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AN228

A CAN Physical Layer Discussion

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INTRODUCTION

Many network protocols are described using the seven layer Open System Interconnection (OSI) model, as shown in Figure 1. The Controller Area Network (CAN) protocol defines the Data Link Layer and part of the Physical Layer in the OSI model. The remaining physical layer (and all of the higher layers) are not defined by the CAN specification. These other layers can either be defined by the system designer, or they can be implemented using existing non-proprietary Higher Layer Protocols (HLPs) and physical layers.

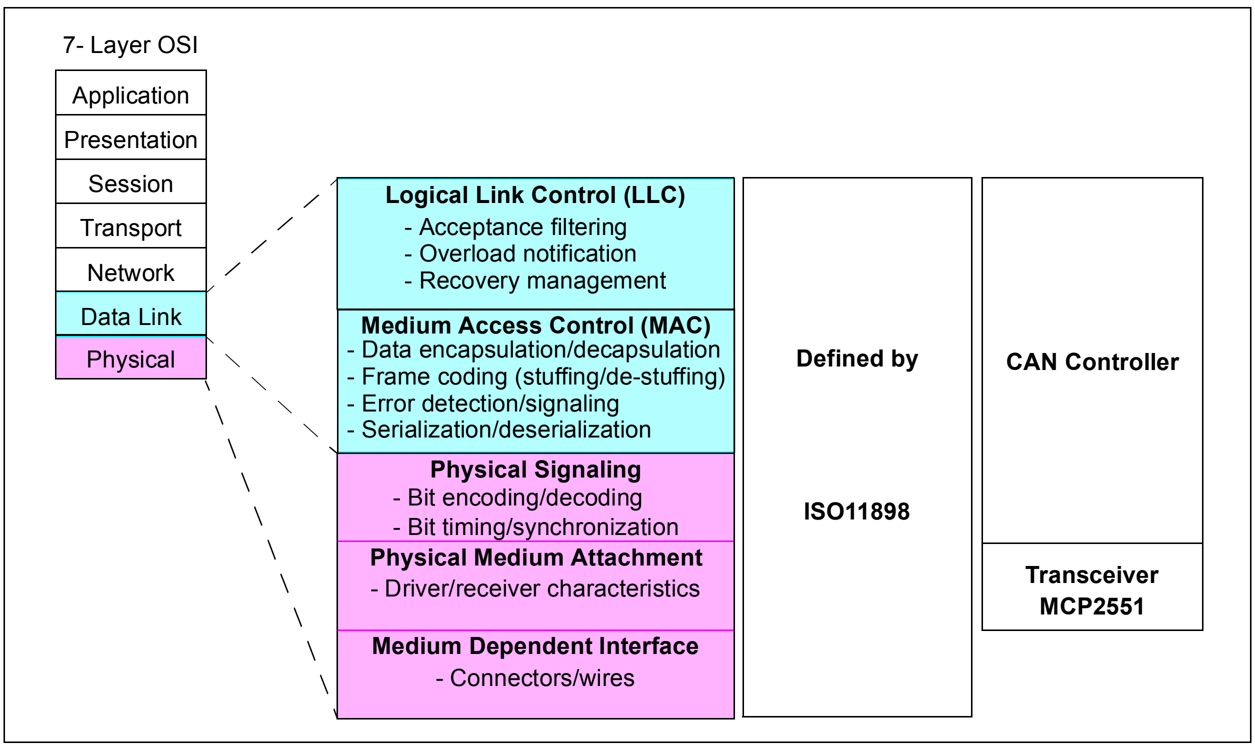
The Data Link Layer is defined by the CAN specification. The Logical Link Control (LLC) manages the overload control and notification, message filtering and recovery management functions. The Medium Access Control (MAC) performs the data encapsulation/decapsulation, error detection and control, bit stuffing/destuffing and the serialization and deserialization functions.

The Physical Medium Attachment (PMA) and Medium Dependent Interface (MDI) are the two parts of the physical layer which are not defined by CAN. The Physical Signaling (PS) portion of the physical layer is defined by the CAN specification. The system designer can choose any driver/receiver and transport medium as long as the PS requirements are met.

The International Standards Organization (ISO) has defined a standard which incorporates the CAN specification as well as the physical layer. The standard, ISO-11898, was originally created for high-speed in-vehicle communications using CAN. ISO-11898 specifies the physical layer to ensure compatibility between CAN transceivers.

A CAN controller typically implements the entire CAN specification in hardware, as shown in Figure 1. The PMA is not defined by CAN, however, it is defined by ISO-11898. This document discusses the MCP2551 CAN transceiver and how it fits in with the ISO-11898 specification.

FIGURE 1: CAN AND THE OSI MODEL



ISO11898-2 OVERVIEW

ISO11898 is the international standard for high-speed CAN communications in road vehicles. ISO-11898-2 specifies the PMA and MDA sublayers of the Physical Layer. See Figure 3 for a representation of a common CAN node/bus as described by ISO-11898.

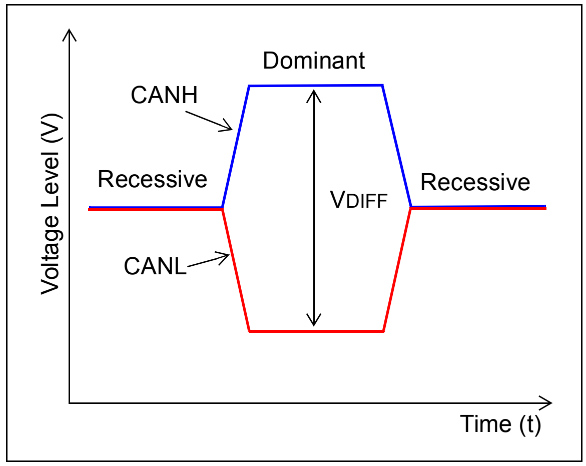
Bus Levels

CAN specifies two logical states: recessive and dominant. ISO-11898 defines a differential voltage to represent recessive and dominant states (or bits), as shown in Figure 2.

