:

Calculate the time to boil water in a microwave A microwave oven has an output power of 800 W. How long will it take to heat 500 grams of water from 20°C to 100°C? Assume 100 percent transfer of microwave energy to the water. The specific heat of water is 4184 J/(kg $\cdot^\circ$ C).

Solution:

1. **Identify Given Data:** $m = 500$ g $= 0.5$ kg
   $\Delta T = 100°\text{C} - 20°\text{C} = 80°\text{C}$
   $c = 4184$ J/(kg $\cdot^\circ$ C)
   $P_{\text{out}} = 800$ W

2. **Calculate Heat Energy (Q):**

$$Q = m \times c \times \Delta T$$

$$Q = 0.5 \times 4184 \times 80 = 167360 \text{ J}$$

3. **Calculate Heating Time (t):**

$$t = \frac{Q}{P_{\text{out}}} = \frac{167360}{800} = 209.2 \text{ seconds}$$

   The time required is approximately 3.48 minutes.

3.3 Air Conditioners and Refrigerators

Methodology:

Cooling Capacity and Efficiency Air conditioners and refrigerators are evaluated computationally based on their cooling capacity and their energy efficiency ratio (EER) or coefficient of performance (COP).

1. Cooling Capacity: Cooling capacity is measured in Tons of Refrigeration (TR) or British Thermal Units per hour (BTU/h).

$$1 \text{ Ton of Refrigeration (TR)} \approx 12000 \text{ BTU/h} \approx 3.517 \text{ kW}$$

2. Energy Efficiency Ratio (EER): EER is the ratio of cooling capacity (in BTU/h) to power input (in Watts).

$$\text{EER} = \frac{\text{Cooling Capacity (BTU/h)}}{\text{Power Input (W)}}$$

3. Coefficient of Performance (COP): COP is the dimensionless ratio of cooling provided (in W) to electrical power consumed (in W).

$$\text{COP} = \frac{\text{Cooling Capacity (W)}}{\text{Power Input (W)}}$$

4. Relationship between EER and COP:

$$\text{EER} = \text{COP} \times 3.412$$

Worked Example:

Calculate EER and COP of an Air Conditioner A 1.5 Ton air conditioner consumes 1500 W of electrical power. Calculate its cooling capacity in BTU/h as well as its Energy Efficiency Ratio (EER) and Coefficient of Performance (COP).

Solution:

1. **Calculate Cooling Capacity in BTU/h:**

$$\text{Cooling Capacity (BTU/h)} = 1.5 \text{ TR} \times 12000 \text{ BTU/h per TR} = 18000 \text{ BTU/h}$$

2. **Calculate EER:**

$$\text{EER} = \frac{\text{Cooling Capacity (BTU/h)}}{\text{Power Input (W)}} = \frac{18000}{1500} = 12 \text{ BTU/(W} \cdot \text{h)}$$

3. **Calculate Cooling Capacity in Watts:**

$$\text{Cooling Capacity (W)} = 1.5 \text{ TR} \times 3517 \text{ W per TR} = 5275.5 \text{ W}$$

4. **Calculate COP:**

$$\text{COP} = \frac{\text{Cooling Capacity (W)}}{\text{Power Input (W)}} = \frac{5275.5}{1500} = 3.517$$

Check using EER relationship:

$$\text{COP} = \frac{\text{EER}}{3.412} = \frac{12}{3.412} \approx 3.517$$

Worked Example:

Calculate heat removed by a refrigerator A refrigerator has a COP of 2.5 and consumes 400 W of power. Calculate the total amount of heat it removes from the refrigerated space in one hour.

