AND8169/D

EMI/ESD Protection Solutions for the CAN Bus

ON Semiconductor®

APPLICATION NOTE

INTRODUCTION

The Controller Area Network (CAN) is a serial communication protocol designed for providing reliable high−speed data transmission in harsh environments. CAN system designers are being challenged to meet stringent Electromagnetic Interference (EMI) and Electrostatic Discharge (ESD) standards and increase reliability, while reducing the size and cost of their products. This document provides guidelines to select a CAN bus protection circuit that can prevent conducted and radiated EMI and ESD noise problems. The attributes of several practical CAN bus protection circuits will be analyzed using discrete filters, common mode chokes and Transient Voltage Suppression (TVS) devices.

Bus protection circuits are used to supplement the noise immunity level of CAN transceivers. Many of the second generation CAN transceivers meet the minimum transient overvoltage test levels; however, higher immunity levels can be easily achieved by adding external EMI/ESD protection circuits. The CAN bus protection circuits improve the reliability of the CAN module, without significantly adding to the cost and complexity of the transceiver circuit.

CAN OVERVIEW

Centralized vs. Distributed Control

Control systems can be implemented using either a centralized or a distributed architecture, as shown in Figure 1. A centralized control system typically consists of a single, relatively complex control unit that is used to perform multiple tasks and monitor several sensors. In contrast, a distributed control system consists of many controllers that perform a specialized task. The sensors, actuators and motors in a centralized system require point to point wiring in order to exchange information with the control unit, while a distributed system requires only a few wires to connect all of the control units. Also, each control unit in a distributed system, such as the CAN bus can be implemented with a low cost microprocessor.
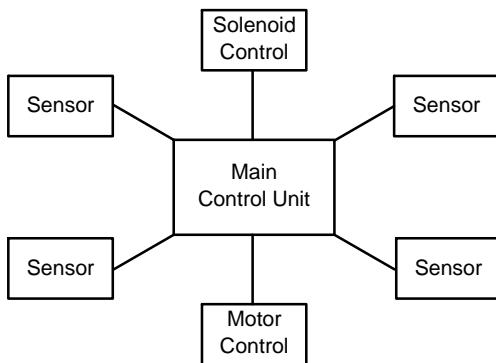
Centralized Control System
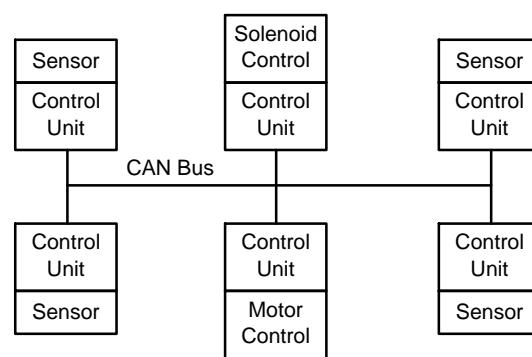
Distributed Control System

Figure 1. Centralized vs. Distributed Control

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Applications

The CAN network is a serial communication protocol initially developed to connect sensors and electronic modules in automobiles and trucks. Since its inception in the mid−1980's, the CAN bus has also gained wide popularity in industrial control and building automation applications.

The CAN network is also becoming popular in other applications that need a communication bus with a high level of data integrity, such as train, marine and medical systems. Figures 2 and 3 provide examples of a typical CAN automotive and industrial control system, respectively.
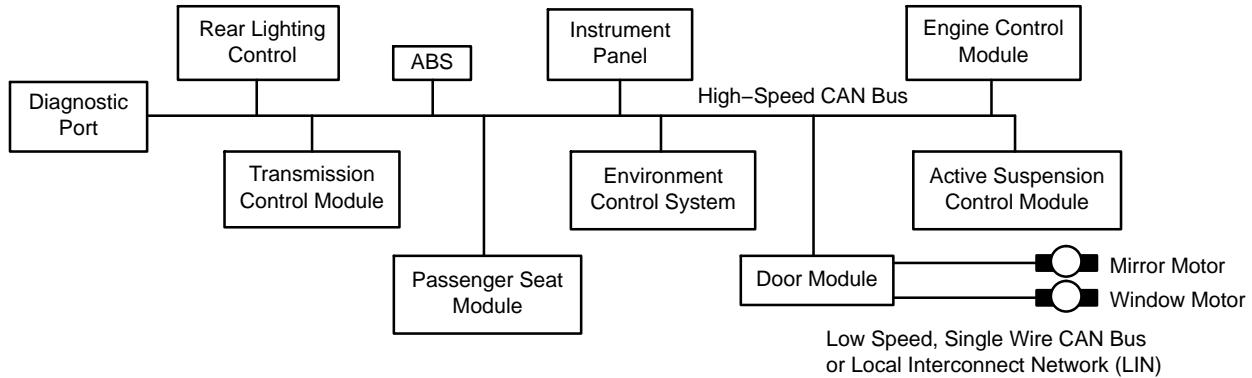
**Figure 2. Example of a Typical Automotive CAN Network**
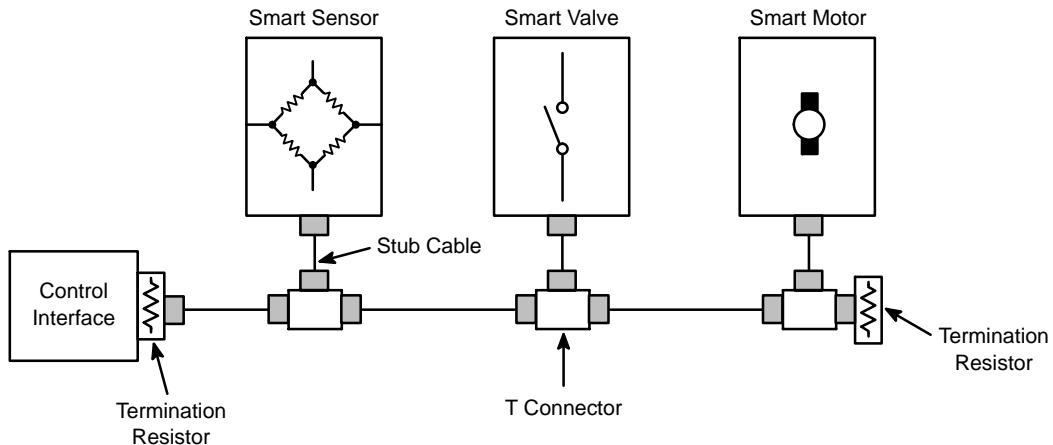
Figure 3. Example of an Industrial CAN Network

