CAN (Controller Area Network) Physical Layer

Technical Training

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Systems Engineering
Industrial Interface

Networking Overview

Networking: OSI 7 Layer Model

- Open Systems Interconnection Basic Reference Model (*OSI Reference Model* or *OSI Model* for short) is a layered, abstract description for communications and computer network protocol design. It was developed as part of the Open Systems Interconnection (OSI) initiative and is sometimes known as the OSI seven layer model. From top to bottom, the OSI Model consists of the Application, Presentation, Session, Transport, Network, Data Link, and Physical layers.

- Data Link Layer = Ethernet MAC / CAN controller on TI MCU / DSP / uP

- Physical Layer = Transceivers / PHY
  - TI CAN, Ethernet, RS-485, RS-232, LIN, etc interface

OSI Model			
	Data unit	**Layer**	**Function**
Host layers	Data	7. Application	Network process to application
		6. Presentation	Data representation and encryption
		5. Session	Interhost communication
	Segment	4. Transport	End-to-end connections and reliability (TCP)
Media layers	Packet/Datagram	3. Network	Path determination and logical addressing (IP)
	Frame	2. Data link	Physical addressing (MAC & LLC)
	Bit	1. Physical	Media, signal and binary transmission

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Controller Area Network (CAN) ISO 11898

Network and Physical Layer Basics

ISO11898 CAN Standard

- ISO 11898 is the general ISO specification for CAN which is based (derived from the original Bosch standard). The original version from 1993 was just ISO11898, but in subsequent updates & revisions the standard has been divided into parts (ISO11898-x).

- Part 1: Data link layer and physical signaling (MAC or CAN controller)
  - TI has this protocol level built into MCUs and DSPs
- **Part 2: High speed medium access (Transceiver)**
  - **SN65HVD25x, SN65HVD23x, SN65HVD10x0, SN65HVDA54x, ISO1050**
- Part 3: Low-speed, fault-tolerant, medium-dependent interface
  - TI doesn't make any LSFT transceivers
- Part 4: Time-triggered communication (MAC or CAN controller)
  - This is digital protocol and TI can support in TI MCUs and DSPs
- **Part 5: High speed medium access unit with low power mode (Transceiver)**
  - **SN65HVD1040, SN65HVDA54x, SN65HVD25x**

Note: Part 5 is a superset of part 2, thus if a transceiver is compliant to part 5, by definition it is also compliant to part 2.

Celebrating the first 25 years of CAN

Innovating for the next 25 years

High-Performance Analog>>Your Way™

ISO1050, SN65HVD230, SN65HVD231, SN65HVD232, SN65HVD233
SN65HVD234, SN65HVD235, SN65HVD251, SN65HVD252, SN65HVD253

SN65HVD1040, SN65HVD1050, SN65HVDA540, SN65HVDA541
SN65HVDA542, SN65HVDA1040A, SN65HVDA1050A

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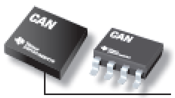

Visit www.ti.com/can-ad
to download datasheets, buy samples and learn more about TI's CAN portfolio

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CAN Based Buses & Protocols

- Various higher level buses and higher level communication protocols have been implemented using or deriving from CAN protocol and physical layer standards. These standards include:

- **ISO11898**: Road vehicles — Controller area network (CAN)
- **SAEJ1939**: Recommended Practice for a Serial Control and Communications Vehicle Network) - the Controller Area Network
- **SAEJ2284**: High-Speed CAN (HSC) for Vehicle Applications
- **ISO 11783**: Tractors and machinery for agriculture and forestry - Serial control and communications data network
- **NMEA 2000**: National Marine Electronics Association – serial network utilizing CAN
- **CANopen (EN 50325-4):** CAN-based higher-layer protocol for embedded control system (www.can-cia.org)
- **DeviceNet**: industrial network system based on CAN (www.odva.org)
- **CAN Kingdom**: communication protocol on top of CAN designed as fieldbus
- **CANaerospace**: communication protocol on top of CAN designed for aerospace
- **ARINC 825**: communication protocol on top of CAN designed for aerospace
- **SafetyBUS p**: communication protocol on top of CAN designed for fieldbus to SIL 3
- **GM LAN Single Wire CAN:** GM's standard for single wire CAN