Solution:

1. **Identify Given Data:** COP = 2.5
   Power Input $P = 400$ W
   Time $t = 1$ hour = 3600 seconds

2. **Calculate Cooling Rate (Cooling Capacity in W):**

$$\text{Cooling Rate} = \text{COP} \times P = 2.5 \times 400 \text{ W} = 1000 \text{ W} = 1000 \text{ J/s}$$

3. **Calculate Total Heat Removed in One Hour:**

$$\text{Heat Removed} = \text{Cooling Rate} \times t$$

$$\text{Heat Removed} = 1000 \text{ J/s} \times 3600 \text{ s} = 3600000 \text{ Joules} = 3600 \text{ kJ}$$

3.4 Washing Machine Water and Power Usage

Methodology:

Washing Machine Cycle Calculations The operational efficiency of a washing machine is evaluated by the water consumed per cycle and the electrical energy used primarily for motor action and water heating.
1. Total Energy Consumption per Cycle (E_{cycle}): A wash cycle typically utilizes distinct power levels for washing and spinning alongside water heating.

$$E_{\text{cycle}} = \sum (P_i \times t_i) + E_{\text{heating}}$$

Where P_i and t_i are the power and duration for mechanical phases.
2. Water Heating Energy (E_{heating}): If the washing machine heats water internally using an electrical element:

$$E_{\text{heating}} = \frac{m_w \times c_w \times \Delta T}{3.6 \times 10^6} \text{ kWh}$$

Where: m_w = Mass of water heated (kg or liters since 1 L $\approx$ 1 kg)
c_w = Specific heat capacity of water (≈ 4184 J/(kg $\cdot^\circ$ C))
ΔT = Temperature rise ($^\circ C$)
The constant 3.6×10^6 converts Joules to kWh.

Worked Example:

Calculate energy required to heat water in a washing machine A front-load washing machine uses 15 liters of water for its main wash cycle. The incoming tap water is at 25°C and the machine is set to a 60°C wash program. Calculate the electrical energy in kWh required just to heat the water assuming 90 percent efficiency of the internal heating element.
Solution:

1. **Identify Given Data:** Volume of water = 15 L $\implies$ Mass $m_w = 15$ kg
   $\Delta T = 60°\text{C} - 25°\text{C} = 35°\text{C}$
   $c_w = 4184$ J/(kg $\cdot^\circ$ C)
   Efficiency $\eta = 0.90$

2. **Calculate Thermal Energy Required (Q):**

$$Q = m_w \times c_w \times \Delta T$$

$$Q = 15 \times 4184 \times 35 = 2196600 \text{ J}$$

3. **Convert Thermal Energy to kWh:**

$$Q_{\text{kWh}} = \frac{2196600}{3.6 \times 10^6} \approx 0.610 \text{ kWh}$$

4. **Calculate Electrical Energy Consumed:** Accounting for the 90 percent efficiency of the heating element:

$$E_{\text{electrical}} = \frac{Q_{\text{kWh}}}{\eta} = \frac{0.610}{0.90} \approx 0.678 \text{ kWh}$$

CHAPTER 4

Office Appliances

While office appliances like printers, scanners, and projectors are commonly studied from a theoretical perspective, maintaining and configuring these devices requires a solid understanding of fundamental computational techniques. This chapter focuses on the mathematical methods used to calculate image memory size, printer throughput, projector throw distance, and uninterruptible power supply (UPS) backup time.

4.1 Scanner and Image Memory Calculations

When scanning documents, it is crucial to estimate the memory required to store the uncompressed digital image. The file size depends on the physical dimensions of the document, the scanning resolution in Dots Per Inch (DPI), and the color depth.

Methodology:

Image Memory Calculation To calculate the uncompressed memory size of a scanned image, follow these steps:

1. Identify the physical dimensions of the document in inches: Width (W) and Height (H).
2. Determine the scanning resolution in Dots Per Inch (DPI).
3. Calculate the total number of pixels in the scanned image:

$$\text{Total Pixels} = (W \times \text{DPI}) \times (H \times \text{DPI})$$

4. Identify the color depth (C) in bits per pixel. Common values include:
   - 1 bit for monochrome (black and white)
   - 8 bits for grayscale
   - 24 bits for true color (RGB)
5. Calculate the total memory in bits:

$$\text{Total Bits} = \text{Total Pixels} \times C$$

6. Convert the total bits into Bytes, Kilobytes (KB), or Megabytes (MB):

$$\text{Bytes} = \frac{\text{Total Bits}}{8}$$

$$\text{MB} = \frac{\text{Bytes}}{1024 \times 1024}$$

Worked Example:

Memory Required for True Color A4 Scan An office worker scans an A4 size document (8.27×11.69 inches) at 300 DPI in 24-bit true color using a flatbed scanner. Calculate the uncompressed image memory size in Megabytes (MB).