Network Model

A seven–layer Open Systems Interconnection (OSI) network layering model is used to define the CAN network. The model, shown in Figure 4, was developed by the International Standards Organization (ISO) to define a standard network that can be implemented with components from different manufacturers that are interchangeable. The CAN specification defines the bit encoding, timing and synchronization information of the transmitted signal. The electrical characteristics of the transceiver are given in the ISO and Society of Automotive Engineers (SAE) physical layer specifications summarized in Table 1. The top layers of the OSI model are not specified by CAN so that users can create unique interfaces that met their specific requirements. The Rockwell (Allen–Bradley) DeviceNet™, Honeywell Smart Distributed System™ (SDS), Kvaser CAN Kingdom, Time Triggered CAN (TTCAN) and SAE J1939 are popular networks that incorporate the CAN protocol.
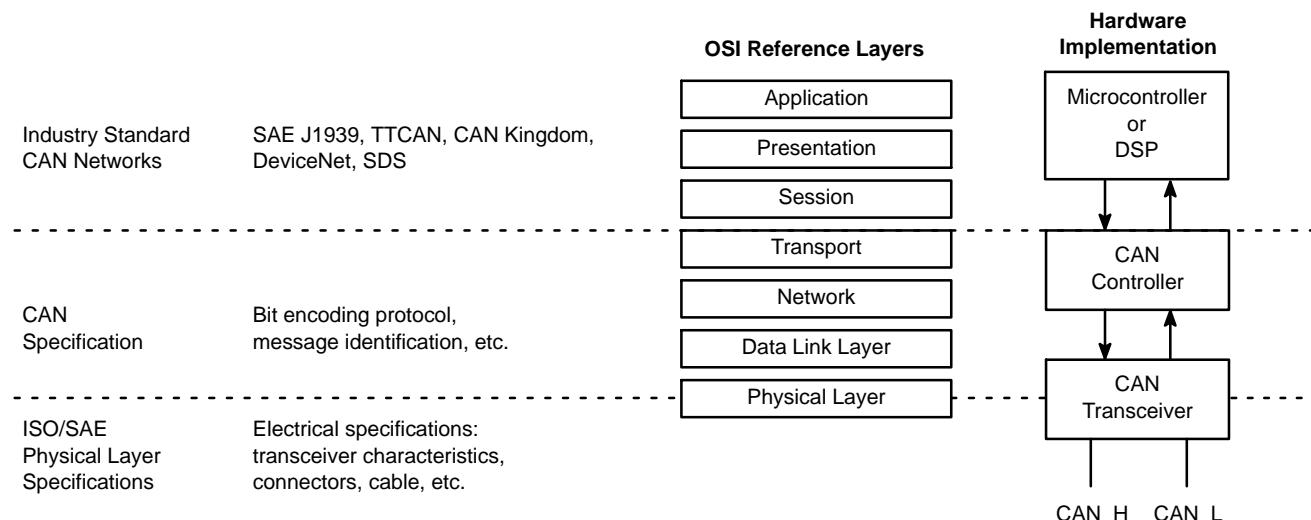
Figure 4. CAN Uses the Seven–Layer OSI Model to Implement a High–Speed Communication Network

CAN Messages

The CAN protocol uses a multi–master broadcast technique where each node can initiate the transmission of a message that is sent to all the other nodes. Each node can also request information from another node. Messages are marked by an identifier field and are sent with Cycle Redundancy Check (CRC) and Acknowledge (ACK) fields that enable the system to detect and correct transmission errors. The growing popularity of the CAN bus results from its ability to provide error–free communications in a high noise environment. Figure 5 provides the bit definitions of a CAN standard data frame.
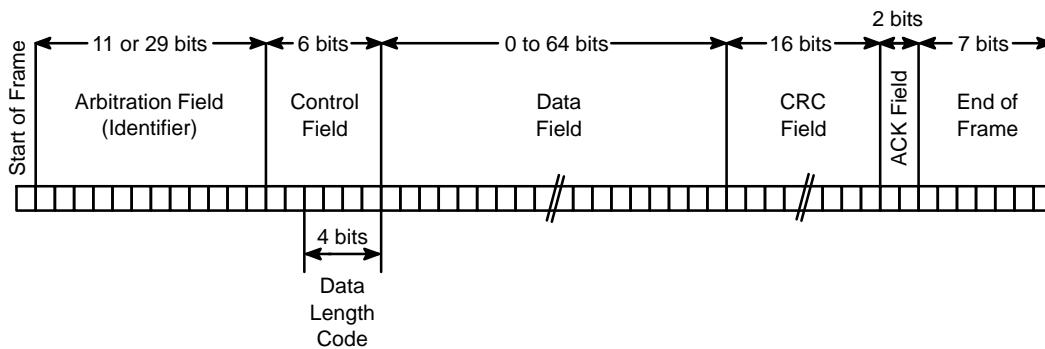
Figure 5. Example of a Standard CAN Data Frame

Hardware Implementation

A CAN node is the portion of the network that consists of a controller that implements a function such as measuring the speed and temperature of an automobile's transmission. Figure 6 shows that a node can be formed by using a microcontroller, an external CAN controller, a CAN Input/Output (I/O) Expander and a CAN transceiver. Typically the connection to the CAN bus is implemented with a CAN transceiver IC that provides the ability to receive and transmit the messages over the bus. Table 1 provides a summary of the physical layer standards defined by ISO and SAE that define the electrical characteristics of the CAN transceivers.

The system designer can create a CAN network by using either a high−speed, fault tolerant or single wire physical layer protocol. Many CAN applications are constructed using a combination of the three major physical layer standards. For example, in many automobiles, the power train will use the high−speed 1.0 Mbits/s differential bus, while less critical functions such as the rear view mirror controls use either a secondary 125 kbits/s differential bus or a single wire bus.
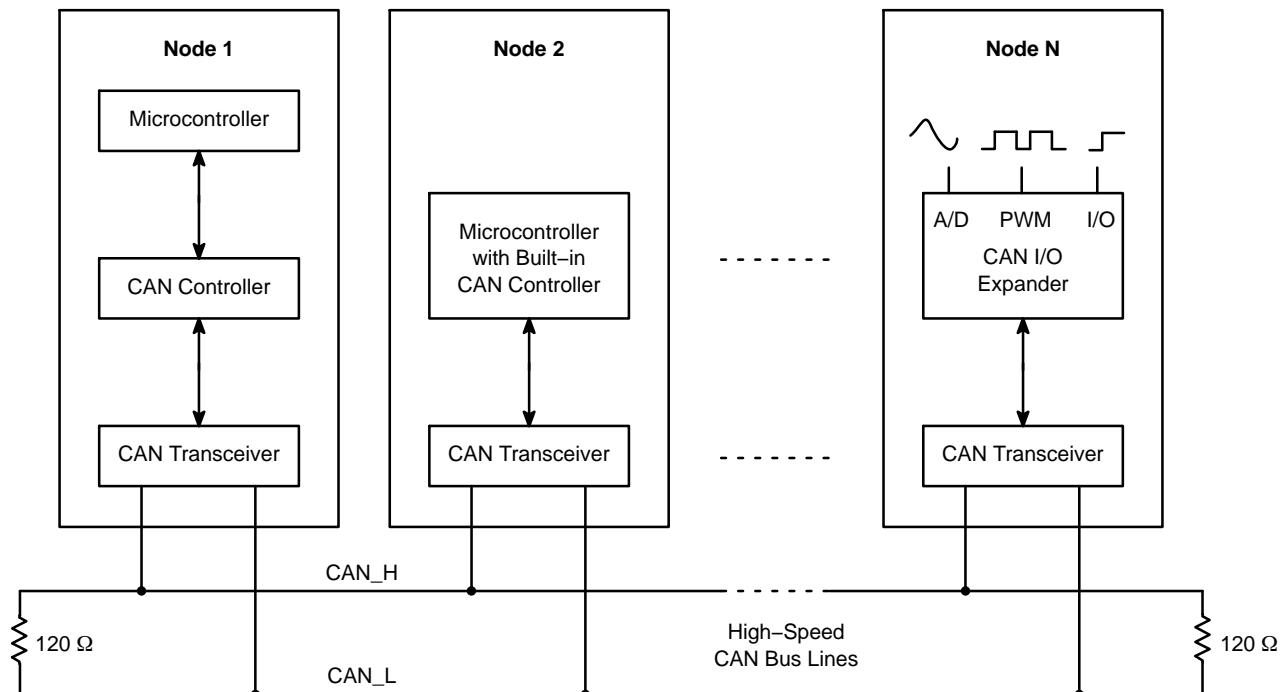
Figure 6. CAN Node Configuration Options

