



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

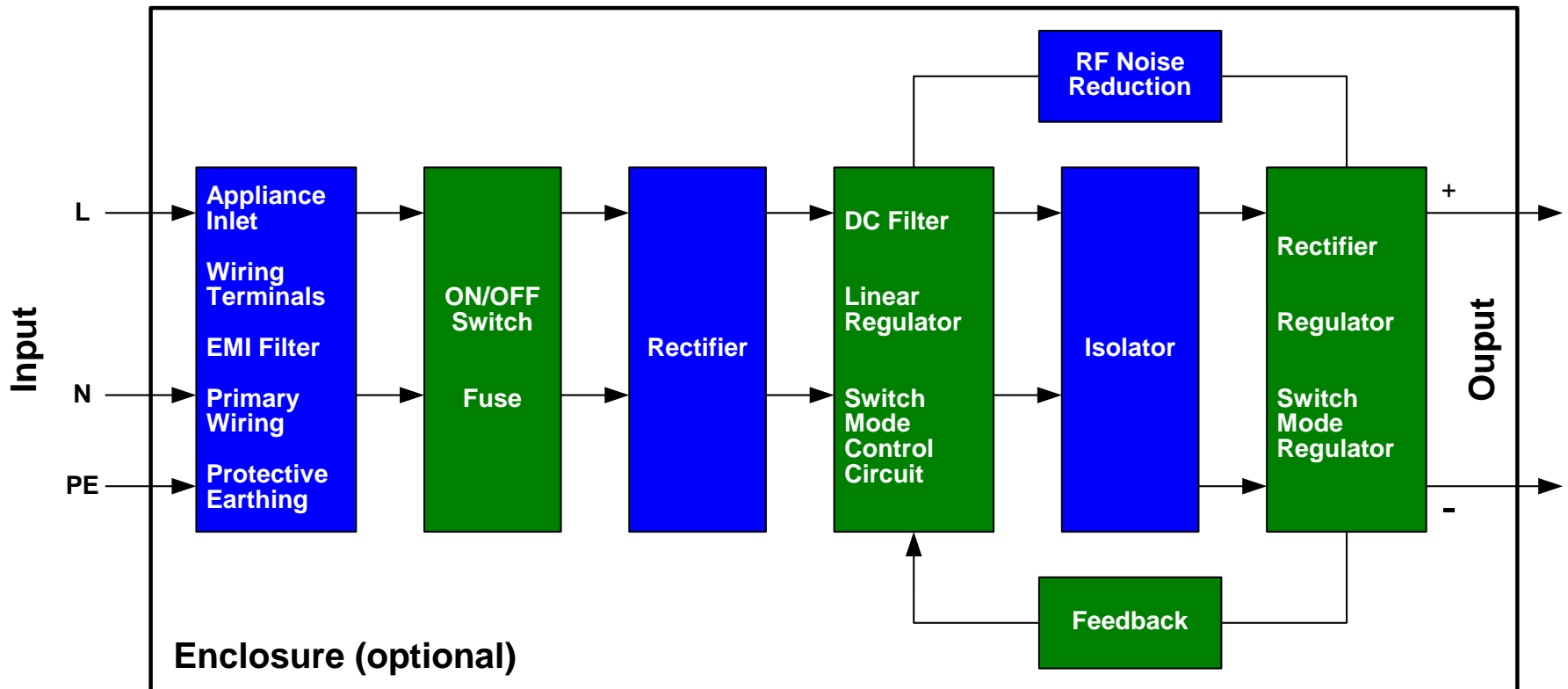
- ◆ Stand-alone or component supply
 - End product standards apply
 - End use determines applicable standards
 - End product evaluation is adequate for some applications
 - Conditions of acceptability known to user

- ◆ 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

Typical Power Supply



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
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- Threshold is 2 mA dc, 0.7 mA peak, 0.5 mA rms
 - Assumes body resistance of 2 k Ω 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:

