

Application Note 1074

Introduction

A major concern of circuit designers is the reliability of an optocoupler when subjected to repeated and long-term, high-voltage stress between its input and output. Most of the technical data on optocouplers adequately address the capability of an optocoupler to withstand one-time high-voltage transients, but they do not adequately address the issues of:

- a) how long one can apply a steady state AC or DC voltage between the input and output of the optocoupler before degrading the semiconductors or the insulation inside the optocoupler, and
- b) how often one can apply high-voltage transients before degrading the optocoupler.

In attempting to answer these questions, a series of operating life tests were conducted on Avago Technologies optocouplers. Several optocoupler lots were subjected to different input-output high-voltage stress tests to examine the failure rate and the time taken to fail. Upon completion of these tests, the test data was analyzed to create safe operating areas for long-term, input-output high-voltage stress. The boundary of the safe operating areas for the steady-state input-output high-voltage stress is referred to as Endurance Voltage.

Figure 1 describes the concept of Endurance Voltage for one family of Avago optocouplers. As shown in this figure, the bottom region is the safe operating area for steady-state ac and dc input-output voltage stress meant for continuous application of a high-voltage stress. The middle region is the safe operating region for transient voltage stress. Operating outside both of these safe operating regions causes the optocoupler to wear-out either in functionality or in isolation capability, and is not recommended for use.

This application note discusses an Avago input-output voltage stress study that was conducted on Avago optocouplers. The results from these tests indicate that Avago optocouplers are robust for long-term survival in applications where a continuous high-voltage stress is applied across the input-output. Avago optocouplers can safely withstand a continuous voltage up to either 800 Vac, or 1000 Vdc. Before discussing the high-voltage stress test details, it is worthwhile to define some of the common high-voltage terminology and put that in context with Endurance Voltage.

High-Voltage Terminology

The basic purpose of an optocoupler is to send signals between two circuits or systems that need electrical insulation from one another. During signal transmission between the two circuits or systems the optocoupler must also have the capability to reject common mode voltages and transients and this capability is referred to as signal isolation. There are several terms used in the industry to define and quantify the signal isolation and electrical insulation capability of an optocoupler. Some of the common terms used in Avago Technologies technical literature are described below.

Signal Isolation

The isolation function of an optocoupler is defined by its ability to pass desired signals and reject unwanted signals or transients. Optocoupler isolation capability is largely determined by its input-output capacitance and the electrical design of the detector circuit. Most optocouplers use the common-mode rejection parameter to define and quantify the signal isolation capability.

Electrical Insulation

When an optocoupler acts as a coupling device between two circuits or systems that have a potential difference, then the insulation capability of the optocoupler is defined by its ability to prevent physical damage to the surrounding circuitry as well as to itself. Electrical insulation is often a safety issue which is regulated by many countries' safety agencies* at both the component level and at the equipment level. Safety standards are often set up to establish the requirements for the insulation barrier between safe and hazardous voltages within equipment. They also define test, material and dimensional requirements based on conditions which are expected to be encountered. Definitions of safe and hazardous voltage levels vary among countries and equipment. Components like optocouplers, which are often part of the insulation barrier, are sometimes addressed separately in order to simplify equipment level qualification. There are five major ways of defining and quantifying the insulation properties of an optocoupler.

Input-Output Resistance: To measure the input-output resistance of an optocoupler, usually 500 Vdc is applied between the optocoupler input and output for a duration of one minute, and the leakage current is measured. With the leakage current value, one can calculate the input-output resistance. The input-output resistance is merely one type of short duration insulation test and it gives the circuit designer an indication of the amount of DC leakage current for a particular input-output voltage.

Input-Output Insulation Voltage or Dielectric Withstand Voltage: This is usually defined by a one minute rating for the maximum voltage that can be applied between the input and output of an optocoupler. Either long duration or repeated application of high-voltage stress may cause permanent damage and functional failure of the optocoupler. The one-minute Dielectric Withstand Voltage does not indicate the capability of the optocoupler to withstand long-term application of high-voltage stress nor does it tell you how often and how many times one can apply these high-voltage pulses.

Internal Clearance: The shortest direct through-insulation distance between the input and output circuitry within the optocoupler.

External Clearance: The shortest air-gap distance between the input and output leads of the optocoupler.

External Creepage: The shortest external surface distance between the input and output leads of the optocoupler.

The Internal Clearance, External Clearance, and External Creepage specifications of optocouplers are useful for obtaining component and equipment regulatory insulation safety approvals in various countries, as well as for determining the Working Voltage of an optocoupler, which is defined below.

