

Common Mode Chokes in CAN Networks: Source of Unexpected Transients

Ole-Kristian Skroppa and Scott Monroe

ABSTRACT

Common-mode chokes are frequently used in automotive CAN networks to increase system reliability with respect to electromagnetic compatibility (EMC). Electromagnetic interference emitted from an Electronic Control Module (ECU) through the CAN transceiver can be filtered, thus limiting unwanted high-frequency noise on the communication bus. Another reason for using a common-mode choke is attempting to improve the susceptibility (immunity) of the transceiver to electromagnetic disturbances on the bus.

While the above mentioned effects of the common-mode choke are beneficial, unexpected results can occur under certain conditions. EMC susceptibility can be degraded in some frequency ranges, bus signal integrity worsened, and extremely high transient voltages under bus-failure conditions can be generated, which, in the worst case, can lead to damage in the CAN transceiver and other network components.

Care should be taken in the choice of common-mode choke (winding type, core type, and inductance value), along with the termination and protection scheme of the node and bus to prevent damage to the CAN transceiver or other network components. This application report addresses some of the system-level considerations to take into account during network and node design.

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1 Application Description

Many modern automotive CAN transceivers are optimized for EMC and a wide common-mode operating range to allow use in automotive CAN systems without a common-mode choke. However, for various reasons, the CAN network architecture scheme being used may sometimes require their use, or they may be used simply out of perceived need.

In general, common-mode chokes may introduce signal-integrity issues and other unexpected results in the CAN network. One of the most severe unexpected consequences from common-mode choke use is the extremely high transient voltages that may be generated by the inductive flyback during a short circuit of a CAN bus line to a dc voltage. As the transceiver drives the bus level from dominant to recessive or recessive to dominant during this short-circuit condition, the change in current through the common-mode choke may flyback in excess of 65 V. The exact transients that are generated highly depend on the common-mode choke (winding type, core type, and inductance value) but are also influenced by the termination, bus load, dc short-circuit voltage level, and short condition, cabling, and other parasitic effects on the PCB and wiring harness. Care must be taken to minimize the exposure of excessive transients to the CAN transceiver and other network components. Any transient outside the maximum operating range of the transceiver, typically -27 V to 40 V , especially for extended periods, may lead to degraded device reliability or even damage.

A simplified schematic of a typical CAN node (terminating) including a common-mode choke along with other bus components is shown in Figure 1. Following the choke in the signal path to the bus is the optional termination circuit. If the node is a stub node (nonterminating), the termination circuit may consist of a high ohmic load or be left open. This example also illustrates the optional use of transient protectors and capacitors, which may be used to improve ESD and EMC (sometimes near the module connectors). The actual circuit components and values depend on node function, network topology, car maker requirements, etc. However, nodes typically see a resistance of roughly $60\ \Omega$ on the bus due to bus termination (two $120\text{-}\Omega$ terminations in parallel). For this example, R_{Term_x} is normally $60\ \Omega$, which leads to a termination of $120\ \Omega$ for this terminating module.

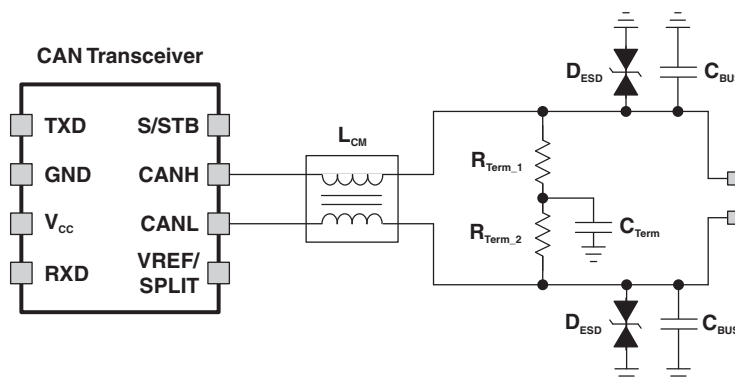


Figure 1. Simplified Schematic of Typical CAN (Terminating) Node With Optional Bus Components

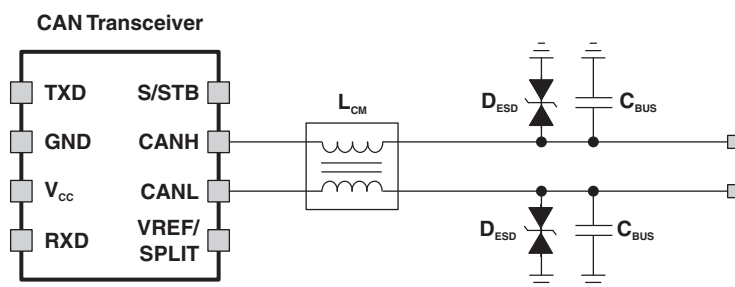


Figure 2. Simplified Schematic of Typical CAN (Nonterminating) Node With Optional Bus Components

The measurements in this document have been performed using a single node with a bus schematic as shown in Figure 3. Different combinations of optional bus components have been used, together with a 1-m FLRY CAN cable with termination in the end to simulate the CAN bus. Transient voltages measured and shown in plots were measured on the CANH and CANL PCB traces between the transceiver and the common-mode choke, in comparison with the voltage level on the bus.

