Topic 1
Safety Considerations in Power Supply Design

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Acknowledgment

- This topic presents a brief overview of a complex subject
- Prepared from information supplied by Underwriters Laboratories, Inc.
- More in-depth coverage is available from UL at:
  UL Customer Service Group
  E-mail: ULAnytime@ul.com
  Phone: 1-877-UL-HELPS in America
Principles of Safety

As applicable to power supply design

◆ Electric shock
  ■ Perception, reaction, not-let-go, fibrillation

◆ Fire
  ■ Abnormal operating conditions, faults, overloads

◆ Energy hazard
  ■ Burns from low voltage but high VA (>240 VA)

◆ Mechanical
  ■ Sharp edges, moving parts (injury, insulation damage)

◆ Heat related hazards
  ■ High temperatures at accessible surfaces
Power Supply Considerations

◆ Stand-alone or component supply
  ■ End product standards apply
  ■ End use determines applicable standards
  ■ End product evaluation is adequate for some applications
  ■ Conditions of acceptability known to user

◆ Accessibility
  ■ To user – two levels of protection from hazardous voltages
  ■ To service personnel – guard from inadvertent exposure
Safety Standards for Power Supplies

◆ UL1310 for limited power (<60 V and <8 A)
◆ UL1012 for general use in the USA only
◆ IEC/EN/CSA/UL 60950-1 primary standard today
  ■ Information technology equipment and telecom
  ■ Nearly world-wide acceptance

◆ Other standards
  ■ IEC/EN/UL 60065 for Audio and video
  ■ IEC/EN/UL 60601 for Medical equipment
  ■ IEC/EN/UL 61010 for Laboratory Supplies
  ■ etc.

◆ Future consideration
  ■ IEC 61204-7 Conformance to multiple standards
Different power supply types may have different or fewer blocks. i.e., battery backup, dc/dc converters
Use Certified Components

Many are available to IEC/EN/CSA/UL standards:

- Power cords or input terminals
- Protective devices (fuses, etc.)
- EMI filters
- Power switch, wiring, PWB, chassis
- Isolators (transformers, optocouplers)
- Rectifier assemblies
- Output connector or terminals
- Cooling devices
- Etc.
Electric Shock Thresholds

- 0.0 – 0.5 mA - Perception, minimal reaction
- 0.5 – 3.5 mA - Inadvertent reaction, can tolerate
- 3.5 – 10 mA - Inability to let go
- 10 – 50 mA - Fibrillation, cell damage

- Threshold is 2 mA dc, 0.7 mA peak, 0.5 mA rms
- Assumes body resistance of 2 kΩ at 110 V
  - Resistance decreases with increasing voltage
- Higher frequencies less harmful
  - Multiply 50/60 Hz value by frequency in kHz
  - Maximum current is 70 mA at any frequency
  - Potential for burns if current density is high
**Accessible Safe Voltages**

- **LCC (Limited Current Circuit)**
  - Current limited to 0.7 mA ac or 2.0 mA dc
    - Under both normal and single-fault conditions
    - Capacitance is limited

- **SELV (Safety Extra Low Voltage)**
  - Voltages less than 42.4 V peak ac or 60 V dc
    - Under both normal and single-fault conditions

- **TNV (Telecommunication Network Voltage)**
  - Contact area or duration must be limited
    - 71 V ac or 120 V dc, normal conditions at connector pin
    - Higher under single fault if duration < 200 ms
    - Subject to transients of shorter duration
Unsafe Circuits

Protection from operator contact required:

◆ Hazardous voltage circuits
  ■ Voltage in excess of SELV or TNV limits, or if not LCC
◆ ELV (Extra Low Voltage)
  ■ Meeting SELV voltages but not safe under single fault
◆ Primary circuits
  ■ AC mains voltage (hazardous)
◆ Secondary circuits with voltage in excess of SELV limits
  ■ No direct connection to primary
Insulation Categories

◆ Functional - Necessary for operation, no protection
◆ Basic - Single level to provide shock protection
  ■ No thickness spec – could have pinholes
◆ Supplementary - Additional level added to Basic
  ■ Includes 0.4 mm min thickness spec for single layer
◆ Double - Two levels, Basic plus Supplementary
◆ Reinforced - Single system equivalent to Double
  ■ 0.4 mm min thickness

Note: Basic + Basic does not equal Double level
Insulating Requirements

◆ One level if circuit is not accessible
◆ Two levels between accessible components and hazardous voltages
◆ Each level of insulation must meet appropriate standards - A single level may fail
◆ Double faults not considered
  ■ Except as a consequence of first fault
◆ One level could be protective earth (enclosure)
Insulation Coordination

Primary Circuitry (Hazardous Voltage)

- 1 L
- 1 L
- 0 L
- 2 L

Internal Floating ELV

Internal Grounded ELV

Internal Primary

Internal Secondary SELV

External Grounded Metal

External Floating Metal

Accessible Secondary Circuitry (Terminals)

