Chapter 4 Synopsis of Key Regulatory Specifications

4.0 How To Use The Regulatory Synopsis Information

Chapter 4 contains a brief regulatory summary of key electrical safety requirements of each of the International or National safety standards addressed in Chapter 3. These summaries only address electrical safety requirements of each standard as indicated through the insulation coordinates (creepage, clearance, or through distance insulation) and test voltage requirements.

The purpose of these summaries is to provide an overview of the electrical safety requirements and pertinent safety parameters of the standard. Key safety standard parameters that have been summarized in these tables are requirements for creepage distance, clearance distance, and test voltage requirements.

The synopsis by its very nature and brevity cannot do full justice to the details and elaboration that are included in the actual document or a safety standard. Thus, in case you desire to find further details of a safety standard, we encourage you to obtain the actual safety standard that you may be interested in. Most safety standard documents can be obtained from the American National Standards Institute located in New York. Or, the document can be purchased directly from the home address of each agency. See the Appendices for pertinent agency addresses.

Once again, Agilent Technologies takes this opportunity to disclaim any or implied equipment level safety standard approval to any of the equipment standards or insulation coordination standards discussed in this chapter as they pertain to Agilent optoisolators. The information provided in this chapter is provided as a service to Agilent optoisolator component users. It is the equipment manufacturer's responsibility to have their equipment approved through appropriate safety standard agency.

4.1 International Standard IEC 1010-1:

Safety Requirements for Electrical Equipment for Measurement, Control, and Laboratory Use.

This is an international safety standard that specifies general safety requirements for electrical equipment for professional, industrial process, and educational use. This includes any peripheral electrical equipment or accessories or computing devices that may be used in conjunction with measurement and test equipment, control devices, or laboratory use devices.

For instance, electrical measurement and test equipment may include any measurement and recording devices such as computers, oscilloscopes, main frame testers, etc. Non-measuring electrical equipment such as signal generators, power supplies, transducers, transmitters, etc., are also within the scope of this standard. Electrical control equipment can be any equipment that controls an output as a function of some input control variable such as programmable logic controllers (PLCs) etc. Electrical Laboratory Equipment is any equipment which measures, indicates, monitors or analyzes substances, or is used to prepare materials.

Environmental Conditions

This standard applies to equipment designed to be safe at least under the following conditions: Indoor use, altitude up to 2000 m, temperature 5°C to 40°C, maximum relative humidity 80% for temperature up to 31°C, decreasing linearly to 50% relative humidity at 40°C. The mains supply voltage fluctuations not to exceed ±10% of nominal value (other supply voltage fluctuations as stated by manufacturer). Transient overvoltages (Table 4.1.1) are according to Installation Categories (Overvoltage Categories) I, II, and III. For mains supply the minimum and normal category is II. The Pollution Degree 1 or 2 in accordance with IEC 664.

According to IEC 664 Insulating Materials are separated into four groups by their Comparative Tracking Index (CTI) values as specified in IEC 112. For more information see IEC 664. All of Agilent Technologies optoisolators are molded from material group IIIa, and have CTI >200.

- Material Group I: 600 < CTI
- Material Group II: 400 < CTI < 600
- Material Group IIIa: 175 < CTI < 400
- Material Group IIIb: 100 < CTI < 175

Table 4.1.1: Maximum Transient Overvoltages vs. Installation Category

Voltage 3-phase 4-wire systems (V)	Voltages 3-phase 3-wire systems (V)	Voltages phase-to-earth (V)	Maximum Transient Overvoltage (V)		
			Installation Category (I)	Installation Category (II)	Installation Category (III)
		50	330	500	800
66/115	120	100	500	800	1500
120/208 120/240	240	150	800	1500	2500
230/400 277/480	500	300	1500	2500	4000
400/690	1000	600	2500	4000	6000
		1000	4000	6000	8000

Clearance and Creepage Distances

The installation category (overvoltage category) is established by the maximum transient overvoltages that a circuit experiences, and thus influences the clearance dimensions. The minimum creepage distance allowed is at least as large as the clearance dimension.

Tables 4.1.2 and 4.1.3 specify Clearances and Creepage Distances in relation to working voltage, as derived from IEC 664. The tables specify values with respect to working voltage, and is defined as "the highest r.m.s. values of the a.c. or d.c. voltage which may occur (locally) across any insulation at rated supply voltage, transients being disregarded".

Table 4.1.2: IEC 1010-1 Clearance / Creepage Requirements
Safety Requirements for Electrical Equipment for Measurement, Control, and Laboratory Use

Working Voltage V rms or dc	Insulation Level	Pollution Degree 1					
		Installation Category I		Installation Category II		Installation Category III	
		Clearance mm	Creepage mm	Clearance mm	Creepage mm	Clearance mm	Creepage mm
50	Basic	0.1	0.1	0.1	0.1	0.1	0.1
	Reinforced	0.1	0.1	0.12	0.12	0.4	0.4
100	Basic	0.1	0.1	0.1	0.1	0.5	0.5
	Reinforced	0.12	0.2	0.4	0.4	1.6	1.6
150	Basic	0.1	0.22	0.5	0.5	1.5	1.5
	Reinforced	0.4	0.45	1.6	1.6	3.3	3.3
300	Basic	0.5	0.7	1.5	1.5	3	3
	Reinforced	1.6	1.6	3.3	3.3	6.5	6.5
600	Basic	1.5	1.7	3	3	5.5	5.5
	Reinforced	3.3	3.4	6.5	6.5	11.5	11.5
1000	Basic	3	3.2	5.5	5.5	8	8
	Reinforced	6.5	6.5	11.5	11.5	16	16

Notes:
1: IEC 1010-1 safety standard derives the creepage / clearance distances from IEC 664.
2: Table lists creepage values for printed wiring boards (not coated)

Table 4.1.3: IEC 1010-1 Clearance / Creepage Requirements
Safety Requirements for Electrical Equipment for Measurement, Control, and Laboratory Use

Working Voltage V rms or dc	Insulation Level	Pollution Degree 2 Installation Category I Clearance mm	Installation Category I Creepage mm	Installation Category II Clearance mm	Installation Category II Creepage mm	Installation Category III Clearance mm	Installation Category III Creepage mm
50	Basic	0.2	0.2	0.2	0.2	0.2	0.2
	Reinforced	0.2	0.4	0.2	0.4	0.4	0.4
100	Basic	0.2	0.2	0.2	0.2	0.5	0.5
	Reinforced	0.2	0.4	0.4	0.4	1.6	1.6
150	Basic	0.2	0.35	0.5	0.5	1.5	1.5
	Reinforced	0.4	0.7	1.6	1.6	3.3	3.3
300	Basic	0.5	1.4	1.5	1.5	3	3
	Reinforced	1.6	2.8	3.3	3.3	6.5	6.5
600	Basic	1.5	3	3	3	5.5	5.5
	Reinforced	3.3	6	6.5	6.5	11.5	11.5
1000	Basic	3	5	5.5	5.5	8	8
	Reinforced	6.5	10	11.5	11.5	16	16

Notes:
1: IEC 1010-1 safety standard derives the creepage / clearance distances from IEC 664.
2: Table lists creepage values for printed wiring boards (not coated)

Test Voltages

Table 4.1.4 lists the test voltages for establishing compliance for respective creepage and clearance of the insulation. Compliance is established if no breakdown or repeated flashover occurs. For the purposes of this safety standard, corona and similar phenomenon are not considered.

This safety standard offers three different test voltage options: Peak impulse test, a.c. test, or a d.c. test. Equipment or component has to pass any one of the three listed alternative test voltages.

Peak impulse test is the 1.2/50 µs test specified in IEC 60, and is conducted for a minimum of 3 pulses of each polarity at 1 s minimum interval. The a.c. and d.c. tests are conducted with the voltage raised gradually within 10 s to the specified value (with no appreciable transient occurring), and the voltages are maintained for 1 minute.

Table 4.1.4: IEC 1010-1 Test Voltages for Dielectric Strength Tests
Safety Requirements for Electrical Equipment for Measurement, Control, and Laboratory Use

Working Voltage V rms or dc	Insulation Level	Pollution Degree 1 or 2								
		Installation Category I			Installation Category II			Installation category III		
		Test Voltage	Test Voltage	Test Voltage	Test Voltage	Test Voltage	Test Voltage	Test Voltage	Test Voltage	Test Voltage
		Peak Impulse 1.2/50μs	rms 50/60 Hz (1 min)	dc or 50/60 Hz peak (1 min)	Peak Impulse 1.2/50μs	rms 50/60 Hz (1 min)	dc or 50/60 Hz peak (1 min)	Peak Impulse 1.2/50μs	rms 50/60 Hz (1 min)	dc or 50/60 Hz peak (1 min)
50	Basic	330	230	330	500	350	500	800	490	700
	Reinforced	560	400	560	850	510	720	1360	740	1050
100	Basic	500	350	500	800	490	700	1500	820	1150
	Reinforced	850	510	720	1360	740	1050	2550	1400	1950
150	Basic	800	490	700	1500	820	1150	2500	1350	1900
	Reinforced	1360	740	1050	2550	1400	1950	4250	2300	3250
300	Basic	1500	820	1150	2500	1350	1900	4000	2200	3100
	Reinforced	2550	1400	1950	4250	2300	3250	6800	3700	5250
600	Basic	2500	1350	1900	4000	2200	3100	6000	3250	4600
	Reinforced	4250	2300	3250	6800	3700	5250	10200	5500	7850
1000	Basic	4000	2200	3100	6000	3250	4600	8000	4350	6150
	Reinforced	6800	3700	5250	10200	5550	7850	13600	7400	10450

NOTES:
1: Any one of the three alternative test voltages can be used.
2: Impulse test is the 1.2/50 μs test specified in IEC 60 (minimum of 3 pulses of each polarity, at 1 s min. interval).
3: Table lists dielectric strength test voltages derived from IEC 664 (on printed wiring boards).

4.2 DIN VDE 0160 or EN50178:

Safety Requirements for Electronic Equipment For Use In Electrical Power Installations and Their Assembly Into Electrical Power Installations

VDE 0160 is a specification that regulates electronic equipment for use in electrical power installations inside Germany, and EN50178 is an equivalent draft specification authored by CENELEC for Europe. A typical industrial application for optocouplers is inverters, which fall under this standard and specification. At the time of this writing EN50178 is a draft document, but DKE has accepted its contents as current requirements for VDE 0160. This description is a short summary of only the EN50178 optoisolator requirements, and some differences with VDE 0160 compliance are highlighted. EN50178 clearly describes certain requirements for creepage and clearance for printed circuit boards. Because optoisolators isolate the high voltages on the boards, these requirements become external creepage and external clearance requirements for the optoisolator.

Clearance

The current EN50178 requirements for clearance are outlined in referenced specifications, IEC664-1. To determine the clearance requirement for the optoisolator, certain parameters are needed – the overvoltage category (or application class), basic or reinforced insulation requirement, as well as the incoming line voltage for the equipment. Another parameter is the pollution degree. Since printed circuit boards are usually in pollution degree 2 environment or lower, this summary assumes that the optoisolator is in a pollution degree 2 environment.

The overvoltage category 2 is applicable for mains supply connected to movable equipment (examples of such equipment are appliances, portable tools, and other household equipment). Whereas, the overvoltage category 3 applies when the equipment is in a fixed installation (examples of such equipment are appliances, portable tools, and other household equipment). Whereas, the overvoltage category 3 applies when the equipment is in a fixed installation (examples of such equipment are switches in the fixed installation and equipment for industrial use with permanent connection to the fixed installation). A simplification is to say that category 2 means that the equipment has a removable plug connector and category 3 involves hard wiring to the building supply line. Per EN50178 the equipment manufacturer must select using basic insulation or reinforced insulation; basic insulation makes for easier component selection but poses other design issues for the equipment.