CAN Applications

- Standard Data Bus PHY: SAEJ1939, SAEJ2284, NMEA 2000, ISO 11783
- CAN Data Bus (PHY): CANopen, DeviceNet, CAN Kingdom, CANaerospace, ARINC 825, SafetyBUS p
- Industrial Automation
- Building automation
- Process control equipment
- Factory automation
- Networked sensors
- Networked actuators
- Motor Control
- Medical
- Telecom
- Robotics
- Low Power & Battery applications
- Agricultural
- Transportation
- Automotive (-Q1 version)

CAN: Data Link Layer (Part 1) Impact on PHY (Parts 2, 3, 5)

- **Event Driven**
- **Half-duplex**
- **Asynchronous Serial (to 1Mbps)**

•*Arbitration*

•When used with a differential bus, a Carrier Sense Multiple Access/Bitwise Arbitration (CSMA/BA) scheme is often implemented: if two or more devices start transmitting at the same time, there is a priority based arbitration scheme to decide which one will be granted permission to continue transmitting. The CAN solution to this is prioritized arbitration (and for the dominant message delay free), making CAN very suitable for real time prioritized communications systems.

•If the bus is free, any node may begin to transmit. If two or more nodes begin sending messages at the same time, the message with the more dominant ID (which has more dominant bits i.e. bit 0) will overwrite other nodes' less dominant IDs, so that eventually (after this arbitration on the ID) only the dominant message remains and is received by all nodes.

→PHY Impacts:

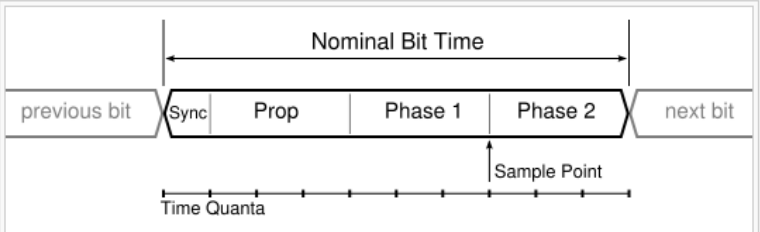
- **CAN drives dominant, weakly biases recessive to make CSMA/BA work**
- **"loop time" / round trip delay / propagation delay is critical to arbitration function**

•*Bit stuffing*

•In a CAN frame, a bit of opposite polarity is inserted after five consecutive bits of the same polarity. This practice is called bit stuffing, and is due to the "Non Return to Zero" (NRZ) coding adopted. The "stuffed" data frames are destuffed by the receiver. Since bit stuffing is used, six consecutive bits of the same type (111111 or 000000) are considered an error. Bit stuffing implies that sent data frames could be larger than one would expect by simply enumerating the bits shown in the tables above.

→PHY Impacts:

- **"TXD DTO" impact to minimum data rate. CAN cannot transmit more than 5 bits of same state in a row except in error condition. In that case worst case single state is 11 bits in a row → 5 dominant bits immediately followed by 6 dominant bit error frame.**



CAN Bit Timing

Extended frame format

The frame format is as follows:

Field name	Length (bits)	Purpose
Start-of-frame	1	Denotes the start of frame transmission
Identifier A	11	First part of the (unique) identifier for the data
Substitute remote request (SRR)	1	Must be recessive (1)Optional
Identifier extension bit (IDE)	1	Must be recessive (1)Optional
Identifier B	18	Second part of the (unique) identifier for the data
Remote transmission request (RTR)	1	Must be dominant (0)
Reserved bits (r0, r1)	2	Reserved bits (it must be set dominant (0), but accepted as either dominant or recessive)
Data length code (DLC)	4	Number of bytes of data (0-8 bytes)
Data field	0-8 bytes	Data to be transmitted (length dictated by DLC field)
CRC	15	Cyclic redundancy check
CRC delimiter	1	Must be recessive (1)
ACK slot	1	Transmitter sends recessive (1) and any receiver can assert a dominant (0)
ACK delimiter	1	Must be recessive (1)
End-of-frame (EOF)	7	Must be recessive (1)

The two identifier fields (A & B) combined form a 29-bit identifier.

