AND8253/D

System Level Surge Suppression Solutions for the CAN Bus

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APPLICATION NOTE

INTRODUCTION

External avalanche transient voltage suppression (TVS) diodes provide a simple low cost solution to increase the surge immunity level of CAN transceivers. Figure 1 shows the relative cost of TVS diodes compared to other CAN transceiver components. In addition, TVS devices are tested with a direct coupled configuration that matches the severe surge environment of many applications. In contrast, a CAN transceiver's internal IC protection circuit surge rating is typically measured with a capacitor that significantly reduces the surge energy.

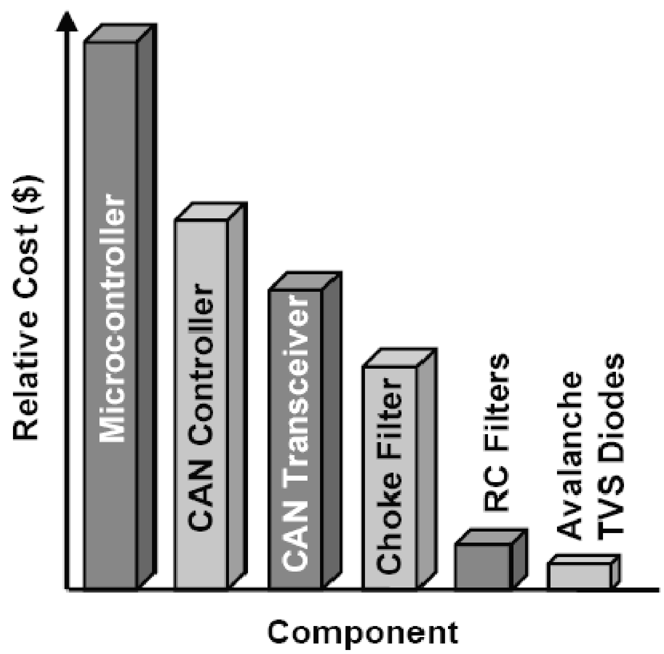

Figure 1. TVS diodes are a low cost solution to increase the surge immunity level of a CAN network.

Internal Transceiver Protection Circuits

Internal transceiver protection circuits can be created using high voltage transistors, Zener diodes, diode arrays, thyristors and overvoltage detection switches. Figure 2 provides an example of an internal Zener diode protection circuit. The surge ability of a silicon device is directly related to its size; thus, it is not practical to incorporate large protection devices inside an IC. The relatively small die size of the IC's internal TVS devices results in a protection circuit with a modest surge rating that is designed to handle only a few surge events. An overvoltage detection circuit provides a clever solution for relatively low frequency surges, but is not fast enough to protect against high frequency surges such as ESD.

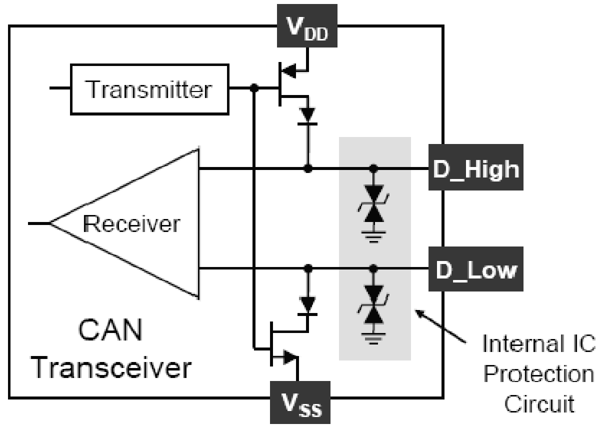

Figure 2. Zener diodes are a popular choice for internal TVS protection circuits.

Figures 3, 4 and 5 provide insight into the internal protection circuit of the Philip Semiconductor TJA1040 high speed CAN transceiver. The current versus voltage plots show that the TJA1040's protection circuit is equivalent to two bidirectional Zener diodes that are located on the CAN_L and CAN_H data lines. The symmetrical appearance of the graphs between the data lines and both ground and the power supply (V_{DD}) indicate that the protection circuits are based on the breakdown voltage of bipolar transistors.