In the recessive state (i.e., logic ‘1’ on the MCP2551 TXD input), the differential voltage on CANH and CANL is less than the minimum threshold (<0.5V receiver input or <1.5V transmitter output)(See Figure 4).

In the dominant state (i.e., logic ‘0’ on the MCP2551 TXD input), the differential voltage on CANH and CANL is greater than the minimum threshold. A dominant bit overdrives a recessive bit on the bus to achieve nondestructive bitwise arbitration.

FIGURE 2: DIFFERENTIAL BUS



Connectors and Wires

ISO-11898-2 does not specify the mechanical wires and connectors. However, the specification does require that the wires and connectors meet the electrical specification.

The specification also requires 120Ω (nominal) terminating resistors at each end of the bus. Figure 3 shows an example of a CAN bus based on ISO-11898.

FIGURE 3: CAN BUS

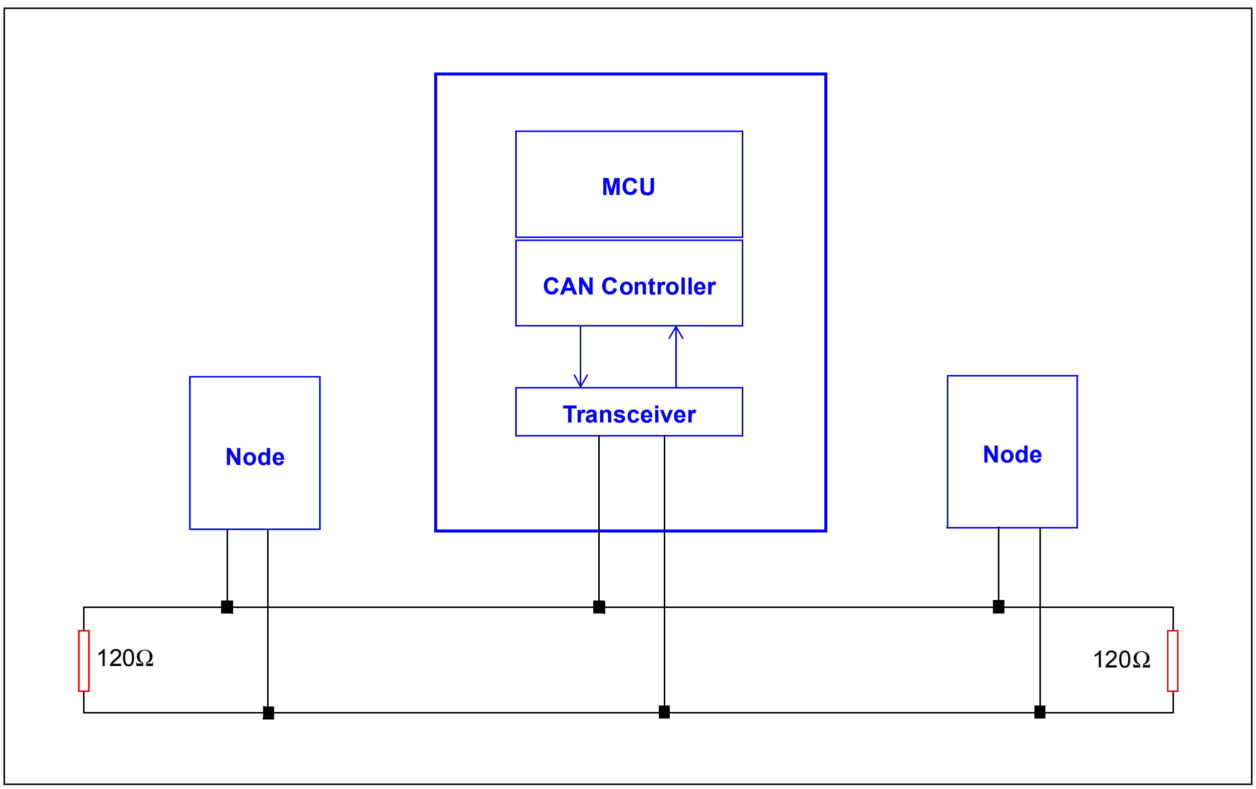


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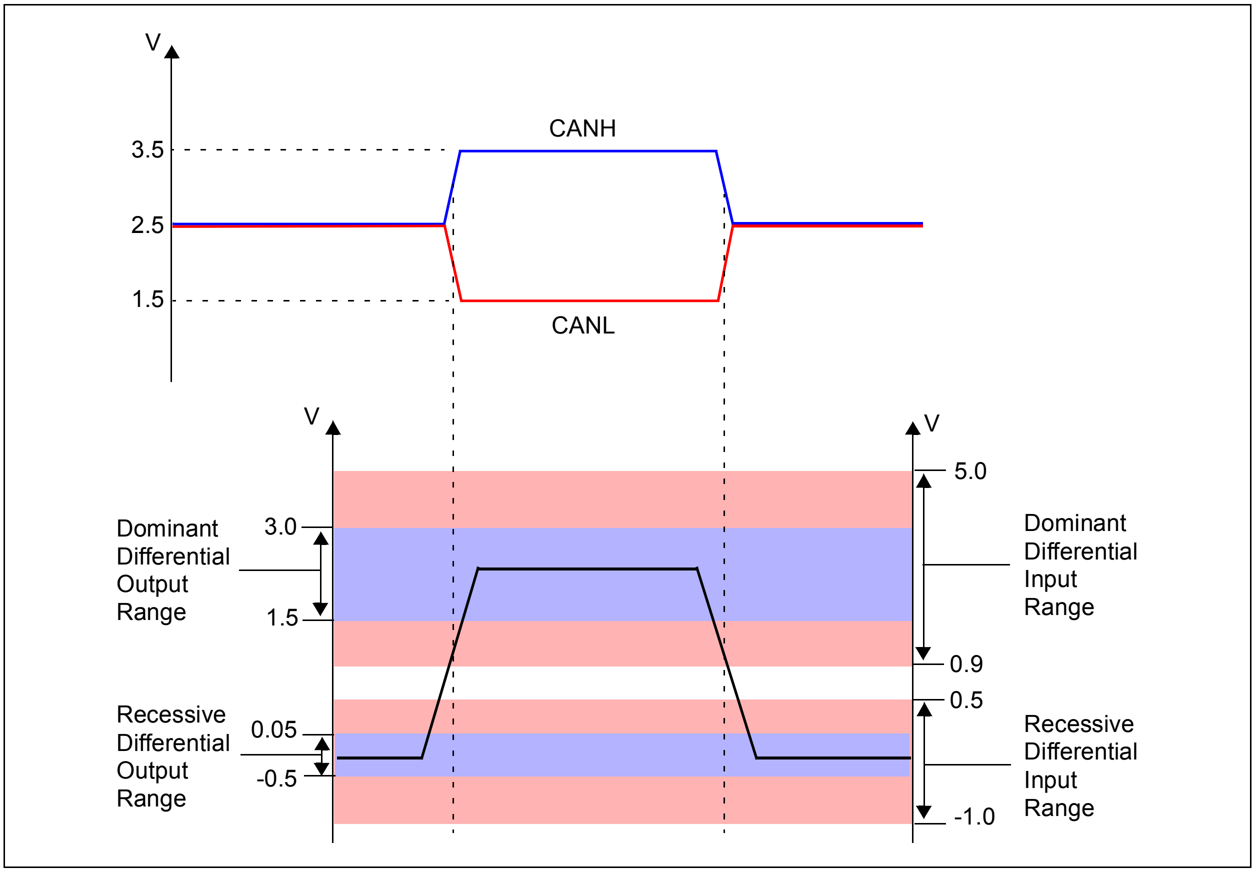
FIGURE 4: ISO11898 NOMINAL BUS LEVELS



Robustness

The ISO11898-2 specification requires that a compliant or compatible transceiver must meet a number of electrical specifications. Some of these specifications are intended to ensure the transceiver can survive harsh electrical conditions, thereby protecting the communications of the CAN node. The transceiver must survive short circuits on the CAN bus inputs from -3V to +32V and transient voltages from -150V to +100V. Table 1 shows the major ISO11898-2 electrical requirements, as well as MCP2551 specifications.

TABLE 1: COMPARING THE MCP2551 TO ISO11898-2

Parameter	ISO-11898-4		MCP2551		Unit	Comments
	min	max	min	max		
DC Voltage on CANH and CANL	-3	+32	-40	+40	V	Exceeds ISO-11898
Transient voltage on CANH and CANL	-150	+100	-250	+250	V	Exceeds ISO-11898