Solution:

1. **Identify Dimensions and Resolution:** Width $W = 8.27$ inches, Height $H = 11.69$ inches, $\text{DPI} = 300$.

2. **Calculate Total Pixels:**

$$\text{Pixels in Width} = 8.27 \times 300 = 2481$$

$$\text{Pixels in Height} = 11.69 \times 300 = 3507$$

$$\text{Total Pixels} = 2481 \times 3507 = 8,700,867$$

3. **Calculate Total Bits:** Color depth $C = 24$ bits.

$$\text{Total Bits} = 8,700,867 \times 24 = 208,820,808 \text{ bits}$$

4. **Convert to Megabytes (MB):**

$$\text{Bytes} = \frac{208,820,808}{8} = 26,102,601 \text{ Bytes}$$

$$\text{MB} = \frac{26,102,601}{1024 \times 1024} = \frac{26,102,601}{1,048,576} \approx 24.89 \text{ MB}$$

The uncompressed image memory size is approximately **24.89 MB**.

4.2 Printer Speed and Throughput

Printer performance is measured differently depending on the technology used. Dot matrix printers are measured in Characters Per Second (CPS), whereas laser and inkjet printers are measured in Pages Per Minute (PPM).

Methodology:

Printer Speed and Time Calculation Follow these steps to calculate the time required for printing jobs:

1. **For Dot Matrix Printers:**
   (a) Determine the printing speed in Characters Per Second (CPS).
   (b) Calculate the total number of characters to be printed: Characters = Lines per Page $\times$ Characters per Line $\times$ Number of Pages.
   (c) Calculate Print Time in seconds: $\text{Time} = \frac{\text{Total Characters}}{\text{CPS}}$.

2. **For Laser or Inkjet Printers:**
   (a) Determine the printing speed in Pages Per Minute (PPM).
   (b) Identify the total number of pages to be printed.
   (c) Calculate Print Time in minutes: $\text{Time} = \frac{\text{Total Pages}}{\text{PPM}}$.

Worked Example:

Dot Matrix Print Time A dot matrix printer operates at a speed of 250 Characters Per Second (CPS). An office needs to print an invoice that spans 3 pages. Each page contains 50 lines, and each line has an average of 70 characters. Calculate the total time required to print the invoice.

Solution:

1. **Calculate Total Characters:**

$$\text{Characters per Page} = 50 \text{ lines} \times 70 \text{ characters/line} = 3500 \text{ characters}$$

$$\text{Total Characters} = 3500 \times 3 \text{ pages} = 10,500 \text{ characters}$$

2. **Calculate Print Time:**

$$\text{Time (seconds)} = \frac{10,500}{250} = 42 \text{ seconds}$$

The total print time is **42 seconds**.

Worked Example:

Laser Printer Output Capacity An office laser printer is rated at 35 Pages Per Minute (PPM). A user sends a batch of 8 brochures, where each brochure consists of 14 pages. How long will it take for the printer to complete the batch?

Solution:

1. **Calculate Total Pages:**

$$\text{Total Pages} = 8 \text{ brochures} \times 14 \text{ pages/brochure} = 112 \text{ pages}$$

2. **Calculate Print Time:**

$$\text{Time (minutes)} = \frac{112}{35} = 3.2 \text{ minutes}$$

3. **Convert to Minutes and Seconds:** 0.2 minutes $= 0.2 \times 60 = 12$ seconds.

The batch will take **3 minutes and 12 seconds** to complete.