Table 4.2.1 Clearance Requirements vs. Transient Overvoltage
Application Class II, Pollution Degree 2

Line Voltage Vrms or dc	Transient Overvoltage Vrms or dc	Basic Insulation Clearance mm	Reinforced Insulation Clearance mm
120 - 240 V Single Phase	1500	0.5	1.5
up to 277 V 3 Phase	2500	1.5	3
up to 400 V 3 Phase	4000	3	5.5
1000 V	6000	5.5	8

Table 4.2.2 Clearance Requirements vs. Transient Overvoltage
Application Class III, Pollution Degree 2

Line Voltage Vrms or dc	Transient Overvoltage Vrms or dc	Basic Insulation Clearance mm	Reinforced Insulation Clearance mm
120 - 240 V Single Phase	2500	1.5	3
up to 277 V 3 Phase	4000	3	5.5
up to 400 V 3 Phase	6000	5.5	8
1000 V	8000	8	14

Creepage

As with clearance, the EN50178 creepage requirements are described inside the referenced document of IEC 664-1. As above, the pollution level is assumed to be pollution degree 2 for a printed circuit board with an optoisolator. The important parameters that determine creepage are the working voltage and basic versus reinforced insulation requirement. The definition of working voltage is the highest AC rms voltage or DC voltage that is placed across the part when the equipment is correctly operating. All Agilent Technologies optoisolators are made using transfer molding compounds that belong to Material group IIIa as defined in IEC 664-1.

Other Requirements

Creepage and clearance are directly described inside EN50178 and its referenced documents. Other requirements can be associated with EN50178, although the specification might only obliquely mention these other requirements. One example is the impulse voltage test, whereby a 1/50 ms impulse voltage is applied across the part. If the clearances are designed as described above, this routine test can be waived. The impulse test voltages match those for the transient overvoltage.

Per EN50178 the equipment must be subjected to an AC or DC voltage test, both as a qualification and a production test. The test time is 5 seconds for qualification and 1 second for routine testing, and the failure criteria is absence of flashover. The test voltage is dependent upon the rated insulation voltage, which is the recurring peak value of the highest voltage appearing continuously across any two live parts of the equipment during operation. The insulation test voltage also varies with the voltage between circuits and accessible surfaces if the surface is not connected to protective earth. The test voltage is represented as AC rms, or the peak AC value can be used for a DC test. Interpolation is permitted.

Table 4.2.3 Creepage Requirements vs. Working Voltage

Working Voltage Vrms or dc	Creepage Basic Insulation	Creepage Reinforced Insulation
200	2	4
250	2.5	5
320	3.2	6.4
400	4	8
500	5	10
630	6.3	12.6
800	8	16
1000	10	20

Table 4.2.4 Rated Insulation vs. Test Voltages

Rated Insulation Voltage Vrms	AC Test Voltages with Basic Insulation and Protective Separation Vrms	Ac Test Voltage Between Circuits and Accessible Surface Vrms
230	1100	1800
300	1200	2200
400	1350	2600
600	1650	3500
690	1800	3800
1000	2250	5000

Another requirement for the EN50178 equipment is to perform a partial discharge test. The requirement is that the equipment is subjected to 1.25 times the rated voltage, which is the recurring peak voltage value. This requirement applies to the optoisolator, and partial discharge free optoisolators are currently available as DIN/VDE 0884 optoisolators. More detailed information regarding DIN/VDE 0884 optoisolators is available in this handbook. Agilent Technologies has a full range of DIN/VDE 0884 optoisolators to meet this requirement.

This specification also refers to an impulse voltage requirement, which can be waived if the clearance requirements are satisfied without reduction or deviation.

4.3 International Standard IEC 65:

Safety Requirements for mains operated electronic and related apparatus for household and similar general use

IEC 65 is an International Standard that specifies safety requirements for household equipment intended for domestic and indoor use. Examples of this type of equipment are radios, VCRs, TVs, amplifiers, cable connected remote control device, motor driven devices etc. The standard applies to equipment for use for a 2000 m maximum altitude. This standard does not apply to equipment designed for a rated supply voltage that exceeds 433 V rms (between phases for a 3 phase supply) and 250 V rms in all other cases. Rated supply voltage is the supply mains voltage for which the manufacturer has designed the apparatus.

Attached Table 4.3.1 lists the creepage and clearance requirements versus the peak operating voltage. This voltage is construed as the peak supply mains voltage, which is the power source for the household equipment. For class I equipment, the accessible metal parts are separated from live parts by basic insulation. For class II equipment, the accessible metal parts are separated from live parts by reinforced insulation. The test voltages are applied for 1 minute. The minimum creepage and clearance shall be a minimum of 0.5 mm for basic insulation and 1 mm for reinforced insulation.

Insulation requirement for accessible parts and live parts shall be able to withstand transient surges. The insulation is subjected to 50 discharges at a maximum rate of 12 per minute, from a 1 nF capacitor charged to a 10 kV. The test circuit for the surge test is shown in figure 4.3.1. The insulation resistance after the surge test shall not be less than 2 Mohm at 500 V dc.

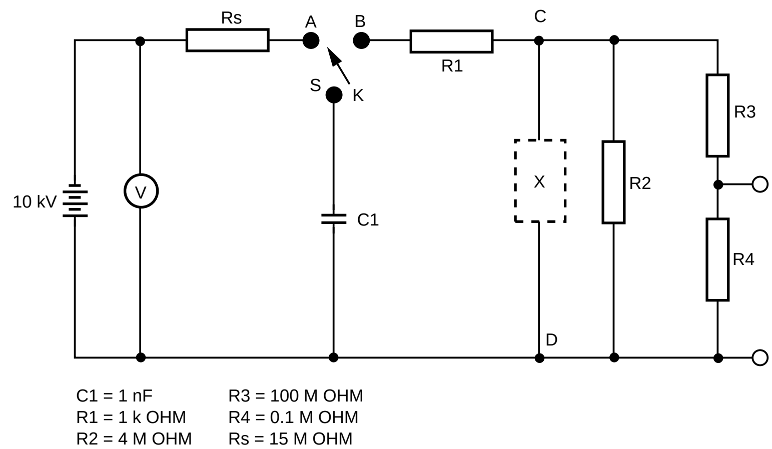


Figure 4.3.1: Circuit for Surge Test IEC 65 Component Under Test Connected across Terminals C and D

Apparatus will be able to operate in humid conditions, and compliance is established by test conditions described in IEC 68-2-3: Test Ca: Damp Heat, Steady State (temperature: 40°C, relative humidity: 90% to 95%).

The apparatus is kept in the humidity chamber for:

- 5 days (120 hours) for apparatus to be used under tropical conditions
- 2 days (48 hours) for other apparatus

The insulation resistance is tested with a 500 Vdc and should be a minimum of 2 Mohm for basic insulation and 4 Mohm for reinforced insulation.

For the measurement of dielectric strength, insulation test voltages are either AC peak voltage or dc voltage (see Table 4.3.1). Where corona, ionization charge effects may occur, a dc test voltage is recommended. The test voltages are applied for 1 minute. Compliance is established after the 1 minute test voltage, if insulation resistance specification is met (at the 500 V dc test), and there is no flashover or breakdown.

Table 4.3.1: IEC 65 Safety Requirements
Safety Requirements for mains operated electronic and related apparatus for household and similar general use

Supply* Mains Voltage Vpeak	Insulation	Creepage mm	Clearance mm	Test Voltage Vpeak
34	Basic	0.6	0.6	707
	Reinforced	1.2	1.2	1410
70	Basic	1	1	1000
	Reinforced	2	2	2000
354	Basic	3	3	2120
	Reinforced	6	6	4240
500	Basic	4	4	2500
	Reinforced	6	6	4240
900	Basic	6	6	3000
	Reinforced	6	6	4240
1200	Basic	7	7	3800
	Reinforced	7	7	4240
1500	Basic	9	9	4000
	Reinforced	9	9	4240
2000	Basic	11	11	5000
	Reinforced	11	11	5000

Notes:
1: Class I equipment uses Basic Insulations, Class II equipment uses Reinforced Insulations.
*2: The voltages are determined with the apparatus connected to the rated supply voltage after the steady state has been reached.

4.4 International Standard 601-1:

General Safety Requirements for Medical Electrical Equipment

The IEC 601-1 safety standard specifies general requirements for the safety of Medical Electrical Equipment and serves as a basis for particular standards. The particular standards take priority in case of any conflicting requirements of the general standard and a particular standard.

Class I equipment is that equipment that does not rely on basic insulation only, but has additional safety precautions such that any accessible parts do not become live in the event of a failure of the basic insulation. Class II equipment is that equipment that does not rely on basic insulation only, but additional safety such as double insulation or reinforced insulation is provided.

This safety standard requires that insulation, components, and construction features the failure of which could produce a safety hazard shall be tested for compliance of the standard. Only insulations with a safety function need be subject to testing. Equipment is classified according to:

a) Type of protection against electric shock and power source
b) Degree of protection against electric shock
c) Methods of sterilization recommended by manufacturer
d) Flammability
e) Mode of operation (continuous or intermittent)

The equipment in this standard is capable of operating in an ambient temperature range of +10°C to + 40°C, relative humidity range of 30% to 75%, and atmospheric pressure range of 500 hPa to 1060 hPa.

Table 4.4.1 lists the creepage, clearance, and test voltages for basic and reinforced insulation. The dielectric strength of the electrical insulation shall be able to meet the test voltages indicated in the table. The test time for the test voltages is 1 minute. The reference voltage indicated in Table 4.4.1 is the voltage to which an insulation is subjected to in normal use and rated supply voltage (or a voltage as specified by the manufacturer, whichever is greater).

Table 4.4.1: IEC 601-1 Safety Standard Requirements
General Safety Requirements for Medical Electrical Equipment

Reference* Voltage dc	Reference* Voltage ac	Insulation	Creepage mm	Clearance mm	Test Voltage (1 minute) V rms
15	12	Basic	1.7	0.8	500
		Reinforced	3.4	1.6	500
34	30	Basic	2	1	500
		Reinforced	4	2	500
75	60	Basic	2.3	1.2	1000
		Reinforced	4.6	2.4	3000
150	125	Basic	3	1.6	1000
		Reinforced	6	3.2	3000
300	250	Basic	4	2.5	1600
		Reinforced	8	5	4200
450	380	Basic	6	3.5	1900
		Reinforced	12	7	4800
600	500	Basic	8	4.5	2200
		Reinforced	16	9	5400
800	660	Basic	10.5	6	2600
		Reinforced	21	12	6200
900	750	Basic	12	6.5	2800
		Reinforced	24	13	6600
1200	1000	Basic	16	9	3200
		Reinforced	32	18	7400

Notes:
* 1: Reference voltage is the voltage which the relevant insulation is subjected in NORMAL USE and RATED supply voltage, whichever is greater.
2: Class I equipment uses Basic Insulations, Class II equipment uses Reinforced Insulations.

4.5 International Standard IEC 664-1:
Insulation Coordination for Equipment Within Low-Voltage Systems

IEC 664-1 safety standard addresses insulation coordination for equipment within low voltage systems. It applies to equipment for use up to 2000 m elevation (extrapolation to higher elevations is allowed), a rated voltage up 1000 V a.c. with rated frequencies up to 30 kHz or a rated voltage up to 1500 V d.c. This standard specifies the requirements for clearances, creepage distances and solid insulation, and includes methods of electric testing with respect to insulation coordination.

IEC664-1 is a basic safety standard and is a guide for Technical Committees responsible for different equipment in order to rationalize their requirements so that insulation coordination is achieved. The insulation coordination is the mutual correlation of insulation characteristics of electrical equipment taking into account the expected microenvironments or voltage environments to which the equipment will be subjected to in their normal use. In other words, the insulation coordination indicates the selection of the electric insulation characteristics of the equipment with regard to its application, and takes into account the working voltage, rated voltage, and rated insulation voltage of the equipment.

The insulation coordination uses a preferred series of rated impulse voltages indicated in Table 4.5.1 for equipment energized directly from the low-voltage mains:

IEC 664-1 insulation coordination standard also indicates that consideration shall be given with regard to recurring peak voltages and to the extent partial-discharge can occur in solid insulation. The micro-environmental conditions are taken into account as quantified by pollution degree. For the purposes of evaluating creepage distances and clearances four degrees of pollution degrees are established:

a) Pollution Degree 1: No pollution or only dry, non-conductive pollution occurs, and pollution has no significant impact. Air-conditioned office environments and labs are an example of pollution degree 1 environment.
b) Pollution Degree 2: Only non-conductive pollution occurs except that occasionally a temporary conductivity caused by condensation is to be expected. Home environments can be considered pollution degree.

