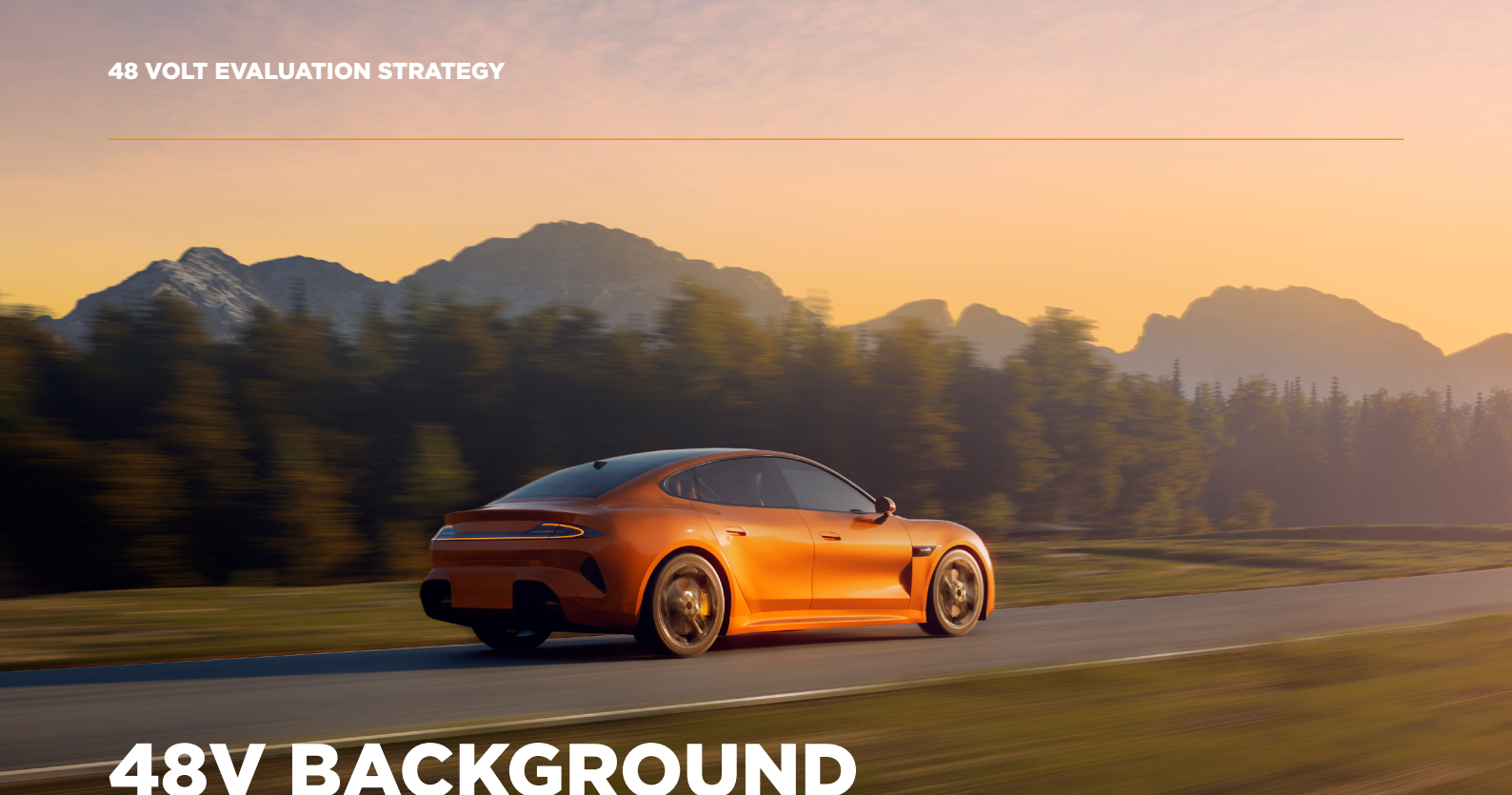
TECHNICAL GUIDE

48 VOLT EVALUATION STRATEGY



48 VOLT READY



48V BACKGROUND

As the transportation industry transitions toward higher-voltage electrical systems, it is increasingly important for TE Connectivity (TE) to provide reliable, up-to-date data regarding product electrical performance characteristics. As vehicle electrical/electronic (E/E) architectures evolve, OEMs are increasingly adopting zonal architectures to reduce wiring complexity, harness weight, and packaging requirements. In parallel, the transition from traditional 12V electrical systems toward 48V distribution enables higher power delivery at lower current levels. For a given power requirement, lower current can enable smaller conductor cross-sections in appropriate applications, further contributing to harness weight and packaging reductions while supporting growing electrical loads and safety-critical applications such as brake-by-wire, steer-by-wire, active suspension, and chassis control.

As operating voltages increase, appropriate electrical evaluation becomes increasingly important to help prevent electrical breakdown over the life of a product and support safe, reliable performance. Connector evaluation must consider the different ways electrical breakdown can occur, including through insulation, across insulation surfaces, and through air between conductive components. TE's connector evaluation process considers these potential breakdown mechanisms when determining the minimum required distances between conductive components for specific applications and operating conditions.

TE's newly created Low Voltage Connector System (LVCS) portfolio has been developed to support this architectural transition, providing connectivity solutions for current 48V applications while establishing a scalable platform to address evolving power distribution and vehicle architecture requirements.