Table 1. Popular CAN Physical Layer Standards

Parameter	High–Speed CAN	Fault Tolerant CAN	Single Wire CAN
Physical Layer Specification	ISO 11898–2	ISO 11519–2, ISO 11898–3, ISO 11992	SAE J2411
Features	High–speed, differential bus, good noise immunity	Ability to detect a wiring error and switch to a single wire mode	Low cost
Popular Applications	Automotive and industrial controls	Large trucks and trailers	Automotive, GM–LAN network
Transmission Speed	1.0 Mbits/s @ 40 meters 125 kbits/s @ 500 meters	125 kbits/s	33.3 kbits/s (normal mode) 83.3 kbits/s (diagnostic mode)
Cable	Twisted or parallel pair wires, shielded or unshielded cable	Twisted or parallel pair wires, shielded or unshielded cable	Single unshielded wire
Termination Resistance	120 Ω resistors located at each end of the bus	Separate CAN_H and CAN_L termination resistors located at each node, resistance determined by number of CAN nodes	Termination resistor located at each node, resistance determined by number of CAN nodes
Min/Max Bus Voltage	12 V System: –3.0/16 V 24 V System: –3.0/32 V	12 V System: –3.0/16 V 24 V System: –3.0/32 V	12 V System: –3.0/16 V
Min/Max Common Mode Bus Voltage	CAN_L: –2.0 (min)/2.5 V (nom) CAN_H: 2.5 (nom)/7.0 V (max)	CAN_L: –2.0 (min)/2.5 V (nom) CAN_H: 2.5 (nom)/7.0 V (max)	CAN_Bus offset voltage = 1.0 V (max)
Transceiver Schematic and Waveform	Figure 7	Figure 8	Figure 9

High−Speed CAN

The ISO 11898−2 high−speed differential bus is the most popular CAN transmission protocol. A differential protocol is good for high−speed (1.0 Mbits/s) and medium−speed (125 kbits/s) applications that require the transfer of large amounts of data. A differential bus also provides excellent noise immunity due to the inherent noise cancellation characteristics achieved by using a shielded cable with a twisted wire pair and a receiver with a differential amplifier.

The ISO 11898−2 bus consists of the CAN_H (high) and CAN_L (low) data lines and a common ground signal. A 120 Ω termination resistor is located at each end of the bus to minimize reflections and ringing on the waveforms. The logic states of the bits are determined by the differential voltage between the CAN_H and CAN_L signals. In most systems, the recessive state represents logic '1', while logic '0' is provided by the dominant state. Figure 7 shows simplified transceiver and system schematics, along with the voltage waveforms of the data line signals.

Bus Logic States
Recessive: $\Delta V \leq 0.5$ V
Dominant: $\Delta V \geq 0.9$ V
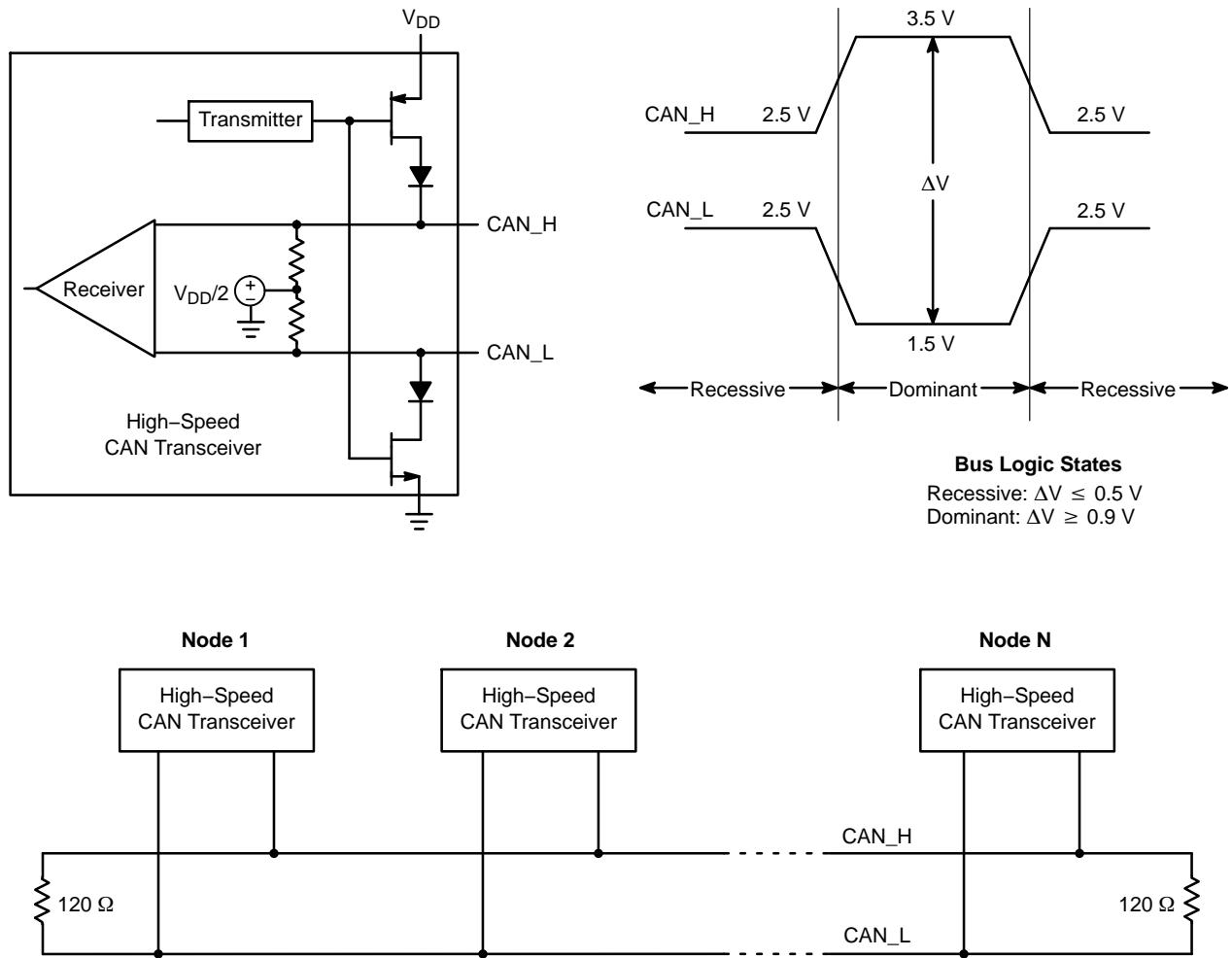
Figure 7. ISO 11898−2 Differential High−Speed CAN Bus