Table 4.5.1: IEC 664-1 Rated Impulse Voltage
Insulation Coordination for Equipment within Low-Voltage Systams

Nominal Voltage of the Supply System V		Voltage Line to Neutral a.c. or d.c V	Rated Impulse Voltage V			
			Overvoltage Category			
Three Phase	Single Phase		I	II	III	IV
		50	330	500	800	1500
		100	500	800	1500	2500
	120-240	150	800	1500	2500	4000
230/400* 277/480*		300	1500	2500	4000	6000
400/690		600	2500	4000	6000	8000
1000		1000	4000	6000	8000	12000

Notes:
*1: The / mark indicates a four-wire three-phase distribution system. The lower value is the voltage line to neutral, while the higher value is the voltage line-to-line. Where only one value is indicated, it refers to three wire, three phase systems and specifies the value line-to-line.

c) Pollution Degree 3: Conductive pollution occurs or dry non-conductive pollution occurs which becomes conductive due to condensation which is to be expected. Industrial warehouses or factory floors may be construed as pollution degree 3 environments.
d) Pollution Degree 4: The pollution generates persistent conductivity caused by conductive dust or by rain or snow. Areas exposed to outside atmosphere can be classified as pollution degree 4 environments.

Equipment is dimensioned based on overvoltage category according to the expected use of the equipment. Four Overvoltage categories are established: I, II, III, and IV:

a) Overvoltage Category I: Equipment of overvoltage category I is equipment for connection to circuits in which measures are taken to limit transient overvvoltages to an appropriately low voltage. Circuits or equipment in this category are well isolated from mains supply. If the voltage were below 42.4 V it would be considered SELV (safety extra low voltage). Protected electronic circuits fall in this category.

b) Overvoltage Category II: Equipment of overvoltage category II is equipment that receives its energy or power from a fixed installation or receptacle from power mains. Examples of such equipment or circuits are home appliances and power tools.

c) Overvoltage Category III: Equipment of overvoltage category III is equipment in fixed installations. Category III is the mains distribution in the building, including duplex outlets. Examples of such equipment are switches in the fixed installation and equipment for industrial use with permanent connection to the fixed installation.

d) Overvoltage Category IV: Equipment of overvoltage category IV is for use at the origin of the installation. Examples of such equipment are electricity meters and primary overcurrent protection equipment.

This standard also uses the comparative tracking index (CTI) to classify the insulation materials. Materials are separated into four groups according to their CTI values, as follows:

- Material Group I 600 < CTI

- Material Group II
  400 < CTI < 600

- Material Group IIIa
  175 < CTI < 400

- Material Group IIIb
  100< CTI < 175

The test for comparative tracking index (CTI) is according to IEC 112. This test consists of dropping aqueous contaminant on insulation placed on a horizontal surface and determining voltage when electrolytic conduction takes place. This test provides both a qualitative and a quantitative comparison between insulation materials having a tendency to arc or form tracks in the presence of voltages.

Dimensioning of Clearances
Clearances shall be dimensioned to withstand the required impulse withstand voltage up to an elevation of 2000 m per tables 4.5.2.and 4.5.3. The clearances of basic insulation shall be as indicated in this table. Clearances of reinforced insulation shall be one step higher in the preferred series of values that are specified in the table below than that specified for basic insulation. For intermediate values of the impulse withstand values of the preferred series, reinforced values are to withstand 160% of of the impulse withstand voltage required for basic insulation. For higher elevation than 2000 meter, this standard also specifies altitude correction factors for clearances.

Dimensioning of Creepage Distances
Creepage distances will be according to table 4.5.4, and takes into account the working voltage (long-term r.m.s. value) across the insulation, and also the influence of the micro-environment as indicated by the pollution degree. A creepage distance cannot be less than the associated clearances (shortest creepage is equal to required clearance). There is no physical relationship between the creepage distances and the clearance distance, other than the dimensional limitation indicated. Reinforced insulation will have creepage distances that are twice the value of the voltage specified for basic insulation.

Requirements of Solid Insulation
Design of solid insulation requires attention to the partial discharge phenomenon. In particular a solid insulation subjected to high frequencies is more sensitive to partial discharges. Accelerated life testing indicates that time to failure is inversely proportional to the frequency of the applied voltage. According to this standard there is no clear relationship between the thickness of the insulation and failure mechanisms related to frequency of operation

Table 4.5.2: IEC 664-1 Minimum Clearances For Insulation Coordination
Insulation Coordination for Equipment within Low-Voltage Systems

Required Impulse Withstand Voltage kV	Minimum Clearances in Air up to 2000 m (mm) Basic Insulation(Inhomogenous Electric Fields) Pollution Degrees			
	1	2	3	4
0.33 *	0.01	0.04	0.8	1.6
0.4	0.02	0.04	0.8	1.6
0.5*	0.04	0.04	0.8	1.6
0.6	0.06	0.2	0.8	1.6
0.8*	0.1	0.2	0.8	1.6
1	0.15	0.2	0.8	1.6
1.2	0.25	0.25	0.8	1.6
1.5*	0.5	0.5	0.8	1.6
2	1	1	1	1.6
2.5*	1.5	1.5	1.5	1.6
3	2	2	2	2
4*	3	3	3	3
5	4	4	4	4
6*	5.5	5.5	5.5	5.5
8*	8	8	8	8
10	11	11	11	11
12*	14	14	14	14

NOTES:
*1: Preferred Values Indicated in Table 4.5.1.
2: For printed wiring material, the values for pollution degree 1 apply except that the value shall not be less than 0.04 mm.
3: These minimum clearances given for pollution degree 2, 3, 4 are based on experience rather than on fundamental data.

Table 4.5.3: IEC 664-1 Minimum Clearances For Insulation Coordination
Insulation Coordination for Equipment within Low-Voltage Systems

Required Impulse Withstand Voltage kV	Minimum Clearances in Air up to 2000 m (mm) Reinforced Insulation(Inhomogenous Electric Fields) Pollution Degrees			
	1	2	3	4
0.33*	0.04	0.04	0.8	1.6
0.4	0.1	0.1	0.8	1.6
0.5*	0.1	0.2	0.8	1.6
0.6	0.15	0.15	0.8	1.6
0.8*	0.5	0.5	0.8	1.6
1	1	1	1	1.6
1.2	1	1	1	1.6
1.5*	1.5	1.5	1.5	1.6
2	3	3	3	3
2.5*	3	3	3	3
3	4	4	4	4
4*	5.5	5.5	5.5	5.5
5	8	8	8	8
6*	8	8	8	8
8*	14	14	14	14
10	25	25	25	25
12*	25	25	25	25

NOTES:
*1: Preferred Values Indicated in Table 4.5.1.
2: For printed wiring material, the values for pollution degree 1 apply except that the value shall not be less than 0.04 mm.
3: These minimum clearances given for pollution degree 2, 3, 4 are based on experience rather than on fundamental data.

Table 4.5.4: IEC 664-1 Minimum Creepage Distances versus Working Voltage
Insulation Coordination for Equipment within Low-Voltage Systems

Working Voltage V rms	Insulation Level	Minimum Creepage Distances (mm) Pollution Degree 2 Material Group III	Pollution Degree 3 Material Group III*
100	Basic	1.4	2.2
	Reinforced	2	3.2
125	Basic	1.5	2.4
	Reinforced	2.5	4
160	Basic	1.6	2.5
	Reinforced	3.2	5
200	Basic	2	3.2
	Reinforced	4	6.3
250	Basic	2.5	4
	Reinforced	5	8
320	Basic	3.2	5
	Reinforced	6.4	10
400	Basic	4	6.3
	Reinforced	8	12.5
500	Basic	5	8
	Reinforced	10	16
630	Basic	6.3	10
	Reinforced	12.6	20
800	Basic	8	12.5
	Reinforced	16	25
1000	Basic	10	16
	Reinforced	20	32

NOTES:
*1: Material group IIIb is not recommended for application in pollution degree 3 above 630 V and in pollution degree 4.

or partial discharges, hence the performance of the solid insulation can only be assessed through testing. This standard does not, therefore, specify any minimum thickness of solid insulation to achieve long-term withstand capability. Partial discharge testing is applicable for components or small assemblies or small equipment.

Verification Tests

For verifying clearances the test voltages are in accordance with withstand voltage requirements (rated impulse withstand voltages). An impulse test is only required for clearances smaller than the values listed in tables 4.5.2 and 4.5.3.

An impulse dielectric test is used to verify that clearances will withstand specified transient overvoltages (this test is carried out with a voltage having 1.2/50 μsec waveform). This test is conducted for a minimum of three impulses of each polarity with an interval of at least 1s between pulses. The table below lists the voltage values for the verification of clearances only.

Table 4.5.5 Test Voltages for Verifying Clearances (at sea level)

Rated Impulse Voltage kV	Impulse Test Voltage kV
0.33	0.35
0.5	0.55
0.8	0.91
1.5	1.75
2.5	2.95
4	4.8
6	7.3
8	9.8
12	14.8

4.6. International Standard IEC 950:

Safety of Information Technology Equipment, Including Electrical Business Equipment

IEC 950 is a well known international standard which specifies the requirements for equipment connected directly to a telecommunication network. This type of equipment includes work stations, personal computers, printers, facsimile machines, cash registers, mail processing machines, document shredders, plotters, postage machines, modems and many more associated with telecommunication. IEC 950 is not limited to, but it is often associated with office equipment. The rated voltage of IEC 950 equipment is not to exceed **600 V** and is applicable to **Installation Category II**. Many country agencies have adopted IEC 950 as their own standard for office and related equipment.

Regarding optocouplers used for insulation, IEC 950 provides its own detailed **creepage** and **clearance** tables, as well as two other requirements which impact the use of optocouplers within the IEC 950 environment: **electric strength test** and **distance through insulation**. These requirements are all interrelated and are affected by not only creepage and clearance of the optocoupler, but also the equipment mains voltage, installation class of the equipment, pollution degree environment, comparative tracking index (CTI) of the optocoupler outermold compound (which categorizes the mold compound to a material group) and insulation level required (operational, basic, supplementary, reinforced). The majority of IEC 950 applications using opto-couplers are at the **reinforced** level.

Electric Strength Test
"The electric strength of the insulating materials used within the equipment shall be adequate."

Table 4.6.1 (IEC 950) shows the minimum test voltages for insulation levels and working voltage ranges. Optocouplers need to be capable of meeting the electric strength tests in Table 4.6.1 and are rated according to their dielectric withstand voltage, which is the capability of a device to withstand without breakdown for 60 seconds, a potential difference equal to the dielectric insulation voltage applied between the input and output leads of an optocoupler. A dielectric voltage rating is not to be interpreted as an input-output continuous working voltage.

In Table 4.6.1, "BODY" refers to all accessible conductive parts, shafts of handles, knobs, grips and the like, and metal foil in contact with all accessible surfaces of insulating material (see paragraph 1.2.7.5, IEC 950). Table 4.6.1 has been summarized to include optocoupler working voltages up to 1000 Vrms.

Table 4.6.1: Test Voltages for Electric Strength Tests, Part 1

	Test voltage volts r.m.s. (1 minute, 50 or 60 Hz) Points of application (as appropriate)				
	Primary to BODY Primary to secondary Between parts in PRIMARY CIRCUITS			Secondary to BODY Between independent secondaries	
Working Voltage (U) / Grade of Insulation	≤130 V r.m.s	130 V < U ≤ 250 V r.m.s.	250 V < U ≤ 1,000 V r.m.s	U ≤ 42.4 V peak, or 60 V d.c.	42.4 V peak or 60 V d.c. < U ≤ 7 kV r.m. s.
Operational	1000	1500	See Va in Table 4.6.1 Part 2	500	See Va in Table 4.6.1 Part 2
Basic, Supplementary	1000	1500	"	No test	"
Reinforced	2000	3000	3000	No test	See Vb in Table 4.6.1 Part 2

Part 2 of Table 4.6.1 lists sequential working voltages and the associated electric strength tests required for those unique working voltages. Agilent Technologies optocouplers meet a minimum dielectric withstand voltage of 2500 Vrms, 3750 Vrms and 5000 Vrms. Other conditions influence working voltage (creepage, distance through insulation, material group, pollution degree) . Once working voltage is established, the required test voltage can be determined from Part 2. An abbeviated Part 2 table is presented below:

Table 4.6.1: Test Voltages for Electric Strength Test, Part 2, volts r.m.s.