CAN Physical Layers

- CAN Data Link Layer (ISO11898-1) or Time Triggered CAN (ISO11898-4) may be used with several CAN physical layers (transceivers).

- **High Speed CAN Physical Layer (HS CAN) up to 1Mbps** Part 2 & 5: High speed medium access**-> Automotive & Industrial**
  - Part 2: Original HS CAN physical layer specification
  - Part 5: High speed medium access unit with low power mode
    - Includes all requirements of Part 2, adds low power mode requirements, improves the specification of some parameters.
    - Devices meeting Part 5 requirements automatically also meet Part 2 which is a subset of Part 5

- **Low Speed Fault Tolerant CAN (LSFT CAN) up to 125kbps Part 3 -> Automotive**
  - Part 3: Low-speed, fault-tolerant, medium-dependent interface
  - Not compatible or interoperable to High Speed (HS) CAN.

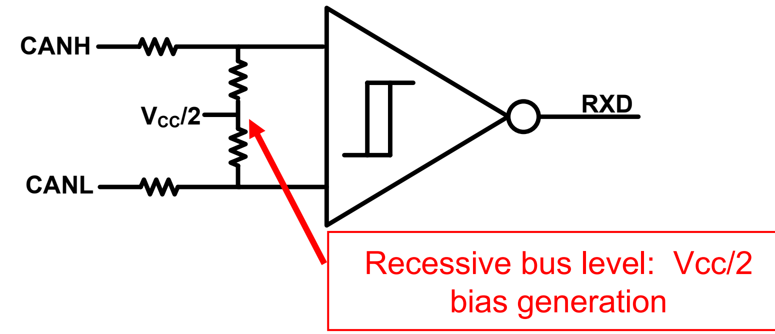
CAN PHY Basics (ISO 11898-2 & -5)

High Speed Medium Access Unit = HS CAN Transceiver with transmission rates of up to 1 Mbit/s
HS CAN is a differential bus (CANH & CANL lines) with 2 states:

- **Recessive**:
  - Logic H
  - Vdiff <=0.5V
  - CANH/CANL Weakly biased to $V_{CC}/2$
- **Dominant**:
  - Logic L
  - Vdiff =>0.9V
  - CANH and CANL driven differentially by PHY Driver
  - ***Dominant overwrites recessive (enables CAN Arbitration to work)***