Working Voltage

The highest steady-state voltage that can be applied across the input-output insulation of an optocoupler as defined by equipment standards and Regulatory Agency guidelines is called the Working Voltage. Some of the considerations for determining the Working Voltage of an optocoupler are the type of equipment the optocoupler is designed into, the relevant safety issues in the use of the equipment, the mains voltage of the equipment, and the environment in which the equipment is used.

In situations where a Regulatory Agency is not involved, then the Working Voltage is defined by the equipment application. In such a case, the Working Voltage is the maximum input-output steady state voltage that the optocoupler encounters in the circuit application.

Endurance Voltage

The Endurance Voltage, a term defined by Avago Technologies, is the maximum voltage that can be applied between the input and output terminals of an optocoupler for extended periods of time without damaging the optocoupler. Damage to an optocoupler can include loss of operation or loss of insulation. Endurance Voltage is based on the inherent properties of the optocoupler and is not based on a Regulatory Agency guideline or the equipment application.

Some factors affecting insulation and operating life include input and output biases, applied input-output voltage, temperature, humidity, moisture, mechanical stress and exposure to a variety of chemical agents. For determining the use of an optocoupler in a particular equipment, a designer should consult the regulatory guidelines and the appropriate Working Voltage for that application. For proper use, the Endurance Voltage of an optocoupler must be equal to or greater than the Working Voltage.

* Examples of Safety Agencies are UL in USA, VDE in Germany, and CSA in Canada.

Description of the Avago-Internal Input-Output Voltage Stress Study

The objectives for the optocoupler input-output voltage stress tests conducted at Avago included determining which temperature is the worst case temperature for partial discharge related wear-out, establishing data bases for demonstration data to extract AC and DC Endurance Voltages, and voltage and temperature acceleration factors. The following table shows the stress cells that were set up with combinations of temperatures and voltages to satisfy these objectives.

The cells at room temperature and 85°C were intended for the demonstration data base and the cells at 100°C and above were intended for determining the acceleration factors. The cells at 2000 Vac, -40°C were used to test whether room temperature or -40°C cell was the worst case and then to profile data at this temperature.

Only 8-pin P-DIP (7.62 mm wide), and SO-8 plastic optocouplers were used in the input-output high-voltage stress tests. The test units consisted of optocoupler and solid state relay samples from several product families. Refer to Figures 1, 2, and 3 for a full list of products that were subjected to these tests. In general, test units were conditioned prior to stress with a solder dip, 500 temperature cycles and 96 hours of pressure pot sequence. The SO-8 surface mount optocouplers were assembled on ceramic carriers and sent through an infra-red solder reflow process. The intent of the conditioning was to accelerate the aging of the optocoupler that would otherwise occur through its normal operating life.

Summary of Results of Input-Output High-Voltage Stress Tests

Input-Output Voltage-AC The insulation failure rate of optocouplers caused by partial discharge related wear-out was worse at -40°C than at room and higher temperatures. The -40°C wear out is accelerated by at least a factor of three over room temperature tests at the high-voltages.

There was no evidence of systematic parametric drift due to AC input-output voltage found in the cells without operating bias. The failure rate with an operating bias is only slightly higher than for the test without the operating bias. The AC Endurance Voltage was set by the results of tests at -40°C as this condition defined the worst case. No failures occurred in all of the 1000 Vac stress cells for the full length of each test group. Some 1000 Vac stress tests were over 15,000 hours.

Table 1. Stress Cell Matrix

	-40°C	Room Temp. (25°C)	85°C	100°C	125°C	150°C
1000 Vac		X	X •		X	X
1500 Vac	X					
1800 Vac		X				
2000 Vac	X			X	X	X
2500 Vac	X	X				
3000 Vac	X				X	X
3800 Vac						X
4000 Vac	X	X				
5000 Vac		X				
2000 Vdc			X •		X •	X •
2500 Vdc						X •
3000 Vdc			X •			
4000 Vdc					X •	
5000 Vdc		X				X •

X Indicates that a high-voltage stress test was conducted for a group of optocouplers.

• Indicates cells with input and output operating biases.

Input-Output Voltage-DC

The failure rate for dc input-output voltage stress is greater at high temperatures than at low temperatures. All the dc stress tests were conducted with an operating bias. No failures occurred in the 85°C, 2000 Vdc and 3000 Vdc cells for the entire test periods. Some of these cells were stressed over 5000 hours.