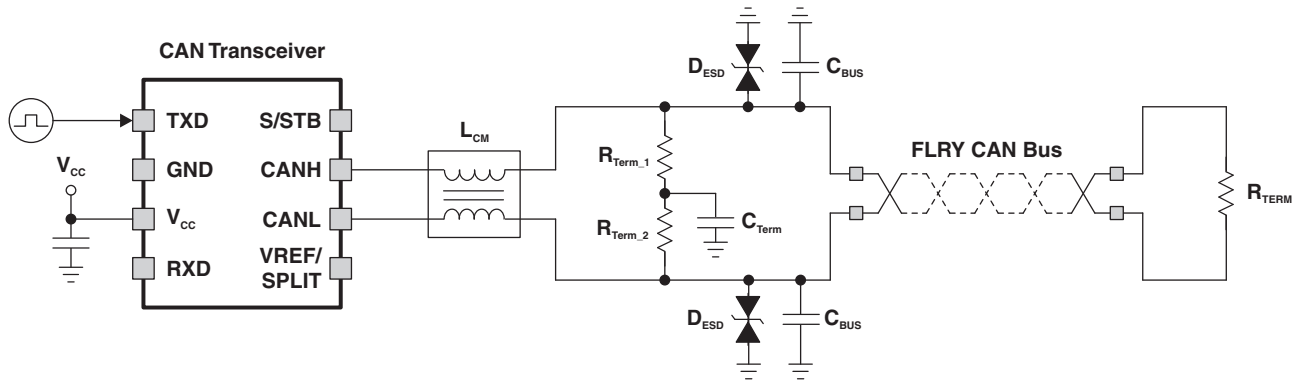


Figure 3. Simplified CAN Node Test Setup

In Figure 4, the voltage levels on the CANL bus line and transceiver pin are measured the moment a dc short circuit to 16 V has been applied on the CANL side at the external load. It can be seen that the transient voltage on the bus is increased by the inductance of the common-mode choke, resulting in higher peak voltages at the transceiver bus pins. As the transceiver attempts to transmit data on the bus, even higher transients are generated, as shown in Figure 5.



Figure 4. CANL Measured at Bus (Green) and Transceiver (Blue) at Short-Circuit Impact

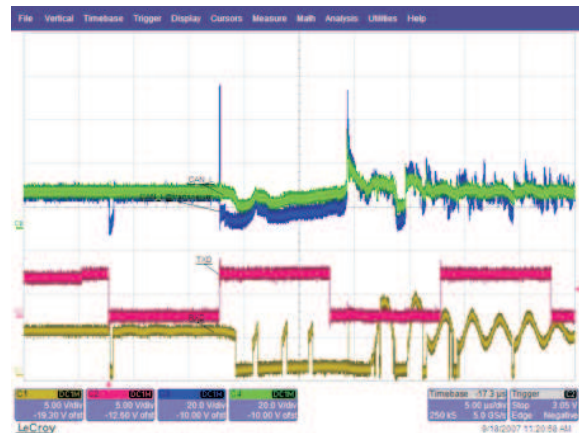


Figure 5. Start of Communication During DC Short Circuit at Bus (Green) and Transceiver (Blue)

2 Application Hint 1: Transient Protector Location in System

During short circuit to dc voltage conditions on the CAN bus, the high transients are seen in the system between the common-mode choke and the transceiver. The first application workaround is to move the transient protectors from the connector side to the transceiver side of the choke, as shown in Figure 6. This circuit effectively clamps all transients before the transceiver, allowing for the best system-level protection.