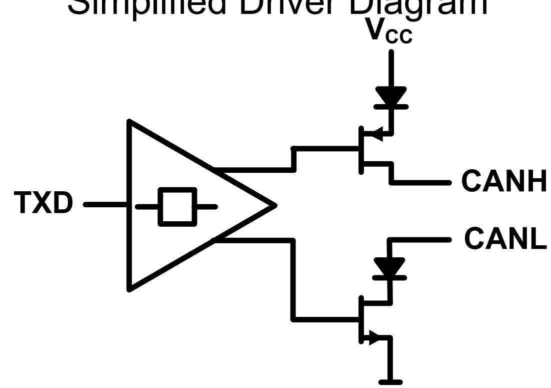
Recessive

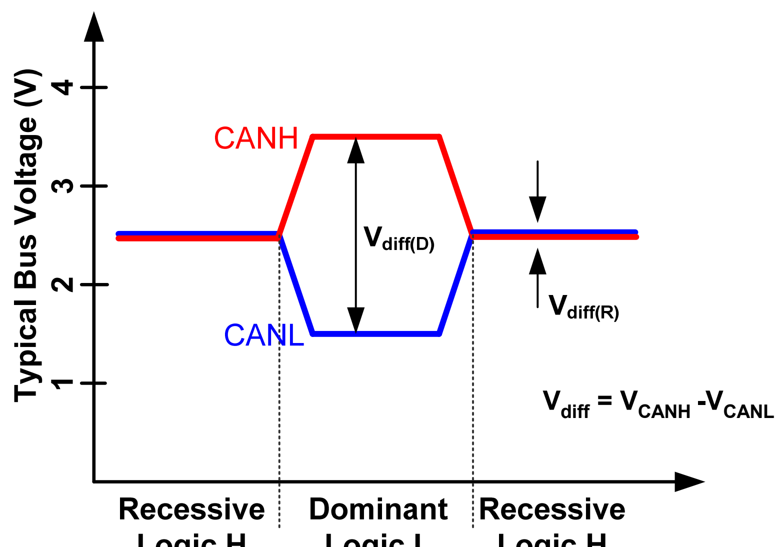
Simplified Receiver & Recessive Biasing Diagram



Dominant

Simplified Driver Diagram





Bus & Logic States

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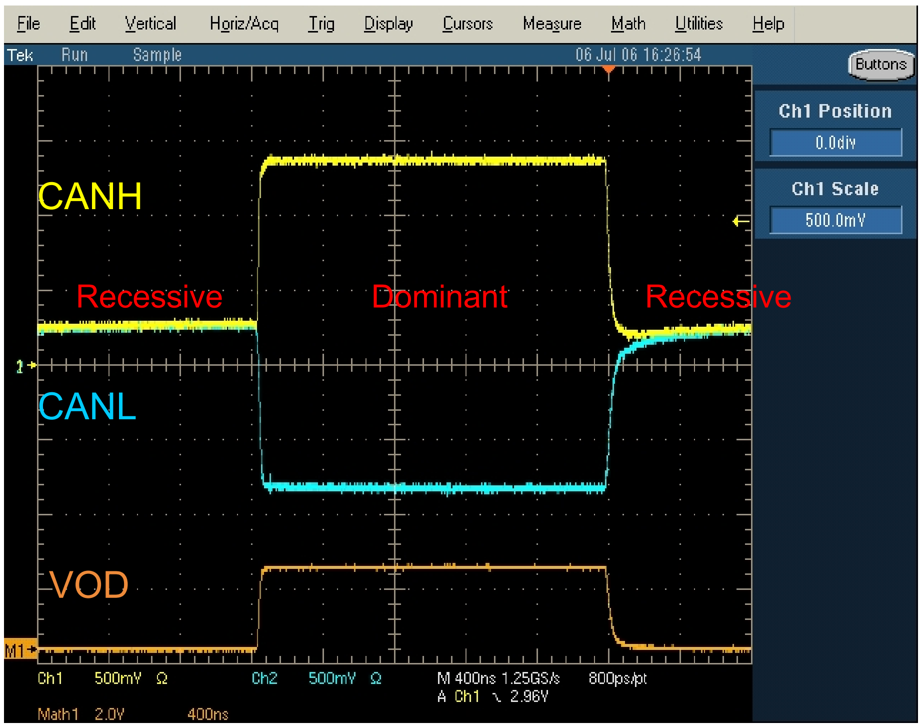
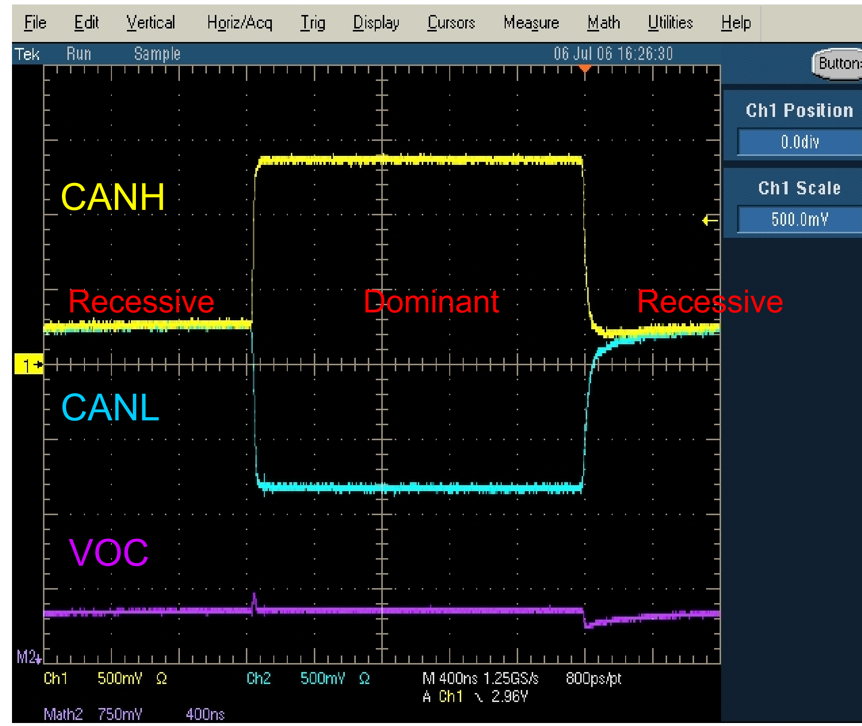
HS CAN: Differential & Common Mode