Recommended Operating Areas

Based on the high-voltage stress study conducted at HP, Endurance Voltage boundaries, and safe operating areas have been drawn up for different Avago optocouplers. Figures 1, 2, and 3 show the recommended operating areas for input-output voltages that can be applied for three categories of Avago optocouplers. Referring to Figures 1, 2, and 3, the safe operating region below 800 Vac is applicable for long-term continuous high-voltage stress. The safe operating region above 800 Vac is applicable only for transient voltages. The X-axis on these figures shows the maximum cumulative time that can be applied for the high-voltage stress. Exceeding this maximum cumulative time may cause either the optocoupler's insulation or its electrical functionality to fail. The safe operating region guidelines are applicable when the optocoupler is used under normal conditions in a pollution free environment and within the maximum operating conditions. This includes operating the optocoupler within its specified ambient temperature range.

Although the Avago time-to-failure tests were conducted at various temperature and voltage stress combinations after conditioning the test units to simulate end use with temperature cycling, solder processing and exposure to humidity, the test environment was relatively clean, where no condensation, precipitation or accumulation of corrosive or conductive material was expected. Consequently, the Endurance Voltage is primarily an indicator of internal characteristics. For the use of an optocoupler in specific equipment and environment, refer to the appropriate Safety Agencies such as UL and VDE for standards that determine the maximum allowable input-output voltages as defined by the Working Voltage. These standards generally consider attributes such as arc track resistance, corrosion resistance, and physical dimensions (creepage and clearance) for determining the Working Voltage and the maximum transient input-output voltages.

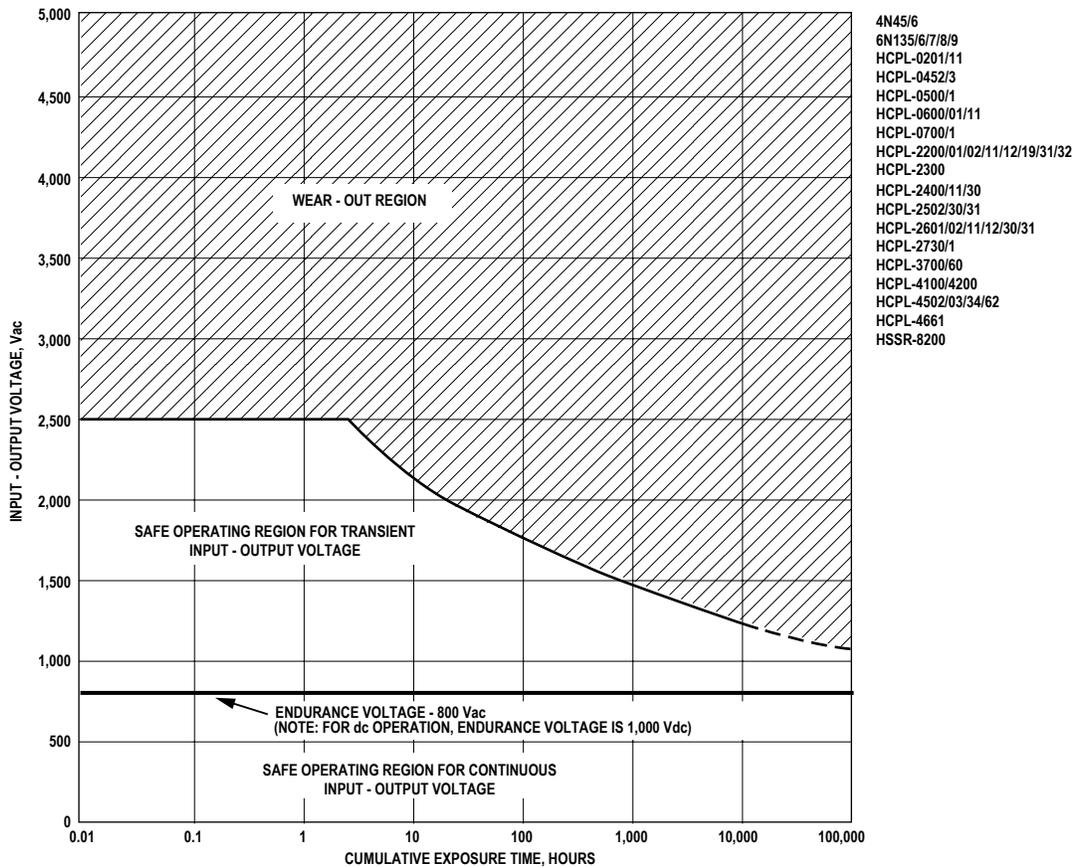


Figure 1. Recommended Safe Operating Area for Input-Output Voltage-Endurance Voltage for Category 1 Optocouplers.