Fault Tolerant CAN

Fault tolerant CAN transceivers normally use a two wire differential bus that is identical to the high−speed bus; however, the transceivers automatically switch to a single wire mode if either the CAN_H and CAN_L signal lines are shorted to ground or power. The fault tolerant bus has a maximum specified data rate of 125 kbits/s. The composite bus termination resistance is equal to 100 Ω and the resistors are located next to each transceiver.

There are three different ISO specifications that are used to define the fault tolerant bus. The ISO 11519−2 and ISO 11898−3 specifications are popular in automobiles, while ISO 11992 is widely used in truck and trailer applications. The voltage levels of the ISO 11519−2 and ISO 11898−3 correspond to a 5.0 V data bus. In contrast, the voltage levels of the ISO 11992 signals are specified at a voltage level of 1/3 and 2/3 of the supply voltage which is typically 24 V. Figure 8 shows a simplified system schematic of the ISO 11898−3 protocol, along with the voltage waveforms of the data line signals.

Bus Logic States
Dominant: CAN_H > CAN_L
Recessive: CAN_H < CAN_L
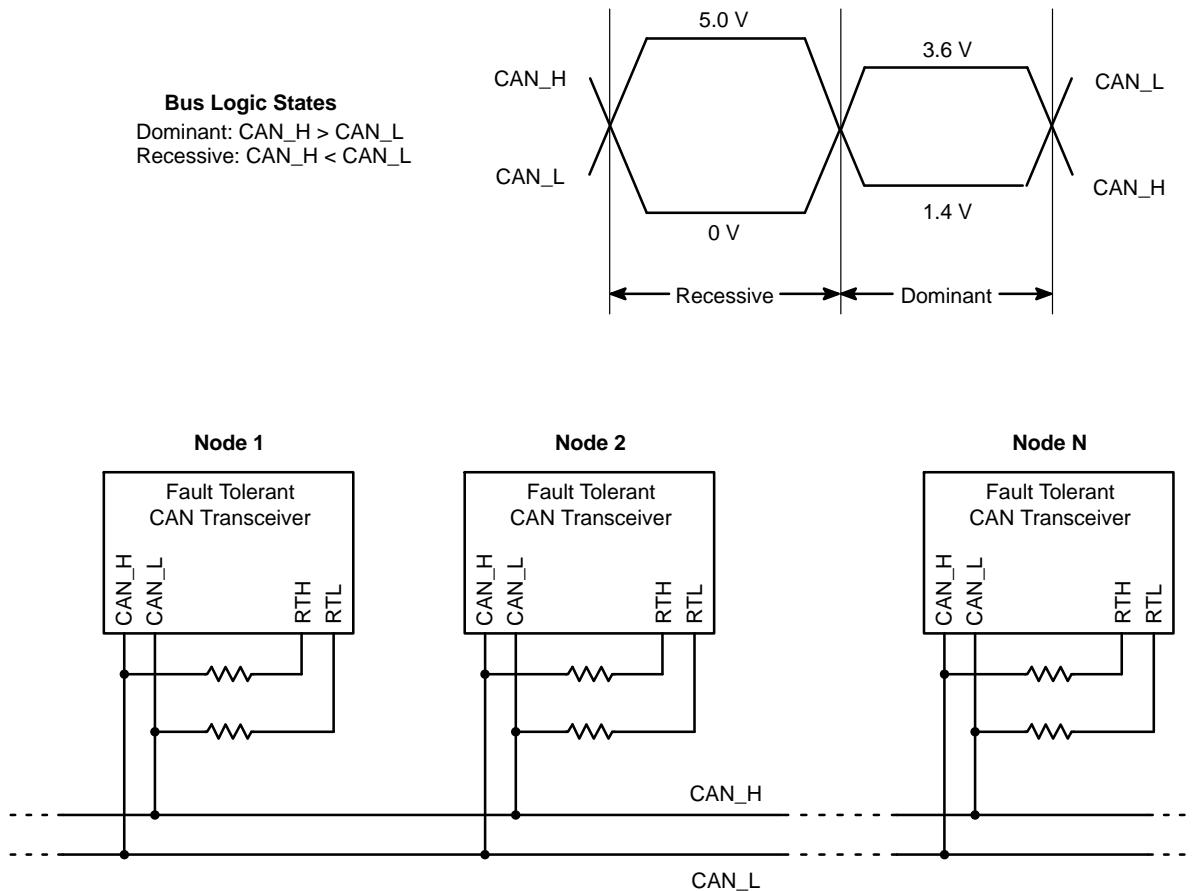
Figure 8. ISO 11898−3 Fault Tolerant CAN Bus

Single Wire CAN

The single wire SAE J2411 bus is used in CAN network applications with low bit rate transmissions requirements and relatively short bus lengths. Typical applications of the single wire bus include non–critical comfort accessories on the automobile with bus lengths less than 1 meter, such as adjustable driver and passenger seats. The normal transmission rate is 33.3 kbits/s; however, the system also

has the provision for an 83.3 kbits rate diagnostic mode. The bus is typically implemented with an unshielded cable with a signal and ground wire. The bus termination resistors are located next to each transceiver and have a value determined by the parallel resistance of all the individual node resistors. Figure 9 shows a simplified system schematic, along with the voltage waveform of the data line signal.


