



## A CAN Physical Layer Discussion

Author: Pat Richards  
Microchip Technology Inc.

### 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.

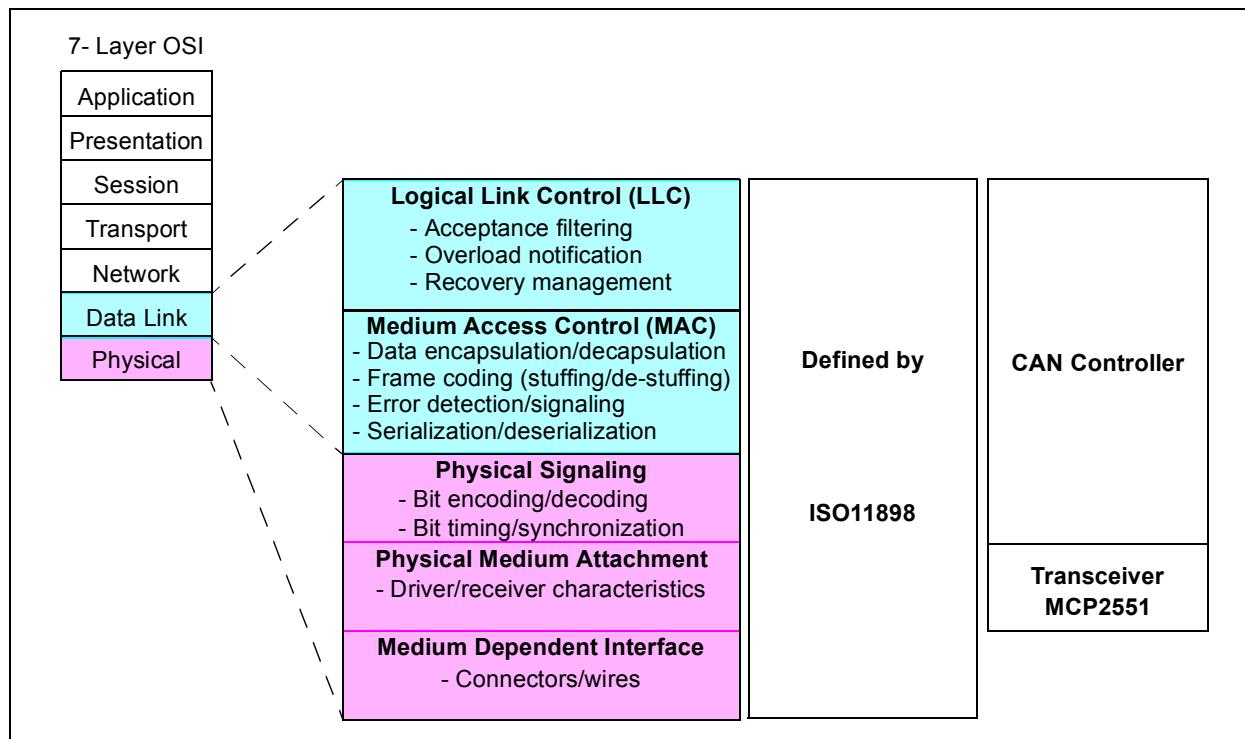
The Data Link Layer is defined by the CAN specification. The Logical Link Control (LLC) manages the overload control and notification, message filtering and recovery management functions. The Medium Access Control (MAC) performs the data encapsulation/decapsulation, error detection and control, bit stuffing/de-stuffing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

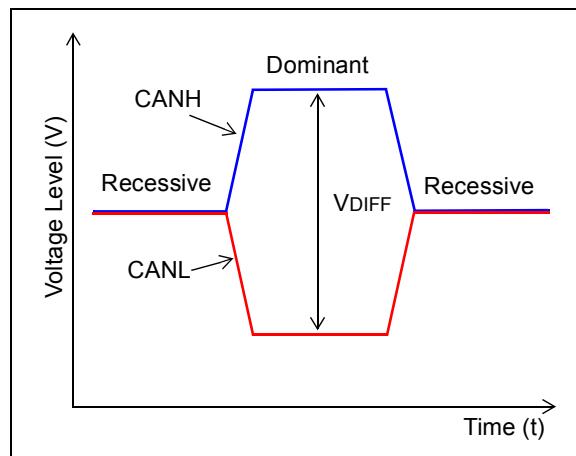
### Bus Levels

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  $120\Omega$  (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

