Safety Considerations in Power Supply Design

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ABSTRACT

Increasingly, the responsibilities of a power supply designer extend beyond merely meeting a functional specification, with designing to meet safety standards an important collateral task. Since all commercial and home-use supplies must eventually be certified as to safety, knowledge of the requirements should be a part of every designer's repertoire. This simplified overview has been prepared with the collaboration of Underwriters Laboratories, Inc. to provide a basic introduction to the issues and design solutions implicit in assuring the safety for both the user and service personnel of your power supply products, as well as easing the certification process.

I. INTRODUCTION

It should come as no surprise that safety is an important issue in the design of any electrical equipment which is liable to come into contact with a human operator or servicing individual. And this issue should be even more obvious when the equipment is designed to operate from a source of power which could experience or deliver voltage levels that could be hazardous to the human body. Recognizing this, a large collection of design standards and certification processes have been developed to define the requirements for insuring the safety of power supplies. A thorough treatment of this information takes much more space and time than available within the context of this seminar program – it is a subject more commonly taught with the dedication of one to two full days of presentation – however it is hoped that the brief overview provided herein will be useful in describing the basics both for designers who may have in-house resources with more detailed expertise, or who plan to follow up with attendance at a more in-depth program as those presented by Underwriters Laboratories, Inc.

Note that UL60950-1 (including Annexes P and Q) was used as the source for all numbers quoted here but many of the conditions and contingencies have been excluded in the interests of simplicity. Reference to the complete and latest revision of the appropriate standard should be made for any and all design decisions.

II. PRINCIPLES OF SAFETY

While one would expect that a safety standard for power supplies would be dominated by consideration of electrical hazards, this is not the only aspect of power supply design affected. A more complete listing of safety issues could include the following:

- **Electric Shock:** This is the shock hazard resulting from the passage of electric current through the human body. The physiological effects can range from perception or a startle involuntary movement, all the way to ventricular fibrillation or, ultimately, death.
- **Energy Hazards:** Even at voltages too low to produce a shock, burns can be caused when metallic objects such as tools, jewelry, etc. get very hot or melt and splash when they bridge sources with high VA potential (typically 240 VA or more).
- **Fire:** Fire is normally considered as a secondary effect from overload, abnormal operating conditions, or fault in some system component. However induced, it should not spread to adjacent components or equipment.
- **Heat Related Hazards:** High temperatures on accessible surfaces or components under normal operating conditions.
- **Mechanical:** Injury or damage resulting from contact with sharp edges or corners, moving parts, or physical instability.

While not usually associated with power supplies, other hazards that might need consideration could include the effects of radiation, chemicals, or hazardous vapors.

There are at least two types of persons whose safety needs must be considered: users (or operators) of the equipment, and service personnel. Users are not expected to identify hazards, and must not be allowed contact with hazardous parts. This is normally accomplished through the use of such means as enclosures or other protective shielding. Service personnel, on the other hand, are assumed to have access to all parts of the system and for their safety, the requirement is to identify the hazardous components or areas and to ensure against inadvertent contact with a hazardous surface, or bridging a tool between parts with high energy levels while working in another part of the equipment.

In addition to the types of personnel coming into contact with the equipment, there is an additional consideration as to the end use for a power supply. Power supplies can typically be divided into two categories:

- whether the supply is to be sold as a stand-alone item, or
- as a component to be installed into a specific system or equipment.

In either case, however, it is the end use conditions that apply and it is the end use standards that must be considered with respect to safety.

In additional principle of safety is that designers must consider not only normal operating conditions, but also likely faults, foreseeable misuse, external influences and environments, and overvoltages that might occur on input or output lines.

III. SAFETY STANDARDS FOR POWER SUPPLIES

Safety standards, like most standards affecting electrical equipment, were originally very specialized and unique to a given country. The driving force for a unified standard was primarily the information technology industry whose efforts led to the first international standard for safety, IEC950, prepared by the International Electrotechnical Commission (IEC). With the release in the late 1980s of UL1950, UL expanded the scope of IEC950 to include electrical business equipment along with ITE, but this standard excluded telecommunication equipment. In the meantime, however, a working group of the IEC (TC-74) had generated a harmonized standard, IEC60950 (third edition), to cover products from all three industries and, upon its release in 1999, it was quickly adopted by most countries and is today the primary standard for safety for most, but certainly not all, users of power supplies. In addition to IEC, designations of this standard can be found as EN (European Union), UL (United States), and CSA (Canada). In the USA, the plan is to withdraw approvals to all earlier standards by July, 2006. The US National Standard, as of this writing, is UL60950-1, first edition, published in November, 2003.

While UL60950-1 is the most widely applied standard for power supplies today, it is intended for use with information technology, business, and telecom equipment. Other standards exist for other industries, such as IEC 60065 for audio and video, IEC 60601 for medical, IEC 61010 for laboratory supplies, and others. Further efforts at harmonization are under way with a sub-committee of the IEC (SC22E) proposing a new standard, IEC 61204-7, which is intended for use with power supplies sold into multiple industries. This standard is currently under development.

The point to remember here is that safety standards, like most things high-tech, represent an evolving field. While UL 60950-1 has been used to prepare this subject, one of the first tasks in any new design activity should be to identify the standards, including recent revisions, which applies to the intended end use.