Bus Logic States
Recessive: CAN_Bus < 1.6 V
Dominant: CAN_Bus > 3.4 V
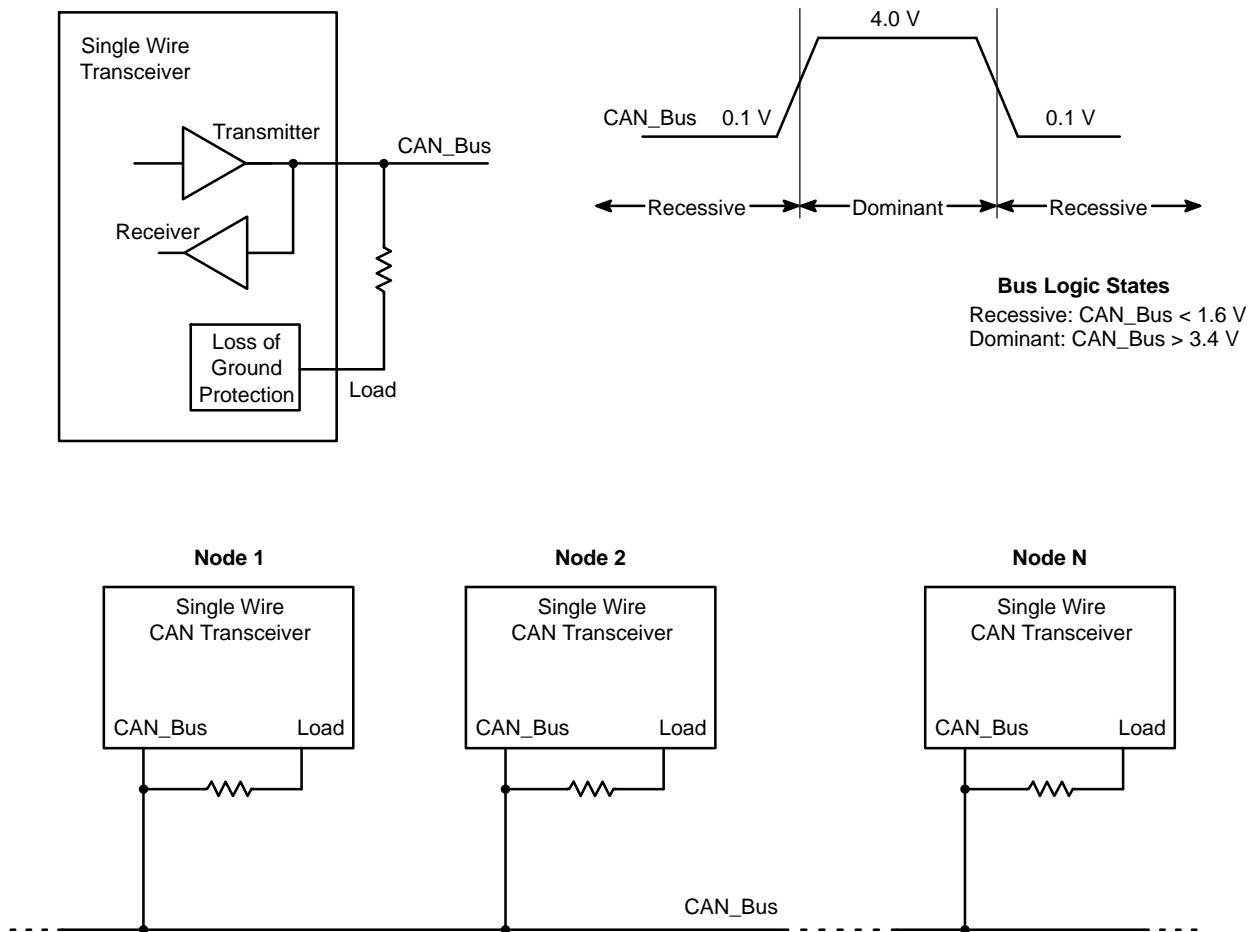
Figure 9. SAE J2411 Single Wire CAN Bus

CAN TRANSCEIVER SPECIFICATIONS

There are several CAN transceiver specifications that must be evaluated in order to pick an appropriate EMI / ESD bus protection circuit. The critical transceiver characteristics include:

1. Maximum supply voltage
2. Common mode voltage
3. Maximum transmission speed
4. ESD rating
5. Coupled electrical disturbance

Maximum Supply Voltage

The ISO and SAE physical layer specifications require that the transceiver must survive an indefinite short between the battery power lines and CAN signal lines. Most CAN transceivers require a 3.3 V or a 5.0 V supply voltage that is created from either a 12 V or 24 V battery. The external protection circuit devices may not be needed to meet the maximum supply voltage requirement because the majority of CAN transceivers are designed to withstand a DC voltage of ±40 V or greater on the signal lines.

The maximum battery voltage is an important factor in the selection of the TVS devices. The TVS devices should be chosen so that the minimum breakdown voltage of the Zener diode or MOV over the operating temperature range is greater than the maximum system supply voltage. TVS devices are designed to dissipate the large peak power of a transient event; however, they should not be used to regulate a steady−state voltage.

Common Mode Voltage

The common mode voltage specification is an important parameter in selecting a TVS device. Often in the case of networks such as CAN, there can be a significant difference in the voltage potential between the ground reference of the transmitting and receiving nodes. The ISO 11898−2 specification requires that a transceiver 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. MOVs are inherently bidirectional and have a breakdown voltage that is equal for both positive and negative voltages. In contrast, a standard TVS diode will function as a Zener diode for a positive voltage (cathode voltage > anode voltage) and as a standard diode for a negative voltage (cathode voltage < anode voltage). A differential transceiver functions by monitoring the voltage difference in two signal lines, rather than the absolute voltage levels. It is essential that the TVS devices do not clamp the transmission signals during normal operating conditions.

Maximum Transmission Speed

The transmission rate of the network is a critical parmenter in the selection process of the CAN bus protection circuit. The inductance and capacitance of the protective devices will cause distortion in the signal waveforms, which often becomes a major design concern at high transmission frequencies. The high−to−low and low−to−high transitions on the CAN signal lines will have rounded transitions that can result in the system being unable to clearly identify a high and low logic state.

It is important to match the filter attenuation on each signal line. Minor distortion on the signal lines in a differential system is acceptable if the amount of filtering on the CAN_H and CAN_L lines are identical. It is typically not possible to tightly match discrete capacitors or the capacitance of a MOV or TVS device; thus, the practical approach is to select a protection device with the minimum possible capacitance. However, a design trade−off exists because the energy absorption rating of Zener TVS diodes and MOVs typically increases with capacitance. 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 250 pF for 125 kbits/s.

ESD Rating

There are many ways that ESD can enter a CAN node. An ESD event can occur when a charged object such as a person touches the CAN module's connector pins or cable. CAN transceivers are designed to have a higher ESD rating than a standard IC because they drive lines that are connected to an external input/output (I/O) connector; however, their ESD levels are typically below the rating that can be achieved by using an external TVS device.