Most CAN transceivers are manufactured with a Bi-CMOS process and the data line circuits use high voltage bipolar transistors. The majority of the IC is built with low voltage devices to take advantage of the low power consumption and size attributes of CMOS. The TJA1040's data sheet specifies a maximum DC voltage of -27/+40 V, which is consistent with bipolar devices and the test data shown in Figures 3 and 4.

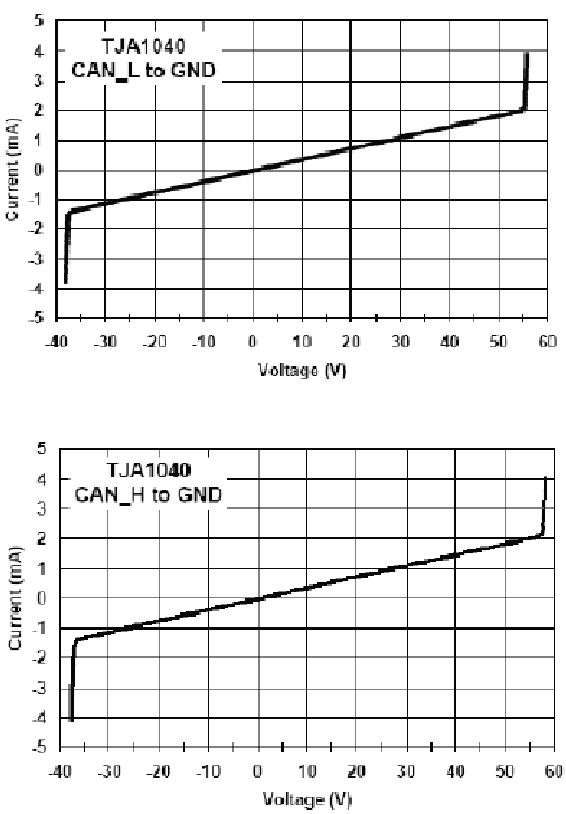

Figure 3. The current versus voltage graphs between the CAN data lines and ground show that the protection circuits are equivalent to two bidirectional Zeners with a breakdown voltage of approximately -40 V/+50 V.

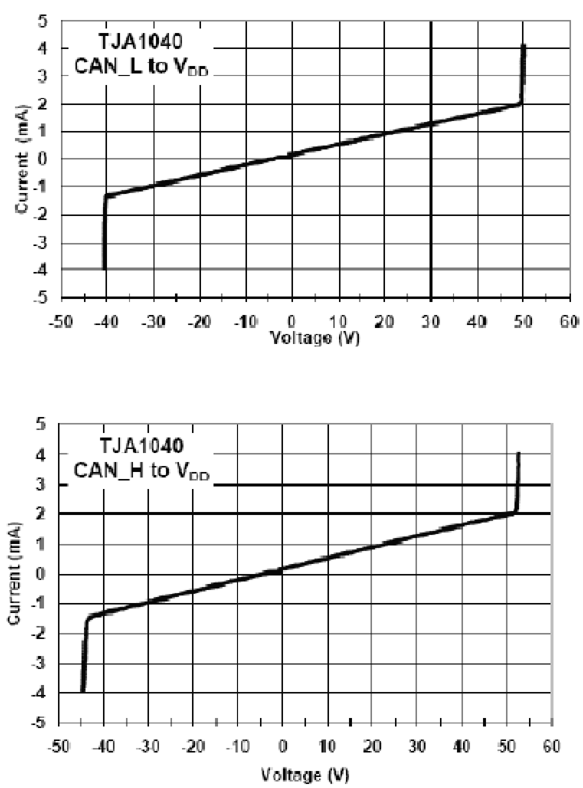

Figure 4. The current versus voltage graphs between the CAN data lines and V_{DD} show that the transistors connected to the data lines have a breakdown voltage of approximately -40/+50 V.