Working Voltage U	Basic Va	Reinforced Vb	Working Voltage U	Basic Va	Reinforced Vb
24	500	800	268	1531	2450
30	558	887	280	1563	2500
37	611	978	305	1626	260
43	655	1048	347	1726	2762
61	771	1233	395	1833	2933
70	821	1314	415	1875	3000
102	978	1565	452	1951	3000
107	1000	1600	537	2114	3000
130	1000	1751	610	2242	3000
155	1188	1900	725	2429	3000
200	1337	2139	825	2579	3000
247	1474	2359	938	2738	3000
257	1502	2403	1000	2820	3000

Distance Through Insulation

As applied to optocouplers, **distance through insulation** is the shortest direct distance between input and output conductors (usually the direct distance between the photoemitter and photodetector, or the input-output bond wires) inside the optocoupler cavity. Another term for distance through insulation is **internal clearance** when applied to optocouplers. For the time being:

- There is no thickness (distance through insulation) requirement for working voltages not exceeding 50 V (71 V_{pk} or d.c.).

- A minimum thickness of **0.4 mm** is required for supplementary and reinforced insulation levels.

Although creepage values of an optocoupler may indicate higher allowable working voltages, any distance through insulation thickness < **0.4 mm** limits the working voltage maximum to 50 V.

Creepage

Table 4.6.2 provides the required minimum creepage distances for associated working voltages for **operational, basic** and **supplementary** insulation. For **reinforced** insulation, the creepage values are twice the values in table 4.6.2 for basic insulation. Pollution Degree (typically 2) and Material Group (CTI) are also needed. Pollution Degree 1 represents a clean room or laboratory with a controlled environment. Components and assemblies are sealed so as to exclude exposure to dust and moisture. Pollution Degree 2 represents the normal office environment. Pollution Degree 3 represents a "dirtier" environment, where equipment is subject to conductive pollution.

Material Group is based on the Comparative Tracking Index (CTI) rating obtained in accordance with IEC 112. All Agilent Technologies optocouplers are molded from Material Group IIIa and have a CTI rating of 200:

Material Group I
$600 \leq CTI$

Material Group II
$400 \leq CTI < 600$

Material Group IIIa
$175 \leq CTI < 400$

Material Group IIIb
$100 \leq CTI < 175$

Table 4.6.2 - Minimum Creepage Distances (mm)

Working Voltage up to and including V r.m.s. or d.c.	Pollution Degree 1 Material Group IIIa		Pollution Degree 2 Material Group IIIa		Pollution Degree 3 Material Group IIIa	
	O, B, S	R	O, B, S	R	O, B, S	R
50	Use appropriate Clearance from Table 4.6.3 or Table 4.6.5 for Pollution Degree 1		1.2	2.4	1.9	3.8
100			1.4	2.8	2.2	4.4
125			1.5	3.0	2.4	4.8
150			1.6	3.2	2.5	5.0
200			2.0	4.0	3.2	6.4
250			2.5	5.0	4.0	8.0
300			3.2	6.4	5.0	10.0
400			4.0	8.0	6.3	12.6
600			6.3	12.6	10.0	20.0
1000			10.0	20.0	16.0	32.0

O = Operational Insulation
B = Basic Insulation
S = Supplementary Insulation
R = Reinforced Insulation

Clearance

IEC 950 provides minimum clearance tables for **primary circuits** (Table 4.6.3) and **secondary circuits** (Table 4.6.5). For **primary circuits**, minimum clearances are specified according to the expected working voltage, nominal mains supply voltage and transient overvoltage ratings according to Installation Category II. Installation Category II includes equipment which derives its power from the building or installation power system, requiring the equipment to be “plugged in”. A primary circuit is an internal circuit which is directly connected to the external supply mains or other equivalent electric power source, such as a motor-generator set.

Secondary circuits have no direct connection to primary power and derive their power from a transformer, converter or equivalent isolation device situated within the equipment. Secondary circuits are subject to Installation Category I and the clearance values are specified in Table 5 under similar conditions as Table 4.6.3: expected working voltage, equipment mains supply voltage and transient overvoltage ratings. Clearance values are not as large as those required for primary circuits.

Clearance values in parentheses apply only if the equipment manufacturer has a quality control program in accordance with Annex R of IEC 950 specification.

If the repetitive peak voltages in a primary circuit exceed the peak values of the mains supply voltage (up to 300 V), then additional clearance must be included according to Table 4.6.4. The voltage values in parentheses apply only if the equipment manufacturer has a quality control program in accordance with Annex R.

Table 4.6.3: Minimum Clearances for Insulation in primary circuits, and between primary and secondary circuits Basic and Reinforced, mm

Insulation working voltage up to and including		Circuits subject to installation Category II									
		Nominal mains supply voltage ≤ 150 V Transient rating 1,500 V				Nominal mains supply voltage > 150 V ≤ 300 V Transient rating 2,500 V				Nominal mains supply voltage > 300 V ≤ 600 V Transient rating 4,000V	
V peak or d.c. V	Vr.m.s. (sisusoidal) V	Pollution degrees 1 and 2		Pollution degree 3		Pollution degrees 1 and 2		Pollution degree 3		Pollution degrees 1, 2, and 3	
		B	R	B	R	B	R	B	R	B	R
71	50	1.0 (0.7)	2.0 (1.4)	1.3 (1.0)	2.6 (2.0)	2.0 (1.7)	4.0 (3.4)	2.0 (1.7)	4.0 ((3.4)	3.2 (3.0)	6.4 (6.0)
210	150	1.0 (0.7)	2.0 (1.4)	1.3 (1.0)	2.6 (2.0)	2.0 (1.7)	4.0 (3.4)	2.0 (1.7)	4.0 (3.4)	3.2 (3.0)	6.4 (6.0)
420	300	B 2.0 (1.7) R 4.0 (3.4)								3.2 (3.0)	6.4 (6.0)
840	600	B 3.2 (3.0) R 6.4 (6.0)									
1400	1000	B 4.2 R 6.4									

B = Basic Insulation
R = Reinforced Insulation

Table 4.6.4: Additional clearances for insulation in primary circuits with repetitive peak voltages exceeding the peak value of the mains supply voltage

Nominal mains supply voltage ≤150 V				Nominal mains supply voltage >150 V ≤300 V		Additional clearance mm	
Pollution degrees 1 and 2		Pollution degree 3		Pollution degrees 1, 2 and 3		Basic Insulation	Reinforced Insulation
Maximum repetitive peak voltage V		Maximum repetitive peak voltage V		Maximum repetitive peak voltage V			
210	(210)	210	(210)	420	(420)	0	0
298	(290)	294	(300)	493	(497)	0.1	0.2
386	(370)	379	(390)	567	(574)	0.2	0.4
474	(450)	463	(480)	640	(651)	0.3	0.6
562	(530)	547	(570)	713	(728)	0.4	0.8
650	(610)	632	(660)	787	(805)	0.5	1.0
738	(690)	716	(750)	860	(881)	0.6	1.2
826	(770)	800	(840)	933	(985)	0.7	1.4
914	(850)	-	-	1006	(1035)	0.8	1.6
1002	(930)	-	-	1080	(1112)	0.9	1.8
1090	(1010)	-	-	1153	(1189)	1.0	2.0
-	-	-	-	1226	(1266)	1.1	2.2
-	-	-	-	1300	(1343)	1.2	2.4
-	-	-	-	-	(1420)	1.3	2.6

Table 4.6.5: Minimum clearances in secondary circuits, Basic and Reinforced mm

<table>
<tr><th colspan="2">Insulation working voltage up to and including</th><th colspan="12">Circuits subject to installation Category I</th></tr>
<tr><th colspan="2"></th><th colspan="4">Nominal mains supply voltage
≤ 150 V
(Transient rating of secondary circuit 800 V)</th><th colspan="4">Nominal mains supply voltage
> 150 V
≤ 300V
(Transient rating of secondary circuit 1500 V)</th><th colspan="2">Nominal mains supply voltage
> 300 V
≤ 600 V
(Transient rating of secondary circuit 2500 V)</th><th colspan="2">Circuits not subjected to transient overvoltage</th></tr>
<tr><th rowspan="2">V peak or d.c. V</th><th rowspan="2">V r.m.s. (sinusoidal) V</th><th colspan="2">Pollution degrees 1 and 2</th><th colspan="2">Pollution degree 3</th><th colspan="2">Pollution degrees 1 and 2</th><th colspan="2">Pollution degree 3</th><th colspan="2">Pollution degrees 1, 2 and 3</th><th colspan="2">Pollution degrees 1 and 2 only</th></tr>
<tr><th>B</th><th>R</th><th>B</th><th>R</th><th>B</th><th>R</th><th>B</th><th>R</th><th>B</th><th>R</th><th>B</th><th>R</th></tr>
<tr><td>71</td><td>50</td><td>0.7
(0.4)</td><td>1.4
(0.8)</td><td>1.3
(1.0)</td><td>2.6
(2.0)</td><td>1.0
(0.7)</td><td>2.0
(1.4)</td><td>1.3
(1.0)</td><td>2.6
(2.0)</td><td>2.0
(1.7)</td><td>4.0
(3.4)</td><td>0.4</td><td>0.8</td></tr>
<tr><td>140</td><td>100</td><td>0.7
(0.6)</td><td>1.4
(0.8)</td><td>1.3
(1.0)</td><td>2.6
(2.0)</td><td>1.0
(0.7)</td><td>2.0
(1.4)</td><td>1.3
(1.0)</td><td>2.6
(2.0)</td><td>2.0
(1.7)</td><td>4.0
(3.4)</td><td>0.7
(0.6)</td><td>1.4
(1.2)</td></tr>
<tr><td>210</td><td>150</td><td>0.9
(0.6)</td><td>1.4
(0.8)</td><td>1.3
(1.0)</td><td>2.6
(2.0)</td><td>1.0
(0.7)</td><td>2.0
(1.4)</td><td>1.3
(1.0)</td><td>2.6
(2.0)</td><td>2.0
(1.7)</td><td>4.0
(3.4)</td><td>0.7
(0.6)</td><td>1.4
(1.2)</td></tr>
<tr><td>280</td><td>200</td><td colspan="8">B 1.4(1.1) R 2.8(2.2)</td><td>2.0
(1.7)</td><td>4.0
(3.4)</td><td>1.1</td><td>2.2</td></tr>
<tr><td>420</td><td>300</td><td colspan="8">B 1.9(1.6) R 3.8(3.2)</td><td>2.0
(1.7)</td><td>4.0
(3.4)</td><td>1.4</td><td>2.8</td></tr>
<tr><td>700</td><td>500</td><td colspan="12">B 2.5 R 5.0</td></tr>
<tr><td>840</td><td>600</td><td colspan="12">B 3.2 R 5.0</td></tr>
<tr><td>1400</td><td>1000</td><td colspan="12">B 4.2 R 5.0</td></tr>
</table>

B = Basic Insulation
R = Reinforced Insulation

4.7 Underwriter Laboratories Inc. Standard for Safety UL 508: Industrial Control Equipment

UL 508 is a safety standard that covers the area of industrial control devices that include devices for starting, stopping, controlling, and protecting electric motors. This standard covers devices rated up to 1500 V or less and intended for use in an ambient of 0°C to 40°C (32°F to 104°F). Examples of other industrial control devices where this standard is applicable are solid state starters and controllers, solid state relays, control circuit switches and relays, programmable controllers, solid state logic controllers, proximity switches, etc.

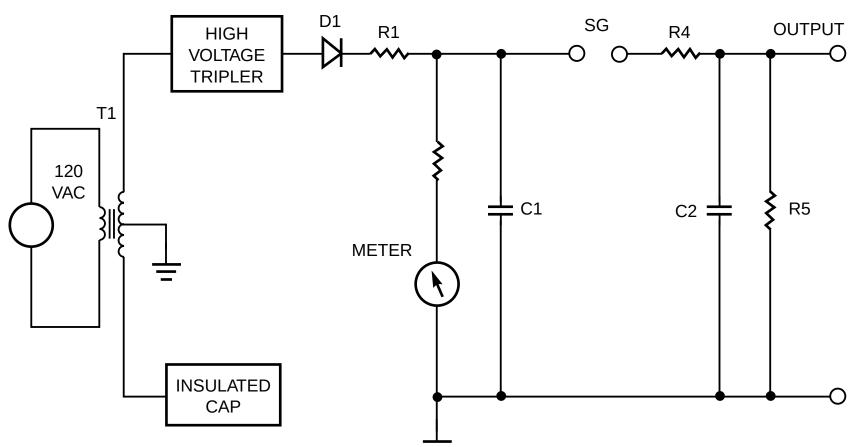
In order to achieve clearance and creepage requirements UL 508 provides for two options. First option is the requirements listed in the UL 508 standard itself. Second option allows that clearance and creepage distances may be evaluated in accordance with the guidelines of UL 840. The UL 840 is a Standard for Insulation Coordination for Electrical Equipment. The safety standard requirements summarized in this section are based on the UL 508 standard. The safety requirements or compliance based on the insulation coordination standard UL 840 are summarized in another section of this regulatory guide.