IV. ELEMENTS OF A POWER SUPPLY

A block diagram for a typical power supply is shown in Fig. 1 where the blocks have been defined in a way to ease the consideration of safety implications. While this figure illustrates an AC-line powered unit which, of course, is clearly an application where hazardous voltage levels could be present or internally generated, a similar blocking of functions could be derived for other designs, i.e., battery chargers or dc-to-dc converters.

The task of certifying a design for safety is made easier by the identification and use of as many components which, in themselves, are already qualified to an appropriate IEC safety standard. Many such power supply components are available, including:

- Power cords and/or input terminal assemblies
- Protective devices (fuses, clamps, etc.)
- EMI filters
- Power switches
- Wiring, PWBs, chassis
- Isolators (optocouplers)
- Transformers
- Rectifier assemblies
- Output connectors or terminals
- Cooling devices
- And many others…

Components which are already certified as conforming to the applicable standards need be evaluated only individually as to their application within their ratings, and then indirectly as a part of the complete power supply or end use application. Non-qualified components may need additional testing to the appropriate standard at the component level. Since this can add a significant amount of time and cost in the qualification process, it is highly advantageous to pick components which have already achieved prior approval.

V. CONSIDERATIONS FOR ELECTRICAL SAFETY

The prevention of electric shock is clearly a major safety goal. The impact on a human body is defined by the flow of current which, in turn, is affected by the body's resistance. The accepted value for the body's resistance is approximately 2000 Ω at a voltage of 110 Vdc; however this value decreases with increasing voltage. Another factor that affects resistance is the amount of surface area of contact. This has been quantized by defining two classifications of skin contact as:

- Full contact, meaning full contact by hand which has a typical area of about 8000 mm^2, but is simulated by a metal contact surface of 20 cm by 10 cm.

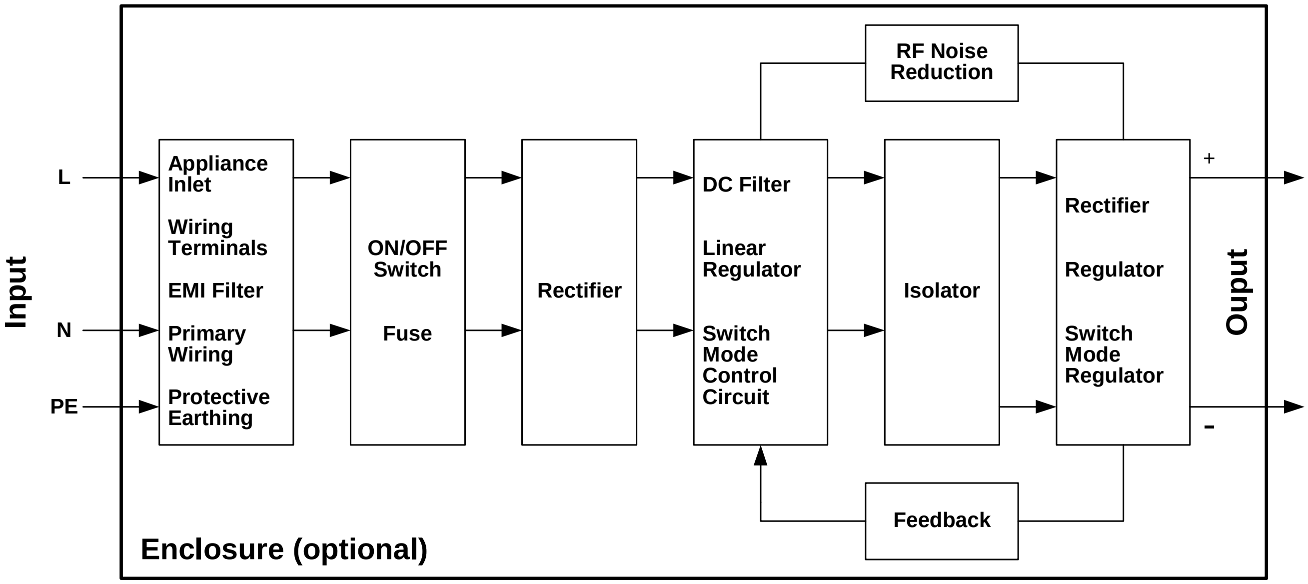

Fig. 1. The elements of a typical power supply.

- Limited contact is described as contact by finger tip and simulated by a metal contact surface of 10 mm^2. A standardized "finger probe" is defined to test for contact in tight regions or through enclosure openings.

In any case, it is current that affects the body and the effects have been categorized according to the table of threshold values in Table 1.

TABLE 1. THRESHOLD VALUES

Current (mA)	Effect
0.0 to 0.5	Perception, minimal reaction
0.5 to 3.5	Startle reaction, but ability to tolerate
3.5 to 10	Muscles contract, inability to let go
10 to 50	Fibrillation, cell damage

The acceptable limit for current is 2.0 mA dc, 0.7 mA pk ac and 0.5 mArms at frequencies up to 60 Hz. High-frequency current is less harmful to the human body and the permitted current is calculated by multiplying the 50/60 Hz threshold by the frequency in kHz, but with a maximum of 70 mA at all frequencies above 100 kHz. However, these limits can still cause burns if one touches a sharp edge or corner, as current density may be high.

