ELECTRICAL SAFETY
As an engineer, you will be required to work around electrical and electronic equipment in which dangerously high voltages may be present. Some work may be done in confined places and now is a good time to develop safe working procedures. Among the hazards that may be encountered in this type of work are electric shock, electrical fires, harmful gases that are sometimes generated by faulty electrical and electronic devices, and injuries caused by the improper use of tools. Because of these dangers, one should formulate safe and intelligent work habits since these are as important as the knowledge of electronics. One primary objective should be to recognize and correct dangerous conditions and unsafe acts. Electricity is extremely useful but may also be extremely dangerous, and should be treated with great respect and care.

ELECTRIC SHOCK
Electric shock may cause burns of varying degree, cessation of breathing and unconsciousness, ventricular fibrillation, or cardiac arrest. The following summarizes the approximate range of currents that produce this effect in a 70 kg man for a one to three second exposure to 60 Hz current applied across the hands, and will also apply anytime that current level is applied across the thorax.

THRESHOLD OF PERCEPTION
The threshold of perception is the minimum current that an individual can detect. When the local current density is large enough to excite nerve endings in the skin, the subject feels a tingling sensation. This threshold varies considerably among individuals and according to the measurement conditions. When someone with moistened hands grasps small copper wires, the lowest thresholds are about 0.5 mA for 60 Hz, and 2 to 10 mA for dc currents. Both levels will be accompanied by a slight warming of the skin.

LET–GO CURRENT
For higher levels of current, the nerves and muscles are vigorously stimulated eventually resulting in pain and fatigue. Involuntary contractions of muscles or reflex withdrawals by a subject experiencing any current above threshold may cause secondary physical injuries such as falling off a ladder. As the current increases further, the involuntary contractions of the muscles can prevent the subject from voluntarily withdrawing. The let–go is defined as the maximum current from which the subject can withdraw voluntarily. For men, the 50 percentile for let–go current is 9.5 mA.

RESPIRATORY PARALYSIS
Still higher currents cause involuntary contraction of respiratory muscles severe enough to cause asphyxiation if the current is not interrupted. During let–go experiments, it was observed that respiratory arrest occurs at 18 to 22 mA. Strong involuntary contractions of the muscles and stimulation of the nerves can be painful and cause fatigue if there is long exposure.

VENTRICULAR FIBRILLATION
The heart is susceptible to electric current in a special way that is particularly dangerous. Part of the current passing through the chest flows through the heart. If the magnitude of the current is sufficient to excite only part of the heart muscle, then the normal propagation of electrical activity in the heart muscle is disrupted. Once activity in the ventricles is desynchronized, the pumping action of the heart ceases, and death occurs in minutes.
This desynchronization of the cardiac muscle is called fibrillation. Unfortunately, it does not stop when the current that triggered it is removed. Ventricular Fibrillation is the major cause of death due to electric shock. The threshold for ventricular fibrillation for the average sized man varies from 75 to 400 mA. Normal rhythmic activity will return only if a brief, high current pulse from a defibrillator is applied to simultaneously depolarize all the cells of the heart muscle. After the cells relax together, a normal rhythm usually returns.

**SUSTAINED MYOCARDIAL CONTRACTION**

When the current is high enough, the entire heart muscle contracts. Although the heart stops beating while the current is applied, the normal rhythm resumes when the current is interrupted, just as in defibrillation. Data from ac fibrillation experiments on animals show that minimum currents for complete myocardial contraction are in the range from 1 to 6A. No irreversible damage to the heart is known to result from short exposure to these currents.

**BURNS AND PHYSICAL INJURY**

Very little is known of the effects of currents in excess of 10A, particularly for currents of short duration. Resistive heating causes burns, usually on the skin at the entry points, because the skin resistance is high. Voltages greater than 240V can puncture the skin. The brain and other nervous tissue lose all functional excitability when high currents are passed through them. Also, excessive currents may force muscular contractions that are strong enough to pull the muscle attachment away from the bone.

The above effects are for a 70kg man and for 60 Hz current applied for 1 to 3 seconds to moistened hands grasping a No. 8 copper wire. All values vary widely with body weight and frequency of the current. It is important to remember that current rather than voltage is the criterion of shock intensity. It should be clearly understood that resistance of the body varies greatly. If the skin is dry and unbroken, the body resistance will be quite high, on the order of 150kΩ to 500kΩ. If the skin is moist or broken, the body resistance may drop to as low as 300Ω. Under these conditions, a voltage of 30V may be fatal.
WORKING ON ENERGIZED CIRCUITS