4.3 Projector Throw Distance and Screen Size

Digital projectors are widely used in conference rooms and classrooms. When installing a projector, technicians must calculate the correct distance from the projector to the screen (throw distance) to achieve the desired image size.

Methodology:

Projector Throw Calculation The relationship between throw distance and image width is governed by the projector's Throw Ratio (TR).

1. Identify the projector's Throw Ratio (TR).
2. If calculating Throw Distance (D) for a given Image Width (W):

$$D = TR \times W$$

3. If calculating Image Width (W) for a given Throw Distance (D):

$$W = \frac{D}{TR}$$

4. For a standard 16:9 aspect ratio screen, the image height (H) and diagonal size (Diag) can be calculated as:

$$H = W \times \frac{9}{16}$$

$$\text{Diag} = \sqrt{W^2 + H^2}$$

Worked Example:

Calculating Image Dimensions and Diagonal A digital projector with a throw ratio of 1.6 is mounted exactly 4.0 meters away from the projection screen. Assuming the projector is set to output a 16:9 aspect ratio, calculate the resulting image width, height, and the diagonal size of the projected image in meters.

Solution:

1. **Calculate Image Width (W):** Throw Distance $D = 4.0$ m, Throw Ratio $TR = 1.6$.

$$W = \frac{D}{TR} = \frac{4.0}{1.6} = 2.5 \text{ meters}$$

2. **Calculate Image Height (H):** For a 16:9 aspect ratio:

$$H = 2.5 \times \frac{9}{16} = 1.40625 \text{ meters}$$

3. **Calculate Diagonal Size:** Using the Pythagorean theorem:

$$\text{Diag} = \sqrt{W^2 + H^2} = \sqrt{(2.5)^2 + (1.40625)^2}$$

$$\text{Diag} = \sqrt{6.25 + 1.9775} = \sqrt{8.2275} \approx 2.868 \text{ meters}$$

The projected image has a width of **2.5 m**, height of **1.41 m**, and a diagonal of **2.87 m**.

4.4 UPS Battery Backup Estimation

Office appliances depend heavily on Uninterruptible Power Supplies (UPS) to prevent data loss during power outages. Estimating the backup time requires evaluating the total power draw of connected devices against the battery capacity of the UPS.

Methodology:

UPS Backup Time Calculation To calculate the expected battery backup time for a given load:

1. Determine the total load power (P) connected to the UPS in Watts.
2. Identify the specifications of the UPS battery array:
   - Total Battery Voltage (V) in Volts (e.g., a single 12V battery, or two in series for 24V).
   - Battery Capacity (Ah) in Ampere-hours.
3. Determine the inverter efficiency (η), typically between 0.8 and 0.95.
4. Calculate Backup Time (T) in hours using the formula:

$$T = \frac{V \times Ah \times \eta}{P}$$

5. Multiply by 60 to convert the backup time into minutes.

Worked Example:

Estimating PC Backup Time A workstation setup including a desktop computer, LCD monitor, and a modem consumes a total of 300 W. It is connected to a line-interactive UPS equipped with a single 12 V, 9 Ah battery. Assuming the UPS inverter has an efficiency of 85%, calculate the expected battery backup time in minutes when a power failure occurs.

Solution:

1. **Identify Parameters:** Load $P = 300$ W, Battery Voltage $V = 12$ V, Battery Capacity $Ah = 9$ Ah, Efficiency $\eta = 0.85$.

2. **Calculate Backup Time in Hours:**

$$T = \frac{12 \times 9 \times 0.85}{300}$$

$$T = \frac{108 \times 0.85}{300} = \frac{91.8}{300} = 0.306 \text{ hours}$$

3. **Convert to Minutes:**

$$\text{Backup Time in Minutes} = 0.306 \times 60 = 18.36 \text{ minutes}$$

The expected battery backup time is **18.36 minutes**.

CHAPTER 5

Maintenance and Troubleshooting

5.1 Reliability and Mean Time Between Failures

In consumer electronics maintenance, analyzing the reliability and downtime of electronic equipment is essential. The two key metrics used are the failure rate and the Mean Time Between Failures (MTBF).

