Lab Manual Solutions

Industrial Control Electronics: Devices, Systems, and Applications

3rd edition

Terry L.M. Bartelt
Operational Amplifiers

Experiment Questions
1. analog
2. linear
3. greater
4. 6, –
5. -5V

<table>
<thead>
<tr>
<th>INPUTS</th>
<th>(V_{\text{IN}})</th>
<th>(V_{\text{OUT}})</th>
</tr>
</thead>
<tbody>
<tr>
<td>+4</td>
<td>+1</td>
<td>-5V</td>
</tr>
<tr>
<td>+2</td>
<td>+3</td>
<td>+5V</td>
</tr>
<tr>
<td>+1</td>
<td>0</td>
<td>-5V</td>
</tr>
<tr>
<td>+4</td>
<td>+4</td>
<td>0V</td>
</tr>
<tr>
<td>0</td>
<td>+1</td>
<td>+5V</td>
</tr>
<tr>
<td>+3</td>
<td>+2</td>
<td>-5V</td>
</tr>
</tbody>
</table>

Figure 1-2 b

<table>
<thead>
<tr>
<th>INPUTS</th>
<th>(V_{\text{IN}})</th>
<th>(V_{\text{OUT}})</th>
</tr>
</thead>
<tbody>
<tr>
<td>+0.2V</td>
<td>-1V</td>
<td></td>
</tr>
<tr>
<td>-0.4V</td>
<td>+2V</td>
<td></td>
</tr>
<tr>
<td>0V</td>
<td>0V</td>
<td></td>
</tr>
<tr>
<td>+0.32V</td>
<td>-1.6V</td>
<td></td>
</tr>
</tbody>
</table>

Figure 1-3 b&c

<table>
<thead>
<tr>
<th>Input Voltage</th>
<th>Output Voltage</th>
<th>Measured</th>
<th>Calculated</th>
</tr>
</thead>
<tbody>
<tr>
<td>+1V</td>
<td>+1V</td>
<td>+1V</td>
<td>-3V</td>
</tr>
<tr>
<td>+1V</td>
<td>-1V</td>
<td>-1V</td>
<td>+1V</td>
</tr>
<tr>
<td>+2V</td>
<td>-1V</td>
<td>-1V</td>
<td>0V</td>
</tr>
<tr>
<td>-3V</td>
<td>-1V</td>
<td>+3V</td>
<td>+1V</td>
</tr>
<tr>
<td>+1V</td>
<td>+2V</td>
<td>-1V</td>
<td>-2V</td>
</tr>
</tbody>
</table>

Figure 1-4b
Schmitt Trigger

Procedure Question Answer
1. No. Because the 7476 J-K flip-flop is negative edge triggered, and reacts only to positive-to-negative-going signals that change abruptly. The rectified sine wave does not change fast enough.

Step 5

<table>
<thead>
<tr>
<th>Point 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{th}^-$ = .9 VDC</td>
</tr>
<tr>
<td>$V_{th}^+$ = 1.7 VDC</td>
</tr>
</tbody>
</table>

Table 2-1

Step 7

<table>
<thead>
<tr>
<th>Waveform</th>
<th>At Point 1</th>
<th>At Point 2</th>
<th>Is the Flip-Flop Toggling (Yes, No)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circuit (a)</td>
<td></td>
<td></td>
<td>NO</td>
</tr>
<tr>
<td>Circuit (b)</td>
<td></td>
<td></td>
<td>YES</td>
</tr>
</tbody>
</table>

Table 2-2

Experiment Questions
1. - Convert electronic signals to square waves.
   - Perform NAND gate and Inverter logic functions.
2. D.
3. edge
4. Low, High
5. hysteresis
6. Because when sine waves are counted, they must be converted to square waves before being applied to a flip-flop.
Magnitude Comparator

Procedure Question Answer

1. If the high order bits are equal, then the output state is determined by comparing the low order bits.

Step 2A

<table>
<thead>
<tr>
<th>Input B</th>
<th>Input A</th>
<th>Outputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>B3 B2 B1 B0</td>
<td>A3 A2 A1 A0</td>
<td>A&lt;B A=B A&gt;B</td>
</tr>
<tr>
<td>0 0 0 0</td>
<td>0 0 0 0</td>
<td>0 1 0</td>
</tr>
<tr>
<td>0 1 0 0</td>
<td>0 0 0 0</td>
<td>1 0 0</td>
</tr>
<tr>
<td>1 0 0 1</td>
<td>1 0 0 0</td>
<td>1 0 0</td>
</tr>
<tr>
<td>0 0 1 1</td>
<td>0 1 0 0</td>
<td>0 0 1</td>
</tr>
<tr>
<td>0 0 0 1</td>
<td>1 1 0 1</td>
<td>0 1 0</td>
</tr>
</tbody>
</table>

Table 3-2

Step 3B

<table>
<thead>
<tr>
<th>Input B</th>
<th>Input A</th>
<th>Expansion Inputs</th>
<th>Outputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>B3 B2 B1 B0</td>
<td>A3 A2 A1 A0</td>
<td>I_A&lt;B I_A=B I_A&gt;B</td>
<td>A&lt;B A=B A&gt;B</td>
</tr>
<tr>
<td>0 0 0 0</td>
<td>1 1 1 1</td>
<td>1 0 0</td>
<td>0 1 0</td>
</tr>
<tr>
<td>0 0 0 1</td>
<td>0 0 0 1</td>
<td>0 0 1</td>
<td>0 0 1</td>
</tr>
<tr>
<td>0 1 1 0</td>
<td>0 1 1 0</td>
<td>0 1 0</td>
<td>0 1 0</td>
</tr>
<tr>
<td>1 1 1 0</td>
<td>1 1 0 1</td>
<td>0 0 1</td>
<td>1 0 0</td>
</tr>
<tr>
<td>0 1 0 1</td>
<td>1 1 1 0</td>
<td>0 1 0</td>
<td>0 0 1</td>
</tr>
</tbody>
</table>

Table 3-4

Experiment Questions

1. 1111
2. Yes. By connecting a Low to the MSB of inputs A and B, and applying the three binary bits to the remaining inputs.
3. I_A > B = 0
   I_A = B = 0
   I_A < B = 1
4. 4
5. When A is greater than B, or B is greater than A, the circuit would operate normally. When A is equal to B, however, output A<B would incorrectly go High—instead of output A=B.
SCR Phase Control Circuit

Step 3 169 volts, yes
Step 4 15 volts, yes

Experiment Questions
1. D.
2. B.
3. 169–15 = 154
4. A.
5. B.
6. B.

