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# AND8181/D

# TVS Diode Selection Guidelines for the CAN Bus

Prepared by: Jim Lepkowski, Paul Lem

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## APPLICATION NOTE

### Introduction

The Controller Area Network (CAN) is a serial communication protocol designed for providing reliable high speed data transmission in harsh environments. This document provides guidelines to select Transient Voltage Suppression (TVS) diodes to protect CAN data bus lines. TVS diodes provide a low cost solution to conducted and radiated Electromagnetic Interference (EMI) and Electrostatic Discharge (ESD) noise problems. The noise immunity level and reliability of CAN transceivers can be easily increased by adding external TVS diodes to prevent transient voltage failures.

### NUP2105L CAN Bus TVS Diode Array

The NUP2105L provides a transient voltage suppression solution for CAN data communication lines. The NUP2105L is a dual bidirectional TVS device in a compact SOT−23 package. This device is based on Zener technology that optimizes the active area of a PN junction to provide robust protection against transient EMI surge voltage and ESD. Figure 1 provides a circuit diagram of the NUP2105L.

The NUP2105L has been tested to EMI and ESD levels that exceed the specifications of popular high speed CAN networks. Listed below is a summary of the NUP2105L’s EMI and ESD specifications.

- 350 W Peak Power Dissipation per line, (8 x 20 μs)
- Human Body Model ESD protection ≥ 16 kV
- IEC−61000−4−2 ESD level ≥ 30 kV for contact discharge
- ISO 7637−1, nonrepetitive EMI surge pulse 2, 9.5 A (1 x 50 μs)
- ISO 7637−3, repetitive Electrical Fast Transient (EFT) EMI surge pulses, 50 A (5 x 50 ns)
- IEC 61000−4−5 lightning and load switch immunity, 10 A (8 x 20 μs)

The NUP2105L uses silicon semiconductor technology to offer distinct advantages over alternative TVS protection devices such as MOVs and choke filters. A TVS diode provides a fast response time, low line capacitance and low clamping voltage. The NUP2105L has a time response time of less than 1.0 ns and is able to clamp fast surge transient voltages before damage can occur. The silicon design has a line capacitance less than 30 pF, which is required for the high 1.0 MHz data transmission rate. The voltage clamping limit of the device, defined by the 8 x 20 μs exponential waveform, is approximately equal to 42 V for a surge current of 10 A. The low clamping voltage ensures that the transient sure voltage will not exceed the CAN transceiver’s maximum voltage specification for the CAN_H and CAN_L data lines.

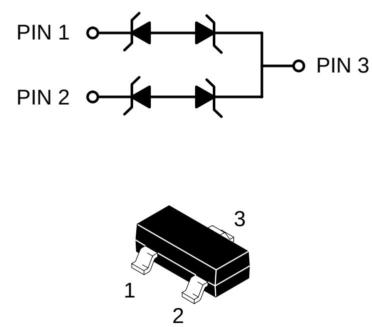



**Figure 1. NUP2105L Bidirectional TVS/ESD Protection Device**

Figure 2 provides an example of a typical CAN bus protection circuit. The circuit provides protection for the CAN_H and CAN_L data lines by clamping the surge voltage to a level that will not damage the CAN transceiver. Further details on CAN protection circuits are provided in reference (1).

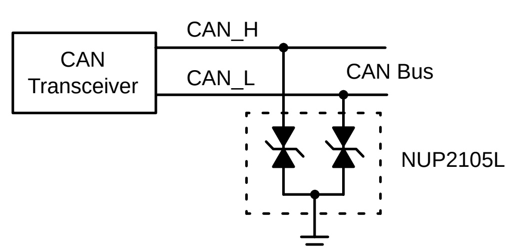



**Figure 2. High−Speed and Fault Tolerant CAN TVS Protection Circuit**

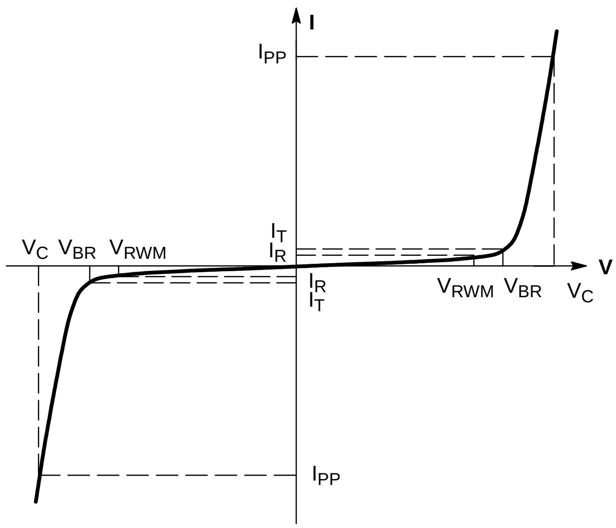


August, 2004 − Rev. 0

Publication Order Number:
AND8181/D

### TVS Diode Terminology

The first step in selecting a TVS diode device is to define the device parameters. Figure 3 provides a graphical definition of the bidirectional TVS diode parameters.