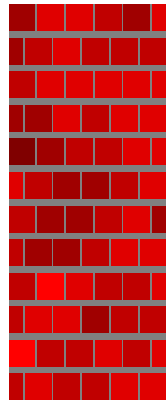
- ◆ Hazardous voltage circuits
 - Voltage in excess of SELV or TNV limits, or if not LCC
- ◆ ELV (Extra Low Voltage)
 - Meeting SELV voltages but not safe under single fault
- ◆ Primary circuits
 - AC mains voltage (hazardous)
- ◆ Secondary circuits with voltage in excess of SELV limits
 - No direct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

Insulation Categories

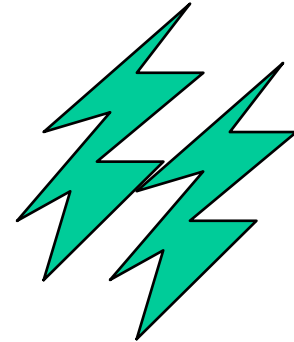
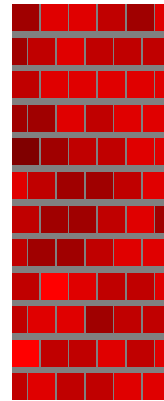
- ◆ Functional - Necessary for operation, no protection
- ◆ Basic - Single level to provide shock protection
 - No thickness spec – could have pinholes
- ◆ Supplementary - Additional level added to Basic
 - Includes 0.4 mm min thickness spec for single layer
- ◆ Double - Two levels, Basic plus Supplementary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