Common Mode Bus Voltage	-2.0	+7.0	-12	+12	V	Exceeds ISO-11898
Recessive Output Bus Voltage	+2.0	+3.0	+2.0	+3.0	V	Meets ISO-11898
Recessive Differential Output Voltage	-500	+50	-500	+50	mV	Meets ISO-11898
Differential Internal Resistance	10	100	20	100	kΩ	Meets ISO-11898
Common Mode Input Resistance	5.0	50	5.0	50	kΩ	Meets ISO-11898
Differential Dominant Output Voltage	+1.5	+3.0	+1.5	+3.0	V	Meets ISO-11898
Dominant Output Voltage (CANH)	+2.75	+4.50	+2.75	+4.50	V	Meets ISO-11898
Dominant Output Voltage (CANL)	+0.50	+2.25	+0.50	+2.25	V	Meets ISO-11898
Permanent Dominant Detection (Driver)	Not Required		1.25	—	ms	
Power-On Reset and Brown-Out Detection	Not Required		Yes		--	

Bus Lengths

ISO11898 specifies that a transceiver must be able to drive a 40m bus at 1 Mb/s. A longer bus length can be achieved by slowing the data rate. The biggest limitation to bus length is the transceiver's propagation delay.

PROPAGATION DELAY

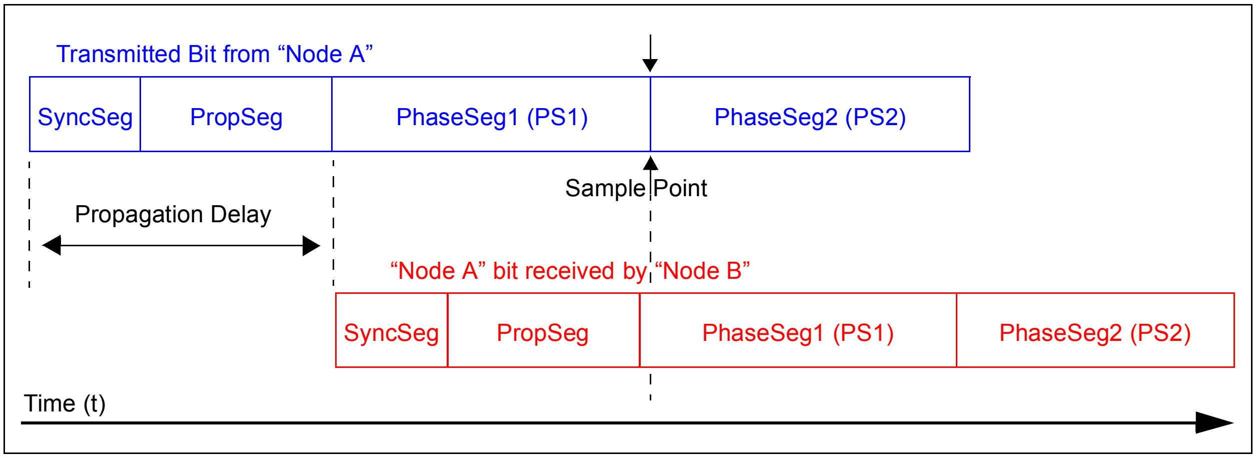
The CAN protocol has defined a recessive (logic '1') and dominant (logic '0') state to implement a non-destructive bit-wise arbitration scheme. It is this arbitration methodology that is affected most by propagation delays. Each node involved with arbitration must be able to sample each bit level within the same bit time. For example, if two nodes at opposite ends of the bus start to transmit their messages at the same time, they must arbitrate for control of the bus. This arbitration is only effective if both nodes are able to sample during the same bit time. Figure 5 shows a one-way propagation delay between two nodes. Extreme propagation delays (beyond the sample point) will result in invalid arbitration. This implies that bus lengths are limited at given CAN data rates.