According to UL these requirements are based upon sound engineering principles, research, field experience, installation, and use derived from consultation with and information obtained from manufacturers. The observance of the requirements of this Standard by a manufacturer is one of the conditions of the continued coverage of the manufacturer's product.

UL 508 safety standard requires a dielectric voltage withstand test for verification purpose. While at its maximum normal operating temperature, industrial control equipment shall withstand 1 minute/ 60 Hz or a d.c. potential without breakdown. The test potential shall be the following values for or 1.414 times the following values for d.c.:

a) 500 V - For industrial control equipment rated not more than 50 V
b) 1000 V plus twice the rated voltage of the equipment - For all other industrial control equipment rated more than 50 Volts.
c) 1000 V - For industrial control equipment rated more than 50 V but not more than 250 V and intended for use in pollution degree 2.

A surge-controlled circuit shall withstand without breakdown a single 1.2 by 50 µsec full-wave impulse with a crest value of 5.0 kV. The transient voltage surge shall not exceed 300 percent of the peak working voltage, or 300 V, whichever is greater (see *Techniques for High Voltage Testing, ANSI/IEEE 4-1978*). Figure 4.7.1 shows a typical impulse generator which can generate the requisite waveform for this test. The impulse generator is connected across the equipment for this test, while the equipment is connected to a single-phase source of supply at rated voltage.



R4 IS 12 OHM SURGE RESISTOR
D1 IS DAMPER DIODE
T1 TRANSFORMER, 7500 VAC EACH SIDE OF CENTER TAP
SG SPARK GAP
R5 IS 350 OHM, 300 WATT

Figure 4.7.1: Typical Impulse Generator

Table 4.7.1: UL 508 Creepage Requirements Between Traces of Opposite Polarity on Printed Wiring Boards
Safety Requirements for Industrial Control Equipment

Volts** V rms or dc	Transient Voltages Not Limited		Transient Voltages Limited***	
	Coated**** mm	Uncoated mm	Coated**** mm	Uncoated mm
50	0.18	0.85	0.025	0.04
100	0.25	1	0.1	0.16
125	0.28	1.05	0.16	0.25
160	0.32	1.1	0.25	0.4
200	0.42	1.4	0.4	0.63
250	0.56	1.8	0.56	1
320	0.75	2.2	0.75	1.6
400	1	2.8	1	2
500	1.3	3.6	1.3	2.5
630	1.8	4.5	1.8	3.2
800	2.4	5.6	2.4	4
1000	3.2	7.1	3.2	5

NOTES:
1: This table is derived from Table IV of International Electrotechnical Commission, Publication 664A. Linear interpolation of values is permitted.
**2: Voltage between the traces where spacing is measured.
***3: The maximum recurring peak voltages shall not exceed the applicable value specified in Table 6.3 of UL 840 (see Table 4.7.2).
****4: The coating shall comply with the requirements of the Printed Wiring Board Coating Performance test, Section 12, in UL 840, or another equivalent method.

Table 4.7.2: UL 508 Maximum Recurring Peak Voltage Related to Creepage on Printed Wiring Boards
Safety Requirements for Industrial Control Equipment

Creepage Distance mm	Maximum Allowable Recurring Peak Voltage
0.025	330
0.1	360
0.2	400
0.25	450
0.4	600
0.5	640
0.75	800
1	913
1.3	1049
1.5	1140
1.8	1250
2	1314
2.4	1443
2.5	1475
3.2	1700
4	1922
5	2200

NOTES:
1: This table is derived from Table 6.3 of UL 840.
2: Voltage and creepage values may be interpolated linearly.
3: The maximum recurring peak voltages appearing across creepage distances on printed wiring boards shall be limited per this table.

Tabel 4.7.3: UL 508 Minimum Acceptable Spacings
Safety Requirements for Industrial Control Equipment

Potential Involved in Vrms or dc		Minimum Spacings (mm)							
		A General Industrial Control Equipment			B Devices having Limited Ratings*		C Other Devices **		D All Circuits ***
		50-150	151-300	301-600	51-300	301-600	51-150	151-300	0-50
Between any uninsulated live part and an uninsulated live part of opposite polarity, uninsulated grounded part other than the enclosure, or exposed metal part	Through air or oil **(Clearance)**	3.2	6.4	9.5	1.6	4.8	3.2	6.4	1.6
	Over Surface **(Creepage)**	6.4	9.5	12.7	3.2	9.5	6.4	6.4	1.6
Between any uninsulated live part and the walls of a metal enclosure including fittings for conduit or armored cable	Shortest Distance	12.7	12.7	12.7	6.4	12.7	6.4	6.4	6.4

NOTES:
*1: The spacings specified in column B of Table 4.7.3 are applicable to equipment: (1) Rated 1 horsepower (746 W output) or equivalent FLA, or less, 720 volt-amperes break pilot duty or less; or not more than 15 amperes at 51 - 150 volts, 10 amperes at 151 - 300 volts, or 5 amperes at 301 - 600 volts. (2) Of the type described in (1) which controls more than one load provided the total load connected to the line at one time does not exceed 2 horsepowers (1492 W output), 1440 volt-amperes, or have a current rating greater than 30 amperes at 51 - 150 volts, 20 amperes at 151 - 300 volts, or 10 amperes at 301 - 600 volts.
**2: The spacings specified in column C of table 4.7.3 apply only to equipment rated at 300 volts or less, and 1 horsepower (746 W output) or less or 2000 volt-amperes or less per pole and to a device that has a current rating per pole of 15 amperes or less at 51 -150 volts, 10 amperes at 301 -600 volts, or both.
***3: Spacings apply as indicated, except as specified in (4) and the spacings between the low potential circuit are in accordance with the requirements that are applicable to the high-potential circuit.
4: The primary circuit spacings in industrial control power supplies intended for use in a pollution degree 2 environment shall be at least those specified in tables 4.7.5 and 4.7.6. See section 34 in UL 508. Spacings at field wiring terminal are per this table.

Table 4.7.4: UL 508 Minimum Acceptable Spacings for Products with Known and Controlled Transient Voltages **

Safety Requirements for Industrial Control Equipment

Short Circuit Power*	Peak Working Voltage	Minimum Spacings (mm): Between any uninsulated live part and an uninsulated live part of opposite polarity, uninsulated grounded part other than the enclosure, or exposed metal part — Through air or oil (Clearance)	Over Surface (Creepage)	Between any uninsulated live part and the walls of a metal enclosure Including fittings for conduit or armored cable — Through air (Clearance)	Over Surface (Creepage)
More than 10 kVA, for use where transient voltages are known and controlled	0 - 50	0.76	0.76	12.7	6.35
	51 - 225	1.91	2.54	12.7	12.7
	226 - 450	3.81	5.08	12.7	12.7
	451 - 900	7.62	10.16	12.7	12.7
More than 500 VA but not more than 10 kVA	0 - 50	0.76	0.76	12.7	6.35
	51 -225	1.52	1.52	12.7	12.7
	226 -450	2.54	2.54	12.7	12.7
	451 - 900	5.08	5.08	12.7	12.7
500 VA or less	0 - 36	0.3	0.3	12.7	6.35
	37 - 72	0.4	0.4	12.7	6.35
	73 - 100	0.76	0.76	12.7	6.35
	101 - 225	1.14	1.14	12.7	6.35
	226 - 450	1.52	1.52	12.7	12.7
	451 - 900	2.54	2.54	12.7	12.7

NOTES:

*1: Maximum short-circuit power is the product of the open-circuit voltage and the short circuit current available at the supply terminals when protective devices are bypassed.

**2: The spacings in industrial control equipment in which transient voltages are known and controlled by a transient suppressive device shall not be less than those specified in Table 4.7.4 except that spacings at a field-wiring terminal shall be in accordance with Table 4.7.3. (the transient suppressive devices shall prevent peak transient voltages from exceeding 300 percent of the instantaneous peak working voltage or 300 V, whichever is greater).

Table 4.7.5: UL 508 Power Supply Primary -Circuit Spacings Other than at Field-Wiring Terminals

Safety Requirements for Industrial Control Devices

Potential Involved in Volts: V rms	V peak	Agilent Optoisolator Groups*: Over Surface (Creepage)	Through air (Clearance)
0 -50	0 - 70.7	1.2	1.2
51 - 125	72.1 - 176.8	1.6	1.6
126 - 250	178.2 - 353.6	2.4	2.4
251 - 600	355.0 - 848.5	12.7	9.5

Table 4.7.6: UL 508 Power Supply Primary-Circuit Spacings at Field-Wiring Terminals

Safety Requirements for Industrial Control Devices

Potential Involved in Volts Vrms	Agilent Optoisolator Product Groups*: Between Field Wiring Terminals — Through air or over Surface (Creepage or Clearance)	Between Field-Wiring Terminals and other Uninsulated parts Not always of the Same polarity — Over Surface (Creepage)	Through air (Clearance)
0 - 50	A, B, C, D	3.2	3.2
51 - 250	A, B, C	6.4	6.4
251 - 600		12.7	9.5

4.8 UL 840: Standard for Insulation Coordination for Electrical Equipment

In order to achieve clearance and creepage requirements, UL 508 provides for two options. First option is the requirements listed in the standard itself. Second option allows clearance and creepage distances may be evaluated in accordance with the guidelines of UL 840. The UL 840 is the Standard for Insulation Coordination for Electrical Equipment. The safety standard requirements summarized here are based on this second alternative, i.e., per the UL 840 insulation coordination standard.

The UL 840 is an insulation coordination standard that does not contain requirements for a specific product, but the ideas and concepts contained in it are applicable to a wide variety of different products. Thus, the requirements listed in UL 840 can be used if and only if an equipment safety standard covering the product category specifically references UL 840. Since the UL 508 specifically indicates an alternative approach based on UL 840 is acceptable, we will use the UL 840 safety standard requirements to indicate compliance to the UL 508. End product standards may contain additional requirements that may take precedence over the UL 840.

Further, the UL 840 is based on the International Electrotechnical Commissions IEC 664-1 standard, which is an Insulation Coordination for Equipment Within Low Voltage Systems. Where the low voltage is defined as up to 1000 V ac with rated frequencies up to 30 kHz, or up to 1500 V dc. Since, the UL 840 is based on IEC 664, this allows for design access to both the U.S. and Europe.

Table 4.8.1 indicates various alternative test voltages (AC impulse, AC peak, DC, or AC rms) to evaluate clearances. The test voltage values are the dielectric voltage withstand test values to determine if the clearance is suitable, and are based on the spacings specified in the end product standard.

Table 4.8.2 indicates minimum clearance values to be used where levels of the overvoltages are controlled through overvoltage protection devices (e.g. filters or air gaps). The clearances can be established through measurement per this table, or alternatively can be evaluated by a dielectric voltage withstand test. The dielectric voltage withstand test for verifying clearances in equipment with overvoltage control will be per full lightening impulse test. The voltage is 1.2 by 50 microsecond impulse as indicated in the *Techniques for High Voltage Testing*, *ANSI/IEEE 4-1978*. Table 4.8.3 lists equivalent other methods to perform this test for verifying clearances.

Tables 4.8.4 and 4.8.5 indicate creepage requirements. Creepage values are dependent upon the operating voltages, comparative tracking index (CTI) of the insulation, and level of pollution. For printed circuit boards recurring peak voltages are evaluated per Table 4.8.6.