Since it is the circuit voltage that drives this current, UL60950-1 categorizes circuits within a power supply as either hazardous or safe according to the maximum voltage or the maximum current possible at all points within the circuit, during both normal operating conditions and under any single fault. Within this criterion, there are three classifications of safe circuits

- **Limited Current Circuits (LCC)** where the maximum available current cannot exceed 2.0 mA dc, 0.7 mA peak ac, or 0.5 mA rms under both normal and single-fault conditions. There are also limits on allowable capacitance.
- **Safety Extra Low Voltage (SELV)** circuits where voltage levels cannot exceed 42.4 V pk ac or 60 Vdc, under both normal and single-fault conditions.
- **Telecommunication Network Voltage (TNV**) voltages may exceed SELV limits but are constrained by either accessibility or duration. The normal operating voltage can be up to 71 V peak ac or 120 V dc where the accessible contact area is limited to that of a connector pin. The voltages under a single fault can be higher for a short duration but must return to normal limits within 200 ms. Higher transient levels (up to 1500 V, but of short duration) are possible from the public switching telecom network.

Note that although all three of the above designations are considered as safe, only SELV and LCC circuits allow the operator unrestricted access to bare circuit components.

Classifications for circuits which are considered as unsafe and which must be protected against operator contact include:

- **Hazardous Voltage** circuits, where voltages above SELV limits can appear on bare components, or which contain components without adequate insulation from a potential high voltage source.
- **Extra Low Voltage (ELV)** circuits, which defines a circuit that meets SELV voltage limits under normal operating conditions but is not safe with a single fault.

Two other circuit classifications are defined by their location within a power supply's architecture:

- **Primary circuits**, where there is a direct connection to the ac mains voltage and clearly have the potential to reach hazardous voltage levels, and
- **Secondary circuits**, which have no direct connection to the primary circuits but may experience hazardous voltage levels.

VI. PROTECTION WITH INSULATION

UL60950-1 defines five categories of insulation.

A. *Types of Insulation*

- **Functional insulation** is that which is only necessary for circuit operation. It is assumed to provide no safety protection.
- **Basic insulation** provides basic protection against electric shock with a single level; however this category does not have a minimum thickness specification for solid insulation and is assumed to be subject to pinholes. Safety is provided by a second level of protection such as Supplementary insulation or protective earthing.
- **Supplementary insulation** is normally used in conjunction with Basic insulation to provide a second level of protection in the event that the Basic level fails. A single layer of insulating material must have a minimum thickness of 0.4 mm to be considered Supplementary insulation.
- **Double insulation** is a two-level system, usually consisting of Basic insulation plus Supplementary insulation.
- **Reinforced insulation** is a single-insulation system equivalent to Double insulation. It also requires a minimum thickness of 0.4 mm for use in a single layer.

Electric circuits rely upon insulation for operator protection, but designing for safety requires the premise that anything can fail. Therefore safety standards demand a redundant system with at least two levels of protection under the assumption that any single level may experience a failure but the chance of two simultaneous failures in the same spot is so improbable as to represent an acceptable risk. It should be noted that while two random failures need not be considered, the possibility of a second failure as a consequence of a first failure is something that the designer must evaluate if the two together would result in a total breakdown.

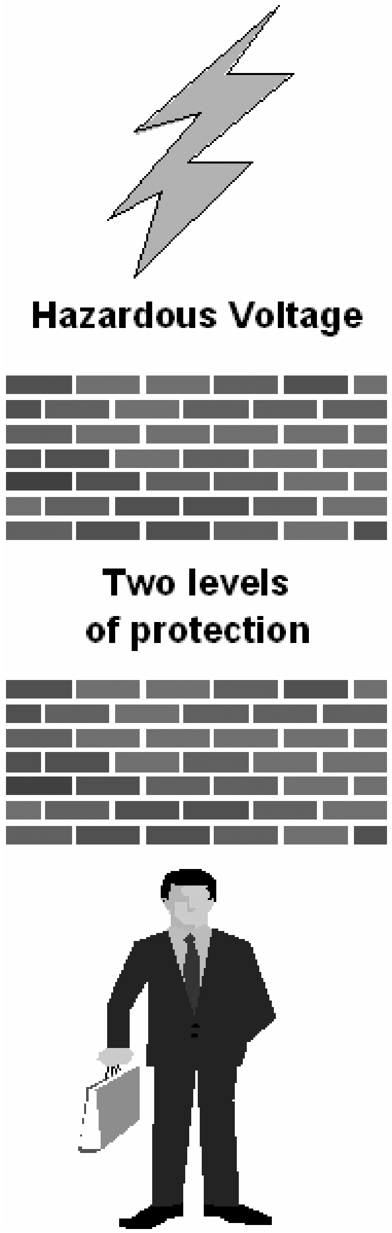

Fig. 2. Safety requires a Double barrier for redundant protection.

The general requirements are that a single level of insulation is acceptable if the circuit is not accessible, but wherever there are accessible components, they must be insulated from hazardous voltages by a Double-level system, and each level must meet the insulation specifications appropriate to the application. One qualification to this statement is that one level of protection could be protective earth provided by a conductive grounded enclosure.