Methodology:

Calculation of Failure Rate and MTBF The failure rate (λ) and Mean Time Between Failures (MTBF) are computational metrics used to assess the reliability of an electronic system.

1. **Identify total operating time:** Determine the total time (T) the system or a batch of systems has been operating.
2. **Identify number of failures:** Count the total number of failures (F) occurring during this period.
3. **Calculate Failure Rate (λ):**
$$\lambda = \frac{F}{T}$$
The unit is usually failures per hour.
4. **Calculate MTBF:** For systems with a constant failure rate, MTBF is the reciprocal of the failure rate:
$$\text{MTBF} = \frac{1}{\lambda} = \frac{T}{F}$$

Worked Example:

Calculating Failure Rate and MTBF A batch of 50 consumer audio amplifiers is tested for 1000 hours. During this testing period, 4 amplifiers fail. Calculate the failure rate and the MTBF of the amplifiers.
Solution:

1. **Total operating time (T):** Since there are 50 amplifiers tested for 1000 hours each:
$$T = 50 \times 1000 = 50,000 \text{ hours}$$
2. **Number of failures (F):**
$$F = 4 \text{ failures}$$
3. **Calculate Failure Rate (λ):**
$$\lambda = \frac{4}{50,000} = 0.00008 \text{ failures/hour}$$
4. **Calculate MTBF:**
$$\text{MTBF} = \frac{1}{0.00008} = 12,500 \text{ hours}$$

The failure rate is 8×10^{-5} failures/hour, and the MTBF is 12,500 hours.

5.2 System Availability Calculation

Availability is the probability that a system is operating properly when requested for use. It depends on both MTBF and the Mean Time To Repair (MTTR).

Methodology:

Calculation of System Availability To determine how often a system is available for use:

1. **Determine MTBF:** Calculate or identify the Mean Time Between Failures.
2. **Determine MTTR:** Calculate the Mean Time To Repair, which is the total maintenance time divided by the number of repairs.
3. **Calculate Availability (A):**
$$A = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}}$$
4. **Percentage Availability:** Multiply A by 100% to express it as a percentage.

Worked Example:

Evaluating Equipment Availability A television set has an MTBF of 5000 hours. On average, it takes 10 hours for a technician to diagnose and repair a fault (MTTR = 10 hours). Calculate the availability of the television set.

Solution:

1. **Identify variables:**
$$\text{MTBF} = 5000 \text{ hours}, \quad \text{MTTR} = 10 \text{ hours}$$
2. **Apply Availability Formula:**
$$A = \frac{5000}{5000 + 10} = \frac{5000}{5010}$$
3. **Calculate value:**
$$A \approx 0.9980$$
4. **Convert to percentage:**
$$A_{\%} = 0.9980 \times 100\% = 99.80\%$$

The availability of the television set is 99.80%.

5.3 Series and Parallel System Reliability

Electronic systems are composed of multiple subsystems. The overall reliability depends on how these subsystems are connected.

Methodology:

System Reliability Evaluation Let $R_1, R_2, \ldots, R_n$ be the reliabilities of individual components.

1. **Series Systems:** If components are in series (all must work for the system to work), the total reliability R_s is the product of individual reliabilities:
$$R_s = R_1 \times R_2 \times \cdots \times R_n$$
2. **Parallel Systems:** If components are in parallel (system works if at least one works), calculate the unreliability of each component $(1 - R_i)$. The total reliability R_p is:
$$R_p = 1 - [(1 - R_1) \times (1 - R_2) \times \cdots \times (1 - R_n)]$$

Worked Example:

Series and Parallel Configuration A consumer electronics device consists of a power supply ($R_1 = 0.95$), a main processing board ($R_2 = 0.90$), and a display unit ($R_3 = 0.98$) connected in series. 1. Calculate the overall system reliability. 2. If a redundant main processing board ($R_2 = 0.90$) is added in parallel to the first one, calculate the new system reliability.