Note: Basic + Basic does not equal Double level

Insulating Requirements



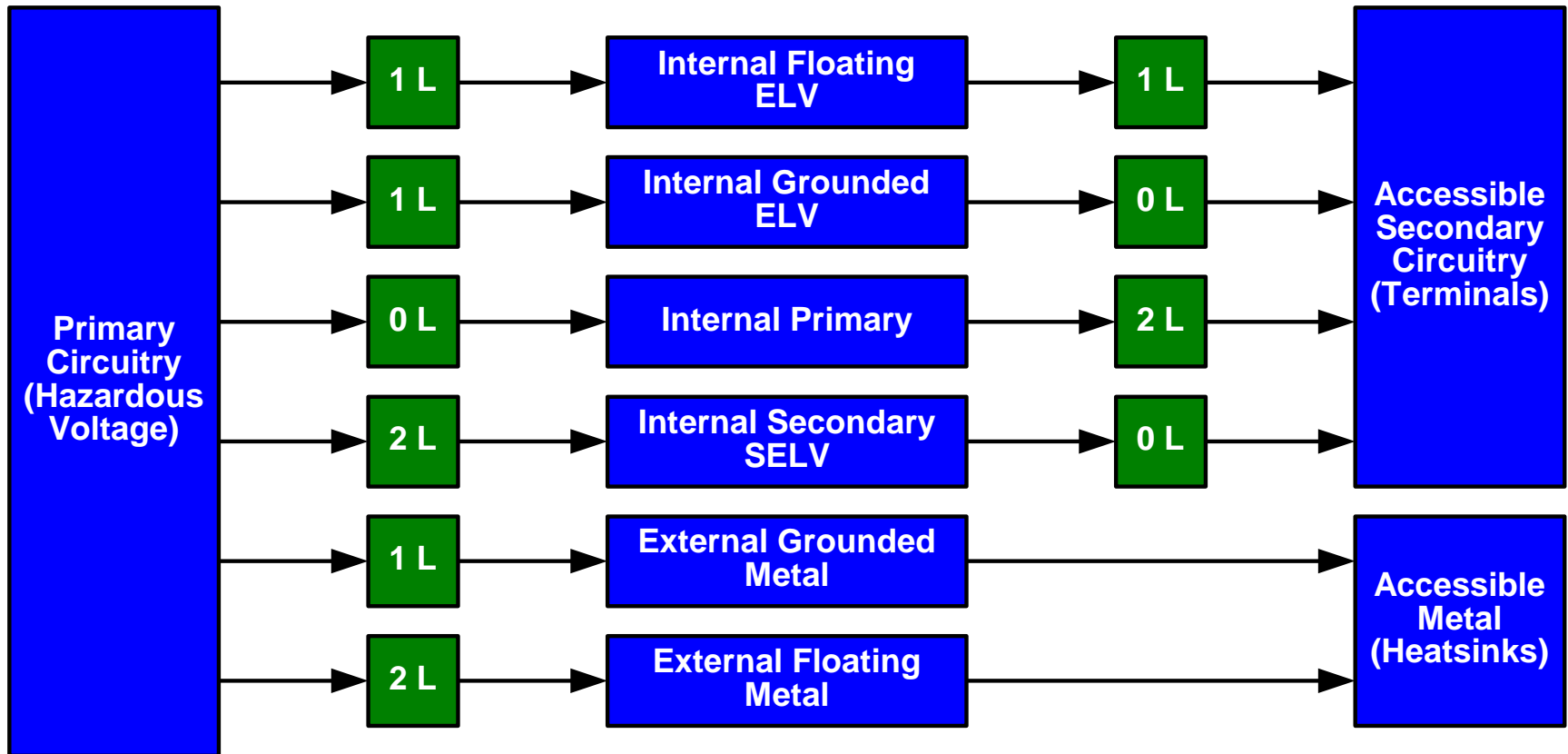
Two levels
of protection



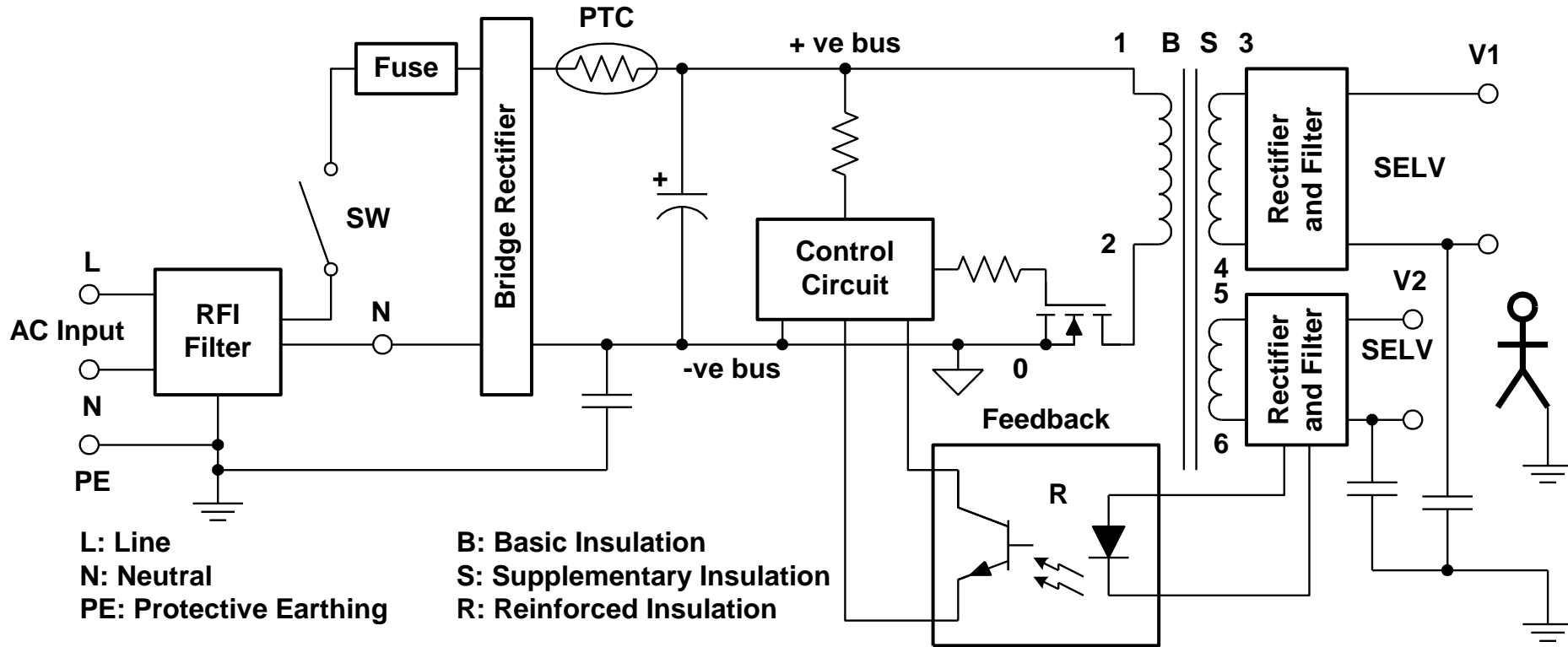
Hazardous Voltage

- ◆ 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



Working Voltage



- ◆ The highest voltage between any two conductive devices
- ◆ Can be peak, rms, or dc measured values
- ◆ Determines spacings and insulation thickness