Differential Signal



VOD = V_{diff} = CANH - CANL

Common Mode



VOC = (CANH + CAN) / 2

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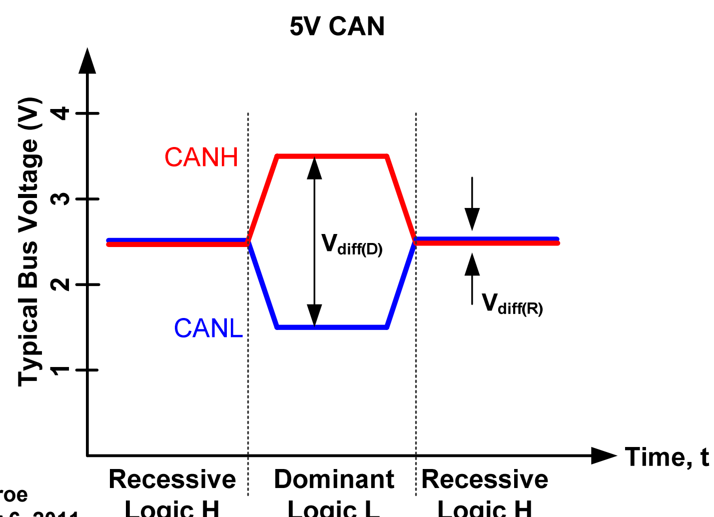
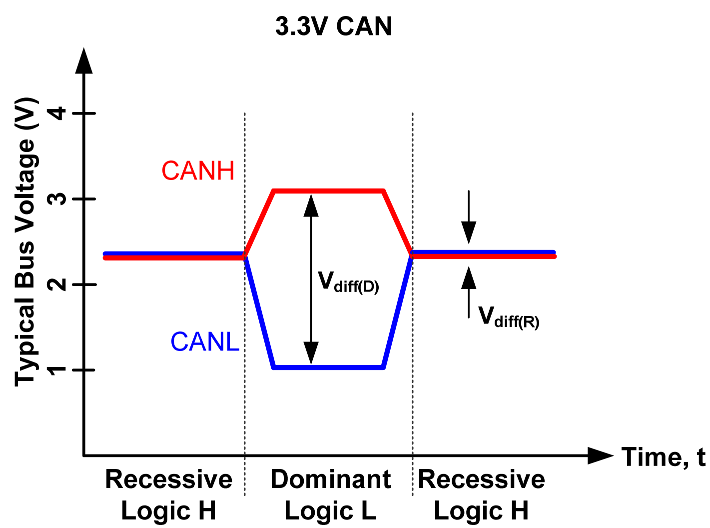
3.3V & 5V CAN Transceiver Mixed Network