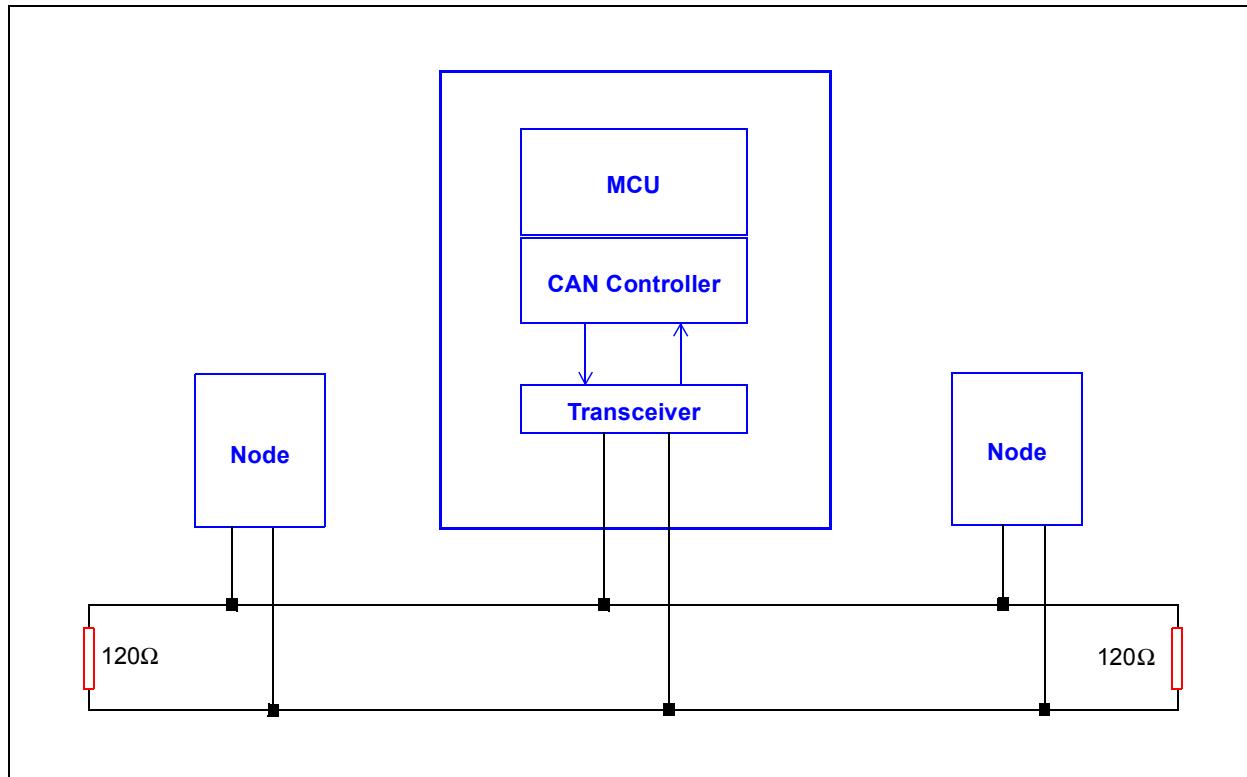
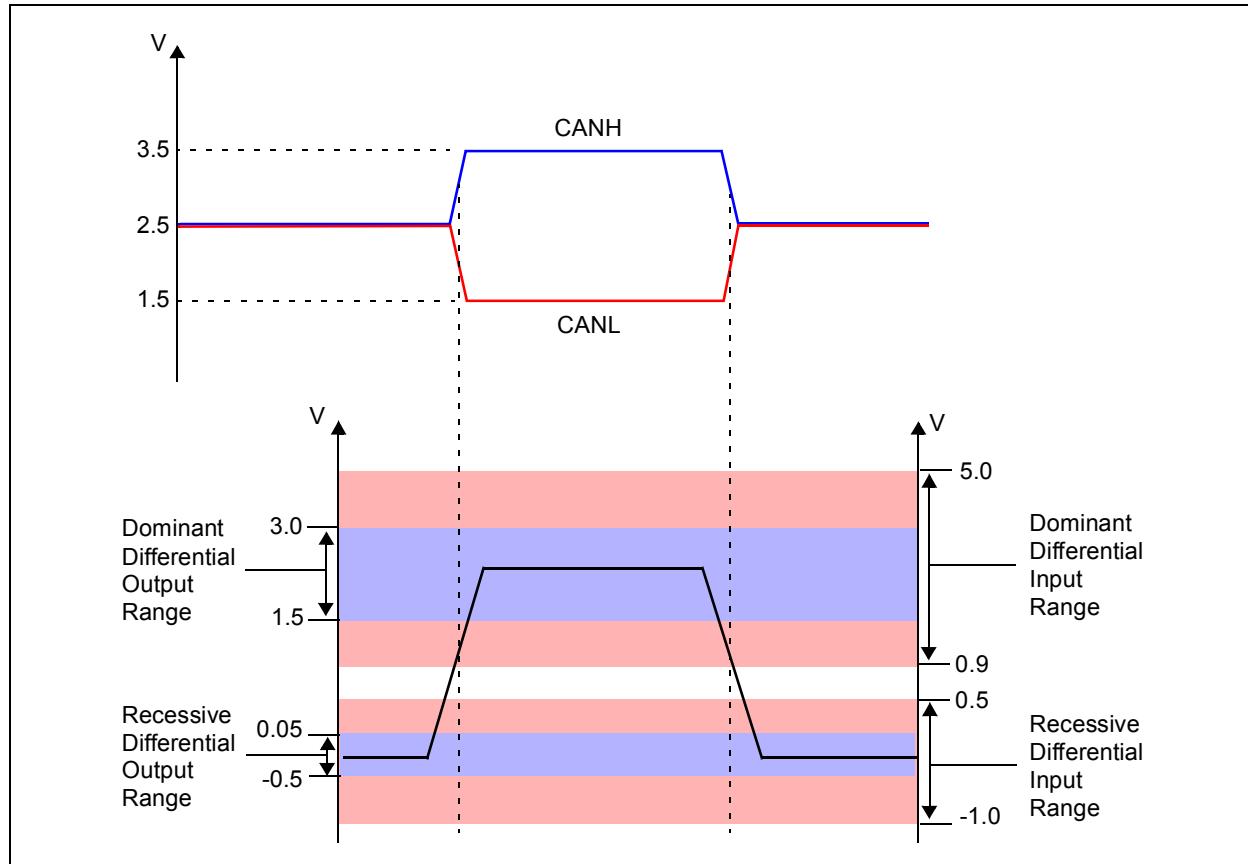