Figure 4-1
Photoresistor

Step 1 Dark Resistance = 40KΩ

Step 3 Ambient light voltage = –8V
  Dark Voltage = +7V

Design Question
Switch the position of R₁ with that of the photoresistor.

Experiment Questions
1. A.
2. B.
3. B.
4. B.
5. A.
Experiment 6

Optocoupler

Step 1 1 Meg ohm
Step 2 150 ohms
Step 4

LED
On/Off
Condition $O_v$

Optoisolator
(Transistor)
Output $O_v$

Step 5 B
Step 6 25KHz
Step 7 $I_C = 3.5mA$
   $I_T = 16mA$
   CTR 22%

Experiment Questions
1. True
2. A.
3. A.
4. 25%
5. C.
Procedure Question Answers

1. A.
2. A.
3. $16 \times (2^4)$
4. 1
5. Eight different voltage levels. When an open is at the LSB input, a binary 1 is always applied to the LSB digital input lead of the D/A converter. This causes the D/A converter to produce the following counts:

<table>
<thead>
<tr>
<th>Desired Count</th>
<th>Count with Pin 12 Open</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>14</td>
<td>15</td>
</tr>
<tr>
<td>15</td>
<td>15</td>
</tr>
</tbody>
</table>
6. 32
   The number of outputs is determined by multiplying 2 by the power of the num-
   ber of inputs applied to the digital input of the D/A converter \(2^5\).

**Experiment Questions**

1. 256
2. 1
3. - Change V\(_{\text{REF}}\) applied to pin 14.
   - Change the resistor value connected to pin 14.
   - Change the R\(_F\) resistor connected to pin 4.
### Experiment 8

#### Analog-to-Digital Converter

**Procedure Question Answer**

1. They should be equal.

**Step 4**

<table>
<thead>
<tr>
<th>Input Measured Analog Voltage</th>
<th>Resolution Values</th>
<th>Output</th>
<th>Resolution Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DB7 2.56V DB6 1.28V DB5 0.64V DB4 0.32V DB3 0.16V DB2 0.08V DB1 0.04V DB0 0.02V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0V</td>
<td>0 0 0 0 0 0 0 0</td>
<td>0 0</td>
<td>0V</td>
</tr>
<tr>
<td>0.4V</td>
<td>0 0 0 1 0 1 0 0</td>
<td>0 0</td>
<td>0.4V</td>
</tr>
<tr>
<td>1.0V</td>
<td>0 0 1 1 0 1 0 0</td>
<td>0 0</td>
<td>1.0V</td>
</tr>
<tr>
<td>1.6V</td>
<td>0 1 0 1 0 0 0 0</td>
<td>0 0</td>
<td>1.6V</td>
</tr>
<tr>
<td>2.3V</td>
<td>0 1 1 1 0 0 1 1</td>
<td>0 0</td>
<td>2.3V</td>
</tr>
<tr>
<td>3.5V</td>
<td>1 0 1 0 1 1 1 1</td>
<td>1 1</td>
<td>3.5V</td>
</tr>
<tr>
<td>4.6V</td>
<td>1 1 1 0 0 1 1 1</td>
<td>1 1</td>
<td>4.6V</td>
</tr>
<tr>
<td>5.12V</td>
<td>1 1 1 1 1 1 1 1</td>
<td>1 1</td>
<td>5.12V</td>
</tr>
</tbody>
</table>

Table 8-1

**Experiment Questions**

1. 8
2. 0.39
3. Low
4. 00110010
555 Clock Timer (Astable Multivibrator)

Step 1

<table>
<thead>
<tr>
<th>RA (Ω)</th>
<th>RB (Ω)</th>
<th>C1(µf)</th>
<th>( f = \frac{1.44}{(R_A + 2R_B)C} ) calculated (Hz)</th>
<th>Fout (Frequency Out) Measured (Hz)</th>
<th>Chart Values (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>47k</td>
<td>10k</td>
<td>1</td>
<td>21</td>
<td>15</td>
<td>25</td>
</tr>
<tr>
<td>22k</td>
<td>10k</td>
<td>1</td>
<td>34.3</td>
<td>23</td>
<td>30</td>
</tr>
<tr>
<td>22k</td>
<td>10k</td>
<td>0.1</td>
<td>343</td>
<td>278</td>
<td>260</td>
</tr>
<tr>
<td>22k</td>
<td>2.2k</td>
<td>0.1</td>
<td>545</td>
<td>435</td>
<td>475</td>
</tr>
<tr>
<td>10k</td>
<td>10k</td>
<td>0.01</td>
<td>4800</td>
<td>4445</td>
<td>4000</td>
</tr>
</tbody>
</table>

Table 9-1

Experiment Questions

1. astable
2. Values of external components
3. Nothing. Just apply power and it runs by itself.
4. They provide pulses that are necessary to time and control the proper sequencing of all events throughout a computing system.
5. 450Hz
6. 900K ohms
555 Clock Pulse (Monostable One-Shot Multivibrator)

Step 3

<table>
<thead>
<tr>
<th>RA (Ω)</th>
<th>C₁ (µf)</th>
<th>( T = 1.1 \frac{R_A C_1}{\text{calculated}} )</th>
<th>( T \text{ measured} )</th>
<th>( T \text{ Chart Value} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1M</td>
<td>10</td>
<td>11 sec</td>
<td>11 sec</td>
<td>11 sec</td>
</tr>
<tr>
<td>470k</td>
<td>10</td>
<td>5.17 sec</td>
<td>5.3 sec</td>
<td>5 sec</td>
</tr>
<tr>
<td>100k</td>
<td>50</td>
<td>5.5 sec</td>
<td>5.7 sec</td>
<td>5 sec</td>
</tr>
<tr>
<td>10k</td>
<td>100</td>
<td>1.1 sec</td>
<td>1.5 sec</td>
<td>1.5 sec</td>
</tr>
<tr>
<td>470k</td>
<td>50</td>
<td>25.9 sec</td>
<td>27.3 sec</td>
<td>25 sec</td>
</tr>
</tbody>
</table>

Table 10-1

Experiment Questions

1. Low, High
2. It automatically does it by itself.
3. - By a mechanical push button
   - By another circuit
4. - Enter numbers into digital circuits
   - Empty numbers out of digital circuits
   - Producing time delay signals
   - Pulse stretchers
   - Bounceless switches
   - Reshaping ragged pulses
5. \( T = 1.1 \times 100K \times 1\text{ufd} \)
   \( = 110 \text{ milliseconds} \)
6. 900 ohms
Integrator Operational Amplifier