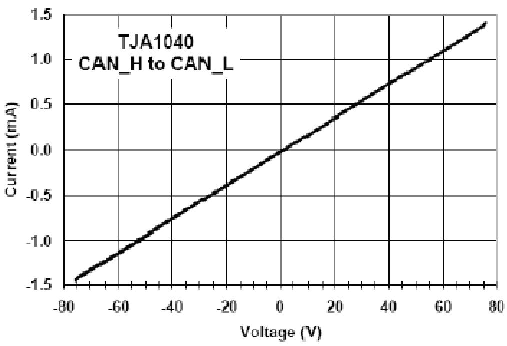

Figure 5. The impedance between the CAN_L and CAN_H data lines is 55 KΩ.

Surge Protection Tests

Test Setups

The test configurations used to determine the surge ratings for a system, transceiver and TVS device are very different, as shown in Figure 6. System level tests typically use a coupling clamp to induce a surge voltage on the data lines. The cable is placed between two parallel metal plates and the test voltage is applied to the plates. A capacitor of approximately 3.0 nF (pulse 3a & 3b) and 0.1 μF (pulse 1 & 2a) can be used as an alternative to the coupling clamp.

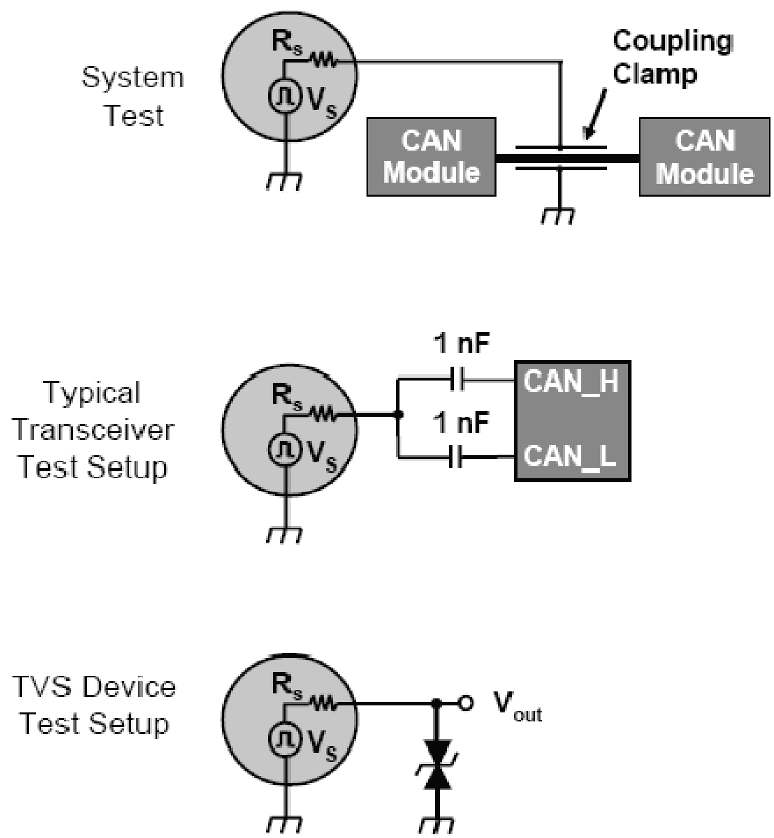

Figure 6. Surge test configurations for a system, transceiver IC and a TVS device.

CAN transceivers are typically surge tested by using a 1.0 nF capacitor to couple the pulse to the IC pins. In contrast, TVS devices are connected directly to the signal generator. The transceiver and TVS device test setups remove the cable as a test variable; however, the test results must be analyzed with respect to the impedance of the coupling device. Also, system level and TVS devices are typically tested with 5000 surge pulses while the transceiver ratings are often determined using just three pulses.