FIGURE 4: ISO11898 NOMINAL BUS LEVELS



### 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

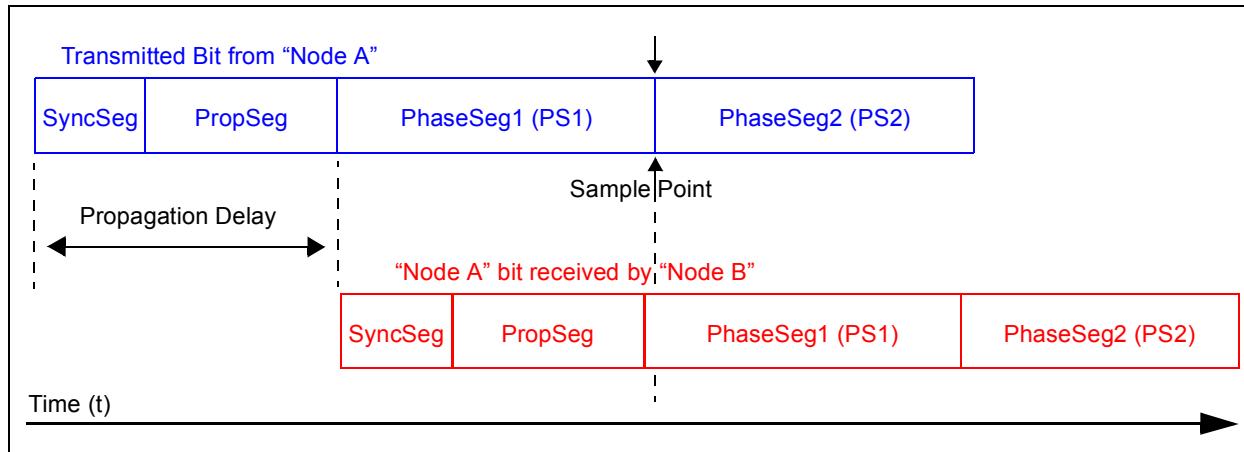
the same bit time. Figure 5 shows a one-way propagation delay between two nodes. Extreme propagation delays (beyond the sample point) will result in invalid arbitration. This implies that bus lengths are limited at given CAN data rates.

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

### EQUATION 1:

$$t_{prop} = 2 \cdot (t_{bus} + t_{cmp} + t_{drv})$$

**FIGURE 5: ONE-WAY PROPAGATION DELAY**



## 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  $\pm 40V$  and transient protection up to  $\pm 250V$ .

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.

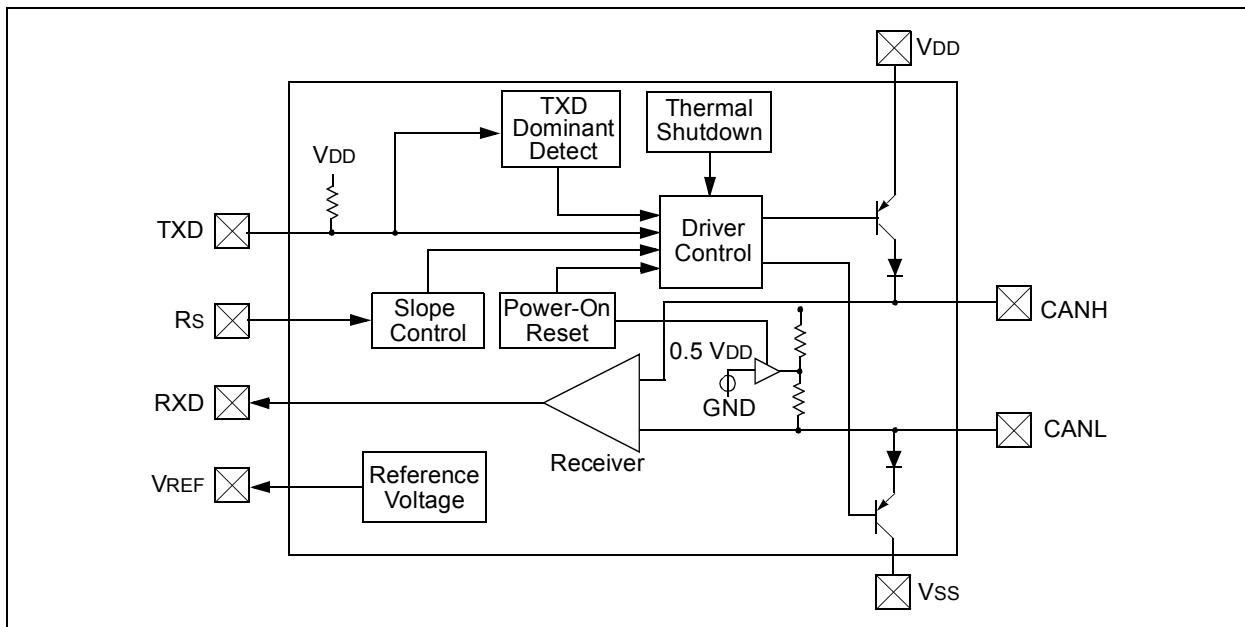
### RECESSIVE STATE

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  $\sim 1V$  higher than the nominal 2.5V recessive state to  $\sim 3.5V$ . CANL drives  $\sim 1V$  less than the nominal 2.5V recessive state to  $\sim 1.5V$ .

**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  $10 \mu A < -I_{RS} < 200 \mu A$ , which corresponds to a voltage on the pin of  $0.4 VDD < V_{RS} < 0.6 VDD$  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.