Step 4

<table>
<thead>
<tr>
<th>Input</th>
<th>Output after 5 seconds</th>
<th>Output after 10 seconds</th>
<th>Output after 15 seconds</th>
<th>Output after 20 seconds</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 VDC</td>
<td>5.7V</td>
<td>7.1V</td>
<td>8V</td>
<td>8.9V</td>
</tr>
<tr>
<td>2 VDC</td>
<td>9.4V</td>
<td>11.9V</td>
<td>12.5V</td>
<td>12.6V</td>
</tr>
<tr>
<td>3 VDC</td>
<td>9.5V</td>
<td>12.4V</td>
<td>12.6V</td>
<td>12.6V</td>
</tr>
</tbody>
</table>

Note: Voltages are all negative

Table 11-1

Experiment Questions

1. yes
2. A.
3. faster
4. saturation
5. directly, directly
Differentiator Operational Amplifier

Step 8

<table>
<thead>
<tr>
<th>Input is a .4VPP Saw Tooth</th>
</tr>
</thead>
<tbody>
<tr>
<td>300Hz</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>PPK</td>
</tr>
<tr>
<td>Square Wave Outputs</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

Table 12-1

**Experiment Questions**

1. directly
2. A.
3. C.
4. C.
5. 1.75K
Pressure Readings with a Manometer

Step 3B Primary Level = 0
Secondary Level = 0

Step 6B Primary Level = –4
Secondary Level = +4

Step 7B Total Change = 8 inches

Step 8B 8 inches changed x .491 = 3.928
14.7 + 4 (PSIG) = 18.7 psia

Step 5C 8.8 difference in inches

Step 6C 8.8 x .491 = 4.3 psid

Experiment Questions
1. B.
2. B.
3. B.
4. 10.3 – 14.7 = –4.4
5. 3.3 psig + 14.7 = 18 psia
6. Zero
Solid State Pressure Transducer

Step 4A .071

Step 7A

<table>
<thead>
<tr>
<th>PSI</th>
<th>( V_{\text{OUT}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>.070</td>
</tr>
<tr>
<td>3</td>
<td>1.78</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>8</td>
<td>4.83</td>
</tr>
<tr>
<td>10</td>
<td>6</td>
</tr>
</tbody>
</table>

Step 7B

<table>
<thead>
<tr>
<th></th>
<th>High Pressure</th>
<th>Low Pressure</th>
<th>Differential Pressure</th>
<th>( V_{\text{OUT}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>B.</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>.72</td>
</tr>
<tr>
<td>C.</td>
<td>5</td>
<td>2</td>
<td>3</td>
<td>1.5</td>
</tr>
<tr>
<td>D.</td>
<td>6</td>
<td>2</td>
<td>4</td>
<td>2.0</td>
</tr>
<tr>
<td>E.</td>
<td>8</td>
<td>2</td>
<td>6</td>
<td>3.36</td>
</tr>
<tr>
<td>F.</td>
<td>10</td>
<td>2</td>
<td>8</td>
<td>4.66</td>
</tr>
<tr>
<td>G.</td>
<td>12</td>
<td>2</td>
<td>10</td>
<td>6</td>
</tr>
</tbody>
</table>

Experiment Questions

1. D.
2. A., B.
3. A., C.
4. A., B.
5. A.
6. B.
7. A., A.
Conversion of Standard Signals

Step 3A

<table>
<thead>
<tr>
<th>Calculated Current</th>
<th>Measured Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 psi</td>
<td>8mA</td>
</tr>
<tr>
<td>9 psi</td>
<td>12mA</td>
</tr>
<tr>
<td>12 psi</td>
<td>16mA</td>
</tr>
</tbody>
</table>

Step 3B

<table>
<thead>
<tr>
<th>Calculated Pressure</th>
<th>Measured Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>8mA</td>
<td>6 psi</td>
</tr>
<tr>
<td>12mA</td>
<td>9 psi</td>
</tr>
<tr>
<td>16mA</td>
<td>12 psi</td>
</tr>
</tbody>
</table>

Step 2C

<table>
<thead>
<tr>
<th>Applied Pressure</th>
<th>P/I Output Current</th>
<th>I/P Output Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 psi</td>
<td>4mA</td>
<td>3 psi</td>
</tr>
<tr>
<td>6 psi</td>
<td>8mA</td>
<td>6 psi</td>
</tr>
<tr>
<td>9 psi</td>
<td>12mA</td>
<td>9 psi</td>
</tr>
<tr>
<td>12 psi</td>
<td>16mA</td>
<td>12 psi</td>
</tr>
<tr>
<td>15 psi</td>
<td>20mA</td>
<td>15 psi</td>
</tr>
</tbody>
</table>

Experiment Questions

1. C.
2. D.
3. C., B.
4. E., D.
5. B.
6. B.
Resistance Temperature Detector (RTD)

Step 3

<table>
<thead>
<tr>
<th>RTD</th>
<th>Hot</th>
<th>Cold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual Temperature (Thermometer Reading)</td>
<td>100°C</td>
<td>0°C</td>
</tr>
<tr>
<td>Ohmmeter Reading</td>
<td>136.6Ω</td>
<td>100.2Ω</td>
</tr>
<tr>
<td>Temperature from the Manufacturer’s Table</td>
<td>100°C</td>
<td>0°C</td>
</tr>
<tr>
<td>Temperature Settling Time</td>
<td>1 Min 50 Sec</td>
<td></td>
</tr>
</tbody>
</table>

Table 16-1

Experiment Questions

1. B.
2. A.
3. –80
RTD Transmitter Calibration

**Step 10A** Cold Bath Measurement 0.4°C

**Step 11A** Hot Bath Measurement 99.8°C

**Step 21B**

**CALIBRATION CHART**

<table>
<thead>
<tr>
<th>% of SPAN</th>
<th>Transmitter Input Values</th>
<th>Transmitter Output Values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Temperature Applied</td>
<td>Ideal Current</td>
</tr>
<tr>
<td>0</td>
<td>0°C</td>
<td>4mA</td>
</tr>
<tr>
<td>25</td>
<td>37.5°C</td>
<td>8mA</td>
</tr>
<tr>
<td>50</td>
<td>75°C</td>
<td>12mA</td>
</tr>
<tr>
<td>75</td>
<td>112.5°C</td>
<td>16mA</td>
</tr>
<tr>
<td>100</td>
<td>150°C</td>
<td>20mA</td>
</tr>
</tbody>
</table>

**Step 4C** Cold Bath Temperature 0°C
Transmitter Output Current 4.08mA

**Step 5C** Hot Bath Temperature 100°C
Transmitter Output Current 14mA

**Experiment Questions**

1. A.
2. A.
3. C., E.
4. C.
5. True
Thermistor

Step 1  9,600 ohms
  B.
  B.