**Bidirectional**

**Figure 3. Bidirectional TVS Characteristic Curve**

The key TVS parameters are:

1. **Reverse Working Voltage ($V_{RWM}$)** is defined as the maximum DC operating voltage. At this voltage the device is in a non−conducting state and functions as essentially a high impedance capacitor. $V_{RWM}$ is also known as the stand−off voltage.
2. **Reverse Breakdown Voltage ($V_{BR}$)** is the point where the device conducts in an avalanche mode and becomes a low impedance. The breakdown voltage is typically measured at a current of 1.0 mA.
3. **Maximum Clamping Voltage ($V_C$)** is the maximum voltage drop across the diode at the maximum peak pulse current.
4. **Reverse Leakage Current ($I_R$)** is the current measured at the reverse working voltage.
5. **Test Current ($I_T$)** is the current where the breakdown voltage is measured.
6. **Peak Pulse Current ($I_{PP}$)** is the maximum surge current specified for the device.

### CAN Transceiver Specifications

There are several CAN transceiver specifications that must be evaluated in order to select an appropriate TVS diode. The critical transceiver characteristics include:

1. Maximum supply voltage
2. Common mode voltage
3. Maximum transmission speed
4. ESD
5. EMI Immunity
   a. Coupled Electrical Disturbance on the Data Lines
      i Nonrepetitive Surge
      ii Repetitive Surge / Electrical Fast Transient (EFT)

Table 1 provides a summary of the system requirements for a CAN transceiver. The ISO 11898−2 physical layer specification forms the baseline for most CAN systems. The transceiver requirements for the Honeywell® Smart Distribution Systems (SDS®) and Rockwell (Allen−Bradley) DeviceNet™ high speed CAN networks are similar to ISO 11898−2. The SDS and DeviceNet transceiver requirements are similar to ISO 11898−2; however, they include minor modifications required in an industrial environment.

**Table 1. Transceiver Requirements for High−Speed CAN Networks**

| **Parameter** | ISO 11898−2 | SDS Physical Layer Specification 2.0 | DeviceNet |
|---|---|---|---|
| **Min / Max Bus Voltage (12 V System)** | −3.0 V / 16 V | 11 V / 25 V | Same as ISO 11898−2 |
| **Common Mode Bus Voltage** | CAN_L: −2.0 V (min) 2.5 V (nom) CAN_H: 2.5 V (nom) 7.0 V (max) | Same as ISO 11898−2 | Same as ISO 11898−2 |
| **Transmission Speed** | 1.0 Mb/s @ 40 m 125 kb/s @ 500 m | Same as ISO 11898−2 | 500 kb/s @ 100 m 125 kb/s @ 500 m |
| **ESD** | Not specified, recommended ≥ ±8.0 kV (contact) | Not specified, recommended ≥ ±8.0 kV (contact) | Not specified, recommended ≥ ±8.0 kV (contact) |
| **EMI Immunity** | ISO 7637−3, pulses ‘a’ and ‘b’ | IEC 61000−4−4 EFT | Same as ISO 11898−2 |
| **Popular Applications** | Automotive, Truck, Medical and Marine Systems | Industrial Control Systems | Industrial Control Systems |

### Maximum Supply Voltage

The TVS diode $V_{RWM}$ and $V_{BR}$ should be greater than the maximum system supply voltage because the transceiver must be immune to an indefinite short between the battery power lines and CAN signal lines. In addition, some applications often have unique short duration maximum supply voltage specifications. For example, some 12 V automotive systems have the provision of allowing a jump start from a 24 V battery. The minimum $V_{RWM}$ and $V_{BR}$ of the NUP2105L are specified at 24 V and 26.2 V, respectively.

The NUP2105L has a nominal $V_{BR}$ of 27 V which is measured with a 1.0 mA, 1.0 ms pulse test current. The TVS's Zener technology produces a breakdown voltage characterized with a sharp knee and very low leakage current. The sharp knee of the NUP2105L provides predictable device performance over potential system deviations. Figure 4 shows the $V_{BR}$ versus $I_T$ characteristics of the NUP2105L over a temperature range of −55°C to +150°C.