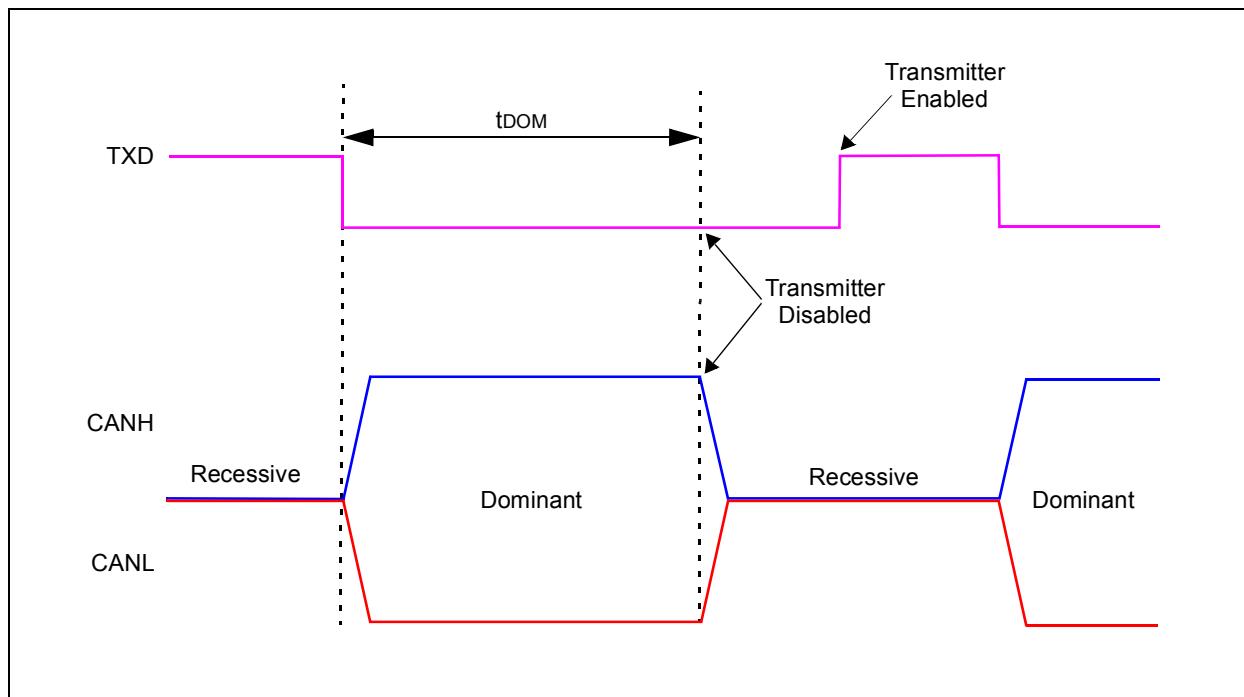
### Permanent Dominant Detection on Transmitter

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**



## 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)

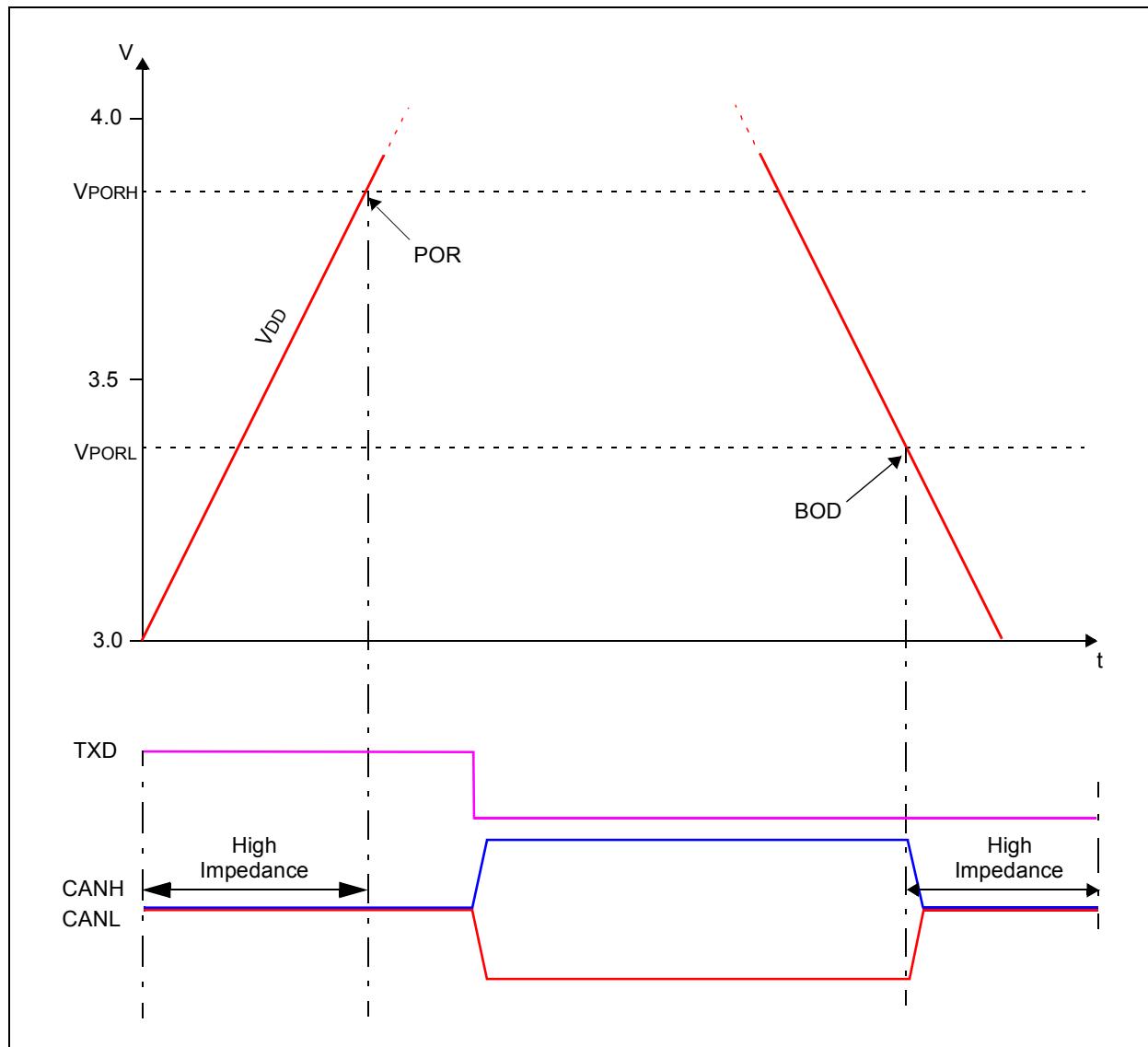
When the MCP2551 is powered on, the CANH and CANL pins remain in the high impedance state until VDD reaches the POR high voltage (VPORH). Additionally, if the TXD pin is low at power-up, the