Step 7  Before
  Inverting Input = Ideally 4.2 volts
  Non-inverting Input = Ideally 4.1 volts
  Output = Ideally – 2 volts

  After
  Inverting Input = Ideally 4.0 volts
  Non-inverting Input = Ideally 4.1 volts
  Output = Ideally +2 volts

Step 8  No
  No

Experiment Questions

1. B.
2. C., B.
3. B., A.
4. holding
5. B.
## Thermocouple Sensor

### Step 4A

<table>
<thead>
<tr>
<th>Thermocouple</th>
<th>Hot</th>
<th>Cold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual Temperature (Thermometer Reading)</td>
<td>100°C</td>
<td>0.2°C</td>
</tr>
<tr>
<td>mV Reading (Voltmeter Reading)</td>
<td>0.004mV</td>
<td>0.0mV</td>
</tr>
<tr>
<td>Temperature from the Manufacturer Table</td>
<td>80°C</td>
<td>0°C</td>
</tr>
<tr>
<td>Temperature Settling Time</td>
<td>3 Seconds</td>
<td></td>
</tr>
</tbody>
</table>

### Table 19-1

### Step 8A Question: No

### Step 2B

<table>
<thead>
<tr>
<th>Thermocouple</th>
<th>Hot</th>
<th>Cold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual Temperature</td>
<td>100°C</td>
<td>0.2°C</td>
</tr>
<tr>
<td>Thermocouple mV Reading (Voltmeter Reading)</td>
<td>5.1mV</td>
<td>0mV</td>
</tr>
<tr>
<td>Temperature from the Manufacturer Table</td>
<td>100°C</td>
<td>0</td>
</tr>
<tr>
<td>Temperature Settling Time</td>
<td>25 Seconds</td>
<td></td>
</tr>
</tbody>
</table>

### Table 19-3

### Step 7B Question: Yes

### Step 2C

<table>
<thead>
<tr>
<th>Thermocouple</th>
<th>Hot</th>
<th>Cold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual Temperature</td>
<td>100°C</td>
<td>0°C</td>
</tr>
<tr>
<td>Thermocouple mV Reading (Voltmeter Reading)</td>
<td>5.2mV</td>
<td>0</td>
</tr>
<tr>
<td>Temperature from the Manufacturer Table</td>
<td>99°C</td>
<td>0</td>
</tr>
<tr>
<td>Temperature Settling Time</td>
<td>2 Min 50 Sec</td>
<td></td>
</tr>
</tbody>
</table>

### Table 19-4

### Step 7C Questions: same, longer

---

20
Experiment Questions

1. subtract from
2. more
3. longer
4. 104
5. 5.1mV; no, but close enough
Thermocouple Transmitter Calibration

Step 9A
Cold Bath Measurement 0.1°C

Step 10A
Hot Bath Measurement 100°C

Step 20B

<table>
<thead>
<tr>
<th>% of Span</th>
<th>(Transmitter Input Values) Temperature Applied</th>
<th>Transmitter Output Values</th>
<th>Ideal Current</th>
<th>As Found Before Calibration</th>
<th>As Read After Calibration</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0°C</td>
<td>4mA</td>
<td>0mA</td>
<td>0mA</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>37.5°C</td>
<td>8mA</td>
<td>7.24mA</td>
<td>8mA</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>75°C</td>
<td>12mA</td>
<td>11.1mA</td>
<td>12mA</td>
<td></td>
</tr>
<tr>
<td>75</td>
<td>112°C</td>
<td>16mA</td>
<td>15.2mA</td>
<td>16mA</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>150°C</td>
<td>20mA</td>
<td>18.8mA</td>
<td>20mA</td>
<td></td>
</tr>
</tbody>
</table>

Table 20-1

Step 4c
Cold Bath Measurement 0°C
Transmitter Output Current 4.09mA

Step 5c
Hot Bath Temperature 100°C
Transmitter Output Current 14.7mA

Experiment Questions
1. A., E.
2. C.
3. C.
4. D.
5. True
Differential Pressure Flow Measurements

Step 2B

<table>
<thead>
<tr>
<th>Pressures (inches of H₂O)</th>
<th>Calibrator Output (mA)</th>
<th>Differential Pressure (Inches H₂O)</th>
<th>Flow rate (GPM)</th>
<th>Pressure Conversion (PSI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>L-Port</td>
<td>H-Port</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5.5</td>
<td>13.75</td>
<td>6.64</td>
<td>8.25</td>
<td>1018.2</td>
</tr>
<tr>
<td>11</td>
<td>27.5</td>
<td>9.28</td>
<td>16.5</td>
<td>2036.1</td>
</tr>
<tr>
<td>16.5</td>
<td>41.25</td>
<td>11.92</td>
<td>24.75</td>
<td>3054.65</td>
</tr>
<tr>
<td>22</td>
<td>55</td>
<td>14.56</td>
<td>33</td>
<td>4072.86</td>
</tr>
</tbody>
</table>

Table 21-1

Experiment Questions

1. A., B.
2. Zero
3. Heating, ventilating, air conditioning
4. C.
5. A., B., A.
6. C., E.
Purge Level Measurement Method

Step 2B

<table>
<thead>
<tr>
<th>Water Level in Inches</th>
<th>Display Module Reading</th>
<th>P/I Converter Output</th>
<th>Static Pressure Head</th>
<th>Calculated Water Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>4 mA</td>
<td>0 psi</td>
<td>0 inches</td>
</tr>
<tr>
<td>25</td>
<td>25</td>
<td>12 mA</td>
<td>0.9 psi</td>
<td>25 inches</td>
</tr>
<tr>
<td>50</td>
<td>50</td>
<td>20 mA</td>
<td>1.8 psi</td>
<td>50 inches</td>
</tr>
</tbody>
</table>

Table 22-1

Experiment Questions

1. A.
2. 4mA, 0 psi, 0 inches
3. 20mA, 1.8psi, 50 inches
4. .7 psi x 27.71 = 19.4 inches
5. 78 inches x 0.036 = 2.8 psi
Differential Pressure Level Measurements

Step 5

<table>
<thead>
<tr>
<th>Water Level Inches/%of Span</th>
<th>Head Pressure</th>
<th>Ideal</th>
<th>As Found Before Calibration</th>
<th>As Read After Calibration</th>
<th>% Error</th>
<th>Error</th>
<th>Level Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>0/0</td>
<td>0</td>
<td>3</td>
<td>3.7</td>
<td>3</td>
<td>5.83</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>12.5/25</td>
<td>0.42</td>
<td>6</td>
<td>7.7</td>
<td>6</td>
<td>14.16</td>
<td>0</td>
<td>12.5</td>
</tr>
<tr>
<td>25/50</td>
<td>0.84</td>
<td>9</td>
<td>11.5</td>
<td>9</td>
<td>20.83</td>
<td>0</td>
<td>25</td>
</tr>
<tr>
<td>37.5/75</td>
<td>1.26</td>
<td>12</td>
<td>15.4</td>
<td>12</td>
<td>28.3</td>
<td>0</td>
<td>37.5</td>
</tr>
<tr>
<td>50/100</td>
<td>1.68</td>
<td>15</td>
<td>19.2</td>
<td>15</td>
<td>35.0</td>
<td>0</td>
<td>50</td>
</tr>
</tbody>
</table>