1. Never hurry. Haste may cause accident.
2. Food, beverages, and smoking are prohibited. Smoking is not allowed in any building. Brookdale is a smoke free environment,
3. Make sure that you have adequate illumination.
4. Where practical, use only one hand.
5. If it appears that someone is being shocked, turn off power immediately. Pull the plug on the power cord or do what is necessary to remove power. Do not touch the person until you are sure the power is off.
6. Do not wear loose or flapping clothing. If possible, wear shoes with rubber or nonconducting soles.
7. Do not work on a circuit with wet clothes or hands.
8. All rings, watches, necklaces, and bracelets should be removed before working on equipment. Do not wear clothing that contains exposed zippers or metal buttons. Cutoff shirts should be avoided.
9. Make sure all equipment is properly grounded and never defeat grounded equipment with cheaters. Remove power when making changes to the circuit.
10. Connect the power source last.
11. Disconnect the power source first.
12. Burns from arcs and charged capacitors may be severe and very painful. Always assume that a voltage is present when working on a circuit that has a large capacitor. Make sure that power is off and use a safety shorting probe to short the capacitor leads before working on the circuit. You could make sure the capacitor is discharged by measuring the voltage across the leads.
13. Always assume that circuit sources are alive.
15. When resetting a circuit breaker and applying power to a circuit, close the breaker first and then apply power.
16. Work carefully.
17. Verify your connections and be sure they are correct and secure. Before applying power, check the circuit to assure the circuit is constructed according to the schematic. Anytime you suspect that a circuit is malfunctioning, such as smoke rising from the circuit or foul smells, remove power at once.
18. Never allow your body to become part of the circuit.
19. Never close a switch until all individuals are clear of mechanical equipment and breakers.
20. Open and close switches rapidly. This prevents arcing. Keep your face away from switches and breakers.
21. Apply power long enough to make the desired measurements. Don't walk away from a live circuit.
22. Avoid the possibility of exposing your eyes to electric arcs. They are powerful generators of ultra-violet light, including wavelengths that may cause serious and painful eye injury even with short exposure.
23. Make sure that you connect the correct type of source – either alternating or direct – before you close the circuit.

24. If a fire should start in the Lab, turn off all power if possible and leave the room at once. If the fire is electrical, removing power may cause the fire to extinguish itself before it can be spread to other flammables. **NEVER USE WATER ON AN ELECTRICAL FIRE.** Use only a CO₂ fire extinguisher, or one that states that it may be used on Class C fires. The ATC laboratories are equipped with a sprinkler system. If the sprinkler system turns on, get out of the room at once.
APPENDIX B

NOTE: VAMP SENSES THE CURRENT I2.

SCHEMATIC SYMBOLS
## ENGI 241 SCHEMATIC SYMBOLS

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Fixed Resistor" /></td>
<td>Fixed Resistor</td>
</tr>
<tr>
<td><img src="image" alt="Potentiometer" /></td>
<td>Potentiometer</td>
</tr>
<tr>
<td><img src="image" alt="Capacitor" /></td>
<td>Capacitor</td>
</tr>
<tr>
<td><img src="image" alt="Variable Capacitor" /></td>
<td>Variable Capacitor</td>
</tr>
<tr>
<td><img src="image" alt="Inductor" /></td>
<td>Inductor</td>
</tr>
<tr>
<td><img src="image" alt="Iron Core Inductor" /></td>
<td>Iron Core Inductor</td>
</tr>
<tr>
<td><img src="image" alt="Variable Inductor" /></td>
<td>Variable Inductor</td>
</tr>
<tr>
<td><img src="image" alt="Lamp" /></td>
<td>Lamp</td>
</tr>
<tr>
<td><img src="image" alt="Transformer" /></td>
<td>Transformer</td>
</tr>
<tr>
<td><img src="image" alt="Voltmeter" /></td>
<td>Voltmeter</td>
</tr>
<tr>
<td><img src="image" alt="Ammeter" /></td>
<td>Ammeter</td>
</tr>
<tr>
<td><img src="image" alt="Wattmeter" /></td>
<td>Wattmeter</td>
</tr>
<tr>
<td><img src="image" alt="Voltage Source" /></td>
<td>Voltage Source</td>
</tr>
<tr>
<td><img src="image" alt="Current Source" /></td>
<td>Current Source</td>
</tr>
<tr>
<td><img src="image" alt="Unconnected Cross" /></td>
<td>Unconnected Cross</td>
</tr>
<tr>
<td><img src="image" alt="Connected Cross" /></td>
<td>Connected Cross</td>
</tr>
<tr>
<td><img src="image" alt="Circuit Breaker" /></td>
<td>Circuit Breaker</td>
</tr>
<tr>
<td><img src="image" alt="Fuse" /></td>
<td>Fuse</td>
</tr>
<tr>
<td><img src="image" alt="SPST" /></td>
<td>SPST</td>
</tr>
<tr>
<td><img src="image" alt="Pushbutton" /></td>
<td>Pushbutton</td>
</tr>
<tr>
<td><img src="image" alt="SPDT" /></td>
<td>SPDT</td>
</tr>
<tr>
<td><img src="image" alt="DPST" /></td>
<td>DPST</td>
</tr>
<tr>
<td><img src="image" alt="DPDT" /></td>
<td>DPDT</td>
</tr>
<tr>
<td><img src="image" alt="Rotary Switch" /></td>
<td>Rotary Switch</td>
</tr>
<tr>
<td><img src="image" alt="Diode" /></td>
<td>Diode</td>
</tr>
<tr>
<td><img src="image" alt="Zener Diode" /></td>
<td>Zener Diode</td>
</tr>
<tr>
<td><img src="image" alt="Light Emitting Diode" /></td>
<td>Light Emitting Diode</td>
</tr>
<tr>
<td><img src="image" alt="Earth Ground" /></td>
<td>Earth Ground</td>
</tr>
<tr>
<td><img src="image" alt="Bipolar Transistor" /></td>
<td>Bipolar Transistor</td>
</tr>
<tr>
<td><img src="image" alt="JFET" /></td>
<td>JFET</td>
</tr>
<tr>
<td><img src="image" alt="MOSFET" /></td>
<td>MOSFET</td>
</tr>
<tr>
<td><img src="image" alt="Chassis Ground" /></td>
<td>Chassis Ground</td>
</tr>
</tbody>
</table>
LOGIC SYMBOLS