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 VDD goes below the power-on reset low voltage (VPORL). At this point, the CANH and CANL pins enter a high impedance state and will remain there until VPORH 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

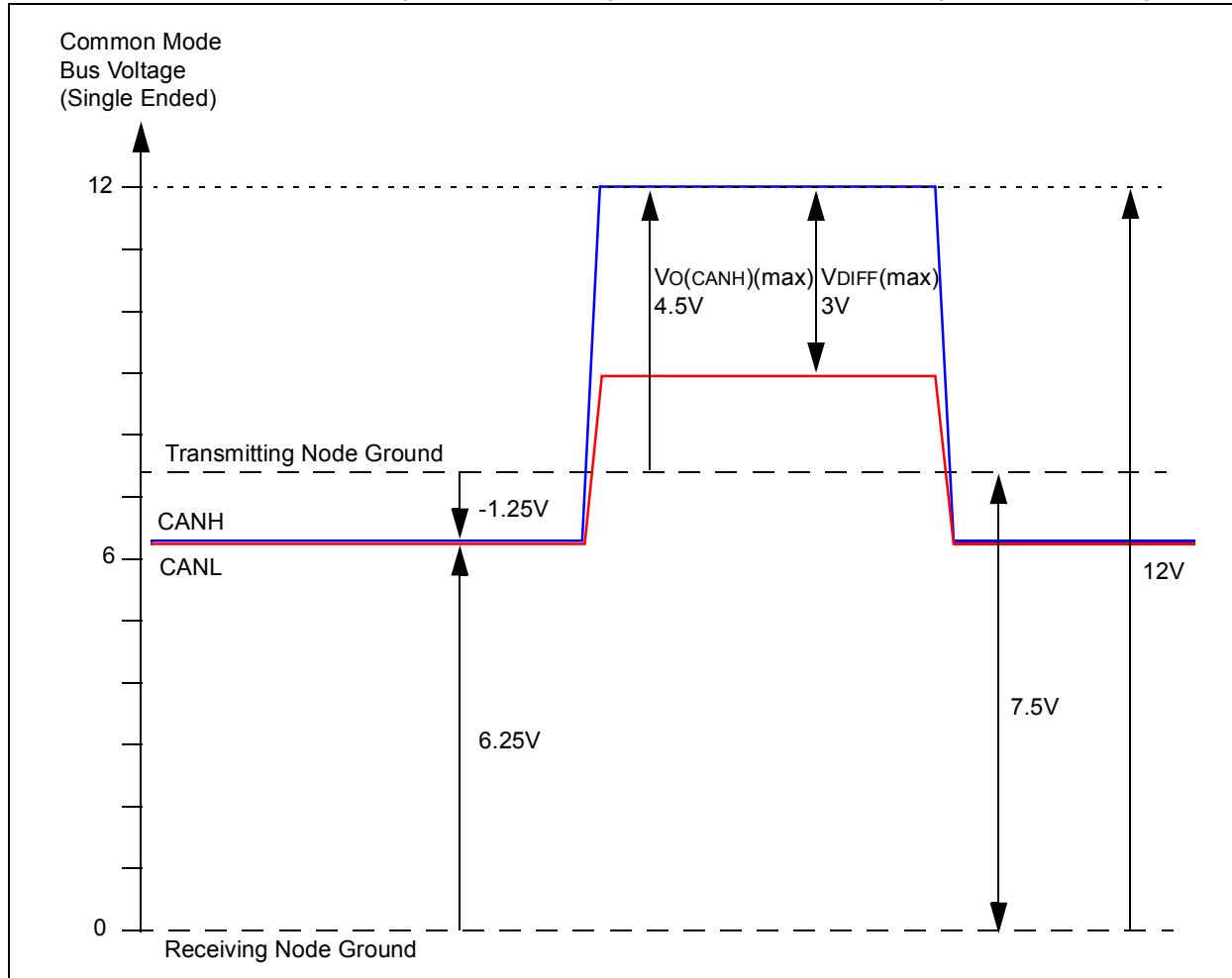
(2.5V typical). However, the resulting common mode voltage in the recessive state becomes 6.25V for the receiving node and -1.25V for the transmitting node.