- CAN is a differential bus with a wide common mode range which allows for 3.3V CAN transceiver to be interoperable with 5V CAN transceiver nodes.
- The differential output (dominant) of the 3.3V devices is the same and meets the CAN differential requirements of 1.2V to 3.0V and recessive differential requirements of -120mV to +12mV.
- 3.3V devices with the lower supply voltage will have a lower common mode point (DC offset lower) which is analogous to a 5V CAN node operating with a ground or supply shift.
- Using split termination will help eliminate any un-wanted shifts in common mode between various transceivers operating in the network and is a useful network design tool even in non mixed networks.
- 3rd party interoperability testing has been done on both the HVD230-232 CAN family and the HVD233-235 CAN families via the internationally recognized GIFT / ICT CAN test.
  - Homogeneous testing (ie only the 3.3V device)
  - Heterogeneous testing (ie where the 3.3V CAN is mixed in 4 out of 16 nodes of the reference network with three other "golden" reference, non TI, 5V transceivers).
  - Both of the TI 3.3V CAN families passed with no findings and the conformance certificate of authentications are available on request.





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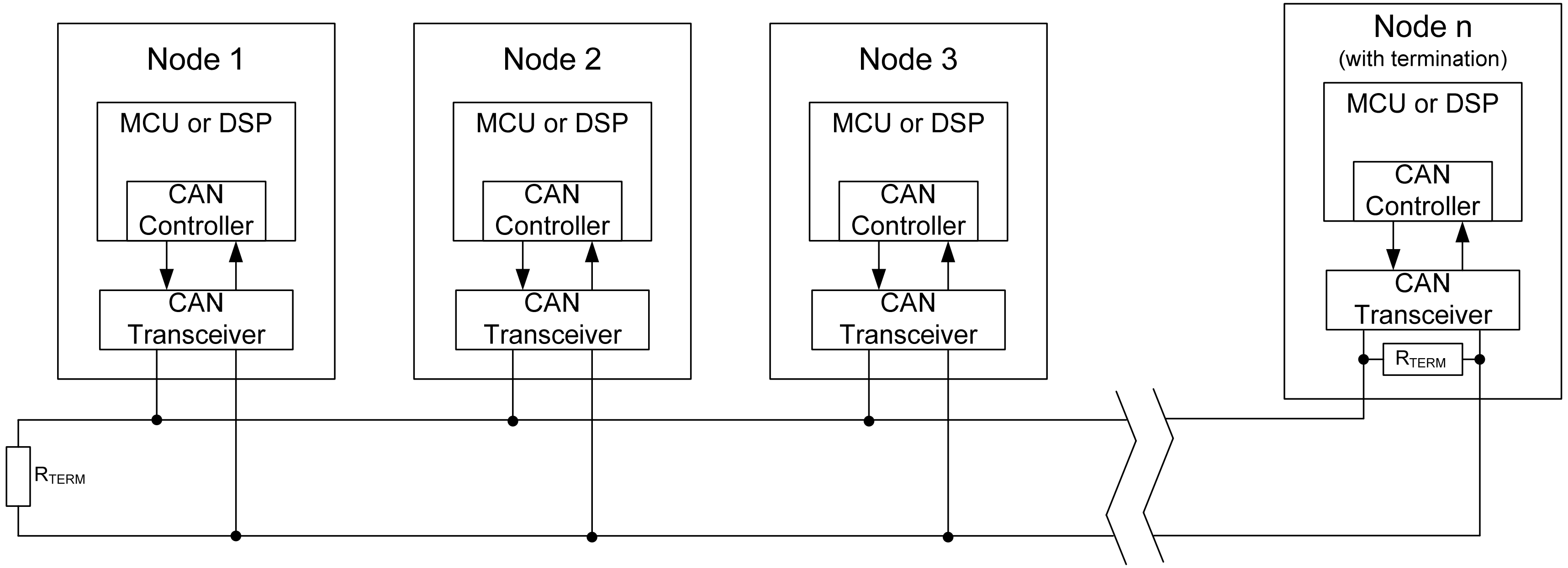
CAN Bus Topology