Solution:

1. **Series Reliability:**
$$R_s = R_1 \times R_2 \times R_3 = 0.95 \times 0.90 \times 0.98 = 0.8379$$
The initial system reliability is 83.79%.

2. **Parallel Redundancy for Processing Board:** The processing stage now has two identical boards in parallel.
$$R_{2p} = 1 - (1 - 0.90) \times (1 - 0.90) = 1 - (0.10 \times 0.10) = 1 - 0.01 = 0.99$$

3. **New Overall Reliability:** The new system consists of the power supply, the parallel processing stage, and the display unit in series.
$$R_{new} = R_1 \times R_{2p} \times R_3 = 0.95 \times 0.99 \times 0.98 \approx 0.9217$$

Adding a redundant processing board increases the system reliability from 83.79% to 92.17%.

5.4 Systematic Troubleshooting Techniques

In maintenance, logically isolating a fault minimizes the time spent on repairs. The Half-Split method is the most efficient computational algorithm for series-connected blocks.

Methodology:

Half Split Troubleshooting Algorithm This method is used when a system consists of a linear sequence of functional blocks.

1. **Verify Input and Output:** Confirm that the primary input is present and the final output is incorrect or missing.
2. **Split the System:** Identify the midpoint of the system's block diagram.
3. **Test the Midpoint:** Measure the signal at this halfway point.
4. **Evaluate the Result:**
   - If the signal is **normal**, the fault lies in the *second half* of the system.
   - If the signal is **abnormal**, the fault lies in the *first half*.
5. **Iterate:** Treat the faulty half as a new system. Split it in half again and repeat the test until the specific faulty block is isolated.
6. **Calculate Maximum Tests:** For N blocks, the maximum number of tests T required is roughly:
$$T = \lceil \log_2(N) \rceil$$

Worked Example:

Applying the Half Split Method An audio system consists of 8 sequential stages: (1) Antenna, (2) RF Amplifier, (3) Mixer, (4) IF Amplifier, (5) Detector, (6) AF Pre-amplifier, (7) Power Amplifier, (8) Speaker.

The final output at the speaker is dead, but the antenna input is present. Trace the fault using the half-split method. Assume the fault is in the Detector (Stage 5).
Solution:

1. **Initial Setup:** The system has $N = 8$ stages. We expect a maximum of $\log_2(8) = 3$ tests.
2. **Test 1 (Split at midpoint):** Test the output of Stage 4 (IF Amplifier). *Result:* The signal is normal (since the fault is in Stage 5). *Conclusion:* Stages 1 to 4 are working. The fault is in Stages 5 to 8.
3. **Test 2 (Split remaining stages):** The remaining stages are 5, 6, 7, 8. The midpoint is between 6 and 7. Test the output of Stage 6 (AF Pre-amplifier). *Result:* The signal is abnormal (because Stage 5 is faulty and corrupts subsequent stages). *Conclusion:* The fault is in Stage 5 or Stage 6.
4. **Test 3 (Split final pair):** Test the output of Stage 5 (Detector). *Result:* The signal is abnormal. *Conclusion:* Since the input to Stage 5 (from Stage 4) was normal, and the output of Stage 5 is abnormal, **Stage 5 (Detector)** is the faulty block.

The fault was isolated in exactly 3 tests, confirming the computational efficiency of the half-split algorithm.

Methodology:

Signal Injection and Tracing These are complementary methods used once a general subsystem is identified.

1. **Signal Injection:**
   - Connect an indicator (e.g., speaker or oscilloscope) to the final output.
   - Inject a known test signal from a signal generator starting from the stage closest to the output and moving backward towards the input.
   - When the injected signal fails to appear at the final output, the current stage being injected is faulty.
2. **Signal Tracing:**
   - Apply a known input signal at the primary input of the system.
   - Use a measuring device (oscilloscope, multimeter) to check the output of each consecutive block starting from the input.
   - The stage where the signal first disappears or becomes distorted is the faulty stage.