TE Transportation Solutions has conducted studies across a wide range of products to evaluate their suitability for 48V applications, using IEC 60664-1, Insulation coordination for equipment within low-voltage systems – Part 1: Principles, requirements and tests, as the reference for determining creepage and clearance requirements. The following pages outline TE's strategy for evaluating connectors for 48V applications and provide a general example of the evaluation approach.

These studies assess whether the insulating materials and terminal spacing are sufficient for operation at 60V in support of 48V systems. The evaluation considers nominal terminal spacing as well as potential terminal movement within connector cavities due to available freedom of movement. Products are evaluated under the assumption of a Pollution Degree 2 environment for sealed connectors and operation at elevations up to 5,000 meters. For applications with more stringent requirements or different operating conditions, application-specific parameters should be reviewed with the responsible TE Product Engineer.

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CONNECTOR OPERATING VOLTAGE: HOW TO DETERMINE THE MAXIMUM SAFE OPERATING VOLTAGE OF ELECTRICAL CONNECTORS

There are two factors that determine the maximum safe operating voltage of electrical connectors: Creepage and Clearance.

Creepage is when unwanted electrical current flows between conductors over the surface of the insulating material that separates them. In electrical connectors, the conductors are the terminals with wires crimped on, and the insulating material is typically the plastic housing that retains the terminals. Under ideal conditions, no current will flow on the surface of the housing between the terminals.

However, if contamination such as dirt and/or moisture is introduced into the housing, a conductive path can form over time if the voltage is high enough. The likelihood of this happening is reduced as the path over the surface between the terminals is made larger, or the sealing rating of the connector is increased to reduce the amount of contamination.