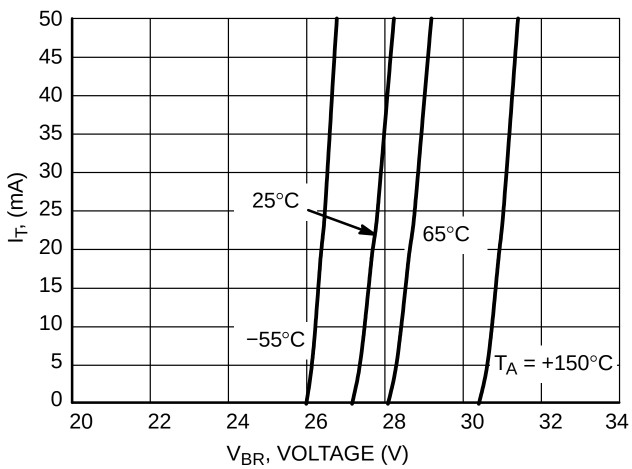



**Figure 4. $V_{BR}$ versus $I_T$ Characteristics of the NUP2105L**

The NUP2105L has very low leakage ($I_R$) characteristics and negligible power consumption in the non−conducting mode. The typical leakage current of the device is approximately 1.0 nA at a 25°C and the $V_{RWM}$ limit of 24 V. In harsh applications that require operation at ambient temperatures of 125°C, the NUP2105L still maintains a sub−microamp leakage level. Figure 5 shows the typical leakage current characteristics of the NUP2105L over a temperature range of −55°C to 150°C.

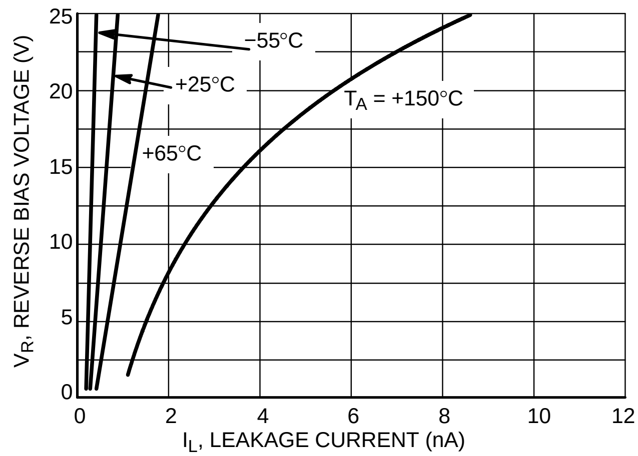



**Figure 5. $I_R$ versus Temperature Characteristics of the NUP2105L**

### Common Mode Voltage

The common mode voltage specification is required because there can be a significant difference in the voltage potential between the ground reference of the transmitting and receiving CAN nodes. The CAN transceivers must be able to function with a signal line voltage that can be offset by as much as 2.0 V above or below the nominal voltage level of the CAN_H and CAN_L signal lines. A solution to the common mode problem is to use bidirectional TVS devices that will not clamp if the voltage at the signal lines is offset.

### Maximum Transmission Speed

The CAN data transmission rate determines the maximum capacitance of the TVS device. A large capacitance on the data lines causes distortion in the signal waveforms. The distortion on the data lines is minimized by selecting a low capacitance TVS device. It is recommended that the maximum capacitance of the protective network measured from each signal line to ground should be less than 35 pF for 1.0 Mbits/s and 100 pF for 125 kbits/s.

The capacitance versus bias voltage relationship of the NUP2105L is shown in Figure 6. The capacitance between the signal lines and ground was measured by varying the DC bias, at a frequency of 1.0 MHz and peak−to−peak amplitude of 60 mV. A diode's data sheet specifies the maximum capacitance at a bias voltage of 0 V; however, the average voltage of the data lines will provide a more accurate estimation of the capacitive loading. The average DC voltage of the high−speed and fault tolerant CAN transceivers can be estimated to be equal to the recessive voltage of 2.5 V. The typical capacitance of the NUP2505L is approximately 19 pF at 2.5 V.