Table 23-1

Experiment Questions

1. atmosphere, L
2. D.
3. B., A.
4. 3, 15
5. 25 x .036 = 0.9 psig
6. 1.35 psig x 27.71 = 37.5 inches
7. The pressure produced by the transmitter output is supplied from this source.
pH Measurement and Control

Step 2A pink, acidic
Step 3A blue, alkaline
Step 1B A.
Step 2B B.
Step 3B C.
Step 4B B.
Step 5B A.
Step 2C 10.1, B.
Step 3C

<table>
<thead>
<tr>
<th>Reagent</th>
<th>pH Reading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before drops</td>
<td>10.1</td>
</tr>
<tr>
<td>After 10 drops</td>
<td>9.68</td>
</tr>
<tr>
<td>After 20 drops</td>
<td>6.27</td>
</tr>
<tr>
<td>After 30 drops</td>
<td>3.13</td>
</tr>
<tr>
<td>After 40 drops</td>
<td>2.65</td>
</tr>
<tr>
<td>After 50 drops</td>
<td>2.57</td>
</tr>
</tbody>
</table>

The solution becomes neutralized as an acid solution is added.

Step 6C 3.32, A.
Step 7C

<table>
<thead>
<tr>
<th>Reagent</th>
<th>pH Reading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before drops</td>
<td>3.32</td>
</tr>
<tr>
<td>After 10 drops</td>
<td>3.34</td>
</tr>
<tr>
<td>After 20 drops</td>
<td>3.60</td>
</tr>
<tr>
<td>After 30 drops</td>
<td>3.68</td>
</tr>
<tr>
<td>After 40 drops</td>
<td>3.86</td>
</tr>
<tr>
<td>After 50 drops</td>
<td>3.96</td>
</tr>
</tbody>
</table>

The solution becomes neutralized as an alkaline solution is added.
### Experiment Questions

1. B.
2. 7
3. C.
4. A.
5. C.
6. B.
Conductivity Measurements

Step 1A

<table>
<thead>
<tr>
<th>Water Supply Sources</th>
<th>Conductivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab Tap Water</td>
<td>.4mS</td>
</tr>
<tr>
<td>Distilled Water</td>
<td>.2mS</td>
</tr>
<tr>
<td>Hard Water</td>
<td>1.6mS</td>
</tr>
<tr>
<td>Softened Water</td>
<td>4.3mS</td>
</tr>
</tbody>
</table>

Table 25-1

Step 2A

*Most Impurities: Softened*

*Fewest Impurities: Distilled*

<table>
<thead>
<tr>
<th>Container</th>
<th>pH Readings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brine Solution A</td>
<td>6.35</td>
</tr>
<tr>
<td>Brine Solution B</td>
<td>6.40</td>
</tr>
<tr>
<td>Brine Solution C</td>
<td>6.45</td>
</tr>
</tbody>
</table>

Table 25-2

<table>
<thead>
<tr>
<th>Container</th>
<th>Conductivity Readings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brine Solution A</td>
<td>18.8</td>
</tr>
<tr>
<td>Brine Solution B</td>
<td>24</td>
</tr>
<tr>
<td>Brine Solution C</td>
<td>40</td>
</tr>
</tbody>
</table>

Table 25-3

Experiment Questions

1. A.
2. B.
3. B.
4. C.
5. False
Humidity Measurements

Step 3A

<table>
<thead>
<tr>
<th>Wet Bulb Reading</th>
<th>Dry Bulb Reading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reading One</td>
<td>57</td>
</tr>
<tr>
<td>Reading Two</td>
<td>56</td>
</tr>
<tr>
<td>Reading Three</td>
<td>55</td>
</tr>
</tbody>
</table>

Step 4A

Relative Humidity 38%

Step 2B

Dew Point Measurements

| Reading One | 12 |
| Reading Two | 13 |
| Reading Three | 12 |
| Reading Four | 11 |

Step 3B

Average Temperature 12

Step 4B

Grams per cubic meter 18.143

Step 5B

Grams per cubic meter 10.574

Step 6B

RH Percentage 58.3

Experiment Questions

1. A.
2. B.
3. A.
4. B.
5. B.
6. C.
Inductive Proximity Sensor

Step 3A

<table>
<thead>
<tr>
<th>Type of Target</th>
<th>Sensing Distance</th>
<th>Ferrous/Non-Ferrous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plastic</td>
<td>Won't Sense</td>
<td>No</td>
</tr>
<tr>
<td>Brass</td>
<td>2mm</td>
<td>No</td>
</tr>
<tr>
<td>Glass</td>
<td>Won't Sense</td>
<td>No</td>
</tr>
<tr>
<td>Mild Steel</td>
<td>4mm</td>
<td>Yes</td>
</tr>
<tr>
<td>Aluminum</td>
<td>1mm</td>
<td>No</td>
</tr>
</tbody>
</table>

Table 27-1

Step 6A C
Step 8A Yes
Step 9A 4mm
Step 10A 2mm, A
Step 2B 100 Hz
Step 3B 200 Hz
Step 4B 420 Hz

Experiment Questions
1. A.
2. B.
3. B.
4. A.
5. A.
6. Switching frequency
Capacitive Proximity Sensor

Step 3A

<table>
<thead>
<tr>
<th>Material</th>
<th>Distance (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass</td>
<td>11</td>
</tr>
<tr>
<td>Plastic</td>
<td>10</td>
</tr>
<tr>
<td>Water</td>
<td>15</td>
</tr>
</tbody>
</table>

Table 28-1

Step 8A 15mm
Step 9A Yes
Step 10A 11mm
Step 11A A.
Step 1C Yes
Step 3C No

Experiment Questions
1. B.
2. C.
3. B., A.
4. A., B.
5. B., A.
6. B.
Hall Effect Sensor

Step 10 3
Step 11 with

Experiment Questions

1. D.
2. • Strength of the magnet
   • The position a magnet is placed with respect to the sensor
   • By using a concentrator
3. • 2 terminals connect to a power supply
   • 2 terminals are the output leads
4. C.
5. A. Increases
6. A., B.
Experiment 30