NAND Gate | NOR Gate | NOT (Inverter) | XNOR Gate
---|---|---|---
AND Gate | OR Gate | NOT (Inverter) | XOR Gate
SIMPSON 260–6XLP

DC Voltage Ranges (full scale) 250 mV, 1.0V, 2.5V, 10V, 25V, 100V, 250V, 500V, and 1000V
Accuracy: ± 2% Full Scale all ranges
Sensitivity: 20,000 ohms/volt

AC Voltage: Ranges (full scale) 2.5V, 10V, 25V, 100V, 250V, 500V, and 1000V
Accuracy: ± 3% Full Scale all ranges
Sensitivity: 5,000 ohms/volt

Frequency Response:

<table>
<thead>
<tr>
<th>DC Current Range (Full Scale)</th>
<th>Voltage Drop (Burden Voltage)</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 50 µA</td>
<td>250 mV</td>
<td>± 1.0% of F.S.</td>
</tr>
<tr>
<td>0 – 0.5 mA</td>
<td>250 mV</td>
<td>± 2.0% of F.S.</td>
</tr>
<tr>
<td>0 – 5 mA</td>
<td>252 mV</td>
<td>± 2.0% of F.S.</td>
</tr>
<tr>
<td>0 – 50 mA</td>
<td>252 mV</td>
<td>± 2.0% of F.S.</td>
</tr>
<tr>
<td>0 – 500 mA</td>
<td>400 mV</td>
<td>± 2.0% of F.S.</td>
</tr>
<tr>
<td>0 – 5 A</td>
<td>250 mV</td>
<td>± 2.0% of F.S.</td>
</tr>
</tbody>
</table>

Ohms Conventional: RX1, RX100, RX1k, and RX10k
Ohms Center: 6, 600, 6000, 60 kΩ
Maximum Scale Reading: 1,000 ohms (RX1)
Accuracy: ±2.5° of an arc on RX1, ±2.0° of an arc on all other ranges.
FLUKE 37 DVM

<table>
<thead>
<tr>
<th>Function</th>
<th>Minimum Display Reading</th>
<th>Maximum Display Reading</th>
<th>Maximum Input</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volts</td>
<td>0.001V</td>
<td>1000V</td>
<td>1000V</td>
</tr>
<tr>
<td>mV</td>
<td>0.1mV</td>
<td>320mV</td>
<td>500V</td>
</tr>
<tr>
<td>Ω</td>
<td>0.1Ω</td>
<td>32.00 MΩ</td>
<td>500V</td>
</tr>
<tr>
<td>nS</td>
<td>0.01nS</td>
<td>32.00 nS</td>
<td>500V</td>
</tr>
<tr>
<td>A</td>
<td>0.01A</td>
<td>20.00A</td>
<td>10A* 600V</td>
</tr>
<tr>
<td>mA</td>
<td>0.01 mA</td>
<td>320.0 mA</td>
<td>320 mA 600V</td>
</tr>
<tr>
<td>µA</td>
<td>0.1 µA</td>
<td>3200 µA</td>
<td>320 mA 600V</td>
</tr>
</tbody>
</table>

* 10A continuous, 20A for 30 seconds.

BURDEN VOLTAGE

The Burden Voltage, VB, is the voltage drop present across an ammeter shunt when a measurement is made. The meter has a typical VB for each range, and the actual reading must be calculated.