B. Class Categories

Categories are used to define different classes of circuits and the type of insulation needed for each, as:

- **Class I Equipment**: Systems which use protective earthing (e.g., a grounded metal enclosure) as one level of protection and thus require only Basic insulation between the enclosure and any part at hazardous voltage
- **Class II Equipment**: The use of Double or Reinforced insulation to eliminate the need for a grounded metal enclosure as well as a grounded power plug.
- **Class III Equipment**: Powered from a SELV source and with no potential for generation of hazardous voltages internally, and therefore requiring only Functional insulation.

The process for defining insulation requirements starts with identifying each circuit block within the system according to the categories described above: LCC, SELV, TNV, ELV, or Hazardous. Then, with this knowledge, the appropriate insulation type and number of levels can be defined for use between blocks and between internal components and the user. A guide to insulation planning for a simple power supply example is shown in Fig. 3, which illustrates that there must always be two levels of protection between a hazardous voltage (on the left) and components accessible to the user (on the right).

For example, the path through a floating ELV circuit must have two levels, and at least one of those must be between the ELV and the user as an ELV could become unsafe with a single fault. However, if the ELV has grounded protection (providing one level), then only one additional level is needed. Similarly, external metal, (typically heatsinks or the power supply's enclosure), must isolate the user from the hazardous voltage with two levels of protection, unless one level is provided by grounding the metal.

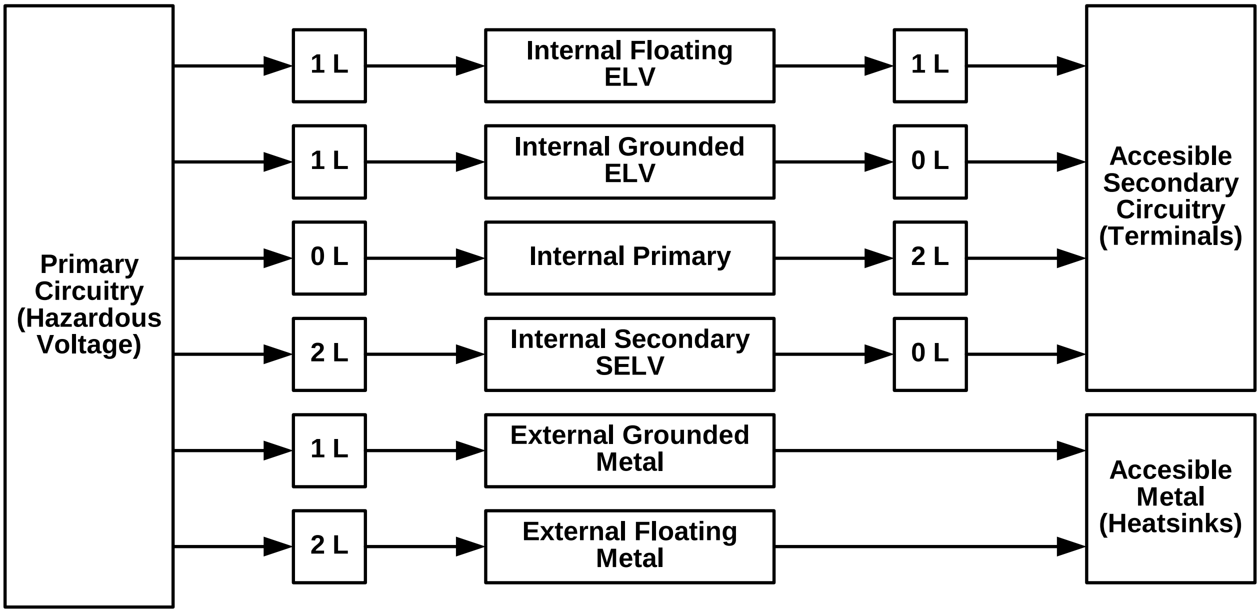

Fig. 3. Insulation coordination for a typical line-powered supply.

VII. WORKING VOLTAGE

With the insulation levels defined, specific requirements for the insulating medium must be considered. This medium can be either a solid material (such as plastic molding); or air (as in the space between components), and the requirements for both are affected by the voltage stress across the medium. Typically, a power supply is evaluated to determine the highest voltage levels possible at all points in the circuitry and under all operating conditions. The highest measured voltage between any two points then defines the **working voltage** for those two points. The working voltage between a primary circuit and a secondary circuit, or between the primary and ground, is taken as the upper limit of the rated voltage range for the supply.

An example is illustrated in Fig. 4 showing the schematic for a simple off-line power supply in which protective isolation is provided in both the transformer and the optocoupler. With all points on the primary referenced to either the line or the neutral power connections, hazardous voltage levels with respect to earth are assumed to be possible at any point on the primary side. The individual working voltages within the primary circuitry are evaluated as the maximum rated or measured voltage (whichever is higher) between any circuit element and either earth or any point on the secondary side of the transformer.