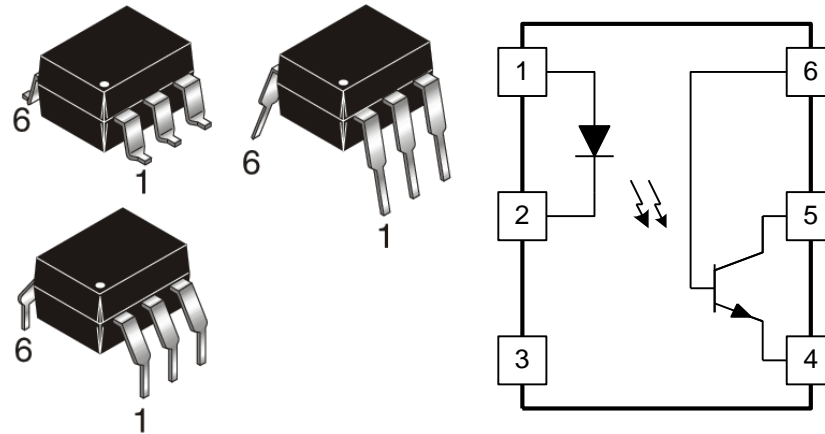
Insulation Materials

- ◆ 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

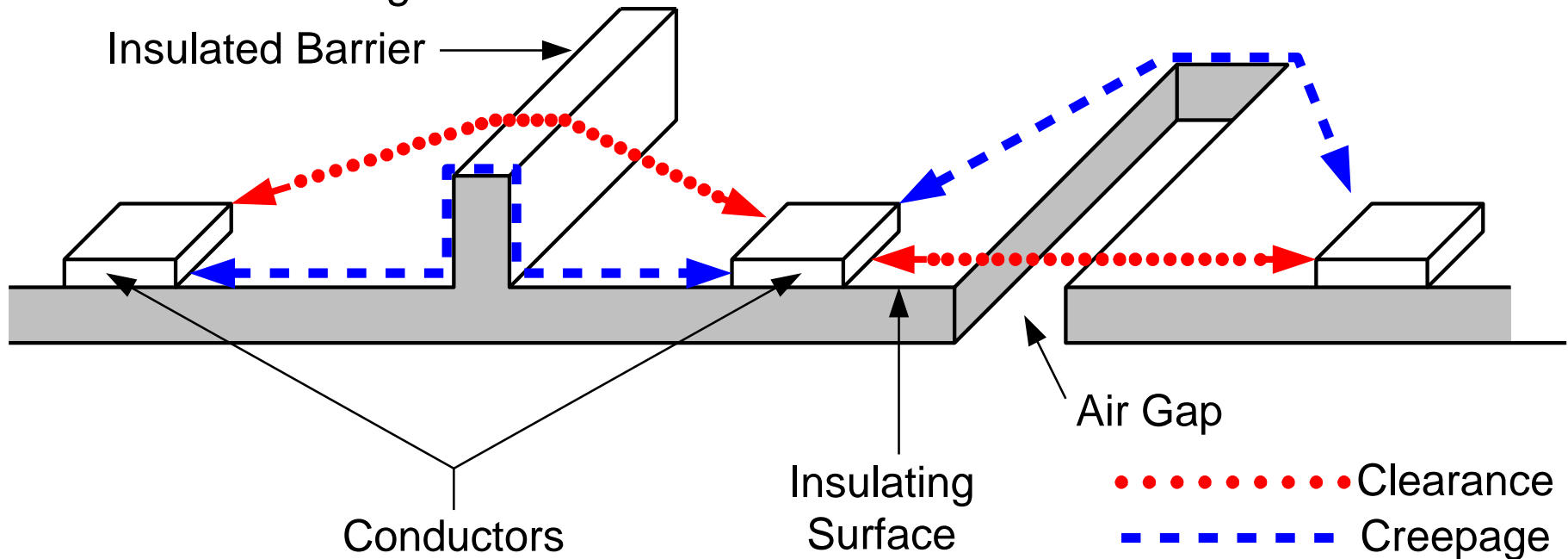
Optocoupler Options



- ◆ 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)

Working Voltage		AC Mains < 150 V (Transient to 1500 V) Pollution levels 1 and 