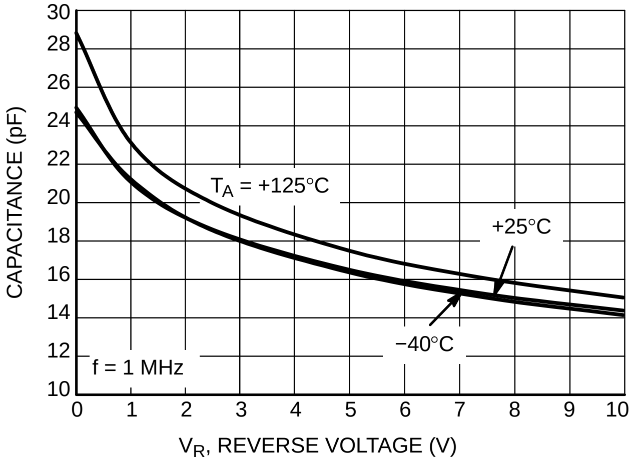



**Figure 6. Capacitance versus $V_R$ Characteristic of the NUP2105L**

## CAN EMI Immunity Tests

### Background

Electromagnetic Compatibility (EMC) has become a major design concern for network products. Designers are being challenged to include EMC protection, without incurring a size and cost penalty. CAN modules must be must be compliant with strigent EMI standards and operate without either becoming effected by or adversely effecting the operation of neighboring units. CAN networks must have good noise immunity because the data lines are a major source and entry point for both conducted and radiated EMI and ESD.

### Pass/Fail Test Criteria

The pass/fail criteria of an EMI test can be is defined by both the operational status of the system and if damage occurs to the module. A communication fault is allowed during the EMI test surge; however, normal data transmission must resume after the completion of the transient event. One of the main advantages of CAN is that the network has the ability to detect a communication error and automatically initiate another transmission of the data.

CAN transceivers define the pass/fail transition as the maximum surge voltage that the IC can be guaranteed to withstand without occurring permanent damage. The pass/fail criterion of a TVS Zener diode is more stringent than the damage limit of a CAN transceiver. A TVS's pass/fail test level is defined by the voltage at which the electrical characteristics of the device begin to shift. This limit is significantly below the value at which permanent damage will occur to the device.

A Zener diode absorbs a transient surge voltage by functioning as a dynamic impedance that shunts the overvoltage to ground. The Zener diode's impedance is varied to maintain a constant clamping voltage; however, at a high current value the clamping voltage will begin to drop. At this point, the other diode characteristics such as leakage current will also significantly increase. If the surge voltage is removed, the Zener diode will recover and resume functioning without any permanent damage or change in its original electrical characteristics. However, if the current is increased over this level, the impedance of the Zener will decrease to a point which is effectively a short, resulting in a large current that will permanently damage the device if the transient is not removed.

### ESD Rating

An external TVS diode can be used to increase the immunity level of the CAN module from ESD failures. The ISO 11898−2, SDS and DeviceNet physical layer specifications do not list an ESD requirement; however, it is generally recommended that a network system should have a contact rating of at least ±8.0 kV and a non−contact or air rating of ±15 kV. The ESD immunity level can be specified by either the Human Body Model (HBM) or the International Electromechanical Commission (IEC) 61000−4−2 tests. The HBM test is typically the specification listed on IC data sheets, while the IEC specification is often used for system level tests. Both ESD specifications are designed to simulate the direct contact of a person to an object such as the I/O pin of a connector; however, the IEC test is more severe than the HBM. The IEC test is defined by the discharge of a 150 pF capacitor through a 330 Ω resistor, while the HBM uses a 100 pF capacitor and 1500 Ω resistor. Figures 7 provides the waveform of the IEC ESD test. A summary of the NUP2105L's ESD immunity is provided in Table 3.