Worked Example:

Troubleshooting via Signal Injection A 4-stage PA amplifier system (Pre-amp $\rightarrow$ Tone Control $\rightarrow$ Driver $\rightarrow$ Power Amp) produces no sound. Apply the Signal Injection method to find a fault in the Driver stage.
Solution:

1. **Step 1:** Inject an audio signal at the input of the Power Amp stage. *Observation:* A loud tone is heard from the speaker. *Conclusion:* The Power Amp and Speaker are functioning.
2. **Step 2:** Move backward and inject the signal at the input of the Driver stage. *Observation:* No sound is heard from the speaker. *Conclusion:* The signal is being lost in the Driver stage.
3. **Step 3 (Verification):** Inject the signal at the input of the Tone Control just to be thorough. No sound is heard.

The fault is successfully isolated to the Driver stage because it was the first point where signal injection failed to produce an output.

Formulae

Appendix: Key Formulae

This appendix provides a quick reference to the key formulae and mathematical relationships discussed in this book.

Unit 1: Audio Systems

- **Electrical Power (P_e):**

  $$P_e = \frac{V^2}{R}$$

  Where V is the voltage and R is the resistance or impedance.

- **Acoustic Power (P_a):**

  $$P_a = \eta \times P_e$$

  Where η is the efficiency of the loudspeaker.

- **Power Gain/Loss (A_p):**

  $$A_p = 10 \log_{10}\left(\frac{P_{out}}{P_{in}}\right) \text{ dB}$$

- **Voltage Gain/Loss (A_v):**

  $$A_v = 20 \log_{10}\left(\frac{V_{out}}{V_{in}}\right) \text{ dB}$$

- **Microphone Sensitivity:**

  $$\text{Sensitivity (V/Pa)} = 10^{\frac{S}{20}}$$

  $$V = P \times \text{Sensitivity (V/Pa)}$$

  Where S is sensitivity in dB relative to 1 V/Pa, and P is sound pressure.

- **Total Sound Pressure Level (SPL_{total}):**

  $$SPL_{total} = 10 \log_{10}\left(\sum_{i=1}^{n} 10^{\frac{SPL_i}{10}}\right)$$

- **Inverse Square Law for SPL:**

  $$SPL_2 = SPL_1 - 20 \log_{10}\left(\frac{d_2}{d_1}\right)$$

  Where SPL_2 is the sound pressure level at distance d_2, and SPL_1 is at distance d_1.

- **Total Room Absorption (A):**

  $$A = S_1 a_1 + S_2 a_2 + \cdots + S_n a_n = \sum S_i a_i$$

  Where S_i is the surface area and a_i is the absorption coefficient of that surface.

- **Sabine's Reverberation Time (RT_{60}):**
$$RT_{60} = \frac{0.161 \times V}{A}$$
Where V is the volume of the room in cubic meters and A is the total absorption in metric Sabins.

- **Transformer Impedance Matching:**
$$\frac{N_p}{N_s} = \sqrt{\frac{Z_p}{Z_s}}$$
Where N_p/N_s is the primary to secondary turns ratio, and Z_p, Z_s are the primary and secondary impedances.

Unit 2: Television Systems

- **Luminance Signal (Y):**
$$Y = 0.30R + 0.59G + 0.11B$$

- **Color Difference Signals (U, V):**
$$U = B - Y, \quad V = R - Y$$
$$(G - Y) = -0.51(R - Y) - 0.19(B - Y)$$

- **Aspect Ratio (a) and Screen Dimensions:**
$$a = \frac{W}{H}$$
$$d = \sqrt{W^2 + H^2}$$
Where W is width, H is height, and d is diagonal length.

- **Scanning Frequencies:**
$$f_p = \frac{f_v}{2}$$
$$f_h = Z \times f_p$$
Where f_p is picture (frame) frequency, f_v is vertical field frequency, f_h is horizontal line frequency, and Z is the total number of lines.