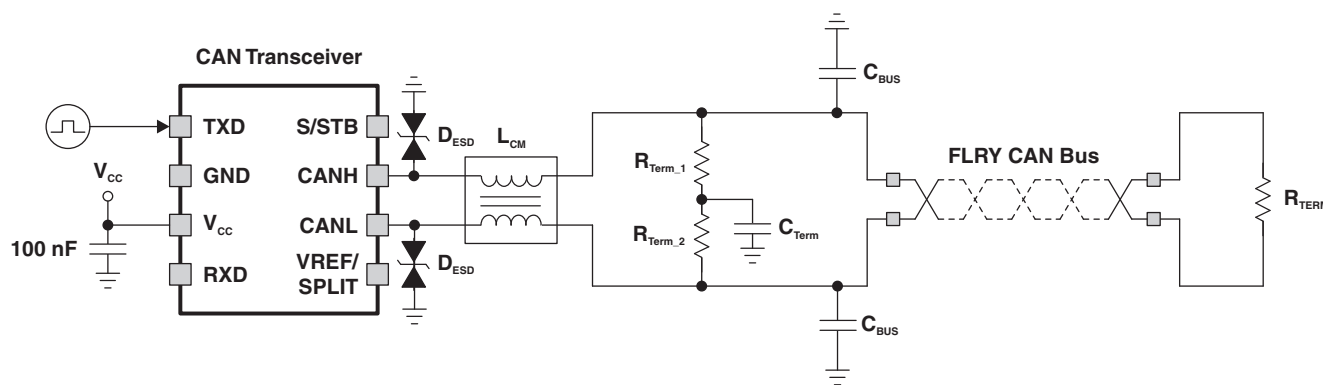


Figure 6. CAN Node With Transient Protectors at Transceiver Pins

Using this circuit, the transient voltages are sufficiently clamped by the protection circuit to prevent damage to the transceiver. Figure 7 shows how the protection diodes effectively limit the transients. Figure 8 shows a similar measurement but with varistors located at the transceiver bus pins.

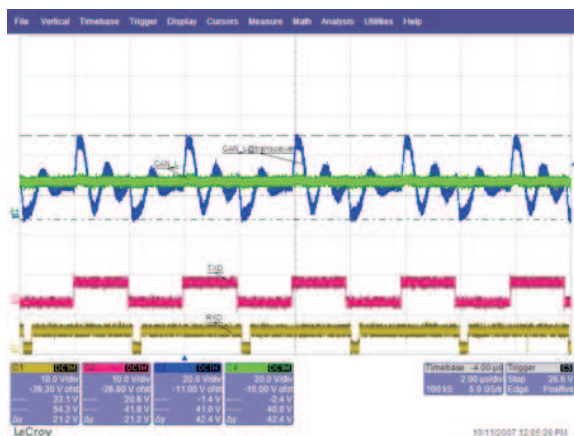


Figure 7. SBMJ30CA TVS Diodes Protecting Transceiver

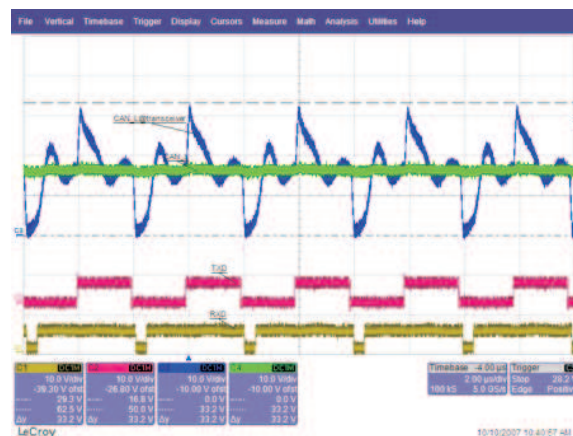


Figure 8. VC060314A300RP Varistors Protecting Transceiver

Care must be taken when selecting the right protection devices. The transient protectors must be fast enough to clamp the transient voltages. In addition, their capacitance must be considered. If the capacitance is too high, it can work together with the choke's inductance and cause ringing on the bus signals. Although this ringing does not corrupt the CAN signals, it might show up as electromagnetic emission at higher frequencies.

3 Application Hint 2: Common-Mode Choke Choice

To completely avoid the situation that causes the transient from a dc short circuit on the bus, the common-mode choke could be removed, which would eliminate the inductively generated voltage transient. However, if a common-mode choke is mandatory, there are various common choke designs and values that minimize the inductive voltage transient generation. With proper selection, the transient effect can be minimized while allowing the benefits of the common-mode choke, if one is required.

Measurements have shown that the transient voltage levels are highly dependent on the common-mode chokes core type and inductance value.

The measurement results for different chokes are summarized in [Table 1](#) and [Table 2](#). The test conditions for these measurements are as shown in [Figure 3](#), where the $R_{Term,x}$, C_{Term} , and D_{ESD} are left open, $C_{BUS} = 100$ pF, and a short circuit to 12 V is applied to either CANL or CANH at R_{TERM} , the external termination at the opposite end of the 1-m long CAN bus cable.