- 1 L
- 0 L
- 2 L
- 0 L

Accessible Metal (Heatsinks)
The highest voltage between any two conductive devices
Can be peak, rms, or dc measured values
Determines spacings and insulation thickness
Insulation Materials

- Can be solid insulation or air
- Each level rated for maximum voltage under single-fault conditions
- Insulating materials rated for operating environment
  - Must be non-hygroscopic
- Thickness/spacings defined by “Pollution Degree”
  - Degree 1 = sealed enclosure
  - Degree 2 = office environment
  - Degree 3 = potential conductive atmosphere
Distance Through Solid Insulation

- Working Voltage < 71 V – No Requirement
- Above 71 V – Functional and Basic have no requirement
- Supplementary and Reinforced – 0.4 mm min thickness
- Semiconductors and Optocouplers – No requirement if:
  - Insulating material is solid
  - Component passes qualification inspection
  - Tested for electric strength during manufacturing
  - External terminations must meet clearance and creepage unless coated
Optocoupler Options

- Terminations to PCB must meet Creepage specs
  - Surface mount pads can meet 8-mm spacing
  - Through-hole pads need special bend or slot
Spacing of Conductors

◆ **Clearance** = Shortest distance through air
  - Minimum determined by peak voltage
  - Damage can be caused by voltage impulses

◆ **Creepage** = Shortest distance along surface
  - Minimum affected by dc or RMS voltage
  - Damage is slow
## Clearance Distances (in millimeters)

<table>
<thead>
<tr>
<th>Working Voltage</th>
<th>AC Mains &lt; 150 V (Transient to 1500 V) Pollution levels 1 and 2</th>
<th>AC Mains &lt; 300 V (Transient to 2500 V) Pollution levels 1 and 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>B/S</td>
</tr>
<tr>
<td>Peak dc V</td>
<td>rms V</td>
<td></td>
</tr>
<tr>
<td>71</td>
<td>50</td>
<td>0.4</td>
</tr>
<tr>
<td>210</td>
<td>150</td>
<td>0.5</td>
</tr>
<tr>
<td>420</td>
<td>300</td>
<td>1.5</td>
</tr>
<tr>
<td>840</td>
<td>600</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Partial data from UL60950-1, Section 2.10.3, Table 2H
## Creepage Distances (in millimeters)

<table>
<thead>
<tr>
<th>Working Voltage</th>
<th>Pollution Level 1 Material Group III</th>
<th>Pollution Level 2 Material Group III</th>
<th>Pollution Level 3 Material Group III</th>
</tr>
</thead>
<tbody>
<tr>
<td>dc or rms</td>
<td>F</td>
<td>B/S</td>
<td>R</td>
</tr>
<tr>
<td>&lt; 50 V</td>
<td>0.4</td>
<td>0.7</td>
<td>1.4</td>
</tr>
<tr>
<td>&lt; 150 V</td>
<td>0.6</td>
<td>0.9</td>
<td>1.8</td>
</tr>
<tr>
<td>&lt; 300 V</td>
<td>1.6</td>
<td>1.9</td>
<td>3.8</td>
</tr>
<tr>
<td>&lt; 600 V</td>
<td>3.2</td>
<td>3.2</td>
<td>5.0</td>
</tr>
</tbody>
</table>

Partial data from UL60950-1, Section 2.10.4, Table 2L
Transformer Construction

- Creepage and Clearance usually identical
  - Creepage = Clearance = A + B
  - Air exists between all layers
  - Thickness of tape is assumed to be negligible
- Enamel wire coating not considered as insulation
Flame Testing

- V-0 Rating = non-flammable, always acceptable
- V-1 Rating = Self extinguishing
- V-2 Rating = Flaming particles ignite cheesecloth
  - V-2 acceptable with solid-bottom enclosure only

- Selected components throughout supply opened or shorted, or output overloaded

- Wire insulation with plasticizers provides increased flexibility, but also add to flammability
Designing For Safety

- Understand requirement early in program
- Materials
  - Choose certified components where available
- Mechanical
  - Securely mounted components
  - No sharp edges or corners
  - No accessible moving parts
- PCB Layout
  - Define isolation boundary
  - Know working voltage levels
  - Anticipate shorted-component testing
Primary-Secondary Isolation

- Isolation spacing clearly visible
- Slot under opto-coupler
Circuit Design for Fault Testing

- High-voltage bias through R1 + R2
- $R_G$ and D1 protect against Q1 D-G short
  - Use fusible resistor for $R_G$
  - Blown input fuse is OK
Safety Evaluation

- Construction analysis
- Worst-case operational testing
- Internal working voltage limits
- Component heating tests
- Humidity
- Electric strength measurements
- Flame tests
- Additional specialized testing
Safety Certification

- Submit documentation package
- Five open and five enclosed units for testing
- Six to eight weeks
For Greater Depth

- UL conducts one- and two-day seminars
- Check [http://www.ul.com/seminars](http://www.ul.com/seminars)
- UL also provides design reviews and EMC testing
- Refer to UL60950-1