Ultrasonic Sensor

Step 2A  10, 13, 7

Part B

3 inches
40 inches
4 inches
30 inches
yes

Step 1B  4 blinks

Step 2B  5 blinks

Step 3B  10 volts
         0 volts
         5 volts

Step 4B  0 volts
         10 volts
         is

Step 5B  10 inches = 0 volts
         12 inches = 2 volts
         14 inches = 4 volts
         16 inches = 6 volts
         18 inches = 8 volts
         20 inches = 10 volts

Experiment Questions

1. 15 minutes
2. 12 blinks
3. 30 inches
4. 152-1016
5. 10 volts
Opposed Sensing Optical Method

Step 6A
   Off

Step 9A
   Off

Step 11A
   On

Step 7B
   2 Sheets of paper

Step 8B
   No, 4 sheets of paper

Step 11B
   ¼ inch

Experiment Questions

1. D.
2. True
3. C.
4. B.
5. C.
6. True
Retro-reflective Optical Sensing

Step 7A
10°

Step 8A
35°

Step 3B
No

Step 4B
largest

Step 6B
15, 17, Plastic reflector

Step 2C
Yes

Step 3C
No

Step 4C
Yes

Step 5C
Yes

Step 6C
No

Step 7C
No

Step 8C
Yes

Step 9C
Yes
Step 13C
No

Step 14C
Blocked,Blocked

Experiment Questions
1. 30°
2. B.
3. A.
4. A.
5. C.
6. A., C., D.
7. A.
Diffuse Optical Sensing Method

Step 7A  Gray  16
         Black  15
         Red    17
         White  18

Step 9A  13”

Step 10A Black  12
         Red    14
         White  15

Step 12A Gray  13
         Black  11
         Red    14
         White  15

Step 13A 10”
Step 14A  4”
Step 15A 2”
         8”
         Yes

Step 2B  18”
Step 3B  15”
Step 4C  no
Step 3D  Yes
Step 4D  No
Step 7E  13mm
Step 9E  8mm
decrease

Experiment Questions

1. A. 5. A., B.
2. B. 6. B.
3. B. 7. C.
4. 3 8. B.
Timing Functions of Sensors

Step 6A
1.5 seconds

Step 8A
3 seconds

Step 11A
12 seconds

Step 13 A
22 seconds

Step 3B
A.

Step 4B
B.

Step 2C
No, 0 seconds

Step 3C
12 seconds

Step 5C
12 second, No

Experiment Questions
1. A.
2. B.
3. C.
4. DNM
   L
   DNM
   Fully CW
5. C.
Sensor Output Wiring

Step 1A  No, Off
Step 2A  1.44mA
Step 3A  Yes, On
Step 4A  10.4mA
Step 1B  Off
Step 2B  No
Step 3B  On, Yes, 18.5
Step 4B  into, sinking
Step 5B  No
Step 6B  No
Step 7B  On, Yes, 15.7mA
Step 8B  out of, sourcing
Step 2C  .04 volts. No
Step 3C  22.86 volts, 1.13 volts
Step 4C  No
Step 5C  Yes
Step 6C  21.94 volts, 2.06 volts, 14 sensors
Step 8C  Off, 0mA
Step 9C  On, 16.72mA
Step 10C  79mA, A

Experiment Questions

1. Brown D.
   Blue A.
   White B.
   Black C.

2. A.
3. B.
4. B.
5. 7
6. B.
Ladder Logic Design Exercise

ANSWERS

1. L1

L2

2. L1

L2

3. L1

L2
Experiment 36  Ladder Logic Design Exercise

4.

5.

6.
Experiment 36  Ladder Logic Design Exercise

7.

Experiment 36  Ladder Logic Design Exercise

8.
9. \( L_1 \)

\[ \begin{array}{c}
\text{CR1} \\
\text{TD1} \\
\text{W} \\
\end{array} \]

\( L_2 \)

10. \( L_1 \)

\[ \begin{array}{c}
\text{CR1} \\
\text{CR2} \\
\text{W} \\
\end{array} \]

\( L_2 \)
Programmable Controller Design Exercise

1. LADDER DIAGRAM DUMP

START

01115  11011

/[/ [ [ ] [ [ [ ] 001114 ]

11012

] [ ]

--- END 0137

11011 - N.O. Start PB
11012 - N.O. Stop
( ) 01114 - Output Coil and Solenoid
] [ 01114 - Latching Contact
( ) 01115 - Output Coil
[/[ 01115 - NC Stop Contact
2. **LADDER DIAGRAM DUMP**

START

11011 11012

\[ \text{01112} \]

\[ \text{01112} \]

END 0135

11011 - Maintained input represented by a toggle switch
11012 - N.O. PB representing a momentary input
( ) 01112 - Output Coil representing output
[ 01112 - Latching Contact

3. **LADDER DIAGRAM DUMP**

START

11012 11014 11013

\[ \text{01100} \]

\[ \text{11011 11016} \]

END 0137

11012 - LSI
11013 - PSI
11014 - TI
11011 - PBI
11016 - T2
01101 - Indicator Lamp representing output
4. LADDERR DIAGRAM DUMP

START

11012  11011
  )/  [  ]
    02000

11011
  [  ]
  02000

02000  02001
  )/  [  ]
    01114

01114
  [  ]
  01100

---END 0142

11012 - NC Stop PB (Wired N.O. Switch)
11011 - Start PB
02000 - Internal Output Coil
02000 - Latching Contact
02001 - Internal Output Coil
01114 - Output Coil and Relay to represent output
01114 - Contact energized by Output Coil
01100 - Output Light (used in addition to Relay to represent output)

5. LADDERR DIAGRAM DUMP

START

11017
  [  ]

035
  (TON)
  1.0
  PR 010
  AC 010

03515 11017
  )/  [  ]
    01100

---END 0133

11017 - Toggle Switch representing maintained input
035 - Timer On (Output turns to a "|" state 10 sec. after an input is supplied)
03515)/[ - N.C. Contact controlled by output of timer
01100 - Indicator Light representing output
6. LADDER DIAGRAM DUMP

START
11012
] [ ]
02001
] [ ]
02001
] [ ]
035
(TOF)
1.0
PR 010
AC 010
02001 03515
] [/ ] [ ]
01100
] [ ]
02001 03515
] [ ]
END 0135

11012 - On/Off Toggle input switch
( ) 02001 - Internal Output
] [ 02001 - Contact
035 (TOF) - Timer Off (Output goes to a "|" state as soon as a "|" state input is applied. The output will remain "HIGH" for 10 seconds after input is removed)
01100 - Indicator Lamp representing output
Experiment 37  Programmable Controller Design Exercise