2			AC Mains < 300 V (Transient to 2500 V) (Pollution levels 1 and 2)		
Peak dc V	rms V	F	B/S	R	F	B/S	R
71	50	0.4	1.0	2.0	1.0	2.0	4.0
210	150	0.5	1.0	2.0	1.4	2.0	4.0
420	300	1.5	2.0	4.0	1.5	2.0	4.0
840	600	3.0	3.2	6.4	3.0	3.2	6.4

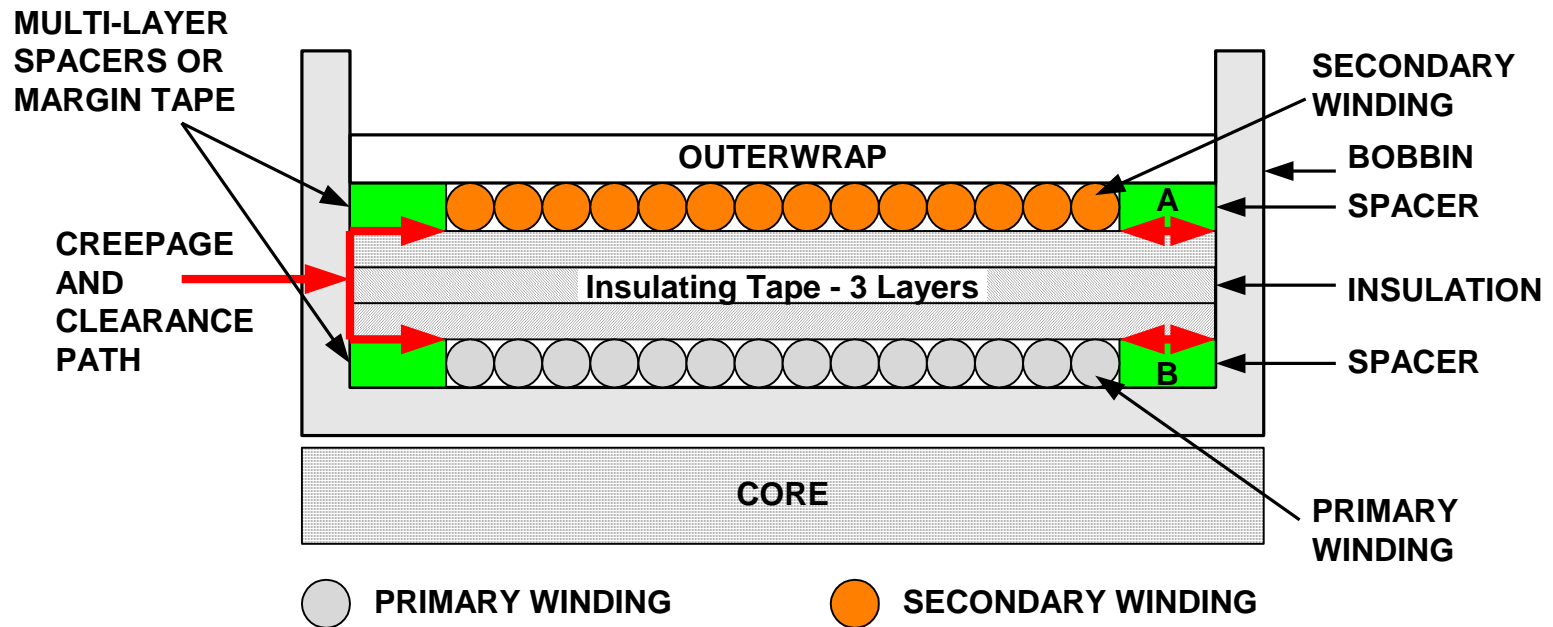
Partial data from UL60950-1, Section 2.10.3, Table 2H