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. There are several different specifications used to measure ESD immunity, including the human body model (HBM) and the IEC 61000−4−2 tests. The HBM test is typically the specification listed on CAN transceiver data sheets, while the IEC specification is gaining popularity as a system level test. 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.

Coupled Electrical Disturbances

A CAN transceiver must be able to survive the high energy transients that are produced by a number of disturbances including load dump, inductive load switching, relay contact chatter and ignition system noise. These transient signals are usually generated on the CAN nodes supply voltage; however, the noise can be coupled into the adjacent data line signals because the power and CAN data lines are typically located inside the same wire bundle.

The severest transient in an automotive application is the load dump which occurs when the battery is inadvertently disconnected from the generator. Studies by the SAE and ISO groups have shown that the load dump produces an exponentially decaying positive voltage with a magnitude of 25 to 125 V and a pulse between 40 to 500 ms. A common method to protect against the high energy load dump surge is to use a TVS device on the power supply line entering the CAN module. The CAN physical layer specifications do not require the transceiver to pass a load dump test. Protection against the load dump surge is provided by TVS devices that are part of the CAN module's power supply circuit, which typically is a low dropout (LDO) linear voltage regulator.

The specifications used to verify the CAN systems immunity to coupled transient noise on the power supply lines are given in ISO 7637−1 (12 V systems) and 7637−2 (24 V systems). The CAN data line immunity requirement for a repetitive high frequency disturbance such as the noise produced by the arcing contacts in a relay is typically tested with ISO 7637−3. The IEC 61000−4−4 Electrical Fast Transient (EFT) test is similar to ISO 7637−3 and is a required test for the SDS CAN network.

CAN BUS PROTECTION OPTIONS

The options available to protect the CAN signal lines from EMI and ESD interference include shielded twisted wire pair cables, differential and common mode filters and TVS devices. In most applications a combination of multiple bus protection devices is required to provide a robust communication system. Also, the location and circuit board layout is critical to maximize the effectiveness of the CAN protection circuit.

Shielded Twisted Wire Pair Cable

A shielded cable is an effective tool to prevent radiated interference from introducing a common mode noise voltage on signal wires. A shielded twisted wire pair cable minimizes the voltage induced on the bus signal lines. There will still be some noise signal coupled into the two signal lines, but the noise level on lines will be essentially equal. The transceiver's differential amplifier ability to cancel the majority of the common mode noise is specified by its common mode rejection ratio (CMRR) specification. The CMRR of the transceiver can be increased by discrete filters or by using a common mode choke.

Filters

Filters can provide bus protection with either discrete resistor−capacitor (RC) and inductor−capacitor (LC) filters or a common mode choke. Filters will attenuate the magnitude of the noise on the CAN signal lines; however, they may distort the signal waveform and do not provide voltage clamping. A filter approach is also limited by the physical layer specifications that specify a maximum capacitance load for each CAN node. A TVS device should always be used in combination with a filter to protect not only the CAN transceiver, but also the discrete filter components such as the capacitors.

TVS Devices

TVS devices can be used to absorb the transient energy of an overvoltage event to prevent damage to the CAN transceiver. The preferred TVS devices to use for a digital bus circuit are TVS Zener diodes and Metal Oxide Varistors (MOVs). These clamping devices have a very fast turn−on time (< 1.0 ns) and limit the overvoltage to a safe value within the transceiver's operating range. Zener diodes and MOVs also have the feature that they function as a capacitor for normal signal transmissions below their breakdown voltage. Low capacitance TVS Zener diodes and MOVs are readily available that make these devices essentially transparent to the operation of a high−speed data bus.

PCB Layout Recommendations

The location and circuit board layout is critical to maximize the effectiveness of the CAN protection circuit. The following guidelines are recommended:

1. Locate the protection devices as close as possible to the I/O connector. This allows the protection devices to absorb the energy of the transient voltage before it can be coupled into the adjacent traces on the PCB.
2. Minimize the loop area for the high−speed data lines, power and ground lines to reduce the radiated emissions and the susceptibility to RF noise.
3. Minimize the path length between the CAN signal lines and protective devices.
4. Use ground planes wherever possible to reduce the parasitic capacitance and inductance of the PCB that degrades the effectiveness of a filter device.

CAN PROTECTION CIRCUITS

There are several different options available to provide EMI and ESD protection to a CAN transceiver. The protective device options available include TVS diodes, MOVs, a common mode choke, a split termination circuit and RC/LC filters. A combination of multiple protection devices is required in many applications to ensure a reliable communication system in a noisy electrical environment.

TVS Diode Protection Circuits

TVS diodes provide protection to a transceiver by clamping a surge voltage to a safe level. TVS diodes have high impedance below and low impedance above their breakdown voltage. A TVS Zener diode has its junction optimized to absorb the high peak energy of a transient event, while a standard Zener diode is designed and specified to clamp a steady state voltage.

A bidirectional TVS diode can be created by combining two unidirectional diodes, as shown in Figure 10. A bidirectional TVS diode is typically required for data line signals that may have an offset voltage. The bidirectional diode can be created from either dual common cathode or common anode arrays and both configurations are equivalent in their clamping characteristics.
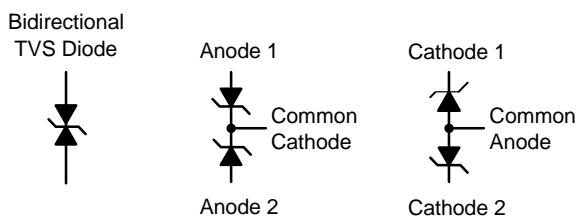
Figure 10. Bidirectional TVS Diodes can be Implemented with Two Zeners and a Common Cathode or a Common Anode Configuration

Figure 11 provides an example of a dual bidirectional TVS diode array that can be used for protection with the high−speed CAN network. The bidirectional array is created from four identical Zener TVS diodes. The clamping voltage of the composite device is equal to the breakdown voltage of the diode that is reversed biased, plus the diode drop of the second diode that is forwarded biased.
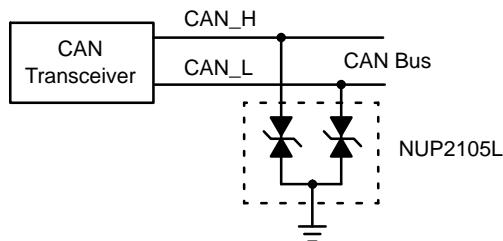
Figure 11. High−Speed and Fault Tolerant CAN TVS Protection Circuit