7. LADDER DIAGRAM DUMP

START

11011 11012             02000  
                  ( )

02000

02000  

035 (TON)

03515 02000  

01100  

END 0140

11011 - Momentary N.O. Input P.B.
11012 - N.C. Stop P.B. (Wired N.O.)
( ) 02000 - Internal Output Coil
] [ 02000 - Latching Contact

035 - Timer On (Output turns to a "|" state 10 seconds after a "HIGH" input is applied)

03515 - N.C. Contact energized from output of Timer

01100 - Indicator Lamp representing output
8. LADDER DIAGRAM DUMP

START
03615

[ ] [ ]
(TON)
1.0
PR 001
AC 001

03515

[ ] [ ]
(TON)
1.0
PR 002
AC 001

03515

[ ] [ ]
01100

END 0134

035 and 036 - Timer On (Output turns to a "|" state 10 seconds after a "HIGH" input is applied)

03515 and 03516 - Contacts controlled by the outputs of each timer

01100 - Indicator lamp representing output
9. LADDER DIAGRAM DUMP

START

11013 11011 02002 03515 02000
[ ] [ ] [ ] [ ]
11012
[ ]

02000 02003 02001
[ ] [ ]

02001 02000
[ ] [ ]

02001 02000 03515 02002
[ ] [ ] [ ]

03515 02000 02003
[ ] [ ]

02000
[ ]

03515
[ ]

END 0158

11011 - LSI
11013 - Pressure Switch
11012 - PBI
02000 - Internal Output
02001 - Internal Output
02002 - Internal Output
02003 - Internal Output
035 - Timer Off (Output goes to a "|") state as soon as a "|") state input is applied. The output will remain HIGH for 10 seconds after the input is removed)
03515 - N.O. and N.C. Contacts that are energized by the output of the timer
01100 - Indicator Lamp representing SV1
01101 - Indicator Lamp representing SV2
10. LADDER DIAGRAM DUMP

START

11002 11001 01101 02000 11010 01100

02000

11011 11012 01100 02000 11010 01101

0149

END

11002 - N.C. P.B. Stop Switch to stop Forward Motor (Wired N.O.)
11011 - N.C. P.B. Stop Switch to stop Reverse Motor (Wired N.O.)
11001 - N.O. Forward Start P.B.
11012 - N.O. Reverse Start P.B.
( ) 01100 - Indicator Lamp representing Forward Motor
] [ 01100 - Latch Contact
( ) 01101 - Indicator Lamp representing Reverse Motor
] [ 01101 - Latch Contact
02000 - Internal Output which deenergizes entire circuit if low voltage occurs
11. LADDER DIAGRAM DUMP

START
11011 02000 01100
] [ [ ] [ [ )
01100 01101
] [ [ )
11012
] [ ] 02000
] [ [ )
11011 02000 01101
] [ [ ] [ [ )
01101 01100
] [ [ )
END 0146

11001 - N.O. Forward P.B.
11011 - N.O. Reverse P.B.
11012 - N.C. Stop P.B. (Wired N.O.)
( ) 01100 - Indicator Lamp and Coil representing Forward direction
( ) 01101 - Indicator Lamp and Coil representing Reverse direction
02000 - Internal Output which deenergizes entire circuit if LOW voltage occurs
12. LADDER DIAGRAM DUMP

START

11000 11001

\[
\begin{array}{c}
\text{11011 02000 01101} \\
\text{02001 01102} \\
\text{11012 02000 01102} \\
\text{02002 01101} \\
\text{01101 01102} \\
\text{02001} \\
\text{01102 01101} \\
\text{02002} \\
\end{array}
\]

END 0165

11000 - N.C. System Power Stop P.B. (Wired N.O.)
11001 - N.O. System Power Start P.B.
02000 - Internal Output representing main power for planer table
11011 - LSI to indicate end of travel to right
11012 - LS2 to indicate end of travel to left
01101 - Indicator Lamp that represents right directional travel
01102 - Indicator Lamp that represents left directional travel

The two bottom rungs ensure that the table will resume the same direction of travel when power is restored after power has been interrupted.
Incremental Encoder

Step 3 64, $360^\circ/256$ counts $= 1.4^\circ$ per count

Step 4 Yes

Step 5 No
The number of pulses produced during one revolution does not equal the maximum count in the counters.

Step 6 No
The number of pulses produced during one revolution does not equal the maximum count in the counters.

Step 7 No

Step 8 128, Yes

Experiment Questions

1. B.
2. A.
3. B.
4. B.
5. B.
Experiment 39

Absolute Encoder

Step 4

<table>
<thead>
<tr>
<th>Column A</th>
<th></th>
<th>Column B</th>
<th></th>
<th>Column C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Gray Code</td>
<td></td>
<td>Dial Range</td>
</tr>
<tr>
<td></td>
<td></td>
<td>L1–L4</td>
<td></td>
<td>(In Degrees)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F11 F12 F13 F14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L1</td>
<td>L2</td>
<td>L3</td>
<td>L4</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0 0</td>
<td>0</td>
<td>0˚ to 22½˚</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0 1</td>
<td>1</td>
<td>23˚ to 45½˚</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>1 0</td>
<td>1</td>
<td>46˚ to 68½˚</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1 0</td>
<td>0</td>
<td>69˚ to 89½˚</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1 1</td>
<td>0</td>
<td>90˚ to 111½˚</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1 1</td>
<td>1</td>
<td>112˚ to 132½˚</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0 1</td>
<td>0</td>
<td>133˚ to 154½˚</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0 0</td>
<td>0</td>
<td>155˚ to 181½˚</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>0 0</td>
<td>0</td>
<td>182˚ to 202½˚</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>0 1</td>
<td>1</td>
<td>203˚ to 225½˚</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1 0</td>
<td>0</td>
<td>226˚ to 245½˚</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1 1</td>
<td>0</td>
<td>246˚ to 269½˚</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>1 0</td>
<td>0</td>
<td>270˚ to 292½˚</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>1 1</td>
<td>0</td>
<td>293˚ to 314½˚</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>1 0</td>
<td>1</td>
<td>315˚ to 337˚</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0 0</td>
<td>0</td>
<td>337½˚ to 360˚</td>
</tr>
</tbody>
</table>

Table 39-1

Experiment Questions
1. True
2. A.
3. \(2^6 = 360/64 = 5.625\)
4. B.
5. B.
Step 2B  992 RPM

<table>
<thead>
<tr>
<th>Generator Load Motor</th>
<th>Motor Speed Before IR Comp Adjustment</th>
<th>Motor Speed After IR Comp Adjustment</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0A</td>
<td>1000 RPM</td>
<td>1040 RPM</td>
</tr>
<tr>
<td>0.2A</td>
<td>992</td>
<td>1032</td>
</tr>
<tr>
<td>0.4A</td>
<td>973</td>
<td>1024</td>
</tr>
<tr>
<td>0.6A</td>
<td>942</td>
<td>1017</td>
</tr>
<tr>
<td>0.8A</td>
<td>912</td>
<td>1011</td>
</tr>
<tr>
<td>1.0A</td>
<td>879</td>
<td>1007</td>
</tr>
</tbody>
</table>

Table 40-1

Step 2C  C. Armature current stays constant  
B. Motor speed decreases

Step 3D  B.