As shown in Fig. 4, the highest working voltages would normally be found on points labeled 0, 1, and 2 on the primary side of the transformer, and these points would then each be measured with respect to both earth and all secondary points labeled 3, 4, 5, and 6 with the condition that when one end of a secondary winding is used as a reference point, then the other end is to be connected to earth. These measurements - dc, rms, or peak - are evaluated to determine the highest value, which then establishes the minimum working voltage requirement for the protective insulation.

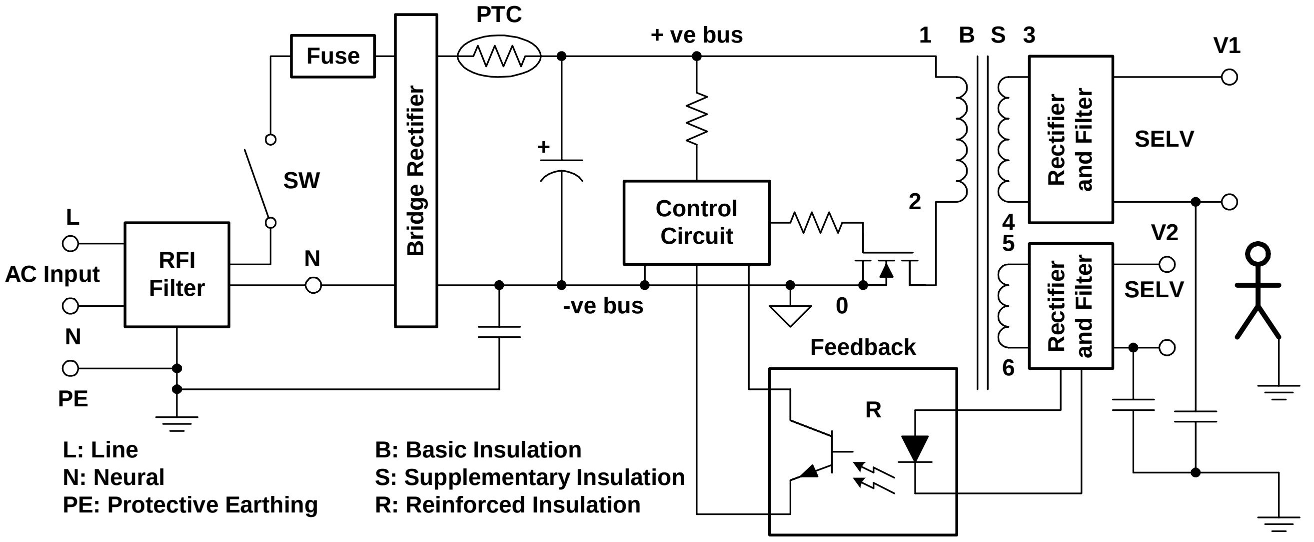

Fig. 4. Measurement points to determine the working voltage in the primary circuitry.

VIII. INSULATING MATERIALS

A. *Solid Insulation*

The choice and application of solid insulating material must consider, in addition to working voltage, the needs for electrical, thermal, and mechanical strength, as well as the operating environment. Only non-hygroscopic and flame resistant materials may be used. With particular respect to wiring insulation, it should be noted that some material compounds may contain plasticizers, intended to make them more flexible but with a side effect of increased flammability.

Semiconductor devices and other components that are molded in solid insulating material typically are independently qualified and inspected in the manufacturing process.

Solid insulation material in sheet form must also conform to the following thickness requirements:

- If a single sheet of insulation is provided, the minimum thickness is 0.4 mm.
- With two sheets together, there is no thickness requirement but each sheet must meet the required electric strength value.
- With three or more sheets, there is also no minimum thickness but every combination of two sheets must have adequate electric strength.
- There is no thickness requirement for Functional or Basic insulation.

B. *Air Insulation*

The use of air as an insulation medium introduces concerns both about the “quality” of the air and the spacing between electrically conducting components. The potential for conduction through air is affected by temperature, pressure, humidity, and pollution, with “pollution” being defined according to the operating environment by the following categories:

- Pollution Degree 1 – Components and assemblies which are sealed to exclude dust and moisture.
- Pollution Degree 2 – General office or home environment.
- Pollution Degree 3 – Equipment where the internal environment is subject to conductive pollution or possible moisture condensation.

The spacing distance between components that are required to withstand a given working voltage is specified in terms of Clearance and Creepage. A visual representation of the distinction between these terms, and their applicability to board-mounted components, is shown in Fig. 5