A CAN system's propagation delay is calculated as being a signal's round-trip time on the physical bus (tbus), the output driver delay (tdrv) and the input comparator delay (tcmp). Assuming all nodes in the system have similar component delays, the propagation delay is explained mathematically:

EQUATION 1:

$$tprop = 2 \cdot (tbus + tcmp + tdrv)$$

FIGURE 5: ONE-WAY PROPAGATION DELAY



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MCP2551 CAN TRANSCEIVER

The MCP2551 is a CAN Transceiver that implements the ISO-11898-2 physical layer specification. It supports a 1 Mb/s data rate and is suitable for 12 V and 24 V systems. The MCP2551 provides short-circuit protection up to ±40V and transient protection up to ±250V.

In addition to being ISO-11898-2-compatible, the MCP2551 provides power-on reset and brown-out protection, as well as permanent dominant detection to ensure an unpowered or faulty node will not disturb the bus. The device implements configurable slope control on the bus pins to help reduce RFI emissions. Figure 6 shows the block diagram of the MCP2551.

General MCP2551 Operation

TRANSMIT

The CAN protocol controller outputs a serial data stream to the logic TXD input of the MCP2551. The corresponding recessive or dominant state is output on the CANH and CANL pins.

RECEIVE

The MCP2551 receives dominant or recessive states on the same CANH and CANL pins as the transmit occurs. These states are output as logic levels on the RXD pin for the CAN protocol controller to receive CAN frames.

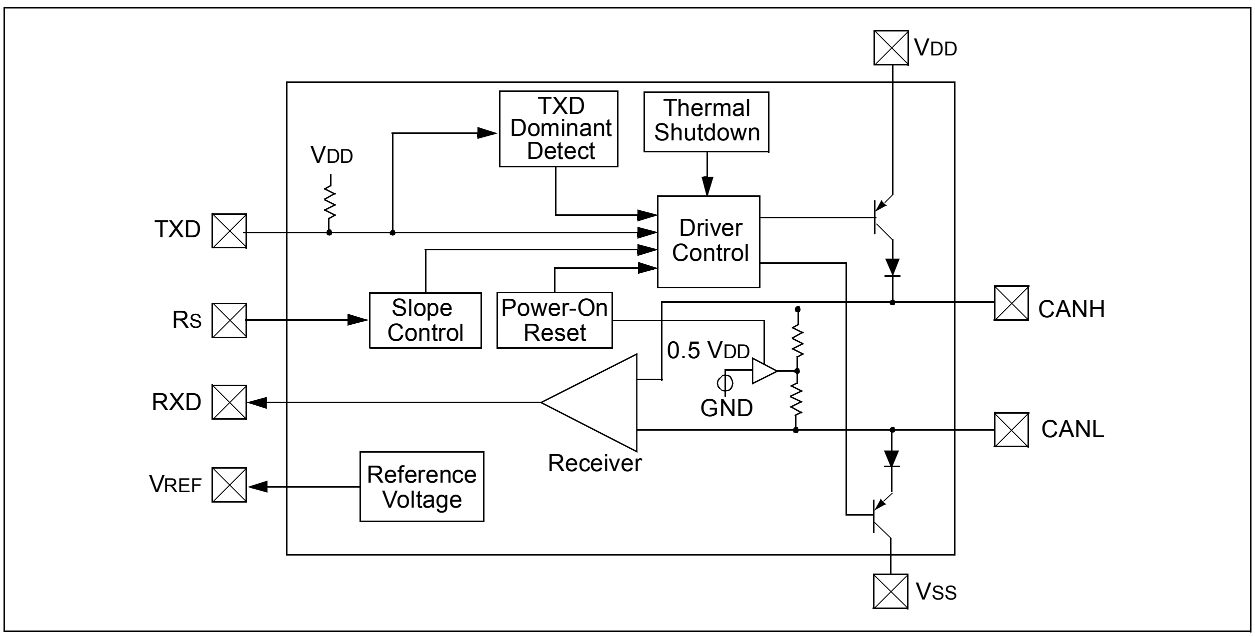
RECESSIVE STATE

A logic ‘1’ on the TXD input turns off the drivers to the CANH and CANL pins and the pins “float” to a nominal 2.5V via biasing resistors.

DOMINANT STATE

A logic ‘0’ on the TXD input turns on the CANH and CANL pin drivers. CANH drives ~1V higher than the nominal 2.5V recessive state to ~3.5V. CANL drives ~1V less than the nominal 2.5V recessive state to ~1.5V.