Step 4D  The motor takes a long time to speed up or to slow down.

Experiment Questions

1. B.
2. B., A.
3. A.
4. A.
5. C.
6. C.
7. C.
**Procedure Questions**

6A -13
7A +13, opposite

**Experiment Questions**

1. A.
2. True
3. B.
4. B.
Time Proportioning DC Circuit

<table>
<thead>
<tr>
<th>Potentiometer Setting</th>
<th>Approximate Duty Cycle</th>
<th>Calculated Average DC Voltage (Pk On-Time Volts x DutyCycle)</th>
<th>Measure Average DC Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>0V</td>
<td>0</td>
<td>0V</td>
<td>0V</td>
</tr>
<tr>
<td>2.5V</td>
<td>25</td>
<td>2.5V</td>
<td>2.5V</td>
</tr>
<tr>
<td>5.0V</td>
<td>50</td>
<td>5.0V</td>
<td>5.0V</td>
</tr>
<tr>
<td>7.5V</td>
<td>75</td>
<td>7.5V</td>
<td>7.5V</td>
</tr>
<tr>
<td>10.0V</td>
<td>100</td>
<td>10V</td>
<td>10V</td>
</tr>
</tbody>
</table>

Table 42-1

Experiment Questions
1. B.
2. B., A.
3. C.
4. A.
## Time Proportioning AC Circuit

<table>
<thead>
<tr>
<th>Potentiometer Setting</th>
<th>Relay Input Waveform TP₂</th>
<th>Number of AC Cycles Across Lightbulb During 1 Period TP₃</th>
<th>Lightbulb Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>0V</td>
<td></td>
<td>0</td>
<td>None</td>
</tr>
<tr>
<td>2.5V</td>
<td></td>
<td>2 to 3</td>
<td>Low</td>
</tr>
<tr>
<td>5.0V</td>
<td></td>
<td>5</td>
<td>Medium</td>
</tr>
<tr>
<td>7.5V</td>
<td></td>
<td>7 to 8</td>
<td>Brighter</td>
</tr>
<tr>
<td>10.0V</td>
<td></td>
<td>10</td>
<td>Brightest</td>
</tr>
</tbody>
</table>

Table 43-1

### Experiment Questions

1. B.
2. C.
3. A.
4. A.
Unijunction Transistor (UJT)

Experiment 44

Experiment Questions
1. B., A.
2. A., A.
3. A., B.
4. A.
5. C.
6. B.

<table>
<thead>
<tr>
<th>Condition</th>
<th>$V_E$</th>
<th>$V_{B1}$</th>
<th>$V_{B2}$</th>
<th>$I_{E} = I_{B1} - I_{B2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before firing</td>
<td>$&lt; V_p$</td>
<td>0</td>
<td>11.9</td>
<td>0 mA</td>
</tr>
<tr>
<td>After firing</td>
<td>$V_V = .7$</td>
<td>11.4</td>
<td>7 mA</td>
<td>6 mA</td>
</tr>
</tbody>
</table>

$|I_B = \frac{V}{R}|
|I_B2 = \frac{-V_V}{R_B2}|

\[ f \approx \frac{1}{R_E C_E} \text{ hertz} \]

<table>
<thead>
<tr>
<th>$R_E$ (kΩ)</th>
<th>$C_E$ (µF)</th>
<th>$f = \frac{1}{R_E C_E}$ (hertz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculated</td>
<td>Measured</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>0.1</td>
<td>625</td>
</tr>
<tr>
<td>22</td>
<td>0.1</td>
<td>455</td>
</tr>
<tr>
<td>47</td>
<td>0.1</td>
<td>213</td>
</tr>
<tr>
<td>16</td>
<td>0.2</td>
<td>312</td>
</tr>
<tr>
<td>16</td>
<td>0.05</td>
<td>1250</td>
</tr>
</tbody>
</table>
Silicon Controlled Rectifier (SCR)

Experiment Questions

1. B.
2. B.
3. A.
4. A.
5. holding current

<table>
<thead>
<tr>
<th>$S_1$ condition</th>
<th>$S_2$ condition</th>
<th>$V_G$</th>
<th>$V_A$</th>
<th>Condition of SCR (on or off)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>A</td>
<td>0</td>
<td>10</td>
<td>off</td>
</tr>
<tr>
<td>B</td>
<td>A</td>
<td>.7</td>
<td>.8</td>
<td>on</td>
</tr>
<tr>
<td>A</td>
<td>A</td>
<td>.7</td>
<td>.8</td>
<td>on</td>
</tr>
<tr>
<td>A</td>
<td>B</td>
<td>0</td>
<td>10</td>
<td>off</td>
</tr>
<tr>
<td>A</td>
<td>A</td>
<td>0</td>
<td>10</td>
<td>off</td>
</tr>
</tbody>
</table>

(b)

Figure 45-1


**Experiment 46**

**DIAC/TRIAC (Thyristors)**

**Experiment Questions**

1. A.
2. B.
3. A.
4. B.
5. C.

<table>
<thead>
<tr>
<th>Circuit condition</th>
<th>$V_T$</th>
<th>Condition of Diac (on, off)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before firing</td>
<td>0 to $V_{BO}$</td>
<td>Off</td>
</tr>
<tr>
<td>After firing</td>
<td>27</td>
<td>On</td>
</tr>
</tbody>
</table>

Reverse Diac in circuit

<table>
<thead>
<tr>
<th>Circuit condition</th>
<th>$V_T$</th>
<th>Condition of Diac (on, off)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before firing</td>
<td>0 to $V_{BO}$</td>
<td>Off</td>
</tr>
<tr>
<td>After firing</td>
<td>27</td>
<td>On</td>
</tr>
</tbody>
</table>

(b)

**Figure 46-1**

- $R_s = 1 \, \text{k} \Omega$
- 100 $V_{pp}$ at 60 Hz
- $0^\circ, 90^\circ, 180^\circ, 270^\circ, 360^\circ$
- Use only a single channel of the oscilloscope