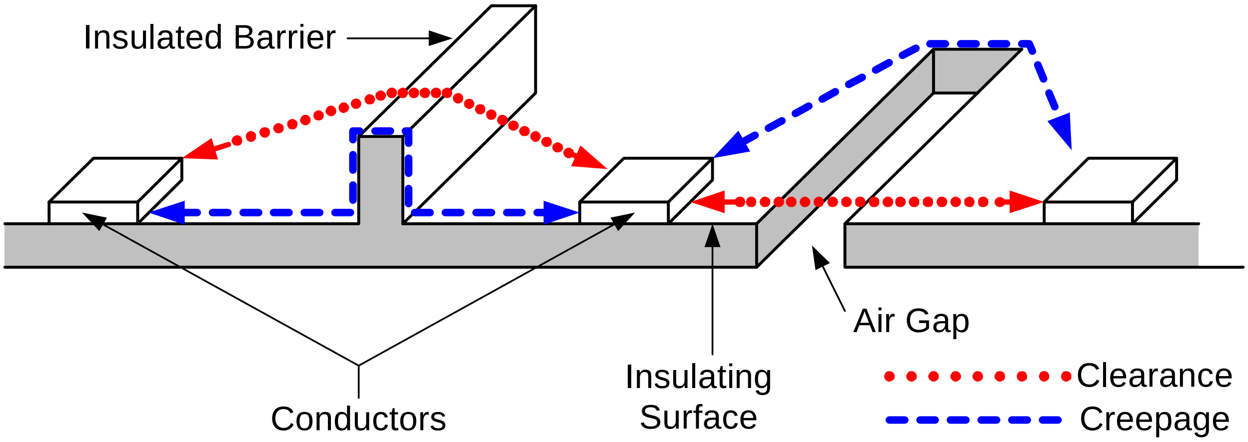

Fig. 5. Definitions of Creepage and Clearance.

IX. CLEARANCE AND CREEPAGE

In the discussion that follows, the tables presented show quantitative values for spacing requirements, in millimeters, which are listed as a function of the voltage, material, and environment. An additional distinction is the category of insulation system of which these spacings are a part, i.e., Functional, Basic/Supplementary, or Reinforced. In other words, if the spacing between components is not needed for safety, the "F" column may be used; if only one level of safety insulation is needed because a second level is provided elsewhere, the "B/S" column is applicable; and for the equivalent of a complete 2-level safety insulation, the "R" column should be used.

A. Clearance

Clearance is defined as the shortest distance through air between two conductive parts. Breakdown along a Clearance path is a fast phenomenon where damage can be caused by a very short duration impulse. Therefore, it is the maximum peak voltage, including transients, that is used to determine the required Clearance spacing according to charts given in the standard. A sample of one of these is shown in Table 2 where the spacing in millimeters required for different levels of insulation is given as a function of working voltage. Additional variables of ac mains voltage and the quality of the air within the space are indicated in this illustration but are applied more quantitatively in additional charts given in the complete standard.

B. Creepage.

Creepage is defined as the shortest distance between two conductive parts along the surface of any insulating material common to both parts. While the path is in the air, it is heavily influenced by the surface condition of the insulating material. Breakdown of the Creepage distance is a slow phenomenon, determined by dc or rms voltage levels rather than peak events. Inadequate Creepage spacing may last for days, weeks, or months before it fails. A sample of a table of Creepage requirements is given as Table 3 where the spacings are given as a function of the steady-state working voltage with additional variables of insulation type, material composition, and content of the air.

TABLE 2. PARTIAL CLEARANCE DIMENSIONS (MM) FROM UL60950-1, SECTION 2.10.3, TABLE 2H

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

TABLE 3. SAMPLE CREEPAGE DIMENSIONS (MM) FROM UL60950-1, SECTION 2.10.4, TABLE 2L

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

Semiconductor components, particularly optocouplers, do not typically have Clearance or Creepage requirements. Clearance and Creepage distances do not exist if the component is completely filled with an insulating compound or molded in solid insulating material, and the component is independently qualified and inspected in the manufacturing process. Creepage, however, can become important with respect to the boards upon which these devices are mounted. This often dictates a requirement for spreading the package pins to maintain the required board spacing.

Fig. 6 illustrates some alternative pin configurations available with the popular 4N25 series of optocouplers. Note that with a surface mount configuration, the shape of the leads allows a board spacing close to 8 mm while with through-hole mounting, meeting an equivalent Creepage spacing would require either a wider lead bend or a slot cut in the PC board between the input and output rows of pins.

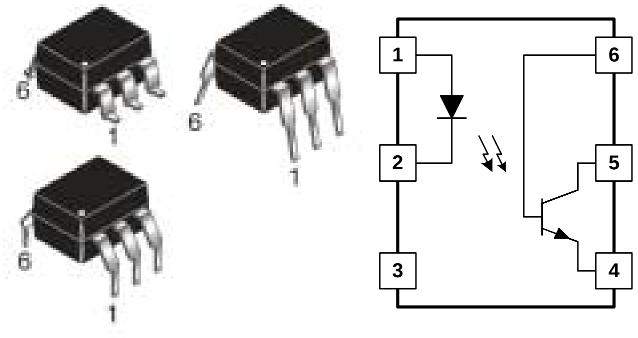

Fig. 6. Three pin configurations are offered with the popular 4N25 optocoupler to accommodate varying Creepage requirements for PCB mounting pads.

C. Transformer Construction

Fig. 7 shows a cross-section view of a typical isolating transformer where primary and secondary windings are wound on a common bobbin. Where hazardous voltages are involved, the insulation between primary and secondary must be at least Double or Reinforced with a minimum of two layers to allow for a single-element failure. Any enamel coating on the wire is not counted as an insulation level, although what is called “triple-insulated winding” wire meets Supplementary or Reinforced status depending upon the number of layers and their method of construction.

Unless the transformer is tested and qualified as a solid structure, completely filled with a solid insulating material, it is always assumed that there is a small amount of air present between the layers, even though there may be adhesive on one side of the insulating tape. In most transformer structures, Clearance and Creepage are the same and are shown in the figure as the sum of distances A and B. (The thickness of the tape is generally not taken into account.)