Frequency Dependence

The frequency content of the surge pulse and the frequency dependent impedance of the IC's coupling capacitor are important parameters. The impedance of a 1.0 nF capacitor has a minimal effect on the high frequency pulse '3a' and '3b' tests; however, the impedance must be considered for the relatively low frequency pulse 1 and 2a tests. The capacitor's impedance must be added to the voltage generator's source impedance (R_S) to determine the maximum current of the surge. Figure 7 provides a Bode plot that can be used to estimate the frequency content of a surge pulse, while Figure 8 shows the impedance plot of a 1.0 nF capacitor. Table 1 provides a summary of the frequency characteristics of several surge pulses.

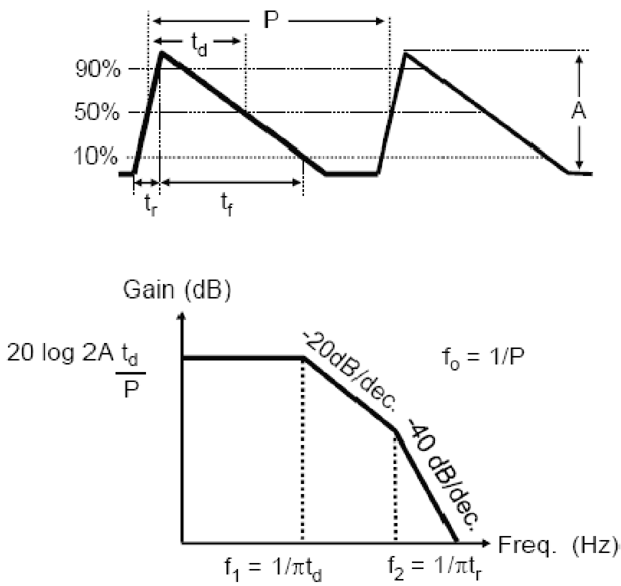

Figure 7. The frequency spectrum of the ISO 7637 surge pulses can be estimated from the rise time (t_r) and pulse duration (t_d).

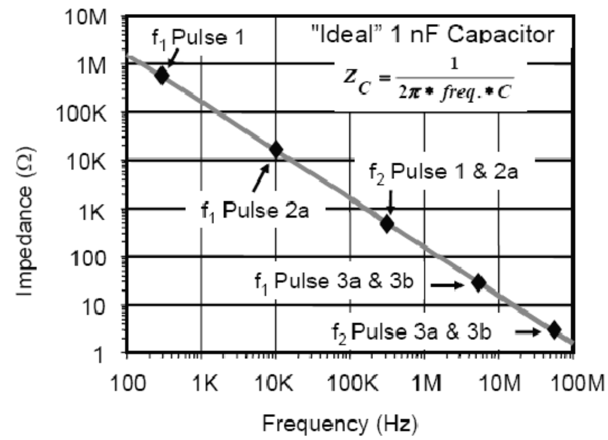

Figure 8. A 1.0 nF capacitor has significant impedance at the frequencies contained in the ISO 7637-2 pulse 1 and 2a surge tests.

Table 1. The rise time and pulse width determine the frequency content of the surge pulse.

Test Pulse	Rise Time (t_r)	Pulse Duration (t_d @ 50%)	Freq. (f_1)	Freq. (f_2)
ISO 7637-2, Pulse 1	1.0 μs	1110 μs	287 Hz	318 kHz
ISO 7637-2, Pulse 2a	1.0 μs	28 μs	11.4 kHz	318 kHz
ISO 7637-2, Pulse 3a & 3b (Eqv. ISO 7637-3, Pulse ‘a’ & ‘b’)	5.0 ns	55 ns	5.8 MHz	64 MHz
HBM ESD	20 ns	200 ns	1.6 MHz	16 MHz
IEC 61000-4-2	0.7 ns	60 ns	5.3 MHz	455 MHz

Surge Test Results

Table 2 provides the surge ratings for an avalanche TVS diode and a typical CAN transceiver. The data shows that a 1.0 nF capacitor increases the apparent surge rating of the device under test. The energy transferred by the coupling capacitor is reduced because the capacitor shortens the duration of the pulse. Figures 9 and 10 provide a comparison of the NUP2105L’s clamping response for a direct and capacitive coupled test setup. A larger capacitance, such as the 0.1 μF value typically used for the ISO 7637-2 pulse 1 and 2a system tests, is required to reduce the coupling impedance.