Creepage Distances (in millimeters)

Working Voltage	Pollution Level 1 Material Group III			Pollution Level 2 Material Group III			Pollution Level 3 Material Group III			
	dc or rms	F	B/S	R	F	B/S	R	F	B/S	R
< 50 V		0.4	0.7	1.4	1.2	1.2	2.4	1.9	1.9	3.8
< 150 V		0.6	0.9	1.8	1.6	1.6	3.2	2.5	2.5	5.0
< 300 V		1.6	1.9	3.8	3.2	3.2	6.4	5.0	5.0	10
< 600 V		3.2	3.2	5.0	6.3	6.3	12.6	10	10	20

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

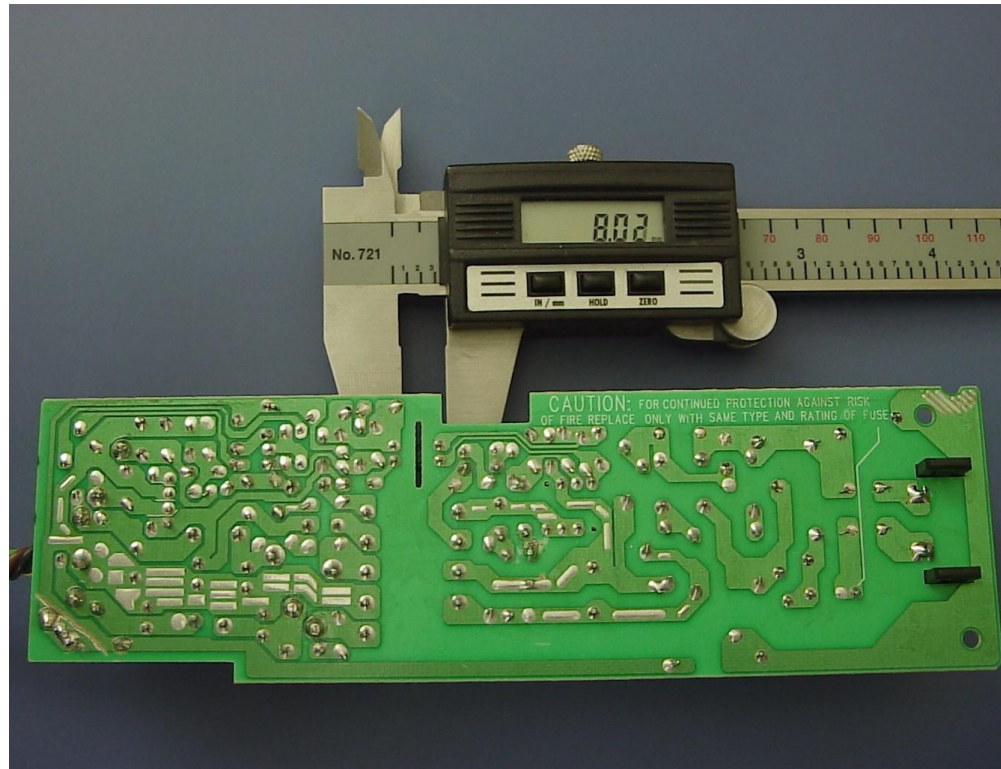
- ◆ Selected components throughout supply opened or shorted, or output overloaded

- ◆ Wire insulation with plasticizers provides increased flexibility, but also add to flammability