Transformer leads, as well as all other wires or cables must meet their own specifications and standards. Wire insulation must be PVC, neoprene, TFE, PTFE, or polyimide, or tested for flammability. Usually, insulating materials are required to meet one of the following classifications:

- V-1. Material is self-extinguishing upon removal of an external flame. Any flaming particles which drop do not ignite a cheese cloth fabric placed underneath.
- V-2. Material is self-extinguishing but cheese cloth may be charred or ignited from dropped flaming particles. V-2 material may only be used within an enclosure having no bottom openings.

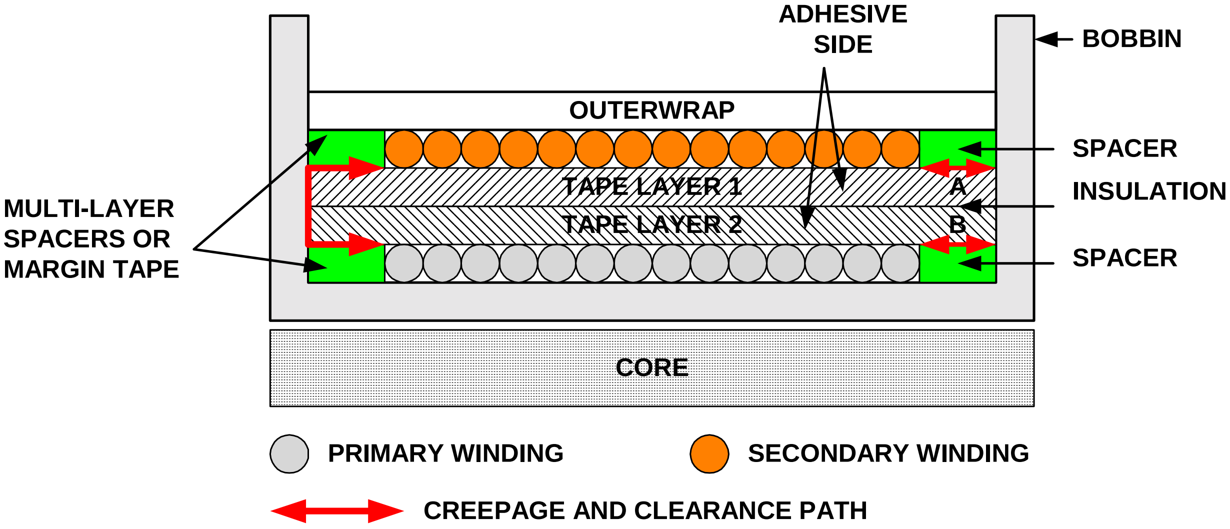

Fig. 7. Definitions insulation requirements for isolating transformers.

XI. DESIGNING FOR SAFETY

Clearly, there are many decisions in the design process where a knowledge of safety requirements and the application of their principles can go a long way toward easing the time and cost of the safety certification process. Particularly if a failure in safety testing requires a redesign effort late in the program. Anticipating the testing which may be required and designing accordingly certainly pays off at the end of the day. While definitely not all-inclusive, a summary of some of the design considerations is given below:

A. Materials

Pick components and materials which have prior safety certification. With certified components, the safety engineer looks only to see that they have been applied correctly and physical testing is done only as a complete system. Without certified components, additional component-level testing or excessively conservative design techniques could be required. As an example, the Y capacitor in an input EMI noise filter would be accepted as a certified device, but otherwise might require two capacitors in series to allow a safety test to short one of them, plus the additional testing of the capacitors themselves.

B. Mechanical

The safety engineer looks for rigid construction with all components securely attached and no sharp edges or corners. All areas containing hazardous voltages have been protected from access by the user, including through any openings in the enclosure. Openings in the enclosure are examined to ensure that there is no user access to hazardous voltage, sharp edges, hot components, fan blades, or any other item that might cause injury. A specified “finger probe” is used to probe all openings. Positive earthing connections and bonding straps must be provided where necessary.

C. Layout

An appropriate isolation strategy must be defined and rigidly applied throughout the design. Creepage and Clearance spacings must separate all hazardous voltages from user accessible points. There should be a very clear channel between primary and secondary circuits, similar to that illustrated in Fig. 8. It should be noted that hazardous voltage levels may be present on some secondary circuits where a low voltage output might be generated from a low duty-cycle, high peak voltage, PWM power pulse.

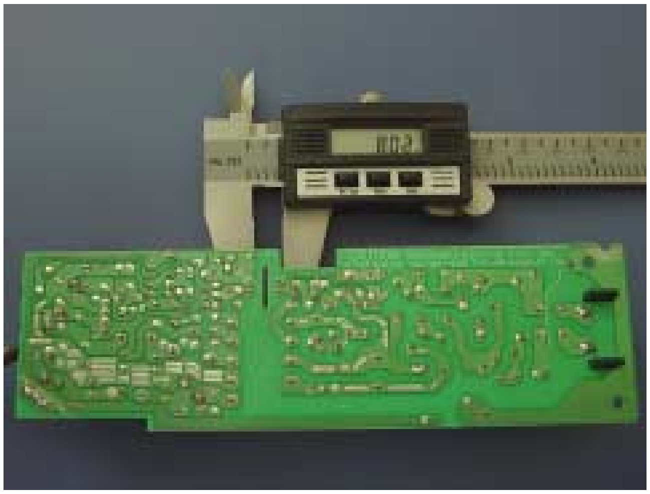

Fig. 8. PCB layout view clearly showing the Clearance spacing and Creepage slot under the optocoupler. between primary and secondary circuitry.