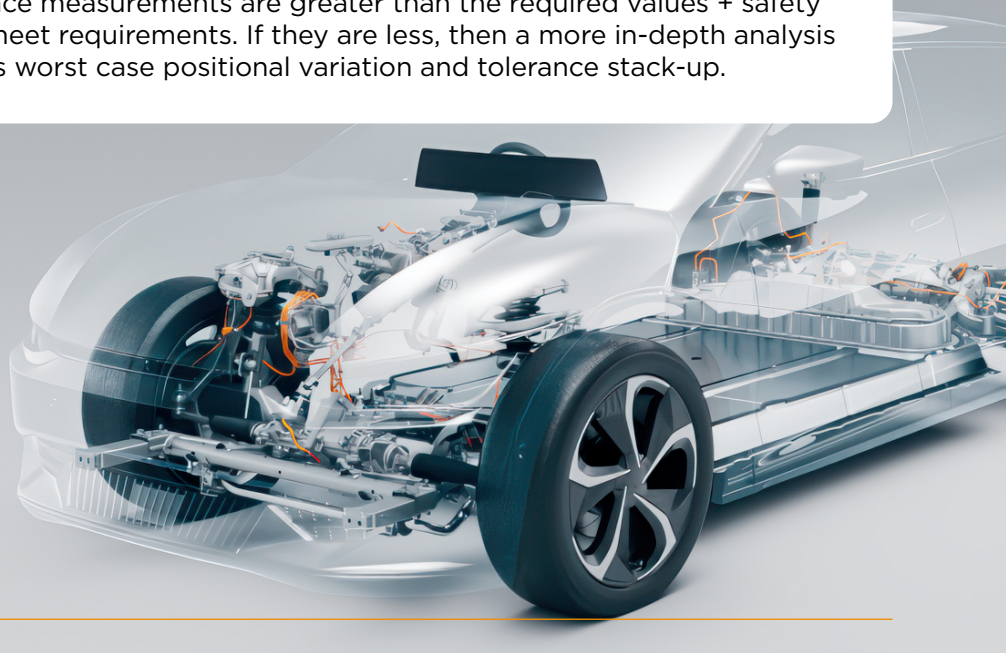
Clearance is the distance measurement, through air, between conductors. Per the IEC 60664-1, for a given nominal voltage rating, a corresponding higher over-voltage rating is given. Over-voltage may occur due to instabilities in the electrical supply. If the over-voltage is sufficiently high, or the distance between the conductors is sufficiently short, an electrical arc may form via dielectric breakdown of air. The dielectric breakdown level is further influenced by humidity, altitude, and contamination. The likelihood of this happening is reduced similarly to creepage: increased distance between conductors, insulating barriers, and reduced contamination via sealing.

48V CONNECTOR EVALUATION METHODOLOGY

To initiate a study, the Creepage and Clearance values from the IEC 60664-1 are determined based on the nominal Operating Voltage, Pollution Degree, Altitude, Overvoltage Category, and Housing Material Properties.

Once the creepage and clearance requirements are found, a CAD model of the subject parts with the electrical terminals is assembled. A cross section of the CAD model is taken and evaluated for the shortest distance between terminal pairs. This can be done manually or via specialized software.

Once the area to be evaluated is chosen, the distance analysis is performed. A safety factor is used to account for positional variations in the actual location of the terminals and dimensional tolerance stack-ups. If the distance measurements are greater than the required values + safety factor, the parts can be said to meet requirements. If they are less, then a more in-depth analysis must be performed that includes worst case positional variation and tolerance stack-up.



DETERMINING CREEPAGE AND CLEARANCE

The first step of TE's 48-volt connector evaluation strategy is to determine the minimum creepage and clearance values of the connector. The following general example explains the basic process of finding creepage and clearance distances for existing connectors to confirm they are compatible with 48V applications. By default, TE's LVCS products already meet these requirements.

This is simply an illustrative example. A copy of IEC 60664-1 should be purchased to conduct actual product evaluations.

THE CREEPAGE AND CLEARANCE CALCULATOR EXAMPLE

The Creepage and Clearance calculator example that is provided here, illustrates the general parameters outlined in the international standard DIN EN 60664-1 guidelines for required distances to ensure safe electrical separation between different circuits. For guidance tailored to your specific application, please consult a TE representative to ensure all requirements are properly addressed.

INPUTS	
Application Voltage	60V
Pollution Degree (Sealed)	2
Pollution Degree (Unsealed)	3
Altitude	5000 m
Overvoltage Category (I-IV)	I
Reinforced Insulation Factor (Clearance)	1.0X
Reinforced Insulation Factor (Creepage)	1.0X

CLEARANCE	
Impulse Voltage	500V
Required Minimum Clearance (@sea level)	0.20 mm
Altitude Correction Factor	1.48 X
Required Minimum Clearance (@5000m)	0.30 mm

CREEPAGE	
Material Group	IIIa
Groove Width	1.00 mm
Required Minimum Creepage	1.24 mm



DETERMINING CREEPAGE AND CLEARANCE

STEP 1:

Determine Material Group

The material group of the insulating material is defined by the CTI (Comparative Tracking Index) and PLC (Performance Level Category) by pulling this information from the part specification or from the appropriate material data sheet provided by the material manufacturer.