FIGURE 6: MCP2551 BLOCK DIAGRAM



Modes of Operation

There are three modes of operation that are externally controlled via the RS pin:

1. High-Speed
2. Slope Control
3. Standby

HIGH-SPEED

The high-speed mode is selected by connecting the RS pin to VSS. In this mode, the output drivers have fast rise and fall times that support the higher bus rates up to 1 Mb/s and/or maximum bus lengths by providing the minimum transceiver loop delays.

SLOPE CONTROL

If reduced EMI is required, the MCP2551 can be placed in slope control mode by connecting a resistor (REXT) from the RS pin to ground. In slope control mode, the single-ended slew rate (CANH or CANL) is basically proportional to the current out of the RS pin. The current must be in the range of 10 µA < -IRS < 200 µA, which corresponds to a voltage on the pin of 0.4 VDD < VRS < 0.6 VDD respectively (or 0.5 VDD typical).

The decreased slew rate implies a slower CAN data rate at a given bus length, or a reduced bus length at a given CAN data rate.

STANDBY

Standby (or sleep) mode is entered by connecting the RS pin to VDD. In sleep mode, the transmitter is switched off and the receiver operates in a reduced power mode. While the receive pin (RXD) is still functional, it will operate at a slower rate.

Standby mode can be used to place the device in low power mode and to turn off the transmitter in case the CAN controller malfunctions and sends unexpected data to the bus.

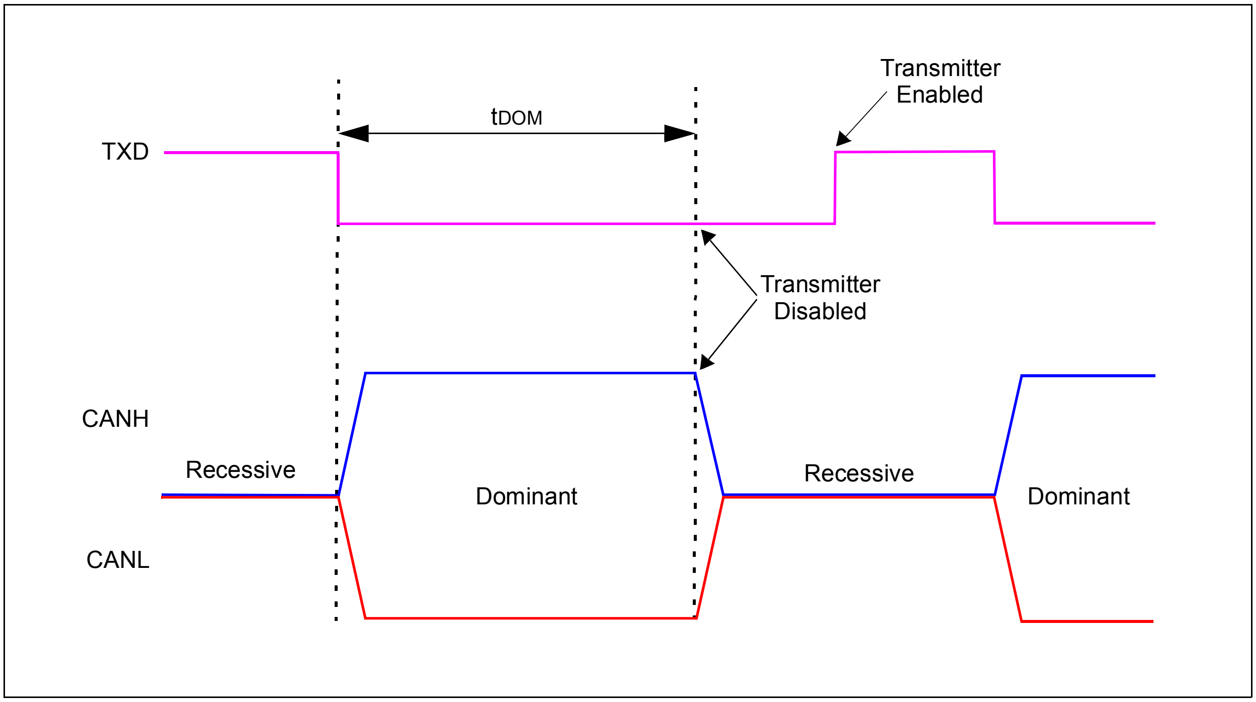
Permanent Dominant Detection on Transmitter

The MCP2551 will turn off the transmitter to CANH and CANL if an extended dominant state is detected on the transmitter. This ability prevents a faulty node (CAN controller or MCP2551) from permanently corrupting the CAN bus.

The drivers are disabled if TXD is low for more than ~1.25 ms (minimum) (See Figure 7).

The drivers will remain disabled as long as TXD remains low. A rising edge on TXD will reset the timer logic and enable the drivers.

FIGURE 7: TXD PERMANENT DOMINANT DETECTION



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Power-On Reset and Brown-Out

The MCP2551 incorporates both Power-On Reset (POR) and Brown-Out Detection (BOD) (see Figure 8).