- **Horizontal Line Time (H) and Active Line Time (t_a):**
$$H = \frac{1}{f_h}$$
$$t_a = H \times (1 - k_h) = \frac{1 - k_h}{f_h}$$
Where k_h is the horizontal blanking period fraction.

- **Number of Active Lines (N_a):**
$$N_a = Z \times (1 - k_v)$$
Where k_v is the vertical blanking period fraction.

- **Resolution (R_v, R_h) and Total Pixels (N_p):**
$$R_v = N_a \times K = Z \times (1 - k_v) \times K$$
$$R_h = R_v \times a = N_a \times K \times a$$
$$N_p = R_v \times R_h$$
Where K is the Kell factor.

- **Video Bandwidth (BW or f_{max}):**
$$BW = f_{max} = \frac{R_h}{2 \times t_a} = \frac{a \times Z \times (1 - k_v) \times K \times f_h}{2 \times (1 - k_h)}$$

Unit 3: Domestic Appliances

- **Sensible Heat (Q):**
$$Q = m \times c \times \Delta T$$
Where m is mass, c is specific heat capacity, and ΔT is the change in temperature.

- **Power and Energy:**
$$P_{\text{out}} = \frac{Q}{t}$$
$$E = P \times t$$
$$\text{Units (kWh)} = \frac{\text{Energy in Wh}}{1000}$$

- **Efficiency (η):**
$$\eta = \frac{P_{\text{out}}}{P_{\text{in}}} \times 100\%$$

- **Air Conditioning Capacity:**
$$1 \text{ Ton of Refrigeration (TR)} \approx 12000 \text{ BTU/h} \approx 3.517 \text{ kW}$$

- **Coefficient of Performance (COP) & EER:**
$$\text{COP} = \frac{\text{Cooling Capacity (W)}}{\text{Power Input (W)}}$$
$$\text{EER} = \frac{\text{Cooling Capacity (BTU/h)}}{\text{Power Input (W)}}$$
$$\text{EER} = \text{COP} \times 3.412$$

- **Cost Calculation:**
$$\text{Total Cost} = \text{Units consumed (kWh)} \times \text{Rate per Unit}$$

Unit 4: Office Appliances

- **Scanner Resolution and Image Size:**
$$\text{Total Pixels} = (W \times \text{DPI}) \times (H \times \text{DPI})$$
$$\text{Total Bits} = \text{Total Pixels} \times C$$
Where W and H are image dimensions in inches, DPI is dots per inch, and C is color depth in bits per pixel.

- **File Size Conversion:**
$$\text{Bytes} = \frac{\text{Total Bits}}{8}, \quad \text{MB} = \frac{\text{Bytes}}{1024 \times 1024}$$

- **Projector Throw Distance (D):**
$$D = TR \times W$$
Where TR is the Throw Ratio and W is the image width.

- **UPS Backup Time (T):**
$$T = \frac{V \times Ah \times \eta}{P}$$
Where V is battery voltage, Ah is the battery capacity in Ampere-hours, η is inverter efficiency, and P is the load power.

Unit 5: Maintenance and Troubleshooting

- **Failure Rate (λ):**

  $$\lambda = \frac{F}{T}$$

  Where F is the number of failures and T is the total operating time.

- **Mean Time Between Failures (MTBF):**

  $$\text{MTBF} = \frac{1}{\lambda} = \frac{T}{F}$$

- **Availability (A):**

  $$A = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}}$$

  Where MTTR is the Mean Time To Repair.

- **System Reliability (R_s, R_p):**

  $$R_s = R_1 \times R_2 \times \cdots \times R_n$$

  Where R_s is the reliability of a system with components in series.

  $$R_p = 1 - [(1 - R_1) \times (1 - R_2) \times \cdots \times (1 - R_n)]$$

  Where R_p is the reliability of a system with components in parallel.

- **Half-Split Method:**

  $$T = \lceil \log_2(N) \rceil$$

  Where T is the maximum number of tests required to isolate a fault among N components.