<table>
<thead>
<tr>
<th>Range</th>
<th>VB Typical</th>
</tr>
</thead>
<tbody>
<tr>
<td>320 µA</td>
<td>160 mV</td>
</tr>
<tr>
<td>3200 µA</td>
<td>1.6 V</td>
</tr>
<tr>
<td>32 mA</td>
<td>180 mV</td>
</tr>
<tr>
<td>320 mA</td>
<td>1.8 V</td>
</tr>
<tr>
<td>10 A</td>
<td>500 mV</td>
</tr>
</tbody>
</table>

Assume the rest of the circuit can be represented as an equivalent voltage VS, and a single resistor RL. The ammeter is represented by the ammeter shunt resistance RS and the typical voltage drop across the shunt VB. VB at the specific current is calculated based on the typical Burden Voltage which is a full scale reading.

\[
V_B = V_{B\text{TYPICAL}} \left( \frac{\text{READING}}{\text{FULL SCALE}} \right) \times 100\%
\]

The maximum current error due to the Burden Voltage in % is:

\[
\% \text{ Error} = \frac{V_B}{V_S - V_B} \times 100\%
\]

Error in mA = \( I_M \left( \frac{V_B}{V_S - V_B} \right) \)

Example: VS = 15V, RL = 50Ω, IM = 270mA. We are using the 320mA range. Therefore:

\[
V_B = \left( \frac{270 \text{ mA}}{320 \text{ mA}} \right) \times 1.8V = 1.519V
\]

\[
\% \text{ Error} = \frac{1.519}{15 - 1.519} \times 100\% = 11.3\%
\]

Therefore, the true current is 11.3% larger than displayed current for this example. The error in mA is:

\[
\text{Error in mA} = 270 \text{ mA} \left( \frac{1.519V}{15V - 1.519V} \right) = 30.41 \text{ mA}
\]
Therefore, the true current is 30.41 mA larger than the displayed current. The Burden Voltage is an example of the effect of meter loading on the circuit.

<table>
<thead>
<tr>
<th>FUNCTION</th>
<th>RANGE</th>
<th>RESOLUTION</th>
<th>ACCURACY*</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCV</td>
<td>3.200 V</td>
<td>0.001 V</td>
<td>±(1% +1)</td>
</tr>
<tr>
<td></td>
<td>32.00 V</td>
<td>0.01 V</td>
<td></td>
</tr>
<tr>
<td></td>
<td>320.0 V</td>
<td>0.1 V</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1000 V</td>
<td>1 V</td>
<td></td>
</tr>
<tr>
<td>DCmV</td>
<td>320.0 mV</td>
<td>0.1 mV</td>
<td>±(1% +1)</td>
</tr>
<tr>
<td>ACV</td>
<td>3.200 V</td>
<td>0.001 V</td>
<td>40 Hz: ±(0.5% +3)</td>
</tr>
<tr>
<td></td>
<td>32.00 V</td>
<td>0.01 V</td>
<td>2 kHz: ±(0.5% +3)</td>
</tr>
<tr>
<td></td>
<td>320.0 V</td>
<td>0.1 V</td>
<td>10 kHz: ±(1% +3)</td>
</tr>
<tr>
<td></td>
<td>1000 V</td>
<td>1 V</td>
<td></td>
</tr>
<tr>
<td>ACmV</td>
<td>320.0 mV</td>
<td>0.1 mV</td>
<td>±(0.5% +3)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FUNCTION</th>
<th>RANGE</th>
<th>RESOLUTION</th>
<th>ACCURACY*</th>
<th>Typical Burden Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCmA/A</td>
<td>32.00 mA</td>
<td>0.01 mA</td>
<td>±(0.75% +2)</td>
<td>5.6 mV/mA</td>
</tr>
<tr>
<td></td>
<td>320.0 mA</td>
<td>0.1 mA</td>
<td></td>
<td>5.6 mV/mA</td>
</tr>
<tr>
<td></td>
<td>10.00 A</td>
<td>0.01 A</td>
<td></td>
<td>50 mV/mA</td>
</tr>
<tr>
<td>DC μ A</td>
<td>320 μ A</td>
<td>0.1 μA</td>
<td>±(0.75% +2)</td>
<td>0.5 mV/μA</td>
</tr>
<tr>
<td></td>
<td>3200 μ A</td>
<td>1 μA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACmA/A</td>
<td>32.00 mA</td>
<td>0.01 mA</td>
<td>±(1.5% +2)</td>
<td>5.6 mV/mA</td>
</tr>
<tr>
<td></td>
<td>320.0 mA</td>
<td>0.1 mA</td>
<td></td>
<td>5.6 mV/mA</td>
</tr>
<tr>
<td></td>
<td>10.00 A</td>
<td>0.01 A</td>
<td></td>
<td>50 mV/mA</td>
</tr>
<tr>
<td>AC μ A</td>
<td>320 μ A</td>
<td>0.1 μA</td>
<td>±(1.5% +2)</td>
<td>0.5 mV/μA</td>
</tr>
<tr>
<td></td>
<td>3200 μ A</td>
<td>1 μA</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FUNCTION</th>
<th>RANGE</th>
<th>RESOLUTION</th>
<th>ACCURACY*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ω (nS)</td>
<td>320.0Ω</td>
<td>0.1Ω</td>
<td>±(0.3% +2)</td>
</tr>
<tr>
<td></td>
<td>3.200kΩ</td>
<td>0.001kΩ</td>
<td>±(0.2% +1)</td>
</tr>
<tr>
<td></td>
<td>32.00kΩ</td>
<td>0.01kΩ</td>
<td>±(0.2% +1)</td>
</tr>
<tr>
<td></td>
<td>320.0kΩ</td>
<td>0.1kΩ</td>
<td>±(0.2% +1)</td>
</tr>
<tr>
<td></td>
<td>3.200MΩ</td>
<td>0.001MΩ</td>
<td>±(0.2% +1)</td>
</tr>
<tr>
<td></td>
<td>32.00MΩ</td>
<td>0.01MΩ</td>
<td>±(1% +1)</td>
</tr>
<tr>
<td></td>
<td>32.00 nS</td>
<td>0.01 nS</td>
<td>±(2% +10)</td>
</tr>
</tbody>
</table>