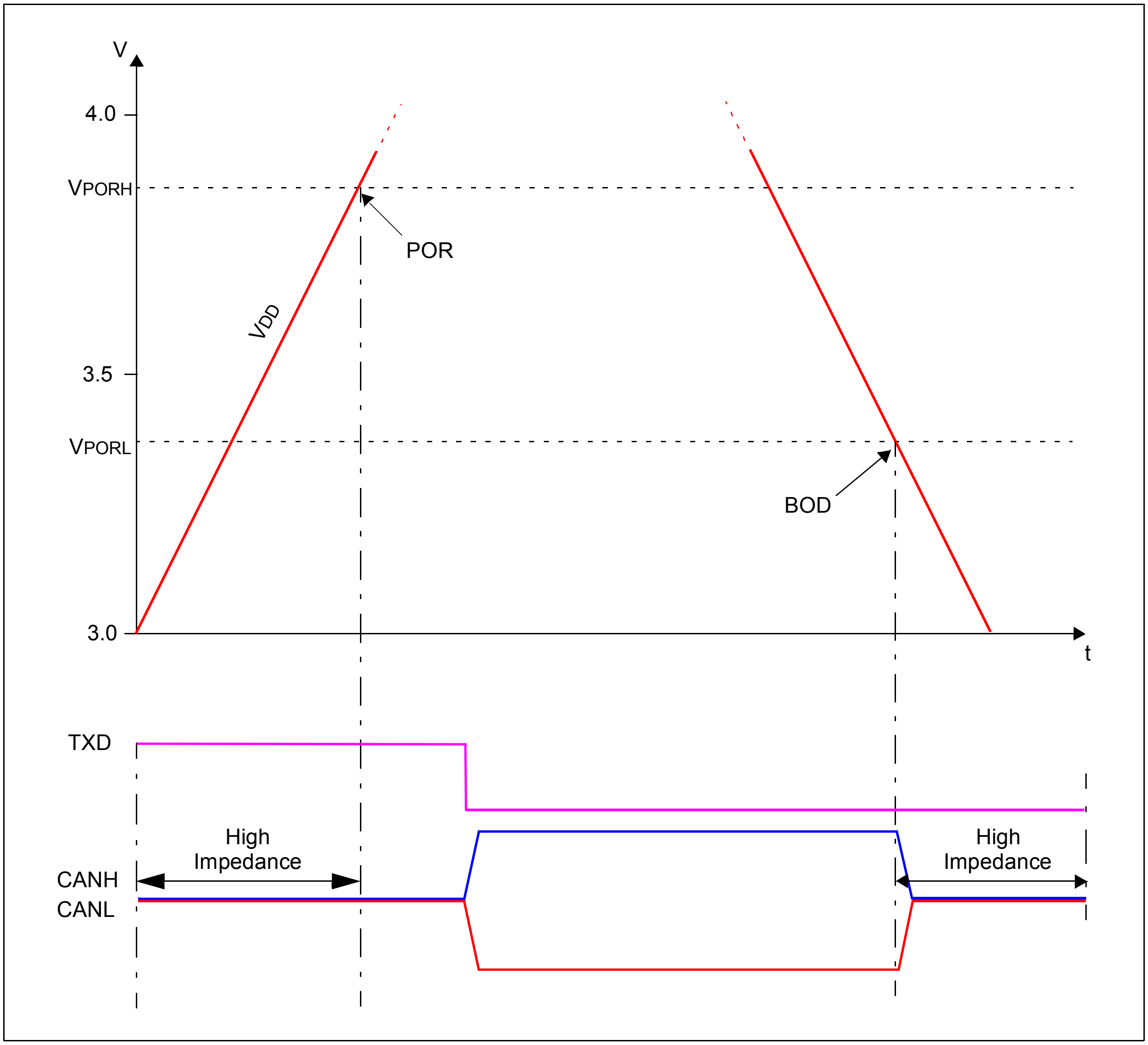
POWER-ON RESET (POR)

When the MCP2551 is powered on, the CANH and CANL pins remain in the high impedance state until V_{DD} reaches the POR high voltage (V_{PORH}). Additionally, if the TXD pin is low at power-up, the CANH and CANL pins will remain in high impedance until TXD goes high. After which, the drivers will function normally.

BROWN-OUT DETECTION (BOD)

BOD occurs when V_{DD} goes below the power-on reset low voltage (V_{PORL}). At this point, the CANH and CANL pins enter a high impedance state and will remain there until V_{PORH} is reached.

FIGURE 8: POWER-ON RESET AND BROWN-OUT DETECTION



Ground Offsets

Since it is not required to provide a common ground between nodes, it is possible to have ground offsets between nodes. That is, each node may observe different single-ended bus voltages (common mode bus voltages) while maintaining the same differential voltage. While the MCP2551 is specified to handle ground offsets from -12V to +12V, the ISO-11898 specification only requires -2V to +7V. Figure 9 and Figure 10 demonstrate how ground offsets appear between nodes.

Figure 9 shows the transmitting node with a positive ground offset with respect to the receiving node. The MCP2551 receiver can operate with CANH = +12V. The maximum CAN dominant output voltage ($V_{O(CANH)}$) from the transmitting node is 4.5V. Subtracting this maximum yields an actual ground offset (with respect to the receiving node) of 7.5V for the transmitting node. In the recessive state, each node attempts to pull the CANH and CANL pins to their biasing levels (2.5V typical). However, the resulting common mode voltage in the recessive state becomes 6.25V for the receiving node and -1.25V for the transmitting node.

Figure 10 shows the transmitting node with a negative ground offset with respect to the receiving node. The MCP2551 receiver can operate with CANL = -12V. The minimum CAN dominant output voltage ($V_{O(CANL)}$) from the transmitting node is 0.5V. Subtracting this minimum yields an actual ground offset, with respect to the receiving node, of -12.5V. The common mode voltage for the recessive state is -6.25V for the receiving node and 6.25V for the transmitting node.

Since all nodes act as a transmitter for a portion of each message (i.e., each receiver must acknowledge (ACK) valid messages during the ACK slot), the largest ground offset allowed between nodes is 7.5V, as shown in Figure 9.

Operating a CAN system with large ground offsets can lead to increased electromagnetic emissions. Steps must be taken to eliminate ground offsets if the system is sensitive to emissions.