Material CTI values between 100 and 600 volts are used to determine whether the material group is group I, group II, group IIIa, or group IIIb. In this example, PEI material is used and a PLC of 4 determines the material group is IIIb.

STEP 2:

Determine Pollution Degree

The presence of contaminants in the connector housing increases the likelihood of a conductive path forming between terminals and of dielectric breakdown of air. Therefore, to find minimum creepage and clearance distances, it is necessary to determine the degree of pollution to which the connector is exposed. Pollution degree is classified by the following:

- **Pollution degree 1**
  Essentially no pollution is present
- **Pollution degree 2**
  Minor surface contaminants
- **Pollution degree 3**
  Some conductive pollutants
- **Pollution degree 4**
  Significant conductive pollution

Most sealed connectors fall between pollution degrees 2 and 3. Since this example is a sealed connector system and only non-conductive pollution is expected if present, the pollution level is 2.

STEP 3:

Determine Minimum Creepage Distance

Minimum creepage distance can now be determined using tabled values. This is accomplished by viewing the appropriate material group and pollution degree along with the desired operating voltage.

For 48V systems, typical charging voltages can be expected up to 60V, so for this example 60V is used as the operating voltage. From the table within IEC 60664-1 the minimum creepage distance is found to be 1.24 mm.

STEP 4:

Altitude Correction Factor

The next step is to determine whether connectors are expected to operate at high altitude levels. Altitude level influences dielectric breakdown of air and thus affects minimum clearance distance. Another table is used to find the altitude multiplication factor by viewing the appropriate altitude between 2,000 and 10,000 meters in altitude.

In this example, the product is expected to operate at 5000 meters, so the correction factor is 1.

STEP 5:

Overvoltage Category

To determine the overvoltage category, the type of equipment must be identified. Electrical connectors are generally considered to be at the power consumption level, so for this example the overvoltage category is II.

- Overvoltage Category IV – Equipment operating as part of the main power supply
- Overvoltage Category III – Equipment operating to distribute power
- Overvoltage Category II – Equipment that consumes the power supplied
- Overvoltage Category I – Equipment operating at signal power levels

STEP 6:

Determine Clearance Distance

Now the clearance distance can be determined. This is accomplished by viewing the clearance distance required based on the overvoltage category and the appropriate pollution degree. If the withstand voltage is 100V (as this is the next level above 60 volts at pollution degree 2), the resulting clearance distance is 0.2 mm.