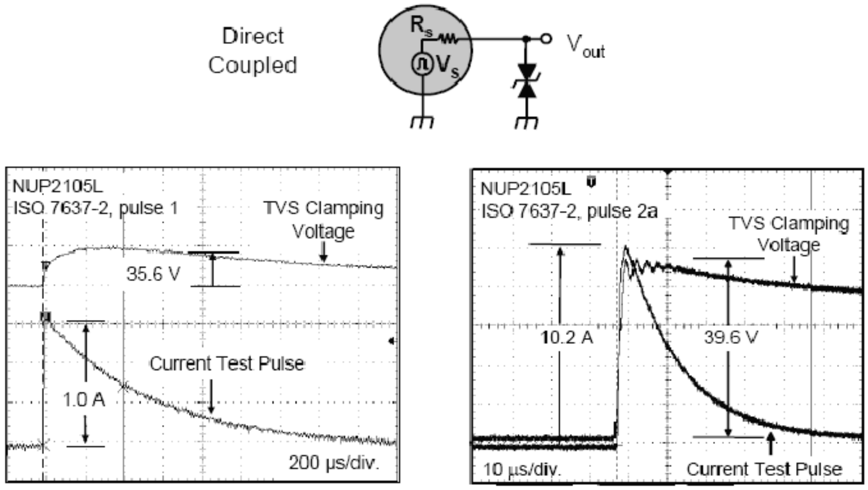

Figure 9. The NUP2105L clamps the pulse 1 and 2a surge pulses to 35.6 V and 39.6 V, respectively.

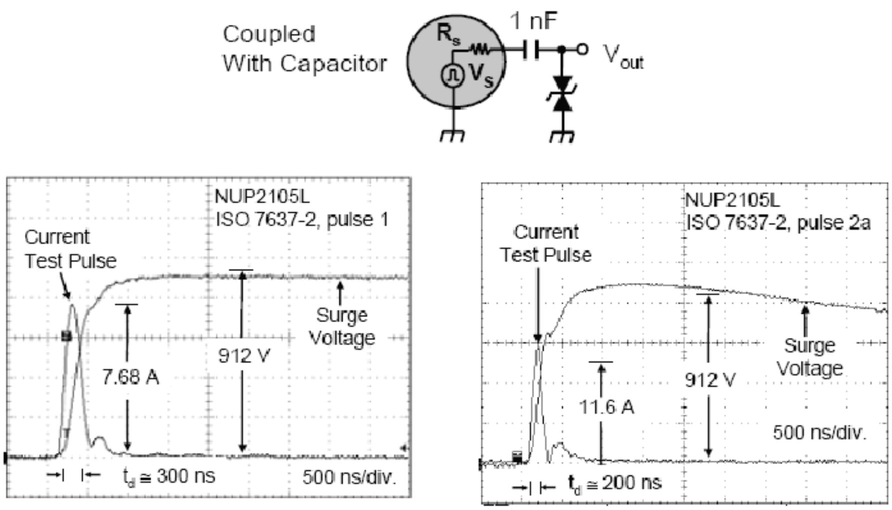

Figure 10. A 1.0 nF coupling capacitor reduces the energy of the pulse 1 and 2a tests by shortening the duration of the surge pulses to 300 and 180 ns, respectively.

In addition to providing surge protection, TVS diodes also prevent ESD failures. The ESD rating of most transceivers is adequate to avert damage that may occur during the board assembly procedure, but often is to low to prevent field failures. The NUP2105L provides an ESD immunity level of 30 kV.

Table 2. ISO 7637 and ESD surge ratings for the NUP2105L and CAN transceivers.