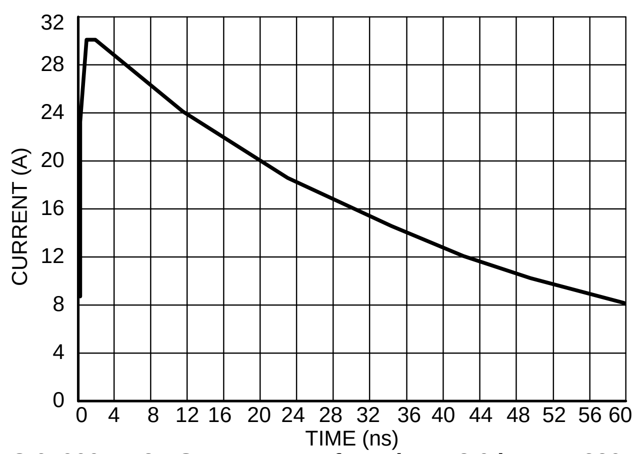



**Figure 7. IEC 61000−4−2 ESD Test Waveform ($V_S$ = 8.0 kV, R = 330 Ω, C = 150 pF)**

**Table 2. ISO 7637 and IEC61000−4−X Test Specifications**

| Test | Waveform | Test Specifications | NUP25050L Test | Simulated Noise Source |
|---|---|---|---|---|
| ISO 7637−1<br>12 V Power Supply Lines | Pulse 1<br>Figure 8 | $V_s$ = 0 to −100 V<br>$I_{max}$ = 10 A<br>$t_{duration}$ = 5000 pulses | $I_{max}$ = 1.75 A<br>$V_{clamp\_max}$ = 31 V<br>$t_{duration}$ = 5000 pulses<br>$R_i$ = 10 Ω, $t_r$ = 1.0 μs,<br>$t_d$ = 2000 μs, $t_1$ = 2.5 s,<br>$t_2$ = 200 ms, $t_3$ = 100 μs | DUT in parallel with inductive load that is disconnected from power supply. |
| | Pulse 2<br>Figure 9 | $V_s$ = 0 to +100 V<br>$I_{max}$ = 10 A<br>$t_{duration}$ = 5000 pulses | $I_{max}$ = 9.5 A<br>$V_{clamp\_max}$ = 33 V<br>$t_{duration}$ = 5000 pulses<br>Ri = 10 Ω, $t_r$ = 1.0 μs,<br>$t_d$ = 50 μs, $t_1$ = 2.5 s,<br>$t_2$ = 200 ms | DUT in series with inductor that is disconnected. |
| ISO 7637−3<br>Data Line EFT | Pulse ‘a’<br>Figure 12 | $V_s$ = −60 V<br>$I_{max}$ = 1.2 A<br>$t_{duration}$ = 10 minutes | $I_{max}$ = 50 A<br>$V_{clamp\_max}$ = 40 V<br>$t_{duration}$ = 60 minutes<br>$R_i$ = 50 Ω, $t_r$ = 5.0 ns,<br>$t_d$ = 0.1 μs, $t_1$ = 100 μs,<br>$t_2$ = 10 ms, $t_3$ = 90 ms | Switching noise of inductive loads. |
| | Pulse ‘b’<br>Figure 13 | $V_s$ = +40 V<br>$I_{max}$ = 0.8 A<br>$t_{duration}$ = 10 minutes | | |
| IEC 61000−4−4<br>Data Line EFT | Figure 14 | $V_{open\ circuit}$ = 2.0 kV<br>$I_{short\ circuit}$ = 40 A<br>(Level 4 = Severe Industrial Environment)<br>$R_i$ = 50 Ω, $t_r$ < 1.0 μs,<br>$t_d$ = 50 ns, $t_{burst}$ = 15 ms,<br>$f_{burst}$ = 2.0 to 5.0 kHz,<br>$t_{repeat}$ = 300 ms<br>$t_{duration}$ = 1 minute | (Note 2) | Switching noise of inductive loads. |
| IEC 61000−4−5 | Figure 10 | $V_{open\ circuit}$ = 1.2 x 50 μs,<br>$I_{short\ circuit}$ = 8 x 20 μs<br>$R_i$ = 50 Ω | See Figure 11 | Lightning, nonrepetitive power line and load switching |

1. DUT = device under test.
2. The EFT immunity level was measured with test limits beyond the IEC 61000−4−4 test, but with the more severe test conditions of ISO 7637−3.

**Table 3. NUP2505L ESD Test Results**

| ESD Specification | Test | Test Level | Pass / Fail |
|---|---|---|---|
| Human Body Model | Contact | 16 kV | Pass |
| IEC 61000−4−2 | Contact | 30 kV (Note 3) | Pass |
| | Non−contact (Air Discharge) | 30 kV (Note 3) | Pass |

3. Test equipment maximum test voltage is 30 kV.

### EMI Specifications

The EMI protection level provided by the TVS device can be measured using the International Organization for Standardization (ISO) 7637−1 and −3 specifications that are representative of various noise sources. The ISO 7637−1 specification is used to define the susceptibility to coupled transient noise on a 12 V power supply, while ISO 7637−3 defines the noise immunity tests for data lines. The ISO 7637 tests also verify the robustness and reliability of a design by applying the surge voltage for extended durations.

The IEC 61000−4−X specifications can also be used to quantify the EMI immunity level of a CAN system. The IEC 61000−4 and ISO 7637 tests are similar; however, the IEC standard was created as a generic test for any electronic system, while the ISO 7637 standard was designed for vehicular applications. The IEC61000−4−4 Electrical Fast Transient (EFT) specification is similar to the ISO 7637−1 pulse 1 and 2 tests and is a requirement of SDS CAN systems. The IEC 61000−4−5 test is used to define the power absorption capacity of a TVS device and long duration voltage transients such as lightning. Table 2 provides a summary of the ISO 7637 and IEC 61000−4−X test specifications.