The circuit shown in Figure 12 is functionally equivalent to the Zener array of Figure 11; however, only three diodes are required to provide the bidirectional feature. The clamping voltage on the data lines for a positive voltage surge will be equal to the forward voltage drop of diode D_1 or D_2 plus the breakdown voltage of the reversed biased diode D_3. The clamping voltage for a negative voltage will be equal to the forward voltage drop of diode D_3 plus the

breakdown voltage of either diode D_1 or D_2. The main advantage of the three−diode configuration is that a smaller IC package can be used to house the array.
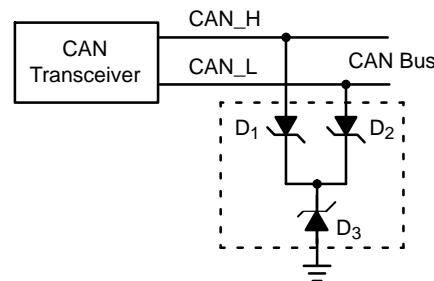

Figure 12. Alternative High−Speed and Fault Tolerant CAN TVS Protection Circuit

A third circuit configuration using TVS diodes is shown in Figure 13. This array consists of four standard diodes and a unidirectional TVS Zener diode. Protection to the CAN bus lines is provided by clamping the signal lines to either a forward diode voltage drop above the supply voltage (V_{DD}) or a forward diode drop below ground. One advantage of this circuit is that the diode array clamps at a voltage closer to the normal amplitude of the waveform and the diodes can be used to remove overshoot or ringing on the signal lines.
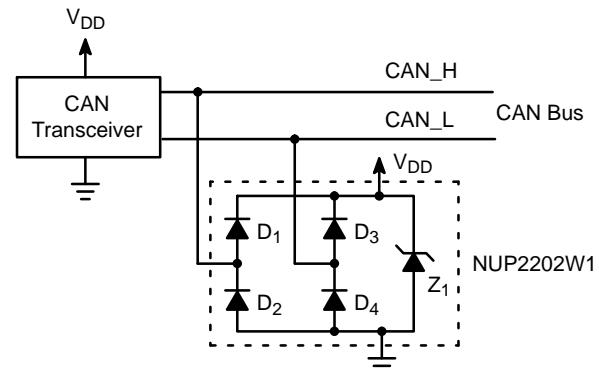

Figure 13. Alternative High−Speed CAN TVS Diode Array Protection Circuit

Another advantage of this configuration is that the capacitive load on the signal lines is typically less than the bidirectional Zener diode circuits shown in Figures 11 and 12. Diodes D_1, D_2, D_3 and D_4 have a low capacitance and are designed to have a fast turn−on time. The TVS diode Z_1 is used to dissipate the majority of the energy when an overvoltage condition occurs. A large capacitance, high energy rated Zener can be used for Z_1 because the capacitive load of the device is on the power supply lines rather than a data line.

The main disadvantage of the diode array circuit is that it may clamp the CAN_L and CAN_H waveforms if a common mode or offset voltage exists. The ISO 11898–2 specification lists a common mode voltage specification of −2.0 V to +7.0 V for the data lines and the array circuit will provide undesired clamping for signals at the minimum and maximum limits of the specification when the transceiver's supply voltage (V_{DD}) equals +5.0 V. The common mode voltage corresponds to the possible offset voltage that may exist from the difference between the two ground references of the transmitting and receiving CAN modules. The diode array circuit of Figure 13 should only be used in a system that can ensure that the offset voltage between the CAN module's ground references will be relatively small and less than the turn–on voltage of the diodes.

MOVs Protection Circuit

MOVs can be used to provide clamping protection for CAN transceivers as shown in Figure 14. A varistor is a non–linear resistor which has electrical characteristics similar to a bidirectional Zener diode. At low voltages below its breakdown voltage, a MOV can be modeled as a very large resistance in parallel with a capacitance. When the voltage of the surge exceeds the breakdown voltage, the resistance of the device decreases to a low value that will clamp the transient event via the resistive divider effect of a low impedance in series with the resistance of the voltage source.
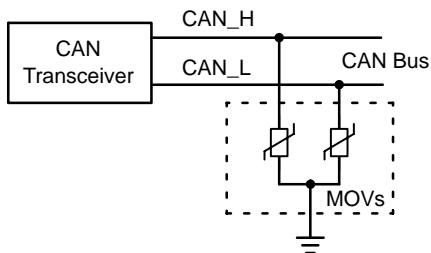
Figure 14. High–Speed and Fault Tolerant CAN MOV Protection Circuit

The main advantage of MOVs is that they provide clamping protection at a relatively low cost. The main disadvantage of a MOV is that its clamping voltage is typically higher than a comparable Zener diode. Also, MOVs traditionally have been used only in cost sensitive applications because their clamping voltage decreased over the life of the part. However, this problem has been minimized in multi–layer MOVs by improvements in their manufacturing process. MOVs are made from ZnO and metal oxides that form a polycrystalline structure with a granular structure. Single layer or "pressed pill" MOVs often had a large variance in their breakdown voltage and

were prone to early high voltage repetitive strike wear out. In contrast, multi–layer varistors are now available that are not prone to the inconsistent grain size problem of single layer devices which resulted in a limited lifetime.

Common Mode Choke Circuit

Common mode chokes are an effective tool for attenuating the noise that is common to both of the transceiver bus lines, as shown in Figure 15. Chokes function by providing high impedance for common mode signals and a low impedance for differential signals, which increases the common mode rejection ratio (CMRR) of the transceiver. Chokes are an effective device to implement filtering without adding a large amount of distortion on high–speed data lines. The common mode choke functions limits the magnitude of an overvoltage surge on the data lines by functioning as a filter; thus, it is recommended that TVS devices be added to the circuit to provide clamping protection.
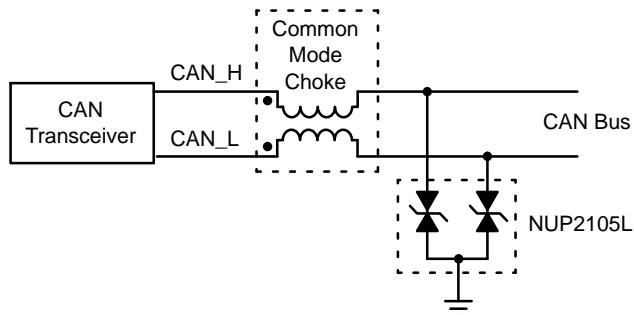

Figure 15. High–Speed and Fault Tolerant CAN Common Mode Choke Circuit

There are several disadvantages of chokes. One issue with chokes is that their inductance and the capacitance of the board and transceiver can form a resonant tank circuit that will oscillate. Oscillations on the CAN signal lines will result in false bit detections at the transceiver. Another issue with choke filters is that any mismatch in the inductance of the two coils will cause distortion in the signal waveforms.