Test Pulse		Maximum Specification	NUP2105L Direct Coupled	NUP2105L 1.0 nF Coupling Capacitor (Note 1)	CAN Transceiver with a 1.0 nF Coupling Capacitor
ISO 7637-2, Pulse 1		V = −100 V I = 10 A	−55 V 1.75 A	> 1000 V	100 to 200 V
ISO 7637-2, Pulse 2a		V = +50 V I = 25 A	142 V 10.2 A	> 1000 V	100 to 200 V
ISO 7637-2 (Eqv. to ISO 7637-3, Pulse a & b)	Pulse 3a	V = −150 V I = 3.0 A	2540 V 50 A	> 1000 V	100 to 200 V
	Pulse 3b	V = +100 V I = 2.0 A	2540 V 50 A	> 1000 V	100 to 200 V
Human Body Model (HBM) ESD Class 3B		8.0 kV	> 16 kV (Note 2)	N/A	2.0 to 15 kV
IEC 61000-4-2 ESD Class 4 Contact Rating		8.0 kV	> 30 kV (Note 2)	N/A	N/A

1. The NUP2105 was tested to the voltage limit of the capacitor which has a rating of 1000 WVDC.
2. The maximum input of the test equipment is 16 kV for the HBM and 30 kV for the IEC ESD tests.

CAN Transceiver Protection Solutions

Surge Protection Circuit

Figure 11 provides an example of a protection circuit using the NUP2105L TVS diode array and a common mode choke. The TVS diodes provide the clamping function, while the common mode choke serves as a filter. A choke provides high impedance for noise signals that are common to both of the data lines and low impedance for differential signals. The effectiveness of the circuit is improved by connecting the TVS devices to chassis ground to prevent the surge signal from being coupled into signal ground.

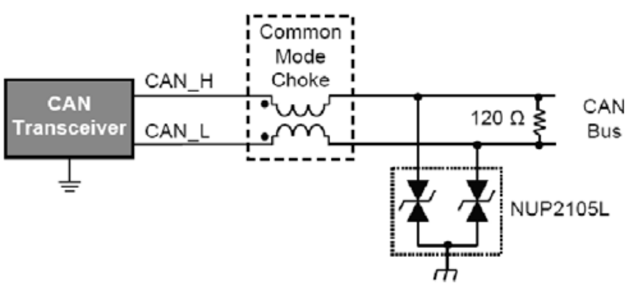

Figure 11. TVS diodes and a common mode choke filter create an effective CAN transceiver surge protection circuit.

Figure 12 provides a circuit that allows the data lines to survive an indefinite short to the power lines. The maximum power supply requirement of ISO 11898-2 is driven by systems that allow their 12 V battery to be jump started by a 24 V power source. The typical breakdown voltage of the NUP2105 is equal to 27 V, which may be too low to ensure that the TVS diodes do not turn-on during the jump start test. Resistor R_T is used to limit the current during the jump start test, which typically is a five minute test. Capacitor C_T is used to provide a low impedance path to connect the NUP2105 to ground during a transient surge event.

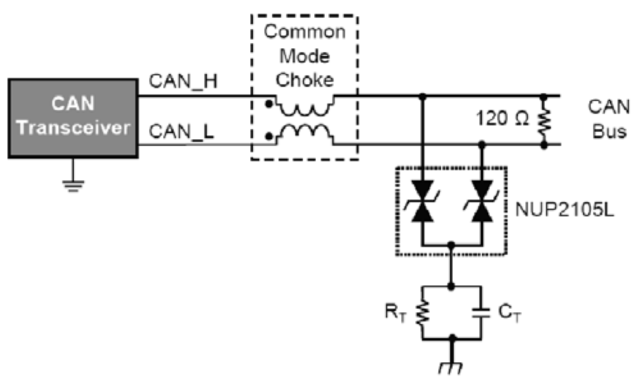

Figure 12. Adding a RC network on the ground connection of the TVS diode array increases the surge immunity by limiting the current through the NUP2105L diodes.