* Accuracy is ±% of Full Scale Reading + number of digits.
### TEKTRONIX CFG250 FUNCTION GENERATOR
After 1 Hour of warm up time at 23°C.

<table>
<thead>
<tr>
<th>OUTPUT</th>
<th>Square wave, sine wave, sawtooth, TTL pulse, and sweep functions for all outputs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency Ranges</td>
<td>1, 10, 100, 1k, 10k, 100k, 1M</td>
</tr>
<tr>
<td>Frequency Multiplier</td>
<td>Variable 0.2 to 2.0 times selected range.</td>
</tr>
<tr>
<td>Frequency Accuracy</td>
<td>± 5% of F.S.</td>
</tr>
<tr>
<td>Sine Wave Distortion</td>
<td>&lt; 1% from 10 Hz to 100 kHz</td>
</tr>
<tr>
<td>Impedance</td>
<td>50 Ω ± 10%</td>
</tr>
<tr>
<td>DC Offset</td>
<td>−10V to +10V open Circuit, −5 to +5 into 50 Ω</td>
</tr>
<tr>
<td>Amplitude</td>
<td>10 mV to 20 VPP open circuit or 50 mV to 10 VPP into 50 Ω</td>
</tr>
<tr>
<td></td>
<td>10 mV to 10 VPP open circuit or 5 mV to 1 VPP into 50 Ω</td>
</tr>
</tbody>
</table>

### TEKTRONIX CFC250 FREQUENCY COUNTER
After 1 Hour of warm up time at 23°C.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency Range</td>
<td>5 Hz to 100 MHz, AC Coupled</td>
</tr>
<tr>
<td>Resolution</td>
<td>1 Hz</td>
</tr>
<tr>
<td>Accuracy</td>
<td>± time base accuracy ± 1 count</td>
</tr>
<tr>
<td>Impedance</td>
<td>1 MΩ shunted by 40 pF</td>
</tr>
<tr>
<td>Sine Wave Sensitivity</td>
<td>5 Hz to 30 MHz (80 mVRMS)</td>
</tr>
<tr>
<td>(Minimum input voltage)</td>
<td>30 MHz to 70 MHz (80 mVRMS)</td>
</tr>
<tr>
<td></td>
<td>70 MHz to 100 MHz (80 mVRMS)</td>
</tr>
<tr>
<td>Maximum Input</td>
<td>5 Hz to 100 kHz 42VP</td>
</tr>
<tr>
<td></td>
<td>100 kHz to 10 MHz 13.8VP</td>
</tr>
<tr>
<td></td>
<td>10 MHz to 100 MHz 5.4VP</td>
</tr>
</tbody>
</table>
TEKTRONIX 2245 OSCILLOSCOPE

Vertical Deflection

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deflection Factor</td>
<td>0.1V per division and 0.5 V per division, within ± 2%</td>
</tr>
<tr>
<td>Step Response</td>
<td>3.5 ns or less</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>DC to 100 MHz</td>
</tr>
<tr>
<td>Chop Mode Switching Rate</td>
<td>625 kHz ± 10%</td>
</tr>
<tr>
<td>Input Impedance</td>
<td>1 MΩ ± 1%, input Cap = 20 pF ± 1pF</td>
</tr>
<tr>
<td>Maximum Safe Input Voltage</td>
<td>400 V (dc + peak AC); 800 VPP at 10 kHz or less</td>
</tr>
<tr>
<td>Trace Shift as V/DIV is varied</td>
<td>1 Division or less</td>
</tr>
</tbody>
</table>