Designing For Safety

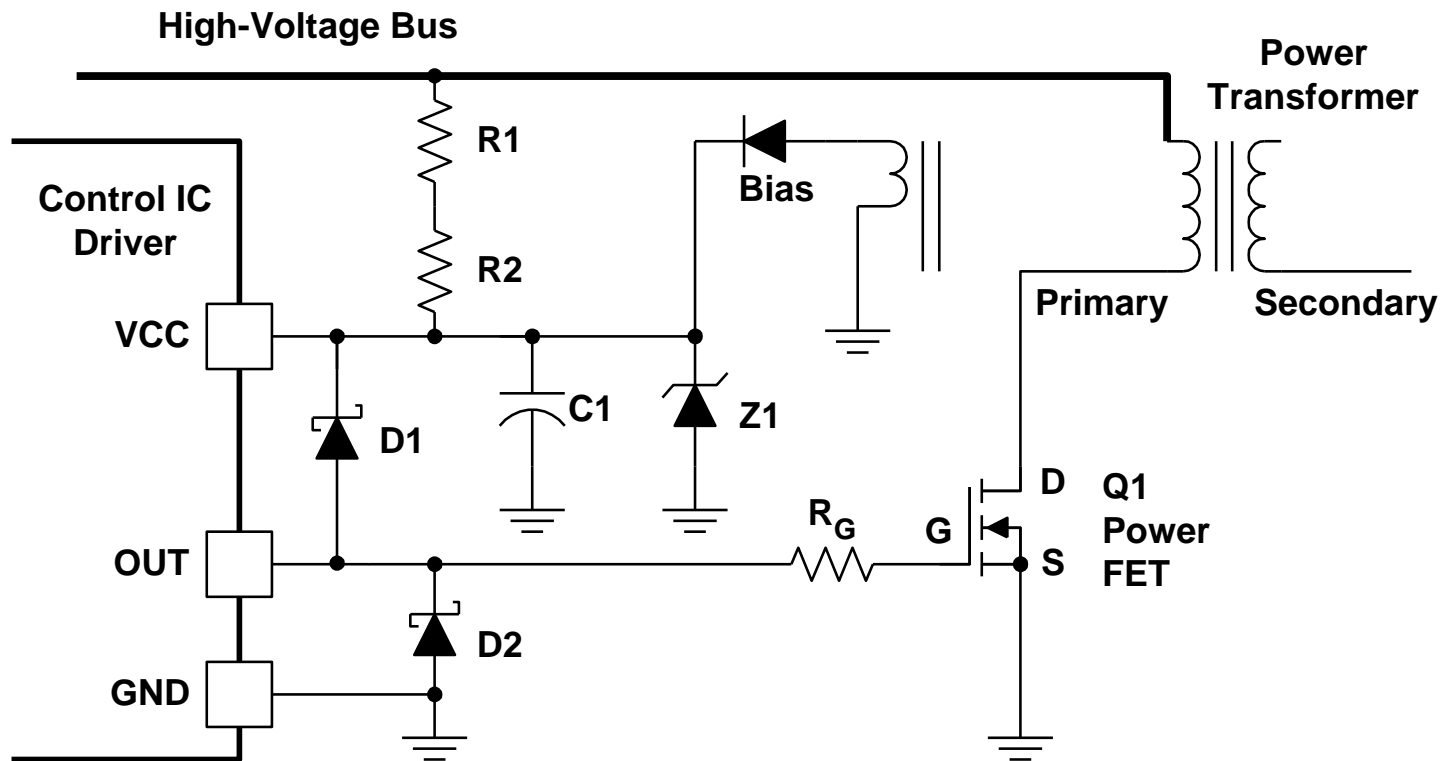
- ◆ Understand requirement early in program
- ◆ Materials
 - Choose certified components where available
- ◆ Mechanical
 - Securely mounted components
 - No sharp edges or corners
 - No accessible moving parts
- ◆ PCB Layout
 - Define isolation boundary
 - Know working voltage levels
 - Anticipate shorted-component 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>
- ◆ UL also provides design reviews and EMC testing
- ◆ Refer to UL60950-1