### Coupled Electrical Disturbances

A CAN transceiver must be able to survive the high energy transients that are produced by nonrepetitive and repetitive transient surge voltages. The definition of nonrepetitive and repetitive surges is determined by the duration of the transient and the time between surges. A nonrepetitive surge is tested by a transient voltage with a pulse width of typically 50 μs to 2000 μs and a repeat rate of usually one pulse per second. Repetitive surges are represented by a burst of 15 ms to 300 ms of 50 ns transient pulses.

The nonrepetitive and repetitive transient voltage signals are typically generated on the supply voltage line and are coupled into the data line signals because the power and CAN data lines are typically located inside the same wire bundle. Example of nonrepetitive noise sources include lightning, load dump, power switching, load changes and short circuit faults. Repetitive noise sources include inductive load switching, relay contact chatter and ignition system noise.

### Nonrepetitive Surge Immunity

The nonrepetitive surge tests are used to test a module’s transient immunity from either a switching or lightning induced surge voltage. The switching transients can be caused by power switching, sudden load changes or a short circuit fault in the power distribution system. For example, a DC motor can produce a surge voltage because it continues to rotate for a short duration because of inertia after the ignition is switched off. The ISO 7637−1 specification test Pulses 1 and 2, shown in Figures 8 and 9, are used to simulate a nonrepetitive surge voltage.

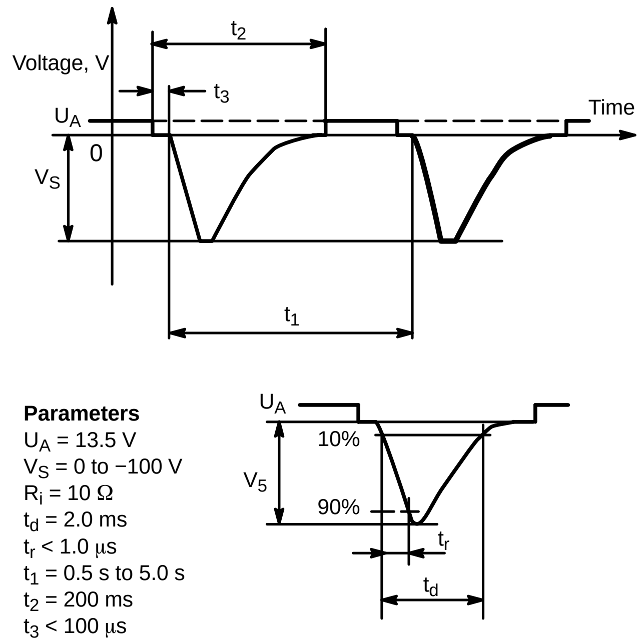



**Figure 8. ISO 7637−1, Test Pulse 1**

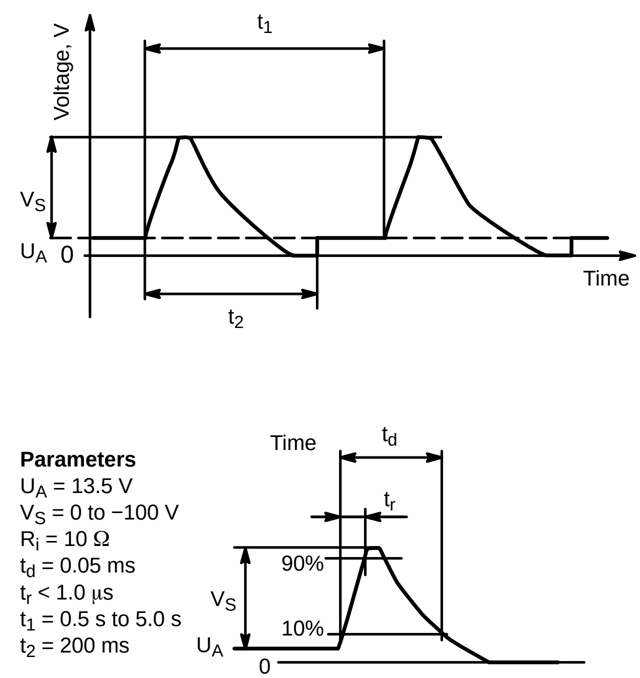



**Figure 9. ISO 7637−1, Test Pulse 2**

Lightning produces a transient surge voltage that can cause significant damage to an electronic system. The transient surge voltage can be caused by either a direct strike or induced voltages and currents that result from an indirect strike. A direct lightning strike is requires a very high energy TVS device such as a gas discharge tube. The indirect strike produces an intense electric and magnetic filed that is coupled into the CAN data and power lines, producing a surge voltage. An indirect strike has a much lower energy level that can be absorbed by a TVS diode. The magnitude of an indirect strike depends on the distance from the lightning strike.