Trigger

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity</td>
<td>dc coupling .35 div dc to 25 MHz increasing to 1.0 div at 150 MHz.</td>
</tr>
<tr>
<td></td>
<td>ac coupling .35 div 50 Hz 25 MHz increasing to 1.0 div at 150 MHz.</td>
</tr>
<tr>
<td>Level Control Range</td>
<td>± 10 div referred to the appropriate vertical input</td>
</tr>
</tbody>
</table>

Horizontal Deflection

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweep Rate A</td>
<td>.5s/div to 20 ns in a 1–2–5 sequence</td>
</tr>
<tr>
<td>Sweep Rate B</td>
<td>5.0 ms/div to 20 ns in a 1–2–5 sequence</td>
</tr>
<tr>
<td></td>
<td>x10 magnifier extends maximum sweet to 2 ns for both.</td>
</tr>
<tr>
<td>Sweep Linearity</td>
<td>± 5%</td>
</tr>
<tr>
<td>Accuracy</td>
<td>± 2% unmagnified, ± 3% magnified</td>
</tr>
</tbody>
</table>

All information in this Appendix was obtained from the Operators Manual for that instrument. For additional specification, ask Learning Assistant for the appropriate Manual.
The accuracy of an electrical measuring instrument is to be distinguished from its sensitivity and its precision. **Sensitivity** is the smallest quantity that can be detected by the instrument. If we make a 224 V measurement on the 300 V scale, a change of 1 mV in the measured voltage cannot be detected on the scale of the meter if the scale is 10 cm. The reason is the sensitivity of the meter is 3 V/mm assuming the scale is linear and a change in voltage of 1 mV doesn't cause a significant change in displacement of the pointer. The sensitivity of the meter is usually given in the units of the measured quantity (volts, amperes, etc.) per unit of displacement (cm, mm, inches, degree, etc.) It may be possible to distinguish differences of 0.5 V in the example. If this is true, then we may say that the reading of 224 V is precise to ± 0.5V.

The **Precision** of an instrument indicates how finely the measurement may be made. The precise measurement of 224 V may differ with a precise reading taken with a meter standardized by the National Bureau of Standards. This discrepancy is called the measurement error. Clearly, a precise measurement doesn't imply an accurate measurement.

The **Accuracy** of an analog meter is an indication of the maximum possible error contained in any precise reading of the meter. Unless otherwise stated, the accuracy of an instrument is usually given in terms of a percentage of the full-scale (f.s.) value. This value may be given as an absolute value, but it is clearly a positive and negative value at any point of the scale, not only at full scale. This discussion is for analog meters and not digital meters. The accuracy of the DVM is given differently.

**EXAMPLE**

Assume a voltmeter has 2% accuracy (±2%) on three voltage scales. The three scales are 0 – 50V, 0 – 150V, and 0 – 300 V. It is used to measure an output voltage \( V_O \) between two points in an electrical circuit. The precise readings on the three ranges are 41.7V, 45V and 44V respectively. What is the voltage represented by this measurement?

**50 V RANGE**

Maximum Possible Error (MPE) on any point of the scale is:

\[
MPE = \text{F. S. Range} \times \text{Accuracy} \\
MPE = 50 \text{ V} \times (\pm 0.02) = \pm 1 \text{V}
\]

The actual reading for \( V_O \) is 41.7 V ± 1V or 40.7 ≤ \( V_O \) ≤ 42.7 V. ± 1V is not the actual error, it is the accuracy limit or the maximum possible error. In addition, 1V does not yield ± 2% of the reading. The percentage error for the reading is:

\[
\% \text{ Error} = \frac{\text{Accuracy}}{\text{Reading}} \times 100\% \\
\% \text{ Error} = \frac{1}{41.7} \times 100\% = 2.4\% 
\]

Therefore, this reading is 41.7V ± 2.4%. Similarly, for the other ranges:

**0 – 150 V Range**

\[
MPE = 150 \text{ V} \times (\pm 0.02) = \pm 3 \text{V} \\
42 \leq V_O \leq 48 \text{ V}
\]
% Error = \frac{3}{45} \times 100\% = 6.66\%

VO = 45 V \pm 6.66\%

0 – 300 V Range

MPE = 300 V \times (\pm0.02) = \pm6V

38 \leq VO \leq 50 V

% Error = \left(\frac{6}{44}\right) \times 100\% = 13.63\%

VO = 44 V \pm 13.63\%

A comparison of the results of the three measurements demonstrates the need to make measurements on the scale that causes the greatest pointer deflection while remaining on the calibrated area of the scale.