Table 4.8.1: UL 840 Test Voltages for Verifying Clearances
Insulation Coordination for Electrical Equipment

End-Product Standard Specified Minimum Clearance mm	Test Voltages (kV) AC Impulse, AC peak, or DC Altitude * (m) or [air pressure**, kPa]					AC rms Altitude* (m) or [air pressure**, kPa]				
	0 [101.3]	200 [98.8]	500 [95.0]	1000 [90.0]	2000 [80.0	0 [101.3]	200 [98.8]	500 [95.0]	1000 [90.0]	2000 [80.0]
0.4	1.7	1.7	1.7	1.6	1.5	1.2	1.2	1.2	1.2	1.1
0.8	2.2	2.1	2.1	2	1.9	1.5	1.5	1.5	1.4	1.3
1.2	2.75	2.7	2.65	2.5	2.3	1.95	1.9	1.9	1.75	1.6
1.6	3.3	3.3	3.2	3	2.7	2.4	2.3	2.3	2.1	1.9
2.4	4.4	4.3	4.1	3.9	3.5	3.1	3	2.9	2.8	2.5
3.2	5.3	5.2	5	4.8	4.3	3.7	3.7	3.6	3.4	3
4.8	6.9	6.8	6.6	6.2	5.6	4.9	4.8	4.7	4.4	4
6.4	8.3	8.2	7.9	7.5	6.8	5.9	5.9	5.6	5.3	4.8
9.5	10.9	10.7	10.3	9.8	8.8	7.7	7.7	7.3	7	6.3
12.7	14	13.7	13.2	12.5	11.2	9.9	9.7	9.3	8.9	7.9
25.4	25.5	24.6	24	22.7	20.2	18.2	17.6	17.1	16.2	14.4

Notes:
* 1: Next lower specified altitude to be used for intermediate altitudes.
**2: Values of air pressure in kilopascals are provided to permit testing at pressures simulating elevations different from the elevation of the test facility.
3: The withstand capability of a clearance is related to air pressure, therefore, the selection of test voltage is based on the altitude of the test location.
4: Test Voltages indicated in this table may be used to evaluate clearances by conducting a dielectric withstand test, using a voltage value as specified in Table 4.8.1.
5: Test voltage is given in AC Impulse, AC peak, DC, or AC rms.

Table 4.8.2: UL 840 Minimum Clearances for Equipment
Insulation Coordination for Electrical Equipment

Phase-to-ground * rated system voltage (rms and dc) Overvoltage Category				Rated Impulse Withstand Voltage peak, KV**	Clearance (mm) Pollution degree			
I	II	III	IV		1	2	3	4
50				0.33	0.01	0.2	0.8	1.6
100	50			0.5	0.04	0.2	0.8	1.6
150	100	50		0.8	0.1	0.2	0.8	1.6
300	150	100	50	1.5	0.5	0.5	0.8	1.6
600	300	150	100	2.5	1.5	1.5	1.5	1.6
1000	600	300	150	4	3	3	3	3
1500	1000	600	300	6	5.5	5.5	5.5	5.5
	1500	1000	600	8	8	8	8	8
		1500	1000	12	14	14	14	14
			1500	16	19.4	19.4	19.4	19.4

NOTES:
*1: For ungrounded systems or systems with one phase grounded, the phase-to-ground voltage is considered to be the same as the phase-to-phase voltage for purposes of using this table.
**2: Clearance Values to use based on the rating of the overvoltage protection means (controlled overvoltages).
3: Linear interpolation of the values is permitted.
4: This table may be used to evaluate clearances where the levels of overvoltage are controlled.
5: If clearances are selected and measured in accordance with this table the dielectric withstand test is not required.
6: Alternatively, Clearances may be evaluated by the dielectric voltage-withstand test in lieu of measuring clearance. The voltage is to be full lightning 1.2/50 µsec impulse in accordance with Techniques for High Voltage TestingANSI / IEEE 4-1978. See Table 4.8.3 for test details, and alternative equivalent methods.

Table 4.8.3: UL 840 Test Methods to be Used to Test Clearances**
Insulation Coordination for Electrical Equipment

Type of Test	Impulse****	AC rms	AC peak or DC	AC peak 1/2 Sine Wave	AC Peak Ramp
Rate of Rise	1.2/50				6000 V /sec
Hertz		50-60	50-60	50-60	50-60
Duration of Test	3 Pos and 3 Neg* Cycles	3 Pos and 3 Neg* Cycles	3 Pos and 3 Neg.* Cycles DC min 10 ms	3 Pos and 3 Neg*	4 -5 mA Leakage Current Detection**

NOTES:
*1: The available current is to be limited to 4 -5 mA. The test equipment can be power limited or designed to shut off by the detection of 4 - 5 mA leakage current.
** 2: The measured voltage must exceed the values in Table 4.8.1and 4.8.2 as appropriate when the leakage current of 4 -5 mA is measured.
***3: This table lists alternative tests to verify proper clearances.
****4: The voltage is to be full lightning 1.2/ 50 microsecond impulse in accordance with Techniques for High-Voltage Testing ANSI/ IEEE 4-1978.

Table 4.8.4: UL 840 Minimum Acceptable Creepage Distances
Insulation Coordination For Electrical Systems

Operating Voltage Vrms or dc	Pollution degree 1	Pollution degree 2	Pollution degree 3	Pollution degree 4
20	0.11	0.48	1.2	1.6
25	0.125	0.5	1.25	1.7
32	0.14	0.53	1.3	1.8
40	0.16	1.1	1.8	3
50	0.18	1.2	1.9	3.2
63	0.2	1.25	2	3.4
80	0.22	1.3	2.1	3.6
100	0.25	1.4	2.2	3.8
125	0.28	1.5	2.4	4
160	0.32	1.6	2.5	5
200	0.42	2	3.2	6.3
250	0.56	2.5	4	8
320	0.75	3.2	5	10
400	1	4	6.3	12.5
500	1.3	5	8	16
630	1.8	6.3	10	20
800	2.4	8	12.5	25
1000	3.2	10	16	32
1250	4.2	12.5	20	40
1600	5.6	16	25	50
2000	7.5	20	32	63

NOTES:
1: Linear interpolation of the values is permitted.
2: Creepage Values shown are for Material Group IIIa only.
3: This table is applicable for equipment subject to long-term stress.
4: Creepage distances will be based on Tables 4.8.4 or 4.8.5.
5: Creepage values are a function of the operating voltage across the insulation, comparative tracking index (CTI), and the level of pollution expected or controlled at the creepage distance.
6: For Printed wiring boards using Table 4.8.5, the existence of recurring voltages is to be evaluated per Table 4.8.6.

Table 4.8.5: UL 840 Minimum Acceptable Creepage Distance On Printed Wiring Boards
Insulation Coordination For Electrical Equipment

Operating Voltage Vrms or dc	Minimum Creepage (mm) Pollution Degree	
	1*	2**
10-50	0.025	0.04
63	0.04	0.063
80	0.063	0.1
100	0.1	0.16
125	0.16	0.25
160	0.25	0.4
200	0.4	0.63
250	0.56	1
320	0.75	1.6
400	1	2
500	1.3	2.5
630	1.8	3.2
800	2.4	4
1000	3.2	5

NOTES:
1: Linear Interpolation of the values is permitted.
*2: This column is applicable to Material Group I, II, IIIa, IIIb.
**3: This column is applicable for Material Group I, II, IIIa. For Material Group IIIb use Table 4.8.4.
4: This Table provides values for Pollution degrees 1 and 2. For Pollution Degree 3 and 4 use Table 4.8.4.
5: Creepage values are a function of the operating voltage across the distance, comparative tracking index (CTI), and the level of pollution expected or controlled at the creepage distance.
6: For Printed wiring boards using Table 4.8.5, the existence of recurring voltages is to be evaluated per Table 4.8.6.
7: For pollution degree 2, the CTI of the printed wiring board must be at least 175.

Table 4.8.6: UL 840 Maximum Recurring Peak Voltages Related to Creepage Distances On Printed Wiring Boards
Insulation Coordination For Electrical Equipment

Creepage Distance mm	Maximum Allowable Recurring Peak Voltage	Creepage Distance mm	Maximum Allowable Recurring Peak Voltage
0.025	330	1	913
0.04	336	1.3	1049
0.063	345	1.5	1140
0.1	360	1.6	1150
0.16	384	1.8	1250
0.2	400	2	1314
0.25	450	2.4	1443
0.4	600	2.5	1475
0.5	640	3.2	1700
0.56	678	4	1922
0.63	723	5	2000
0.75	800		

NOTES:
1: Voltage and Creepage values may be interpolated linearly.
2: The affect of recurring peak voltages must be considered if the creepage distances on printed wiring boards are used.
3: Creepage values are a function of the operating voltage across the distance, comparative tracking index (CTI), and the level of pollution expected or controlled at the creepage distance.
4: For Printed wiring boards using Table 4.8.5, the existence of recurring voltages is to be evaluated per Table 4.8.6.
5: For pollution degree 2, the CTI of the printed wiring board must be at least 175.
6: Devices having a coated wiring board are tested in the uncoated condition.
7: Maximum recurring peak voltage is tested under operating conditions, over 100 cycles, and voltage over the creepage distance is monitored with an oscilloscope having a bandwidth of at least 1 megahertz.

4.9 VDE 0884 Optoisolator Safety Standard

Introduction

In most optocoupler applications, where there is a significant potential difference between the isolation barrier, the most important safety parameter becomes the maximum continuous permitted voltage, also called the maximum working insulation voltage (Viorm). For VDE 0884 approvals, optoisolator components undergo a unique amount of stringent qualification tests that include environmental, mechanical, isolation, and electrical tests. The criterion for passing the components is the partial discharge test with a rigorous limit of 5 pC.

The philosophy underlying the partial discharge testing is that an insulation for safe electrical isolation needs to withstand not only a breakdown voltage, but also a voltage that prevents any imperceptible degradation due to high electrical fields which may cause the insulation to break down over time or over repetitive cycles. Or, to look at this concept in another light, it is not necessarily a thicker insulation that is safer. A thinner insulation may be superior if it has no micro voids, air gaps, impurities, or greater capability to resist erosion or decomposition or degradation. Thus, partial discharge, which is also known as a corona discharge, is symptomatic of incipient damage, which will eventually lead to catastrophic damage over time. Therefore, the dielectric strength of an insulating material is a function of the quality of the insulation and not merely thickness of the insulation.

In addition, the VDE 0884 optoisolator component standard specifies maximum safety limiting values of input LED current, detector power dissipation, and package/case temperature, that an optocoupler can be exposed to under a single fault condition for safe operation over the lifetime of the equipment. Table 4.9.1 lists the VDE 0884 Approved Agilent Technologies Optoisolator Product Groups. This table also lists the VDE 0884 data sheet and parameters that the optocoupler components are rated and approved for under the VDE 0884 optoisolator safety standard.

Table 4.9.1: Agilent Technologies VDE 0884 Approved Optocoupler Ratings

Description	Symbol	VDE 0884 Group A (HCNWXXXX) (HCNRXXXXX)	Group B (HCPL-7XXX, -JXXX & -XXXJ)	Group C PDIP #060	Group D SO-8	Unit
Installation Classification (DIN VDE 0110/1.89, Table 1)						
Rated Mains Line Voltage < 1000 V rms		I - III				
Rated Mains Line Voltage < 600 V rms		I - IV	I - III	I - III	I - II	
Rated Mains Line Voltage < 300 V rms			I - IV	I - IV	I - III	
Rated Mains Line Voltage < 150 V rms					I - IV	
Climatic Classification		55/100/21	40/100/21	55/100/21	55/85/21	
Pollution Degree (DIN VDE 0110/1.89)		2	2	2	2	
Maximum Working Insulation Voltage	Viorm	1414	848 / 891	630	566	V peak
Production Input to Output Test Voltage, 1 second Vpr = 1.875 x Viorm, Partial discharge < 5 pC	Vpr	2652	1590	1181	1063	V peak
Qualification Input to Output Test Voltage, 60 second Vpr = 1.5 x Viorm, Partial Discharge < 5 pC	Vpr	2121	1272	945	849	V peak
Maximum Transient Overvoltage t ini = 10 seconds Qualification Test	Viotm	8000	6000	6000	4000	Vpeak
Comparative Tracking Index	CTI	200	175	175	175	V
Isolation group (DIN VDE 0110/1.89, Table 1)		IIIa	IIIa	IIIa	IIIa	
Insulation Resistance at Tsi = 25°C, Vio = 500 V	Rs	$> 10^9$	$> 10^9$	$> 10^9$	$> 10^9$	ohms
Safety Limiting Ratings						
Maximum package/case temperature	Ts	150	175	175	150	°C
Maximum LED Input Current	Is	400	80	230	150	mA
Maximum Detector Power Dissipation	Ps	700	250	600	600	mW

* NOTES:

1: See Table 2.4 for Agilent Optoisolator Product Groups:
Group A = 400 mil Widebody Package (HCNW/HCNR), Group B = 300 mil DIP Package (HCPL-7XXX/JXXX) and SO-16 package (HCPL-XXXJ), Group C = 300 mil DIP Package (HCPL-XXXX), Group D = SO-8 Package.