Table 1. Measurement of Transients for Different Common-Mode Chokes With CANL Shorted to 12 V

Choke	Winding	Core	L_r (μ H)	L_s , typ (nH)	I_R (mA)	R_{max} (m Ω)	Measured Transient Voltage at Transceiver Bus Pins (V)	
							CANL	CANH
Bourns DR331-513AE	Sector	Toroid	51	2000	500	300	38,7	34,7
Bourns DR331-513BE	Bifilar	Toroid	51	600	500	300	48,8	46,6
Epcos B82789C0113	Bifilar	I Bar	11	60	300	250	39,1	37,8
Epcos B82789C0223	Bifilar	I Bar	22	100	250	580	53,5	51,9
Epcos B82789C0513	Bifilar	I Bar	51	100	250	550	68,7	66,1
Epcos B82789C0104	Bifilar	I Bar	100	250	150	1500	70,1	67,4
Epcos B82790S0513	Sector	Toroid	51	2000	500	160	49,7	45,7
Epcos B82799S0513	Sector	Toroid	51	2700	200	310	40,9	37,8
Epcos B82799C0104	Bifilar	Toroid	100	150	300	180	31,6	29,0
Epcos B82799C0224	Bifilar	Toroid	220	200	200	250	34,3	33,4
Epcos B82799C0474	Bifilar	Toroid	470	350	200	410	37,3	36,0
Murata DLW43SH510XK2B	Bifilar	I Bar	51		230	1000	68,3	66,1
Murata DLW43SH101XK2B	Bifilar	I Bar	100		200	2000	70,5	67,4
TDK ACT45B-510-2P	Bifilar	I Bar	51	150	200	1000	67,0	39,6
TDK ACT45B-101-2P	Bifilar	I Bar	100	200	100	3000	67,4	68,3
Würth SL2 744222		Toroid	1000		800	310	42,7	40,9

Table 2. Measurement of Transients for Different Common-Mode Chokes With CANH Shorted to 12 V

Choke	Winding	Core	L_r (μ H)	L_s , typ (nH)	I_R (mA)	R_{max} (m Ω)	Measured Transient Voltage at Transceiver Bus Pins (V)	
							CANL	CANH
Bourns DR331-513AE	Sector	Toroid	51	2000	500	300	33,8	34,3
Bourns DR331-513BE	Bifilar	Toroid	51	600	500	300	46,6	47,5
Epcos B82789C0113	Bifilar	I Bar	11	60	300	250	35,6	37,3
Epcos B82789C0223	Bifilar	I Bar	22	100	250	580	50,2	52,4
Epcos B82789C0513	Bifilar	I Bar	51	100	250	550	64,3	66,1
Epcos B82789C0104	Bifilar	I Bar	100	250	150	1500	67,4	70,1
Epcos B82790S0513	Sector	Toroid	51	2000	500	160	42,7	45,3
Epcos B82799S0513	Sector	Toroid	51	2700	200	310	36,9	36,9
Epcos B82799C0104	Bifilar	Toroid	100	150	300	180	29,4	29,4
Epcos B82799C0224	Bifilar	Toroid	220	200	200	250	33,4	32,5
Epcos B82799C0474	Bifilar	Toroid	470	350	200	410	35,6	36,5
Murata DLW43SH510XK2B	Bifilar	I Bar	51		230	1000	63,9	66,1
Murata DLW43SH101XK2B	Bifilar	I Bar	100		200	2000	67,8	67,0
TDK ACT45B-510-2P	Bifilar	I Bar	51	150	200	1000	58,6	67,8
TDK ACT45B-101-2P	Bifilar	I Bar	100	200	100	3000	67,4	69,6
Würth SL2 744222		Toroid	1000		800	310	40,0	42,2

As can be seen from these results, common-mode chokes based on a toroid core generally generate much lower transients than the other common-mode choke core types. Secondary to the core type in transient generation are the winding type and the inductance value of the common-mode choke.

4 Summary

The use of common-mode chokes in CAN systems might cause extremely high transient voltages at the bus pins of the transceiver. These transients are generated by the change in current through the inductance of the common-mode chokes if the CAN bus is shorted to dc voltages. The actual transients that might be generated are highly dependent on the common-mode type and value but also depend on the CAN system architecture, termination, components, and location and the severity of the short circuit.

For systems where common-mode chokes are required, care should be used in the choice of the common-mode choke and the system circuit to avoid the introduction of severe transients during dc short-circuit conditions on the bus.

The best methods to avoid transients generated from common-mode chokes during CAN bus line shorts to dc voltages are:

- Remove common-mode chokes from systems, where applicable.
- Move transient suppression circuits between the common-mode choke and the CAN bus pins on the transceiver.
- Choose a common-mode choke type and value and a CAN termination scheme to minimize transients.

While the measurements presented in this paper can be reproduced in the lab, they are still theoretical and at a worst-case level. A complete CAN network in a modern vehicle consists of advanced network topologies where total capacitance, inductance, and resistance are distributed among cabling, termination, and each node. DC short circuits from CAN bus lines to high battery voltages (alternator running) in automotive environments are not often experienced, and are also very seldom clean zero-ohmic. Therefore, it is difficult to completely characterize what might happen in a real CAN system. This application report serves to raise awareness of one of the unexpected impacts of the use of common-mode chokes in CAN systems.

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