MULTIPLE MEASUREMENTS

It is often necessary to mathematically combine measurements to verify theory, e.g. to verify Kirchhoff’s Voltage Law by adding the voltage drops around a closed loop. We must, therefore, consider the accuracy of the resulting combination. Assume the sum is designated by the symbol S, the first reading is X, the second reading is Y, and the last reading is Z. Associated with each reading is a corresponding MPE which will be designated as ΔS, ΔX, ΔY, and ΔZ. If we merely add the three readings, we obtain:

\[ S = X + Y + Z \]

The actual errors associated with X, Y, and Z may not have the same sign. However, we are focusing on the accuracy limits, not the actual error. Hence, we must consider the worst possible cases which are:

\[ S + \Delta S = (X + \Delta X) + (Y + \Delta Y) + (Z + \Delta Z) \]
\[ S + \Delta S = (X + Y + Z) + (\Delta X + \Delta Y + \Delta Z) \]

and

\[ S - \Delta S = (X - \Delta X) + (Y - \Delta Y) + (Z - \Delta Z) \]
\[ S - \Delta S = (X + Y + Z) - (\Delta X + \Delta Y + \Delta Z) \]

Therefore, the maximum possible error is \( \Delta S = \pm(\Delta X + \Delta Y + \Delta Z) \). Hence, the maximum percentage error in S is:

\[ \pm \Delta S = \pm \left( \frac{\Delta S}{S} \right) \times 100\% = \pm \left( \frac{\Delta X + \Delta Y + \Delta Z}{X + Y + Z} \right) \times 100\% \]

SUBTRACTION

\[ S + \Delta S = (X + \Delta X) - (Y + \Delta Y) \]
\[ S + \Delta S = (X - Y) + (\Delta X + \Delta Y) \]

and

\[ S - \Delta S = (X + \Delta X) - (Y + \Delta Y) \]
\[ S - \Delta S = (X - Y) - (\Delta X + \Delta Y) \]
Therefore, the maximum possible error is $\Delta S = \pm (\Delta X + \Delta Y)$. Hence, the maximum percentage error in S is:

$$\pm \Delta S = \pm \left( \frac{\Delta S}{S} \right) \times 100\% = \pm \left( \frac{\Delta X + \Delta Y}{|X - Y|} \right) \times 100\%$$

**MULTIPLICATION**

\[
S + \Delta S = S \left( 1 + \frac{\Delta S}{S} \right) = (X + \Delta X)(Y + \Delta Y)(Z + \Delta Z)
\]

\[
S \left( 1 + \frac{\Delta S}{S} \right) = (X + \frac{\Delta X}{X})(Y + \frac{\Delta Y}{Y})(Z + \frac{\Delta Z}{Z})
\]

\[
S \left( 1 + \frac{\Delta S}{S} \right) = XYZ \left[ (1 + \frac{\Delta X}{X})(1 + \frac{\Delta Y}{Y})(1 + \frac{\Delta Z}{Z}) \right]
\]

Likewise, it may be shown that:

\[
S - \Delta S = S \left( 1 - \frac{\Delta S}{S} \right) \approx XYZ \left[ 1 - ( \frac{\Delta X}{X} + \frac{\Delta Y}{Y} + \frac{\Delta Z}{Z} ) \right]
\]

The maximum percentage error in S, therefore, is $\pm \left[ \frac{\Delta X}{X} + \frac{\Delta Y}{Y} + \frac{\Delta Z}{Z} \right] 100\%$

**DIVISION**

\[
S + \Delta S = S \left( 1 + \frac{\Delta S}{S} \right) = \frac{X + \Delta X}{Y - \Delta Y}
\]

\[
S \left( 1 + \frac{\Delta S}{S} \right) = \frac{X}{Y} \left[ \frac{1 + \frac{\Delta X}{X}}{1 - \frac{\Delta Y}{Y}} \right]
\]

\[
S \left( 1 + \frac{\Delta S}{S} \right) = \frac{X}{Y} \left( 1 + \frac{\Delta X}{X} \right) \left( 1 - \frac{\Delta Y}{Y} \right)^{-1}
\]

\[
S \left( 1 + \frac{\Delta S}{S} \right) \approx \frac{X}{Y} \left[ 1 + \left( \frac{\Delta X}{X} + \frac{\Delta Y}{Y} \right) \right]
\]

AND

\[
S - \Delta S = S \left( 1 - \frac{\Delta S}{S} \right) \approx \frac{X}{Y} \left[ 1 - \left( \frac{\Delta X}{X} + \frac{\Delta Y}{Y} \right) \right]
\]
Therefore, the maximum percentage error is \( \pm \left( \frac{\Delta X}{X} + \frac{\Delta Y}{Y} \right) \times 100\% \)

The maximum possible error can be stated as follows:
For addition and subtraction, the MPE is the sum of the individual maximum possible errors.
For multiplication and division, the MPE is the sum of the individual maximum possible percentage errors.