2: See Table 2.3 for VDE 0884 approved optoisolators.

3: Climatic Classification of some products in Group B is (40/100/21) and for others it is (40/85/21).

4: Maximum Working Insulation Voltage (V_{iorm}) for HCPL-JXXX and HCPL-XXXJ products is 891 Vpeak, and for HCPL-7XXX products V_{iorm} is 848 Vpeak.

VDE 0884 Data Sheet Parameters and Ratings

Installation Class / Installation Category/ Application Class
The four Installation Classifications or Installation Categories are based on the transient overvoltages that are expected under a rated supply mains voltages. This classification is based on insulation coordination standards such as the DIN/VDE 0110 and/or the IEC 664. Table 4.9.2 lists the installation classification as a function of the rated impulse/transient voltage expected under a nominal power supply system or line voltage or distribution system per IEC 664-1.

As can be seen from this table, highest overvoltage transients are expected at the installation category IV and most benign transients are expected at the installation category I. For instance, for a 300 V rms line voltage the maximum transients expected for various installation classes are listed in table 4.9.3 below.

According to IEC 664-1, equipment of overvoltage category IV is for use at the origin of the installation. Examples of such equipment are electricity meters and primary overcurrent protection equipment. Equipment of overvoltage category III is equipment in fixed installations. Examples of such equipment are switches in the fixed installation and equipment for industrial use with permanent connection to the fixed installation. Equipment of overvoltage category II is energy consuming equipment to be supplied from the fixed installation. Examples of such equipment are appliances, portable tools and other household and similar loads. Equipment of overvoltage category I is equipment for connection to circuits in which measures are taken to limit transient overvoltages to an appropriately low level. Installation category I includes portable electrical equipment that generally obtain power from secondary voltage of a transformer. Examples are protected electronic circuits, telecommunication circuits, computers, etc.

Table 4.9.2: Installation Categories and Rated Transient Impulse Voltages

Nominal Voltage of the Supply System (V)		Voltage Line to Neutral up to and Including V rms or dc	Rated Transient/Impulse Voltages V peak Installation/Overvoltage Categories			
Three Phase	**Single Phase**		**I**	**II**	**III**	**IV**
		50	330	500	800	1500
		100	500	800	1500	2500
	120 - 240	150	800	1500	2500	4000
230/400 277/480		300	1500	2500	4000	6000
460/690		600	2500	4000	6000	8000
1000		1000	4000	6000	8000	12000

Table 4.9.3: Transient Voltages and Installation Categories

Rated Mains Voltage V rms	Transient Voltage V peak Installation Categories			
	I	**II**	**III**	**IV**
300	1500	2500	4000	6000

Climatic Classification

The climatic classification and rating in Table 4.9.1 is indicated as 55/100/21 for the HCNW/HCNR products (Group A) and as 55/85/21 for the PDIP devices (Group C). These numbers denote the environmental conditions under which the product was qualified for by the VDE 0884. The first number (e.g. 55) represents the lowest maximum storage temperature (low temperature storage at -55°C, two hours). The second number (e.g. 100) represents the maximum operating temperature (dry heat storage, 16 hours). The third number, 21, represents 21 days of constant damp heat conditions at 85% RH and 85°C ambient temperature.

Pollution Degree

Pollution degree captures the impact of both micro-environment and macro-environment. For the purposes of evaluating creepage distances and clearances, the following four degrees of pollution in the micro environment are established per IEC-664-1.

(a) Pollution Degree 1: This is the most benign pollution environment, and implies no pollution or only dry, non-conductive pollution, which has no real impact. This type of environment can be construed as an air-conditioned clean environment as can be found in laboratory clean rooms or offices.

(b) Pollution Degree 2: In this environment only non-conductive pollution occurs except that occasionally a temporary conductivity caused by condensation may be expected. This type of environment could be non-temperature controlled home environment. Thus, any household appliance such as electric cookers, laundry washing machines, dishwashers, stereos, amplifiers, radios, and electric musical instruments will be subjected to.

(c) Pollution Degree 3: In this environment pollution occurs or dry non-conductive pollution occurs which becomes conductive due to condensation. This type of environment can be expected in industrial warehouses or other industrial storage or manufacturing areas.

(d) Pollution Degree 4: In this environment pollution generates persistent conductivity caused by dust or by rain or snow. This is the most stringent environment and is generally seen in exposed outside environment.

Maximum Working Insulation Voltage

The prime voltage that the VDE 0884 qualification testing attempts to extract is the working voltage of the optocoupler component. This is the most important parameter which indicates what the maximum continuous operating voltage that a device or insulation can be exposed to without any danger of the insulation being catastrophically destroyed. For instance, in table 4.9.1 the maximum working voltages for the Agilent Technologies optocouplers are listed as summarized in Table 4.9.4 below.

As long as the optocouplers are exposed to voltages up to or below the maximum working insulation voltage, it is expected that no partial discharge takes place, there is no degradation of the insulating material of the optocoupler, and safety imposed limits have not been exceeded. Table 4.9.5 below lists the test voltages vs. the working voltages.

Table 4.9.4: Maximum Working Voltage for Agilent Optocouplers

Description	Symbol	Rating Group A HCNW HCNR	Rating Group B HCPL-7XXX, -JXXX & -XXXJ	Rating Group C PDIP #060	Rating Group D SO-8 TUV per VDE 0884	Units
Maximum Working Insulation Voltage	Viorm	1414	848 / 891	630	566	V peak

Table 4.9.5: Insulation Test Voltages vs. Maximum Working Voltage

Working Voltage Vrms	Test Voltage V peak I	Test Voltage V peak II	Test Voltage V peak III	Test Voltage V peak IV
50	330	500	800	1500
100	500	800	1500	2500
150	800	1500	2500	4000
300	1500	2500	4000	6000
600	2500	4000	6000	8000
1000	4000	6000	8000	12000

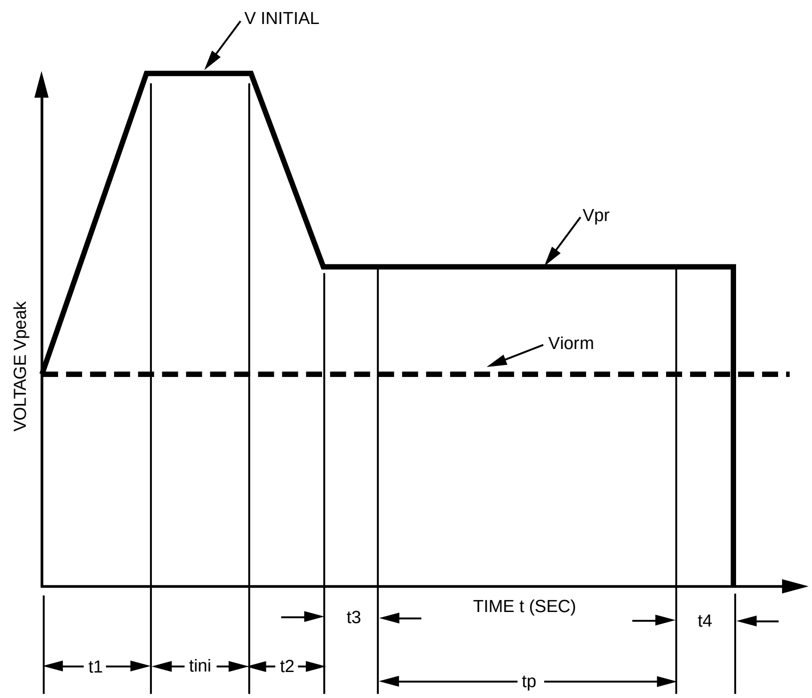
Partial Discharge Test Methods per VDE 0884

The VDE 0884 standard specifies two test methods for the partial discharge testing. Test Procedure (A) is for type (characterization) and sample testing, and is construed to be a destructive test, as at the test voltages some partial discharge can be assumed to be initiated. Test Procedure (B) is for manufacturer's 100% production testing, and is a non-destructive test procedure. Figures 4.9.1 and 4.9.2 indicate the voltage versus time relationships for the type and production tests respectively. The voltages indicated are Peak AC voltages.

Partial discharge is measured during the voltage indicated as Vpr. For Type testing the magnitude of the partial discharge test voltage (Vpr) is equal to 1.5 x Viorm for 60 seconds, where the Viorm is the maximum working voltage that is established for the device. For production testing the partial discharge voltage is equal to 1.875 x Viorm for 1 second. The maximum charge that can accumulate during the partial discharge testing, either in type testing or production testing, is 5 pC.

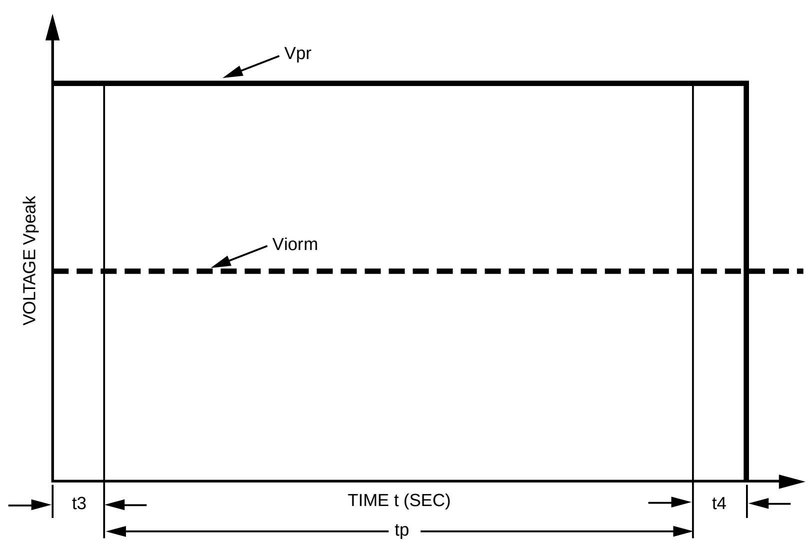
Maximum Transient Overvoltage - Viotm

This is the maximum initial voltage that an optocoupler is subjected to for 10 seconds during the partial discharge qualification testing. In Type testing partial discharge may occur between Vinitial (= Viotm) and Vpr, but they shall have discontinued when the voltage is reduced to Vpr (see figure 4.9.1). Type testing is considered a destructive test, as the voltages and times may have initiated some partial discharge damage.



Vpr = 1.5 × Viorm
t1, t2 = 1 TO 10 SEC
tini = 10 SEC
tp (PARTIAL DISCHARGE) = 60 SEC
t3 = t4 = 1 SEC

Figure 4.9.1: Type and Sample Testing: Method (A) – Destructive Test



Vpr = 1.875 × Viorm
t3 = t4 = 0.1 SEC
tp (PARTIAL DISCHARGE) = 1 SEC

Figure 4.9.2: 100% Production Testing: Method (B) – Non-destructive Test

Thus, the maximum transient overvoltage (Viotm) is the maximum transient voltage that is expected in a particular installation category, and is also the initial voltage during the type testing. Table 4.9.6 summarizes the transient overvoltage ratings for Agilent Technologies VDE 0884 Optoisolator product families. To comply with the VDE 0884 safety standard for optoisolators, the components in a particular application will not be subjected to any transient overvoltage equal to or above this voltage level. If the transient overvoltage rating is exceeded then it may be expected that some partial discharge damage possibly has occurred which may eventually lead to a failure of the insulation.

Table 4.9.6: VDE 0884 Maximum Transient Overvoltages for Agilent Optoisolators

Description	Symbol	Rating Group A HCNW HCNR	Rating Group B HCPL-7XXX and -XXXJ	Rating Group C PDIP Option 060	Rating Group D SO-8 TUV	Units
Maximum Transient Overvoltage	Viotm	8000	6000	6000	4000	V peak

See Tables 2.4 for Optocoupler Product Groups

Creepage and Clearance Spacings

The creepage distance is defined as the shortest distance along the surface of the insulating material between two conductive parts or leads. This shortest distance may be either over the package or under the package or side of the package. The clearance distance is the shortest distance in the air between two conductive parts or leads. The VDE 0884 standard specifies the spacings per DIN VDE 0110 part 1, Tables 2 and 4.