FIGURE 9: RECEIVING (NODE GROUND) BELOW TRANSMITTING (NODE GROUND)

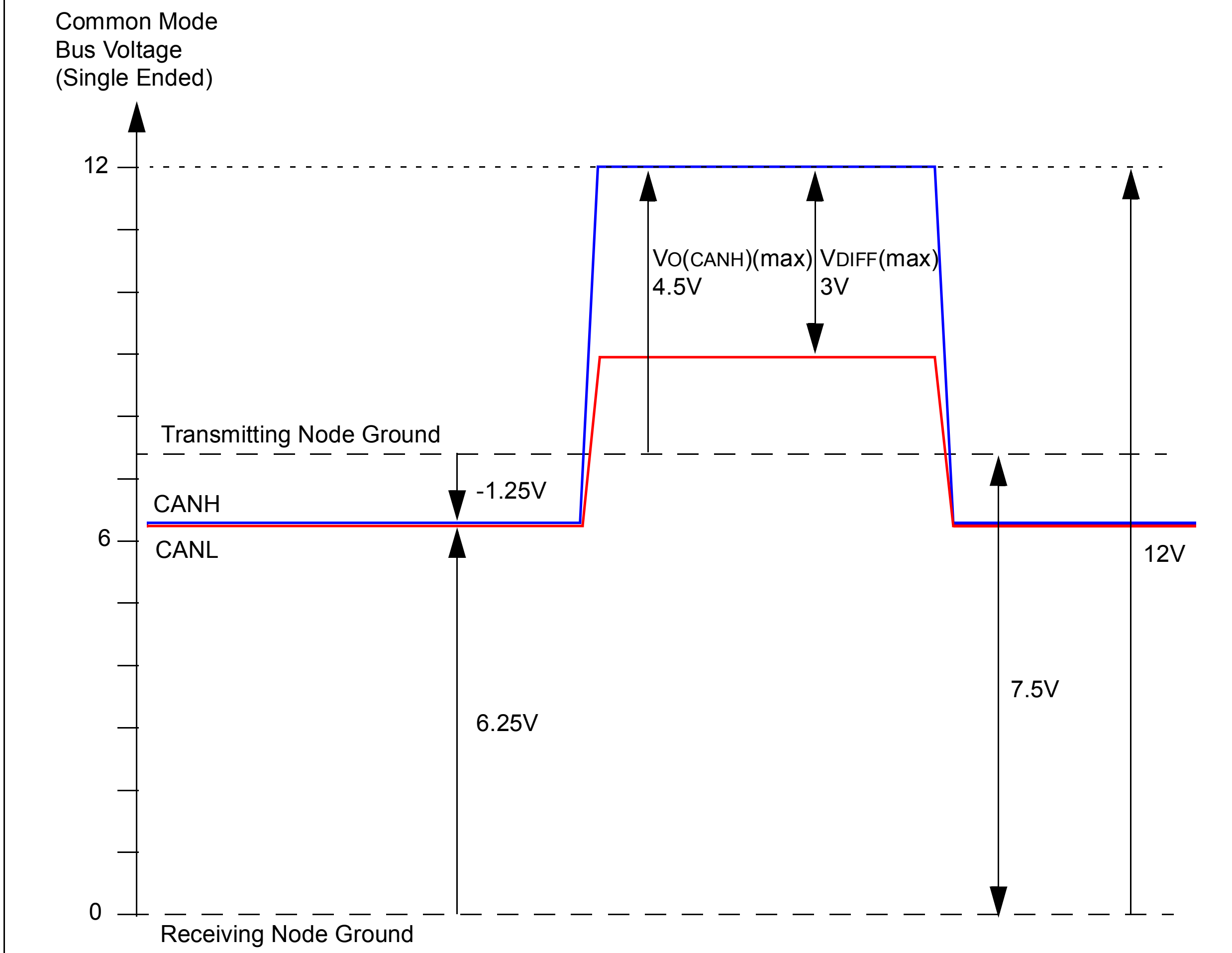


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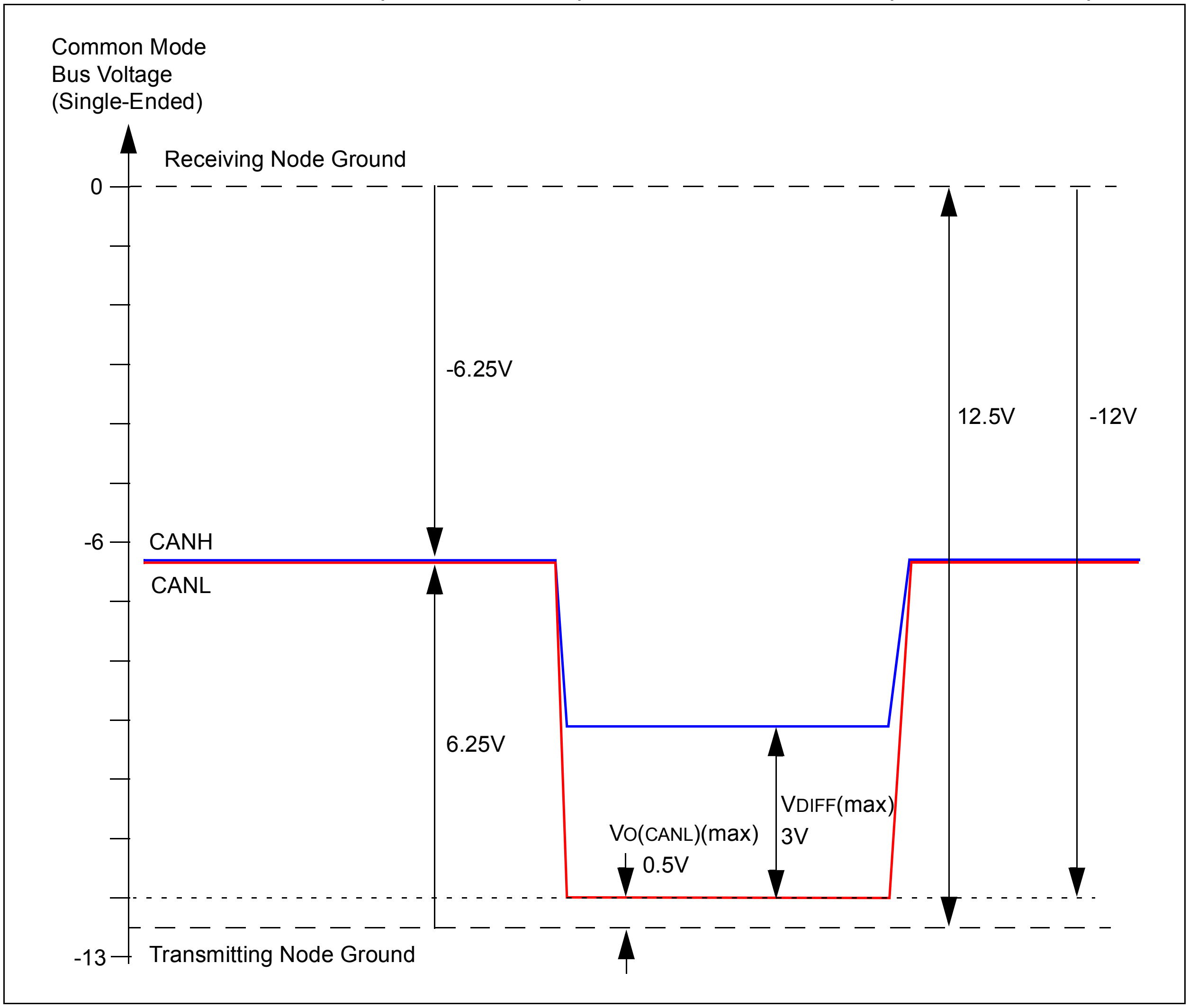
FIGURE 10: RECEIVING (NODE GROUND) ABOVE TRANSMITTING (NODE GROUND)