TESTING ALTERNATIVE

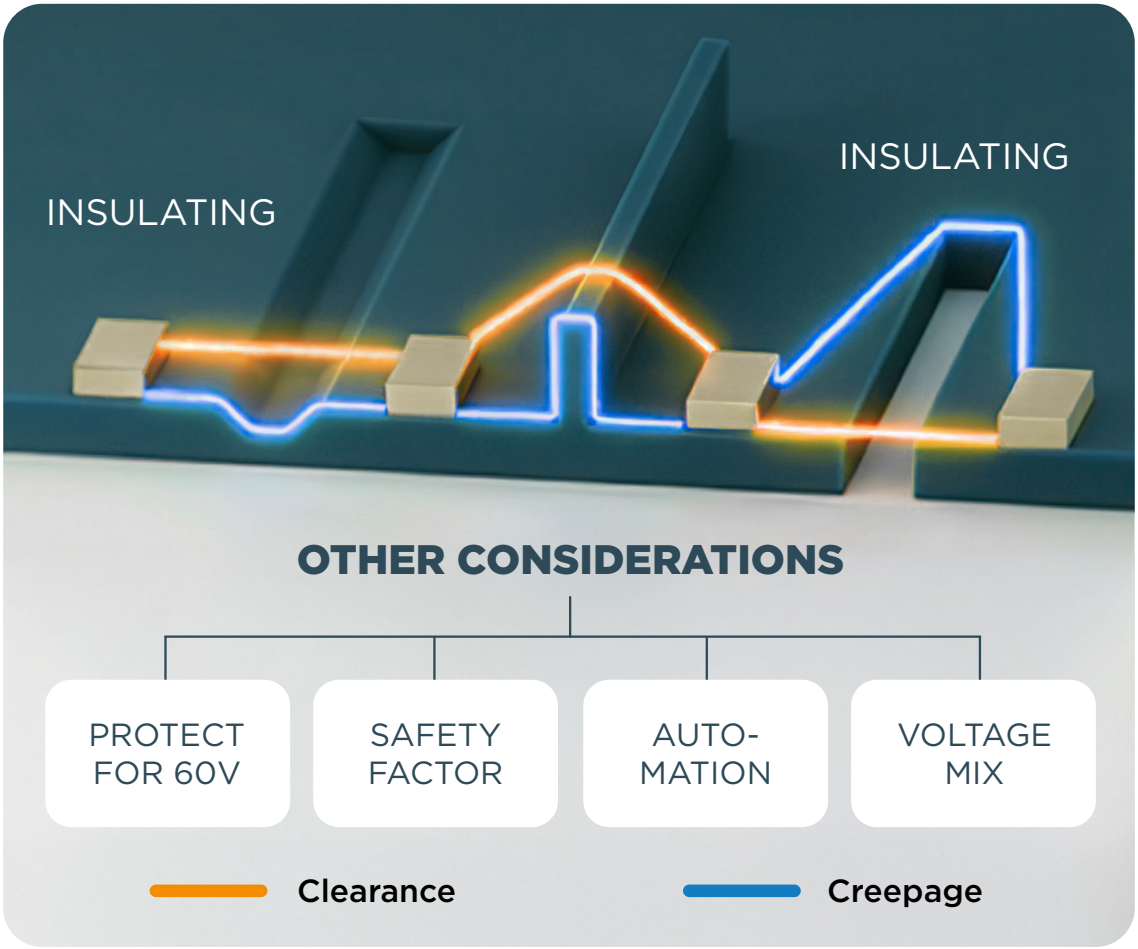
If the evaluation of a connector returns results that do not meet the desired requirements, IEC 60664-1 specification allows testing as a viable alternative to physical measurement.

Note that this testing can only be performed to validate Clearance (overvoltage) requirements; there is no defined test method for Creepage. Testing should be reviewed against the applicable IEC requirements and organizational preferences prior to beginning any tests.

TERMINAL DAMAGE AND SAFETY CONSIDERATIONS

An electrical arc during a connector un-mating operation can be very destructive for the terminal surfaces in the range of voltages of a 48 volt system, so current should always be discontinued before separating a mated connector pair. There is also risk of a destructive arc during a connector mating operation due to potential breaking of current due to terminal misalignment, contact sliding, bounce, etc.; therefore, it is also recommended current be discontinued before engaging a mating connector pair in a 48 volt system.

As with any power system, operating at 48-60 volts can create potentially harmful conditions. Care must always be taken to avoid direct contact with exposed connector terminals, whether with a human finger or with any conductive device or hand tool. Shorting between terminals may result in heavy arcing, terminal damage, or even the potential for fire under certain conditions.



CONCLUSION

The process of using IEC 60664-1 for determining Creepage and Clearance distances is relatively straightforward given knowledge of the connector application and materials used. However, evaluating the parts to find the correct path lengths can be more challenging, particularly when complicated geometries and dimensioning & tolerancing schemes are used. Therefore, engineering judgement must be used on a case-by-case basis, with an appropriate safety factor applied, or tolerance stack-up analysis performed before a definite conclusion can be made regarding the connector voltage rating.

As 48V adoption expands alongside zonal vehicle architectures and into higher-power, safety-critical functions, consistent evaluation of creepage, clearance, material properties, environmental conditions, and application requirements become increasingly important. TE's evaluation approach, together with the evolving LVCS portfolio, is intended to support connector selection for current 48V applications while addressing the requirements of future vehicle electrical architectures. Anyone conducting product ratings should acquire an official copy of the appropriate IEC 60664-1 specification to review the published material and work through the steps involved.

Connect With Us

Contact TE for voltage rating studies related to any Automotive or ICT product of interest.

www.te.com/48v

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