The ISO 61000−4−5 specification serves as the standard test to verify the immunity of an electronic system to a nonrepetitive surge such as lightning. This specification categorized the severity levels of the surge event by the location of the cables and electronic system. The surge voltage is defined by a double exponential pulse with a specified rise time and duration or decay time. A double exponential waveform has an exponential rise to the peak measure by the rise time from 10 to 90% and an exponential decay measured at the 50% point. The 8 x 20 μs waveform, shown in Figure 10, has a rise time of 8.0 μs and a decay time of 20 μs. Figure 11 shows that the NUP2105L provides an 8 x 20 μs immunity level of 10 A that corresponds to a partially protected environment that is representative of most CAN systems. In applications that have the CAN data lines located in cables on the outside of a building, a crowbar shunting device such as a thyristor or GDT maybe required in addition to a TVS diode to withstand an indirect lightning strike.

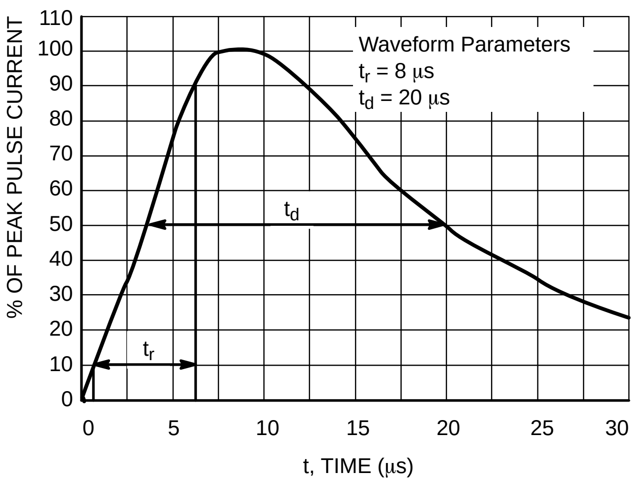



**Figure 10. IEC 61000−4−5 Surge Test**

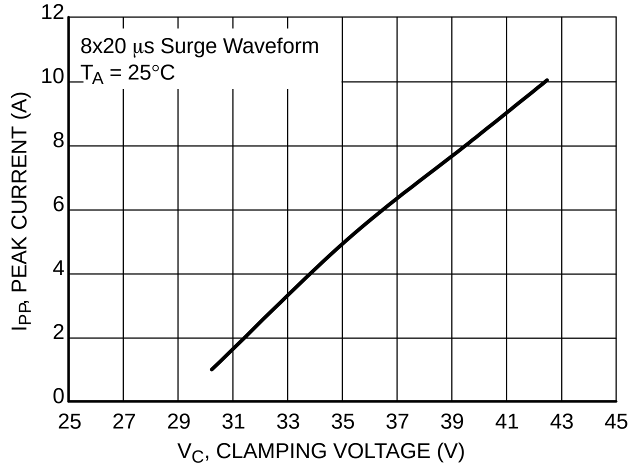
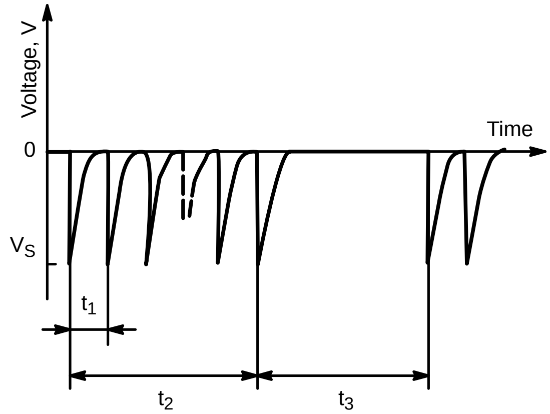



**Figure 11. NUP2105L's Response to the 8/20 μs IEC 61000−4−5 Surge Test**

**Repetitive Surge Immunity**

The repetitive surge tests are used to test a module's transient immunity from noise sources such as inductive load switching, relay contact chatter and ignition system noise. Repetitive switching transients are coupled into the data line cables because of the parasitic capacitance and inductance inherent in a wiring harness. The ISO 7637−3 test pulses 'a' and 'b', along with the IEC 61000−4−4 specification are used to define the repetitive surge immunity of the system. Repetitive surges are also identified as electrical fast transients (EFT) and are modeled by a recurring pattern of a burst of high voltage spikes. Figures 12 and 13 show the ISO 7637−3 pulse 'a' and 'b' test waveforms, while Figure 14 shows the IEC 61000−4−4 waveform.