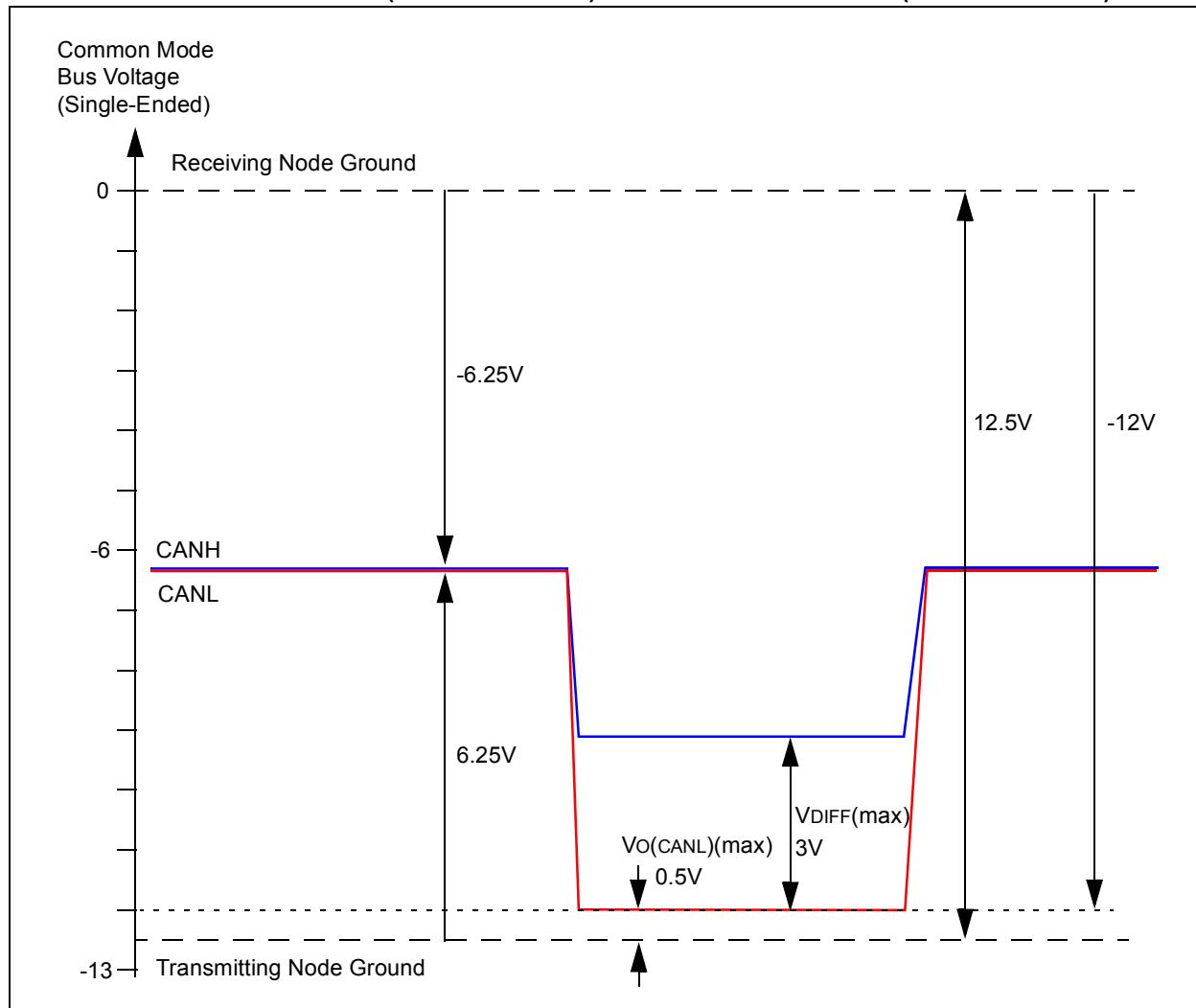
Figure 10 shows the transmitting node with a negative ground offset with respect to the receiving node. The MCP2551 receiver can operate with CANL = -12V. The minimum CAN dominant output voltage ( $V_o(CANL)$ ) from the transmitting node is 0.5V. Subtracting this minimum yields an actual ground offset, 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)**



**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  $120\Omega$ . Therefore, the typical terminating resistor value for each end of the bus is  $120\Omega$ . 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  $120\Omega$  resistor at each end of the bus. This method is acceptable in many CAN systems.

## Split Termination

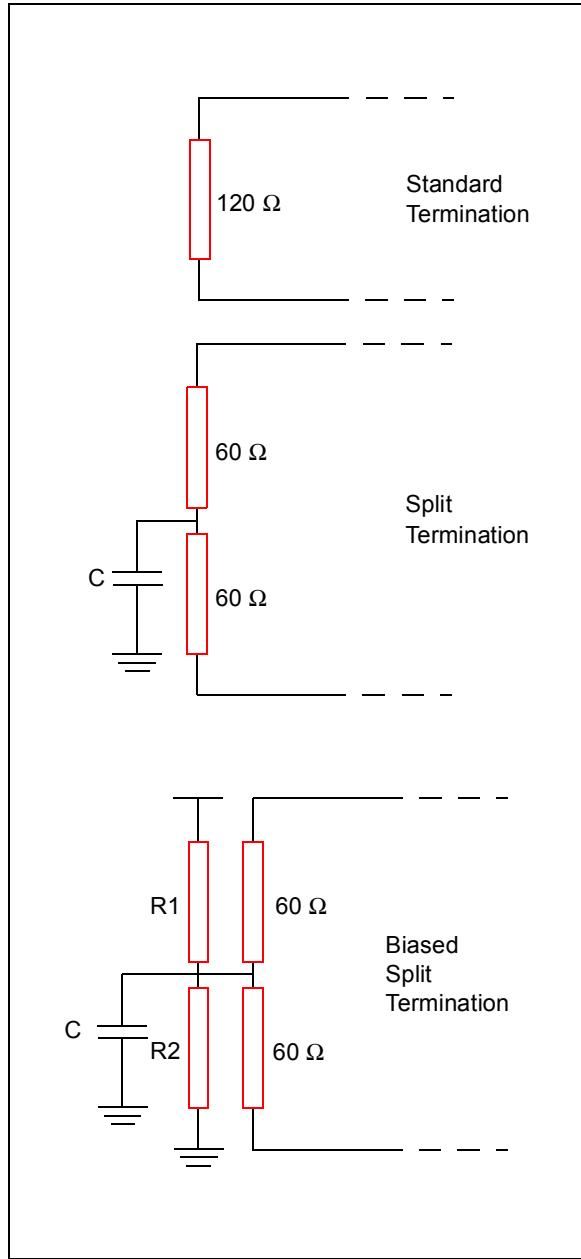
Split termination is a concept that is growing in popularity because emission reduction can be achieved very easily. Split termination is a modified standard termination in which the single  $120\Omega$  resistor on each end of the bus is split into two  $60\Omega$  resistors, with a bypass capacitor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