BUS TERMINATION

Bus termination is used to minimize signal reflection on the bus. ISO-11898 requires that the CAN bus have a nominal characteristic line impedance of 120Ω. Therefore, the typical terminating resistor value for each end of the bus is 120Ω. There are a few different termination methods used to help increase EMC performance (see Figure 11).

1. Standard Termination
2. Split Termination
3. Biased Split Termination

> **Note:** EMC performance is not determined solely by the transceiver and termination method, but rather by careful consideration of all components and topology of the system.

Standard Termination

As the name implies, this termination uses a single 120Ω resistor at each end of the bus. This method is acceptable in many CAN systems.

Split Termination

Split termination is a concept that is growing in popularity because emission reduction can be achieved very easily. Split termination is a modified standard termination in which the single 120Ω resistor on each end of the bus is split into two 60Ω resistors, with a bypass capacitor tied between the resistors and to ground. The two resistors should match as close as possible.

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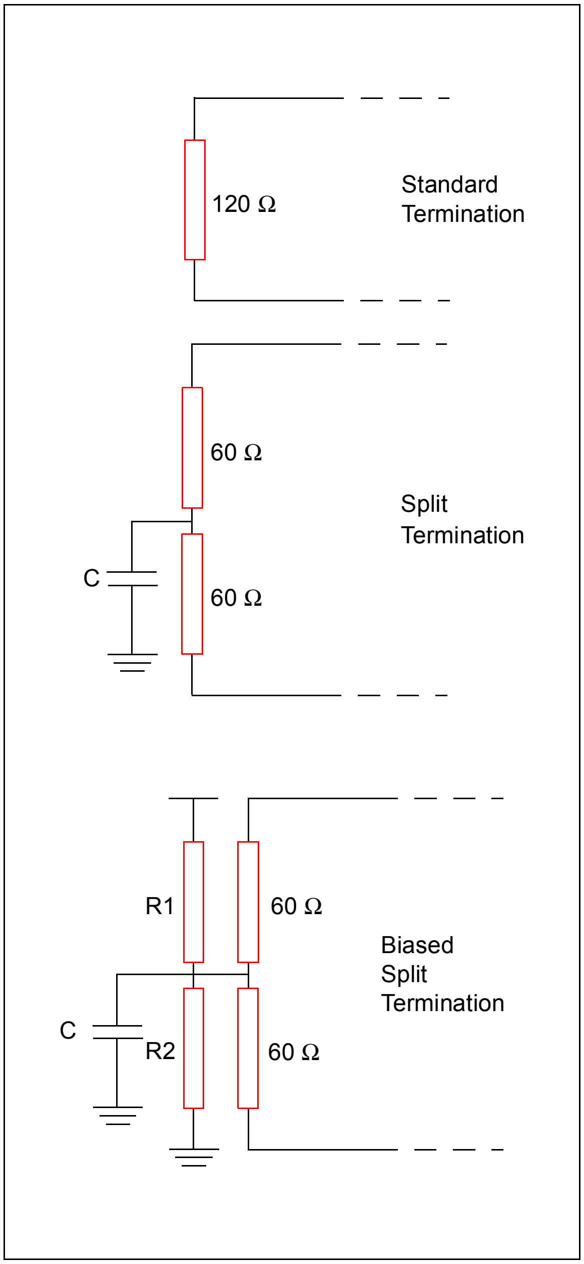
Biased Split Termination

This termination method is used to maintain the common mode recessive voltage at a constant value, thereby increasing EMC performance. This circuit is the same as the split termination with the addition of a voltage divider circuit to achieve a voltage of $V_{DD}/2$ between the two 60 Ω resistors (see Figure 11).

> **Note:** The biasing resistors in Figure 11, as well as the split termination resistors, should match as close as possible.

FIGURE 11: TERMINATION CONCEPTS



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