D. Design

Remember that hazardous conditions may also exist on low-voltage outputs where high power is possible (>240 VA). As a minimum, effective current limiting may be required. The power supply should also be able to withstand an overload test consisting of blocking the air vents, stopping the fan, and overloading or shorting the output until the condition becomes stabilized or the ultimate result is achieved. Failure would certainly include flame and smoke, excessive heating of components, flying shrapnel from an exploding component, or failure to pass an appropriate HiPot test.

The design must also ensure that no single failure causes any of the above hazardous conditions. The safety engineer randomly and selectively opens or shorts any component with flame-detecting cheese cloth draped around the unit under test. Anticipating these tests and designing for them is a necessary task. As an example, Fig. 9 shows a typical application of a low-voltage controller for an off-line supply, but modified in two simple ways. First, the start-up resistor to initially power the IC controller has been divided into two resistors, R1 and R2, allowing either to be shorted while still limiting current from the high-voltage bus. And secondly, anticipating a short applied between drain and gate of the power FET, the designer has used a fusible resistor for Rg, and added D1 to shunt excessive current around the IC and to ground through Z1.

In anticipation of these safety tests to simulate failures by shorting components, consideration should be given to insuring that either the input fuse blows (which is acceptable) or that, at least, dramatic failures (such as exploding capacitors) are prevented. Placing MOV protection devices across large electrolytic capacitors is a common way to limit over-voltage. Where voltage is not an issue, two capacitors in series may allow one to be safely shorted – a technique useful when adding a noise-reducing bypass capacitor between primary and secondary grounds.

XII. POWER SUPPLY CERTIFICATION

While testing procedures may vary according to test agency, type of power supply, and application or end use, they typically include the following steps:

- A construction analysis on open or unsealed test samples, checking:
    - Insulation coordination
    - Clearances, Creepage, and solid insulation dimensions
    - Accessibility
    - Protective earthing
    - Strain relief
    - Mechanical evaluation
- Determination, using both analysis and physical measurement, of internal working voltage limits
- Worst-case operational testing, exercising both input voltage and load variations.
- Single fault and overload testing including short circuits
- Heating tests under normal operating conditions
- Humidity
- Hi Pot leakage current measurements
- Flame tests
- And whatever additional specialized testing is deemed necessary

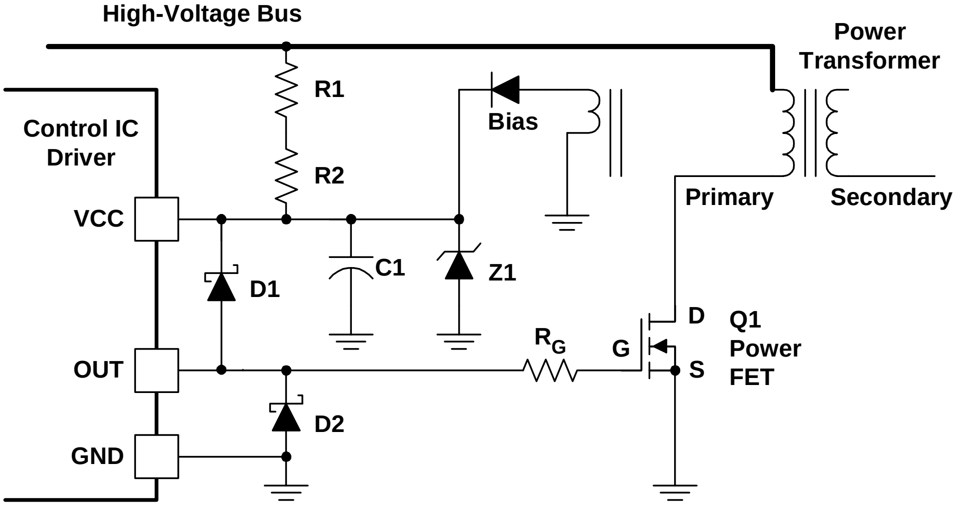

Fig. 9. An example of start-up circuitry with components R2 and D1 added in the interests of safety.

The certification process starts with the submittal of an application and documentation package to completely describe the power supply and all its component parts and materials. A number of units for testing are also provided, often five without an enclosure and five in completed form, together with a purchase order for the cost which typically ranges between $6000 and $8000 for the average small power supply. The certification process can take as little as 6 to 8 weeks, but with a product containing design deficiencies, can go much longer.

XIII. ACKNOWLEDGEMENT

Texas Instruments recognizes and appreciates the technical material and support provided by Underwriters Laboratories in the preparation of this seminar topic. For additional information on this subject or about the specialized seminars presented by UL, use the following contact information.
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