The Endurance Voltage defines a stable region for operation. Operation within this region for input-output voltage and within the other recommended operating parameters, allows the optocoupler to maintain the performance specified within its data sheet. Operation above the optocoupler Endurance Voltage region may result in damage leading to failure of the optocoupler either in insulation or in electrical functioning.

Temperature is another key factor for operating life. The insulating materials within Avago's plastic optocouplers are organic polymers and one would expect that an Arrhenius

relationship exists between insulation life and temperature. However, the temperature characteristics are such that the life time of the optocoupler does not appear to be limited by the temperature induced insulation failures if the optocoupler is operated within the Endurance Voltage. This appears to be the case within the recommended operating region. But due to the construction of the optocoupler, a worst case condition exists at the coldest operating temperature that, in turn, defines the maximum acceptable AC Endurance Voltage.

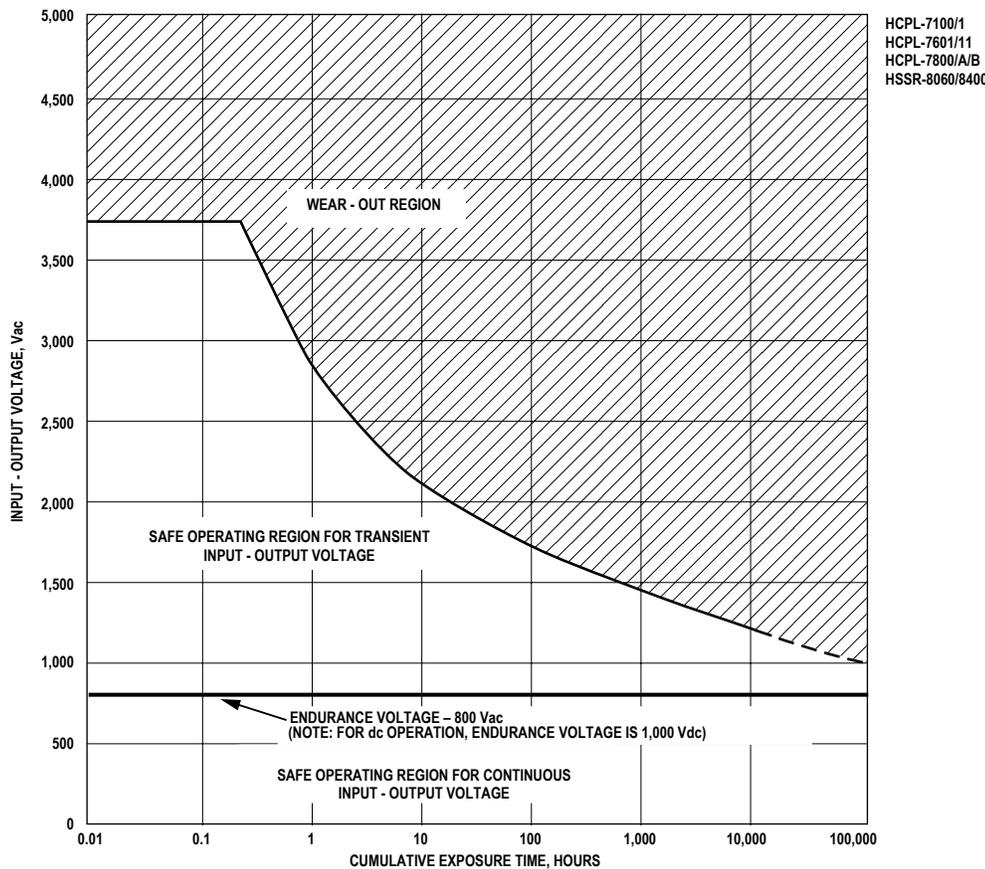


Figure 2. Recommended Safe Operating Area for Input-Output Voltage-Endurance Voltage for Category 2 Optocouplers.

Conclusion

Technical data specified on an Avago optocoupler is valid at the time of shipment from Avago's factory, or at the beginning of product life. Just like any semiconductor product, an optocoupler can potentially have some parameters degrade over the life of the product even though the optocoupler continues to be functional. The circuit designer who uses an optocoupler must consider any parameter that is likely to degrade over the product life, and must design sufficient margin so that the optocoupler still functions. This application note specifically addresses the insulation capability of an optocoupler as measured by a term called Endurance Voltage. The Endurance Voltage of an optocoupler is defined as the maximum voltage that can be applied between the input and output of an optocoupler for extended periods of time without causing functional failure of the optocoupler. By following the Endurance Voltage guidelines shown in Figures 1, 2, and 3, the opto-

coupler can be operated normally for its useful life without unduly increasing the risk of insulation or electrical failure.