## 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  $VDD/2$  between the two  $60\ \Omega$  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**



## REFERENCES

MCP2551 Data Sheet, "High Speed CAN Transceiver", DS21667, Microchip Technology, Inc.

AN754, "Understanding Microchip's CAN Module Bit Timing", DS00754, Microchip Technology, Inc.

ISO-11898-2, "Road Vehicles - Interchange of Digital Information - Part 2: High Speed Medium Access Unit and Medium Dependant Interface", International Organization for Standardization.

CAN System Engineering, "From Theory to Practical Applications", Wolfhard Lawrenz, Springer.

---

---

**Note the following details of the code protection feature on Microchip devices:**

- Microchip products meet the specification contained in their particular Microchip Data Sheet.
- Microchip believes that its family of products is one of the most secure families of its kind on the market today, when used in the intended manner and under normal conditions.
- There are dishonest and possibly illegal methods used to breach the code protection feature. All of these methods, to our knowledge, require using the Microchip products in a manner outside the operating specifications contained in Microchip's Data Sheets. Most likely, the person doing so is engaged in theft of intellectual property.
- Microchip is willing to work with the customer who is concerned about the integrity of their code.
- Neither Microchip nor any other semiconductor manufacturer can guarantee the security of their code. Code protection does not mean that we are guaranteeing the product as "unbreakable."

Code protection is constantly evolving. We at Microchip are committed to continuously improving the code protection features of our products.

---

Information contained in this publication regarding device applications and the like is intended through suggestion only and may be superseded by updates. It is your responsibility to ensure that your application meets with your specifications. No representation or warranty is given and no liability is assumed by Microchip Technology Incorporated with respect to the accuracy or use of such information, or infringement of patents or other intellectual property rights arising from such use or otherwise. Use of Microchip's products as critical components in life support systems is not authorized except with express written approval by Microchip. No licenses are conveyed, implicitly or otherwise, under any intellectual property rights.

#### Trademarks

The Microchip name and logo, the Microchip logo, KEELOQ, MPLAB, PIC, PICmicro, PICSTART and PRO MATE are registered trademarks of Microchip Technology Incorporated in the U.S.A. and other countries.

FilterLab, microID, MXDEV, MXLAB, PICMASTER, SEEVAL and The Embedded Control Solutions Company are registered trademarks of Microchip Technology Incorporated in the U.S.A.

dsPIC, dsPICDEM.net, ECONOMONITOR, FanSense, FlexROM, fuzzyLAB, In-Circuit Serial Programming, ICSP, ICEPIC, microPort, Migratable Memory, MPASM, MPLIB, MPLINK, MPSIM, PICC, PICDEM, PICDEM.net, rfPIC, Select Mode and Total Endurance are trademarks of Microchip Technology Incorporated in the U.S.A. and other countries.

Serialized Quick Turn Programming (SQTP) is a service mark of Microchip Technology Incorporated in the U.S.A.

All other trademarks mentioned herein are property of their respective companies.

© 2002, Microchip Technology Incorporated, Printed in the U.S.A., All Rights Reserved.

 Printed on recycled paper.



Microchip received QS-9000 quality system certification for its worldwide headquarters, design and wafer fabrication facilities in Chandler and Tempe, Arizona in July 1999 and Mountain View, California in March 2002. The Company's quality system processes and procedures are QS-9000 compliant for its PICmicro® 8-bit MCUs, KEELOQ® code hopping devices, Serial EEPROMS, microperipherals, non-volatile memory and analog products. In addition, Microchip's quality system for the design and manufacture of development systems is ISO 9001 certified.



# MICROCHIP

## WORLDWIDE SALES AND SERVICE

### AMERICAS

#### Corporate Office

2355 West Chandler Blvd.  
Chandler, AZ 85224-6199  
Tel: 480-792-7200 Fax: 480-792-7277  
Technical Support: 480-792-7627  
Web Address: <http://www.microchip.com>

#### Rocky Mountain

2355 West Chandler Blvd.  
Chandler, AZ 85224-6199  
Tel: 480-792-7966 Fax: 480-792-4338

#### Atlanta

500 Sugar Mill Road, Suite 200B  
Atlanta, GA 30350  
Tel: 770-640-0034 Fax: 770-640-0307

#### Boston

2 Lan Drive, Suite 120  
Westford, MA 01886  
Tel: 978-692-3848 Fax: 978-692-3821

#### Chicago

333 Pierce Road, Suite 180  
Itasca, IL 60143  
Tel: 630-285-0071 Fax: 630-285-0075

#### Dallas

4570 Westgrove Drive, Suite 160  
Addison, TX 75001  
Tel: 972-818-7423 Fax: 972-818-2924

#### Detroit

Tri-Atria Office Building  
32255 Northwestern Highway, Suite 190  
Farmington Hills, MI 48334  
Tel: 248-538-2250 Fax: 248-538-2260