**Parameters**
$V_S$ = −60 V
$R_i$ = 50 Ω
$t_d$ = 0.1 μs
$t_r$ = 5 ns ± 30% at $V_S$ = −50 V, 50 Ω
$t_1$ = 100 μs
$t_2$ = 10 ms
$t_3$ = 90 ms

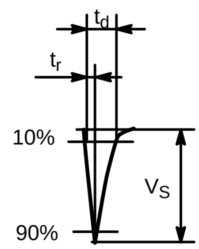
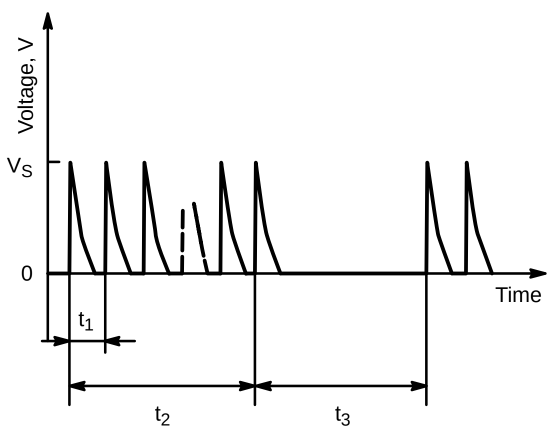



**Figure 12. ISO 7637−3 Test Pulse ‘a’**




**Parameters**
$V_S$ = +40 V (12 V System)
$R_i$ = 50 Ω
$t_d$ = 0.1 μs
$t_r$ = 5 ns ± 30% at $V_S$ = +50 V, 50 Ω
$t_1$ = 100 μs
$t_2$ = 10 ms
$t_3$ = 90 ms

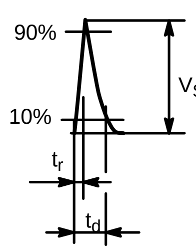



**Figure 13. ISO 7637−3 Test Pulse ‘b’**

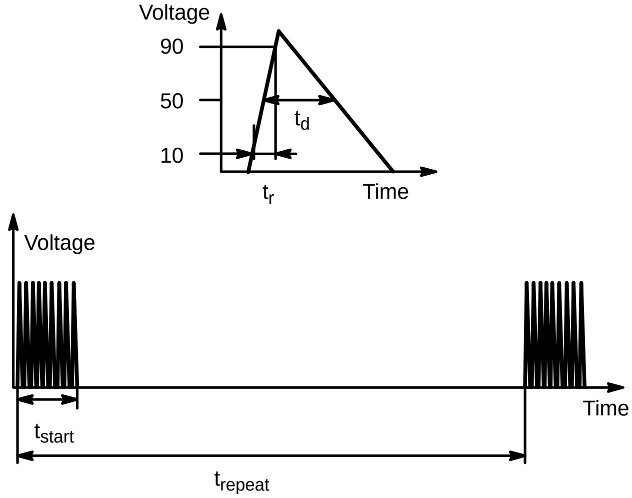



**Figure 14. IEC 61000−4−4 Electrical Fast Transient (EFT)**

The ambient test temperature for the ISO 7637 and IEC 61000−4−X bench tests is defined to be 23°C. The NUP2105L TVS array has a maximum power dissipation specified at a temperature of 25°C. The power rating of a TVS device must be derated for operation at elevated temperatures, as shown in Figure 15. The derating curve is generally valid for pulses up to 10 ms, occurring at intervals of approximately 100 ms to 1000 ms. The derating required for longer pulse duration surges can be determined experimentally.

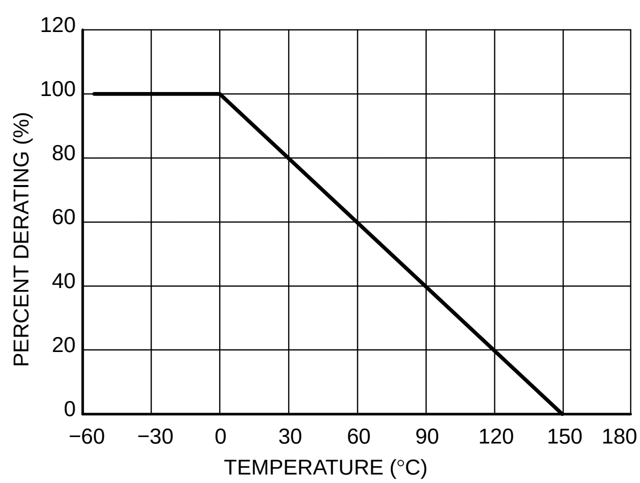



**Figure 15. Temperature Power Dissipation Derating of the NUP2505L**

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### EMI Specifications

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### CAN Physical Layer Specifications

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3. “Smart Distributed System (SDS) Physical Layer Specification − Version 2.0”. Honeywell MICRO SWITCH. 1999.

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