Design Guidelines

The first step in designing a surge protection circuit is to select a TVS device with a working voltage that is greater than the supply voltage and a clamping voltage less than the transceiver's maximum surge voltage rating. Next, bidirectional TVS devices are required to meet the ISO 11898-2 ±2.0 V common mode offset specification. Finally, the choke filter and the TVS devices should have a capacitance of 30 pF or less to minimize the signal distortion for a 1.0 MHz transmission.

Figure 13 shows the impedance versus frequency plot of the NUP2105L. The NUP2105L has a resonant frequency (f_R) of 616 MHz, which is produced by the inductance of the IC package. The TVS diode's resonant frequency can be a design issue for high frequency EMI tests such as bulk current injection (BCI). Adding 5.0 pF RF ceramic capacitors in parallel with the TVS diodes, as shown in Figure 14, provides a simple solution to attenuate high frequency noise signals.

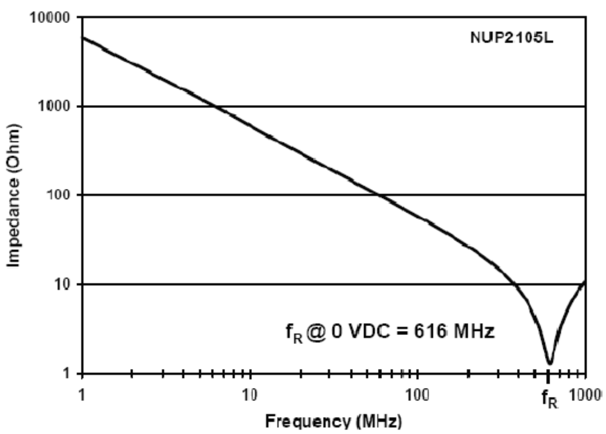

Figure 13. The NUP2105L functions as a capacitor at frequencies below the resonant frequency (f_R); however, the inductance term must be included at frequencies greater than f_R.

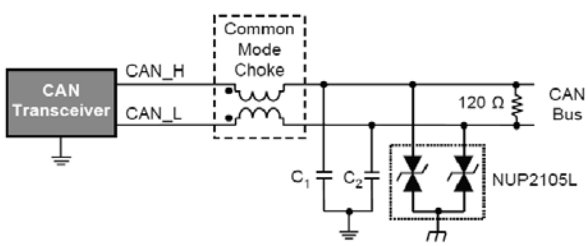

Figure 14. Capacitors C_1 and C_2 can be used to filter high frequency noise signals.

The PCB layout is a key factor in the effectiveness of the protection circuit. The TVS devices should be located close to the I/O connector so that the surge pulse entering the PCB is clamped before the voltage can be coupled into adjacent traces. Also, the length of the traces to the TVS device should be short to minimize the connection impedance. This helps to ensure that the majority of the surge energy will be dissipated by the TVS device instead of the IC's internal protection circuit. Also, using a SMT TVS device and short PCB trace reduces the magnitude of the voltage spike that is produced by parasitic inductances ($V = L\,\Delta I/\Delta t$) during the clamping process.

Conclusion

Many CAN transceivers have transient voltage ratings that exceed the ISO 7637 specification; however, an external protection circuit still should be used. The surge capability of a transceiver is determined using a test setup that reduces the surge current and does not accurately match the conditions of a system test. TVS devices provide a simple solution and achieve a high surge immunity level without significantly adding to the cost and complexity of the circuit.

References

1. "ISO 11898-2, Road Vehicles – Controller Area Network (CAN), Part 2: High-Speed Medium Access Unit", International Standard Organization (ISO), 2003.
2. "ISO 7637-2, Electrical Disturbance from Conduction and Coupling - Electrical Transient Conduction along Supply Lines Only", ISO, 2004.
3. "ISO 7637-3, Electrical Disturbance by Conduction and Coupling – Electrical Transient Transmission by Capacitive and Inductive Coupling via Lines Other Than Supply Lines", ISO, 1995.
4. Lepkowski, J. and W., "Surge Suppression Solutions for the CAN Bus", CiA CAN Newsletter, November 2005.

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