Table 4.9.7: Creepages and Clearances for Agilent Optoisolators

Spacing	Rating Group A HCNW HCNR	Rating Group B HCPL-7XXX, -JXXX & -XXXJ	Rating Group C PDIP Option 060	Rating Group D SO-8	Units
Creepage	10	8	7.4	4.8	mm
Clearance	9.6	7.4	7.1	4.9	mm

See Tables 2.4 for Optocoupler Product Groups

Comparative Tracking Index (CTI)

The insulation materials can be classified according to their comparative tracking indicies, which attempts to capture the resistance to leakage currents or resistance to insulation deterioration in the presence of aqueous contaminants when a high voltage is applied to such surface. The test is performed according to IEC 112. Aqueous contaminants are dropped on the insulating material, and voltage is determined when electrolytic conduction or tracking occurs. Insulating materials are separated into four isolation groups according to their CTI values as follows:

Material Group I
600 < CTI

Material Group II
400 < CTI < 600

Material Group IIIa
175 < CTI < 400

Material Group IIIb
100 < CTI < 175

Maximum Safety Limiting Ratings
The maximum safety ratings indicate the absolute maximum power and temperature that an optocoupler can be exposed or subjected to during a single fault condition. Where a single fault condition is defined as a condition in which one means for protection against a hazard is defective. An application circuit configuration must guarantee that the maximum safety ratings will never be exceeded during the single fault condition to prevent damage to the optocoupler or its insulation. These ratings are not normal operating ratings, but values that should not be exceeded. The safety ratings list the maximum case temperature, maximum input LED current, and maximum detector power dissipation, and pertinent derating curves are provided in case of a single failure mode.

Insulation Resistance / Isolation Resistance

For the insulation resistance test both the input terminals (emitter side) and the output terminals (detector side) are short circuited respectively. The insulation resistance of the optocoupler is determined by applying 500 V across the shorted input terminals and shorted output terminals 60 seconds after application of this high voltage.

VDE 0884 Qualification / Type Test Procedure

A total of 130 optoisolators are supplied to the VDE to perform the qualification tests. Five test batches are formed, with batch one consisting of 20 devices, batch two and three consisting of 30 devices each, batch four consisting of 40 devices, and the fifth consisting of 10 devices. All test devices should pass the test requirements of a particular test batch. In case of any failure, the relevant tests are repeated on a further test batch of the same size, and no further failures are allowed. Devices that have been subjected to the type testing are not used again.

The following sequence of tests is performed:

a) Visual Inspection (n = 80)
b) Soldering heat withstand (260°C for 5 seconds, n = 80)
c) Dielectric strength measurement (test voltage = 1.875 Uiorm / 1 sec, n = 80)
d) Functional Check (n = 80)
e) Insulation Resistance (500 V for 1 minute, n = 80)

Test Batch #1, Sample size = 20 devices
a) Temperature Cycles - Five temperature cycles with a dwell time of 3 hours at the specified minimum and maximum storage temperatures, with subsequent storage times of 2 minutes minimum and 3 minutes maximum at each temperature extreme.

b) Vibration - Frequency range of vibration is 10 Hz to 500 Hz, Amplitude of vibration is 0.75 mm, maximum acceleration of 10 g, duration of stressing is 10 cycles per axis.

c) Mechanical Shock - Three shocks in each direction, with an acceleration of 100 g. Duration of each shock is 6 ms, and form of shock is half sine wave.

d) Dry Heat - Input and Output stressed at not less than working Voltage (Uiorm) or a minimum of 700 V at not less than 100°C for 16 hours.

e) Damp Heat - one cycle at 55°C

f) Low Temperature - Two hours at the minimum ambient temperature.

g) Damp Heat - Stressing period of 21 days at 85 / 85 (85°C at 85% RH).

h) Final Measurements - As a pretreatment devices are dried at room temperature for one to two hours. Final measurements are made within 6 hours after the pretreatment according to manufacturer's data sheet at room temperature, and no failures are allowed. Partial discharge test is performed at 1.5 x Uiorm, with a maximum discharge limit of 5 pC. Then insulation resistance is measured at 500 V at room temperature, and this must be greater than $1\text{x}10^{12}$ ohms. After this an Impulse voltage test is performed with 50 discharges at 10,000 V over 1 nF capacitor, with a maximum discharge rate of 12 per minute. Subsequently, an insulation resistance is measured at 500 V, and the insulation resistance (Ri-o) will not be less than $1\text{x}10^{9}$ ohms.

Test Batch # 2, Sample size = 30 devices
a) Input Overload Safety Test - Input loaded at safe current and/or power limit for 72 hours (LED If = Is, Ta = Ts).

b) Final Test - Partial discharge tested at 1.2 x Uiorm, with a partial discharge maximum limit of 5 pC. Subsequently, Insulation resistance is measured at 500 V and insulation resistance must not be less than $1\text{x}10^{9}$ ohms.

Test Batch # 3, Sample Size = 30 devices

a) Output Overload Safety Test - Ouput is loaded at safe output power for 72 hours, (Output power = Ps, Ta = Ts, input loading may be necessary).

b) Final Test - Partial discharge tested at 1.2 x Uiorm, with a partial discharge maximum limit of 5 pC. Subsequently, insulation resistance is measured at 500 V and insulation resistance must not be less than $1x10^9$ ohms.

Test Batch # 4, Sample Size = 40 devices

a) Insulation Resistance at Elevated Temperature - The Insulation resistance is measured at a maximum ambient temperature or a minimum of 100°C, and also at room temperature. The resistance is measured at 500 V, and the insulation resistance must be higher than $1x10^{11}$ ohms at high temperature and greater than $1x10^9$ ohms at Ta = Ts.

Test batch # 5, Sample size = 10 devices

a) Creepage and Clearance Spacings - External creepage distances and clearances are measured in accordance with the rated insulation voltage and relevant degree of pollution.

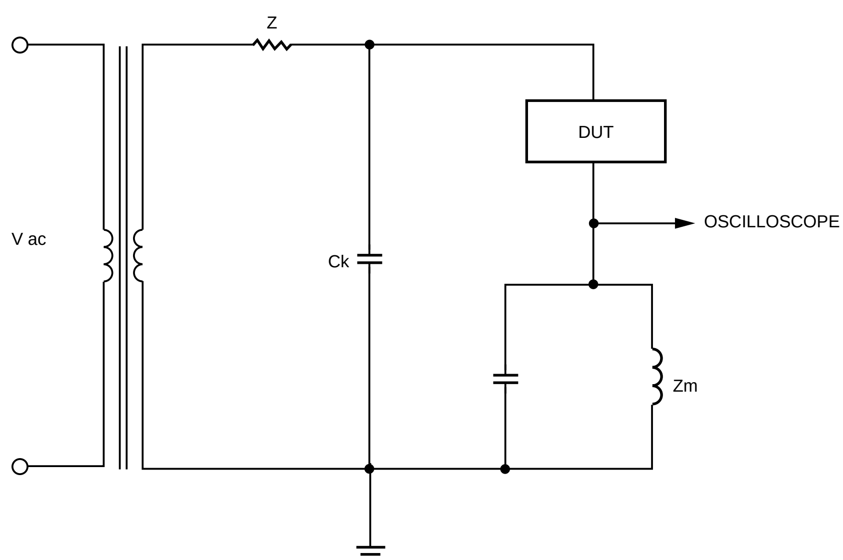
b) Flammability Test - The thermal behavior of insulants is determined in accordance with DIN IEC 695 part 2-2 / VDE 0471 part 2-2. The time of application of the test flame is 10 seconds.

Partial Discharge Measurement

One method to measure partial discharge consists of a narrow band test method. VDE uses narrow band test method because of their higher accuracy and lower interference or noise levels. Narrow band is defined by VDE to be a 3 dB frequency of the test circuit to be not less than 15 kHz. The center frequency of the measurement circuit, which can be an LC resonance circuit, may be any frequency between 150 kHz and 5 MHz. No measurements are made at the resonance frequency.

Figure 4.9.3 shows a typical narrowband partial discharge circuit. Z is either a current limiting resistor or any other impedance or filter to reduce interference from the a.c. supply voltage. Ck is a coupling capacitor. Zm is the measuring circuit, and in the case of narrow band test method, this consists of an LC resonance circuit. Calibration of the measuring circuit is done so that peak voltage proportional to the partial discharge is observed at the measuring instrument, and can be observed on an oscilloscope. The response of the LC resonance circuit is a damped oscillatory waveform at the resonance frequency.

Calibration of the measurement circuit is done such that the circuit is capable of measuring a charge value as low as 1 pC. Measuring circuit and calibration procedures are in accordance with DIN VDE 0434/05.83.



Ck = COUPLING CAPACITOR
DUT = TEST DEVICE
Z = RESISTOR OR FILTER
Zm = IMPEDANCE OF THE MEASURING CIRCUIT
(LC RESONANCE CIRCUIT)

Figure 4.9.3: Narrowband Partial Discharge Test Circuit

4.10 UL 1577 Third Edition, March 31, 1995 (Optical Isolators - Standard for Safety)

UL 1577 is the Underwriters Laboratories (UL) standard which covers the insulation requirements for optocouplers; it does not cover electrical properties. The requirements of UL 1577 are also intended for optocouplers used in equipment with a supply voltage not exceeding 600 V ac rms or dc. Successful completion of the requirements and regular follow-up inspections by UL allow these components to be listed in UL's Component Recognition Program. Other terms used for optocouplers are optical isolators, optical couplers or photocouplers.

Construction

The construction requirements for optocouplers are straightforward. Optocouplers must provide corrosion protection for their metal leadframes by enameling, galvanizing, plating or other equivalent means. Metal for current carrying parts shall be copper, silver, gold, nickel, aluminum, an alloy of the same materials or an equivalent material.

The insulating material (body molding and internal cavity) must meet the requirements of UL746C, *Standard for Polymeric Materials - Use in Electrical Equipment Evaluations*. Normally, the Dielectric Voltage-Withstand Test is sufficient to evaluate the insulating material, but if the generic temperature rating of the material is exceeded, then the optocoupler must be subjected to a Limited Thermal Aging Test (per UL 746B and Section 12, UL 1577).

External "spacings" are determined by the end product spacing requirements. UL 1577 does not impose any internal or external construction requirements on optocoupler manufacturers. There is no minimum distance through insulation requirement of 0.4 mm minimum for reinforced insulation applications as imposed by some equipment standards. (Distance through insulation distance is the direct distance between the emitter and detector, conductor to conductor, inside the optocoupler cavity.)

Performance

The primary test of an optocoupler's insulation capability is the Dielectric Voltage-Withstand test. This is a one minute test where a voltage (ac rms or dc) is applied between the input and output terminals of the optocoupler. This voltage is the rating of the optocoupler's insulation which includes the outer body mold and any other materials used inside the cavity which houses the photo-emitter LED and photo-detector. The Dielectric Voltage-Withstand Rating is a safety parameter, does not mean a continuous voltage rating and is considered a destructive test. Typical withstand voltage ratings range from 2500 Vrms - 5000 Vrms.

Optocoupler qualification testing consists of environmental conditioning which includes storage at the LED maximum rated junction temperature, storage at the maximum rated operating temperature, high humidity storage, low temperature storage, and operating life at 150% of maximum rated power, all followed by the one minute dielectric withstand-voltage test and visual inspection for no cracking or warping of the encapsulating material.

Manufacturing and Production-Line Tests

Each optocoupler is tested at 120% of the rated dielectric insulation voltage for one second.

Ratings and Markings

The following ratings shall be provided as a minimum (usually listed in a manufacturer's data sheet or catalog), in either graphic or tabular form:

- Maximum continuous power
- Maximum continuous current
- Voltage rating for the photo-emitter
- Voltage rating for the photo-detector
- Dielectric voltage-withstand rating (Vrms or Vdc)
- Maximum operating temperature, derating specifications

Each optocoupler shall be marked with the manufacturer's name or trademark, and the catalog designation. There is very little room for much else, but usually a datecode is provided for traceability as well as the pin one orientation mark. The backwards UR symbol, which designates a recognized component, is optional and not required to be placed on the optocoupler body. UL symbology or marks are placed on the next level of shipping container. Markings in compliance with UL 1577 are listed in UL's Recognized Component Directory under product category FPQU2.

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