Always take the Endurance Voltage guideline as having a lower precedence to the Safety Agency and equipment use standards such as Working Voltage. The Endurance Voltage guideline is applicable in a pollution free laboratory environment and is useful for determining the likelihood of failure of an optocoupler's insulation or electrical operation. The Avago optocouplers tested in this study have been proved to withstand a continuous voltage of either 800 Vac, or 1000 Vdc, and this allows Avago optocouplers to be safely used in a wide array of industrial applications.

WARNING: In all cases where regulatory compliance is required, Working Voltage sets the maximum allowable steady state input-output voltage. Working Voltage cannot be exceeded in a design that has to meet regulatory requirements.

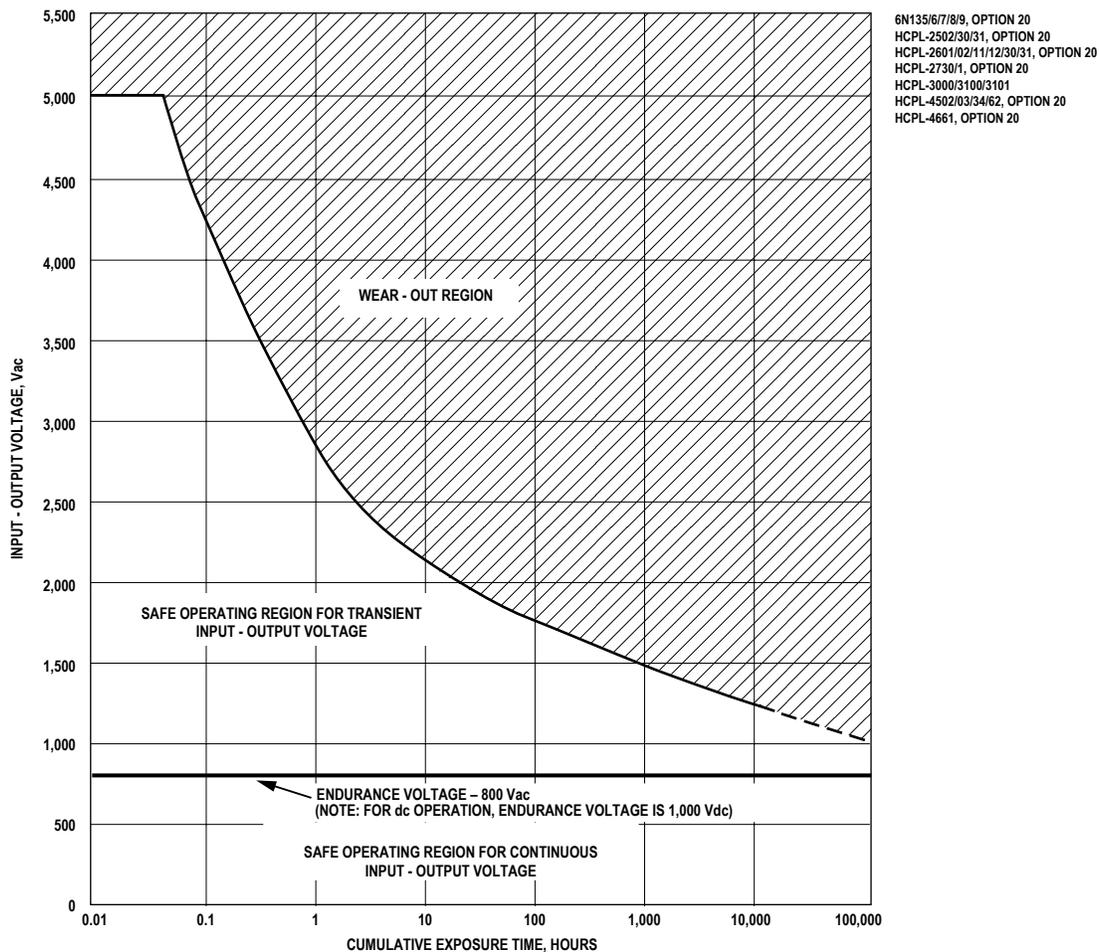


Figure 3. Recommended Safe Operating Area for Input-Output Voltage-Endurance Voltage for Category 3 Optocouplers.

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