#### Kokomo

2767 S. Albright Road  
Kokomo, Indiana 46902  
Tel: 765-864-8360 Fax: 765-864-8387

#### Los Angeles

18201 Von Karman, Suite 1090  
Irvine, CA 92612  
Tel: 949-263-1888 Fax: 949-263-1338

#### San Jose

Microchip Technology Inc.  
2107 North First Street, Suite 590  
San Jose, CA 95131  
Tel: 408-436-7950 Fax: 408-436-7955

#### Toronto

6285 Northham Drive, Suite 108  
Mississauga, Ontario L4V 1X5, Canada  
Tel: 905-673-0699 Fax: 905-673-6509

### ASIA/PACIFIC

#### Australia

Microchip Technology Australia Pty Ltd  
Suite 22, 41 Rawson Street  
Epping 2121, NSW  
Australia  
Tel: 61-2-9868-6733 Fax: 61-2-9868-6755

#### China - Beijing

Microchip Technology Consulting (Shanghai)  
Co., Ltd., Beijing Liaison Office  
Unit 915  
Bei Hai Wan Tai Bldg.  
No. 6 Chaoyangmen Beidajie  
Beijing, 100027, No. China  
Tel: 86-10-85282100 Fax: 86-10-85282104

#### China - Chengdu

Microchip Technology Consulting (Shanghai)  
Co., Ltd., Chengdu Liaison Office  
Rm. 2401, 24th Floor,  
Ming Xing Financial Tower  
No. 88 TIDU Street  
Chengdu 610016, China  
Tel: 86-28-86766200 Fax: 86-28-86766599

#### China - Fuzhou

Microchip Technology Consulting (Shanghai)  
Co., Ltd., Fuzhou Liaison Office  
Unit 28F, World Trade Plaza  
No. 71 Wusi Road  
Fuzhou 350001, China  
Tel: 86-591-7503506 Fax: 86-591-7503521

#### China - Shanghai

Microchip Technology Consulting (Shanghai)  
Co., Ltd.  
Room 701, Bldg. B  
Far East International Plaza  
No. 317 Xian Xia Road  
Shanghai, 200051  
Tel: 86-21-6275-5700 Fax: 86-21-6275-5060

#### China - Shenzhen

Microchip Technology Consulting (Shanghai)  
Co., Ltd., Shenzhen Liaison Office  
Rm. 1315, 13/F, Shenzhen Kerry Centre,  
Renmin Lu  
Shenzhen 518001, China  
Tel: 86-755-82350361 Fax: 86-755-82366086

#### China - Hong Kong SAR

Microchip Technology Hongkong Ltd.  
Unit 901-6, Tower 2, Metropiazza  
223 Hing Fong Road  
Kwai Fong, N.T., Hong Kong  
Tel: 852-2401-1200 Fax: 852-2401-3431

#### India

Microchip Technology Inc.  
India Liaison Office  
Divyasree Chambers  
1 Floor, Wing A (A3/A4)  
No. 11, O'Shaugnessy Road  
Bangalore, 560 025, India  
Tel: 91-80-2290061 Fax: 91-80-2290062

### Japan

Microchip Technology Japan K.K.  
Benex S-1 6F  
3-18-20, Shinyokohama  
Kohoku-Ku, Yokohama-shi  
Kanagawa, 222-0033, Japan  
Tel: 81-45-471-6166 Fax: 81-45-471-6122

### Korea

Microchip Technology Korea  
168-1, Youngbo Bldg. 3 Floor  
Samsung-Dong, Kangnam-Ku  
Seoul, Korea 135-882  
Tel: 82-2-554-7200 Fax: 82-2-558-5934

### Singapore

Microchip Technology Singapore Pte Ltd.  
200 Middle Road  
#07-02 Prime Centre  
Singapore, 188980  
Tel: 65-6334-8870 Fax: 65-6334-8850

### Taiwan

Microchip Technology (Barbados) Inc.,  
Taiwan Branch  
11F-3, No. 207  
Tung Hua North Road  
Taipei, 105, Taiwan  
Tel: 886-2-2717-7175 Fax: 886-2-2545-0139

### EUROPE

#### Austria

Microchip Technology Austria GmbH  
Durisolstrasse 2  
A-4600 Wels  
Austria  
Tel: 43-7242-2244-399  
Fax: 43-7242-2244-393

#### Denmark

Microchip Technology Nordic ApS  
Regus Business Centre  
Lautrup høj 1-3  
Ballerup DK-2750 Denmark  
Tel: 45 4420 9895 Fax: 45 4420 9910

#### France

Microchip Technology SARL  
Parc d'Activite du Moulin de Massy  
43 Rue du Saule Trapu  
Batiment A - 1er Eteage  
91300 Massy, France  
Tel: 33-1-69-53-63-20 Fax: 33-1-69-30-90-79

#### Germany

Microchip Technology GmbH  
Steinheilstrasse 10  
D-85737 Ismaning, Germany  
Tel: 49-89-627-144 0 Fax: 49-89-627-144-44

#### Italy

Microchip Technology SRL  
Centro Direzionale Colleoni  
Palazzo Taurus 1 V. Le Colleoni 1  
20041 Agrate Brianza  
Milan, Italy  
Tel: 39-039-65791-1 Fax: 39-039-6899883

#### United Kingdom

Microchip Ltd.  
505 Eskdale Road  
Winnersh Triangle  
Wokingham  
Berkshire, England RG41 5TU  
Tel: 44 118 921 5869 Fax: 44-118 921-5820

10/18/02