Split Termination Circuit

Figure 16 shows a split termination circuit that can be used to provide noise protection to a CAN transceiver. The termination circuit functions as a low–pass filter and is formed by two equal valued resistors and a capacitor. The common mode signal is terminated through a capacitor that shunts a high frequency noise signal to ground. The tolerance of the termination resistors should be as good as possible (R tol. ≤ 1%) in order to maintain waveform symmetry between the CAN_H and CAN_L signals.
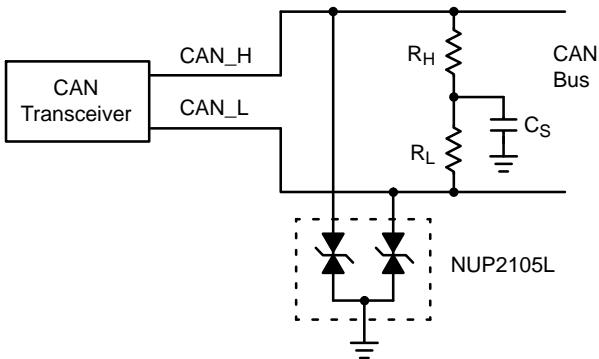
Figure 16. High−Speed and Fault Tolerant CAN Protection Circuits Using Split Termination

The split termination circuit can be combined with either a TVS diode or a MOV clamping diode. A resistor−capacitor (RC) circuit provides protection by functioning as a low−pass filter and by limiting the slew rate of an ESD or transient overvoltage signal. A TVS clamping device should be added to the split termination circuit to ensure that the bus line voltage does not exceed the maximum voltage rating of the transceiver and capacitors.

Typically the termination resistors for the high−speed CAN bus are located at the two ends of the network. If the CAN node is located at the end of the bus, two resistors of 60 Ω are used instead of one 120 Ω resistor. Otherwise, if the transceiver is located at a CAN stub node that would not normally contain a termination resistor, higher value resistors are required so that the parallel value of the termination resistance remains at 60 Ω.

Multiple Suppression Device Circuit

A combination of a common mode choke, capacitors and TVS diodes can be used to solve the most stringent EMI emission and immunity requirements, as shown in Figure 17. Noise entering the CAN node is attenuated by the second order filters formed by the inductance of the choke filter and capacitors C_{H1} and C_{L1}. In contrast, capacitors C_{H2} and C_{L2} provide a filter to reduce the emissions or noise that exits the transceiver. The bidirectional TVS diodes function to clamp a transient voltage disturbance on the CAN bus lines to a safe value.
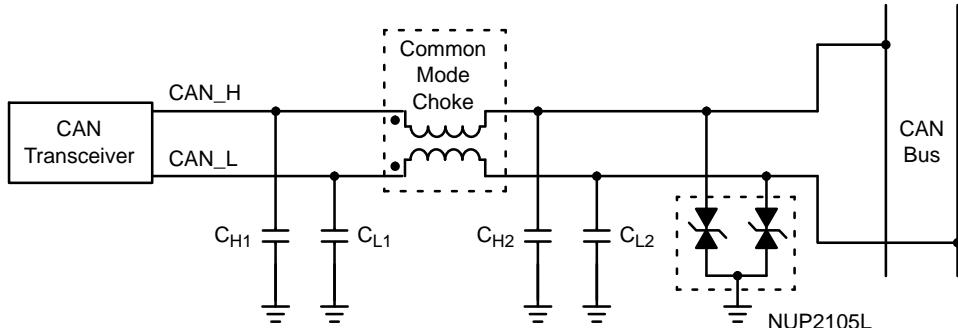
Figure 17. High−Speed CAN Protection Circuits Combining Choke, Capacitors and TVS Diodes

Single Wire CAN Protection Circuit

Figure 18 shows the protection circuit that is recommended by the SAE J2411 specification for a single wire CAN transceiver. The circuit consists of a bidirectional TVS diode to provide overvoltage protection and a discrete filter. The inductor and capacitor form a low−pass filter to attenuate the emissions or noise exiting the CAN node. In contrast, the inductor and resistor combination form a filter that reduces the noise entering the node. The transceiver's "load" pin is connected to a "loss of ground protection circuit" that serves to compensate for a broken ground connection.
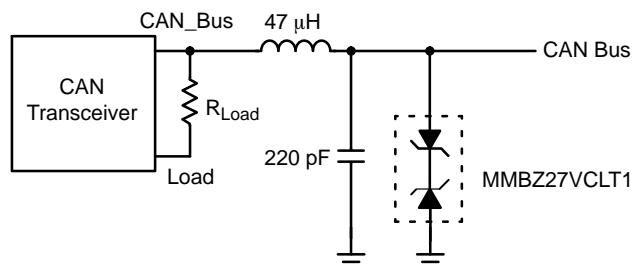

Figure 18. J2411 Single Wire CAN Recommended Bus Interface Circuit

CONCLUSION

The Controller Area Network (CAN) is a popular serial communication protocol that provides reliable high–speed data transmission in a multitude of applications ranging from automotive to industrial control. Bus protection circuits can be used to increase the CAN transceivers noise immunity for EMI and ESD. The bus protection circuits improve the reliability of the CAN module, without significantly adding to the cost and complexity of the transceiver circuit.

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Industry Websites for Further Information

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- CAN Kingdom, *www.kvaserinc.com/*
- CANopen, *http://www.canopensolutions.com/*
- International Organization for Standardization (ISO), *www.iso.org*
- IXXAT Automation GmbH, *www.ixxat.com/*
- Open DeviceNet Vendor Association (ODVA), *www.odva.org*
- Robert Bosch GmbH, *www.can.bosch.com*
- Smart Distributed System (SDS), *http://content.honeywell.com/sensing/prodinfo/sds/*
- Society of Automotive Engineers (SAE), *www.sae.org*

APPENDIX I: ON SEMICONDUCTOR TVS SOLUTIONS FOR CAN

TVS Zener Diode Selection Guidelines

1. Select a device with a working reverse voltage (V_{RWM}) that is greater than or equal to the maximum bus voltage. The maximum bus voltage or DC voltage is equal to 16 V for a 12 V system and 32 V for a 24 V system, per the ISO and SAE physical layer specifications.

2. Select a device with a clamping voltage (V_C) less than the maximum specified voltage for the CAN transceiver's bus lines.

3. A bidirectional TVS device should be used in most applications to meet the common mode voltage specification. The common voltage specification is required because there can be a significant difference in the voltage potential between the ground reference of the transmitting and receiving nodes.

4. The diode array circuit of Figure 13 should only be used in a system that can ensure that the offset voltage between the CAN module's ground references will be relatively small and less than the turn−on voltage of the diodes.

Table 2. Recommended ON TVS Devices

System Voltage	High−Speed CAN	Fault Tolerant CAN	Single Wire CAN
12 V	NUP2105L • SOT−23 Package • Dual Bidirectional TVS Zener LC03−6R2 • SO−8 Package • Low Capacitance Diode Array Plus TVS Zener • Recommended only for short cable lengths	NUP2105L • SOT−23 Package • Dual Bidirectional TVS Zener LC03−6R2 • SO−8 Package • Low Capacitance Diode Array Plus TVS Zener • Recommended only for short cable lengths	MMBZ27VCLT1 • SOT−23 Package • Dual Common Cathode TVS Zener