An approximate general expression for the maximum possible error, whatever the combination of measurements, is:

\[
\frac{\Delta S}{S} = \left| \frac{\partial S}{\partial X} \right| \Delta X + \left| \frac{\partial S}{\partial Y} \right| \Delta Y + \left| \frac{\partial S}{\partial Z} \right| \Delta Z
\]

Where \( \frac{\partial S}{\partial X} \), \( \frac{\partial S}{\partial Y} \), and \( \frac{\partial S}{\partial Z} \) are the partial derivatives of \( S \) with respect to \( X \), \( Y \), and \( Z \) respectively.

Recall that the partial derivative of \( S \) with respect to a variable, say \( X \) for our example, is the derivative of \( S \) with respect to that variable while all other variables (\( Y \) and \( Z \)) are held constant.

Applying the general formula for addition will give the same result we obtained earlier.

Applying this rule for division, we obtain:

\[
\frac{\Delta S}{S} = \frac{1}{Y} \Delta X + \frac{X}{Y^2} \Delta Y
\]

\[
\frac{\Delta S}{S} = \frac{Y}{X} \left[ \frac{1}{Y} \Delta X + \frac{X}{Y^2} \Delta Y \right] = \frac{\Delta X}{X} + \frac{\Delta Y}{Y}
\]

which is the same result that we obtained earlier. Now let us apply the general formula to obtain new results.

\[
S = \sqrt{X^2 + Y^2}
\]
\[
\frac{\partial S}{\partial X} = \frac{X}{\sqrt{X^2 - Y^2}} \quad \frac{\partial S}{\partial Y} = \frac{Y}{\sqrt{X^2 - Y^2}}
\]

\[
\Delta S = \left| \frac{X}{\sqrt{X^2 - Y^2}} \right| \Delta X + \left| \frac{-Y}{\sqrt{X^2 - Y^2}} \right| \Delta Y
\]

\[
\Delta S = \frac{\Delta S}{S} = \frac{X^2}{X^2 - Y^2} \left( \frac{\Delta X}{X} \right) + \frac{Y^2}{X^2 - Y^2} \left( \frac{\Delta Y}{Y} \right)
\]
APPENDIX E

LABORATORY REPORT FORMAT
THE FORMAL LABORATORY REPORT FORMAT

Title Sheet
Laboratory reports must have a cover sheet which is available in ATC 106. The Date and Time that the laboratory work is performed must be stamped on the cover sheet and initialed by the Learning Assistant. The cover and all work should be typed, or filled out completely and neatly in ink.

Schematic Diagrams
The diagram of the circuit that was tested using measured component values. These schematic diagrams must be created using PSpice. The title block must contain the students name, course code, and a unique descriptive title for each circuit.

Data Sheets
The original data sheet must be dated, filled out in ink, and initialed by the laboratory supervisor before you leave the lab. You may make copies of the data tables and fill it out as you make your measurements, but the original data sheet from the manual completed in ink and signed must be submitted with your report. See Graphs Section.

Calculations
All calculations must be shown, but only one sample calculation showing and mathematical manipulation of equations is required for each type of calculation. The methods employed should be explained, and any terms and symbols should be identified or defined. units of measurement must also be resolved. Equations and formulae borrowed from reference material must be endnoted.

Phasor Diagrams
When phasor diagrams are needed, such as in AC circuit analysis, they should be plotted to scale on quadrille paper. A scale should be chosen so a quantitative appraisal of the shortest vector can be made. A neat diagram made with a 2H pencil is acceptable.

Discussion
Topics for discussions are often made in the instructions. These suggestions provide a minimum framework around which the student should build his/her discussion. The discussion provides the student with an opportunity for original thought and logical reasoning. A thoughtful clear discussion can greatly increase the value of the report.

Conclusions, results, comments on sources of error and their probable magnitude should be made. It may be appropriate to make recommendations on means to minimize results. The discussion of results, at least one page in length, should be a student's Individual effort.

Endnotes
When it is necessary to use others work, it must be identified. Although you may use footnotes, endnotes are preferable. Examples of technical reports are readily available in various I.E.E.E. technical publications. The student should read these and other technical papers for ideas about the way a technical paper is written. Endnotes and footnotes should be in the proper format.

Bibliography
A complete bibliography using the proper format should be included, especially if footnotes and endnotes are used. The bibliography should also give credit to other individual's work, even if unpublished.

Style
The technical report is written in standard American English. It should use the past tense and in the third person.