ISO11898 defined CAN as a linear bus topology. The original standard defined the electrical characteristics of a 30 node, 40m bus capable of 1Mbps. This basic topology has been easily modified by various organizations* to support various configurations through the use of trade offs in data rate, number of nodes and bus length. Termination can be in network or on node.



***Organizations taking CAN out of the original standard: ODVA (DeviceNet), CiA (CANopen), CAN Kingdom, CANaerospace, SafetyBUS p**

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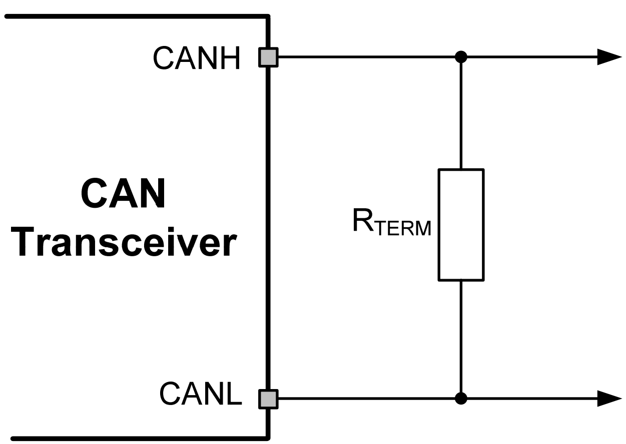
CAN Bus Termination

•CAN is design for use with **twisted pair cabling of 120Ω characteristic impedance** in a bus topology. The bus should be properly terminated at both ends with 120Ω resistors that match this impedance to avoid signal reflections. If nodes may be removed from the bus care must be used where to place the termination such that it is not removed from the bus.

•Termination may be a single 120Ω resistor at the end of the bus or if filtering and stabilization of the common mode voltage of the bus is desired then "split termination" may used. Utilizing split termination in a CAN network improves signal integrity and electromagnetic emissions behavior of the network by eliminating fluctuations in the bus common mode voltage levels at the start and end of message transmissions. Keep in mind this is a common mode filter not a differential filter on the signal.

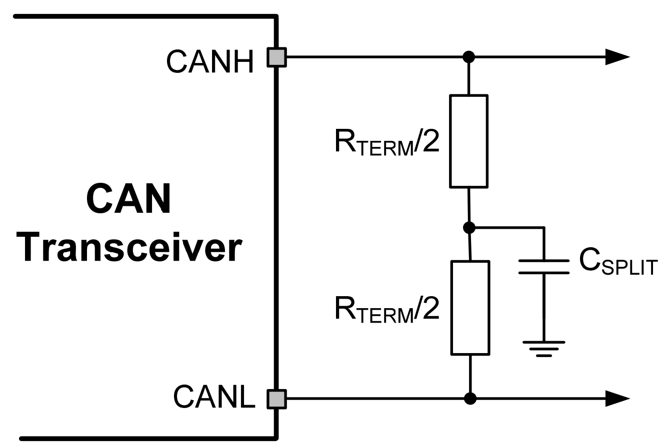
•**FAULT case**: CAN network may be shorted to voltage sources the power ratings of the termination resistors should take into account the short circuit current protection of the CAN transceivers in the network and design for worst case power. Normally this will be approximate 0.5W in standard termination or 0.25W for split termination resistors.

Standard Termination



R_{TERM} = 120Ω

Split Termination



C_{SPLIT} = 4.7nF to 100nF

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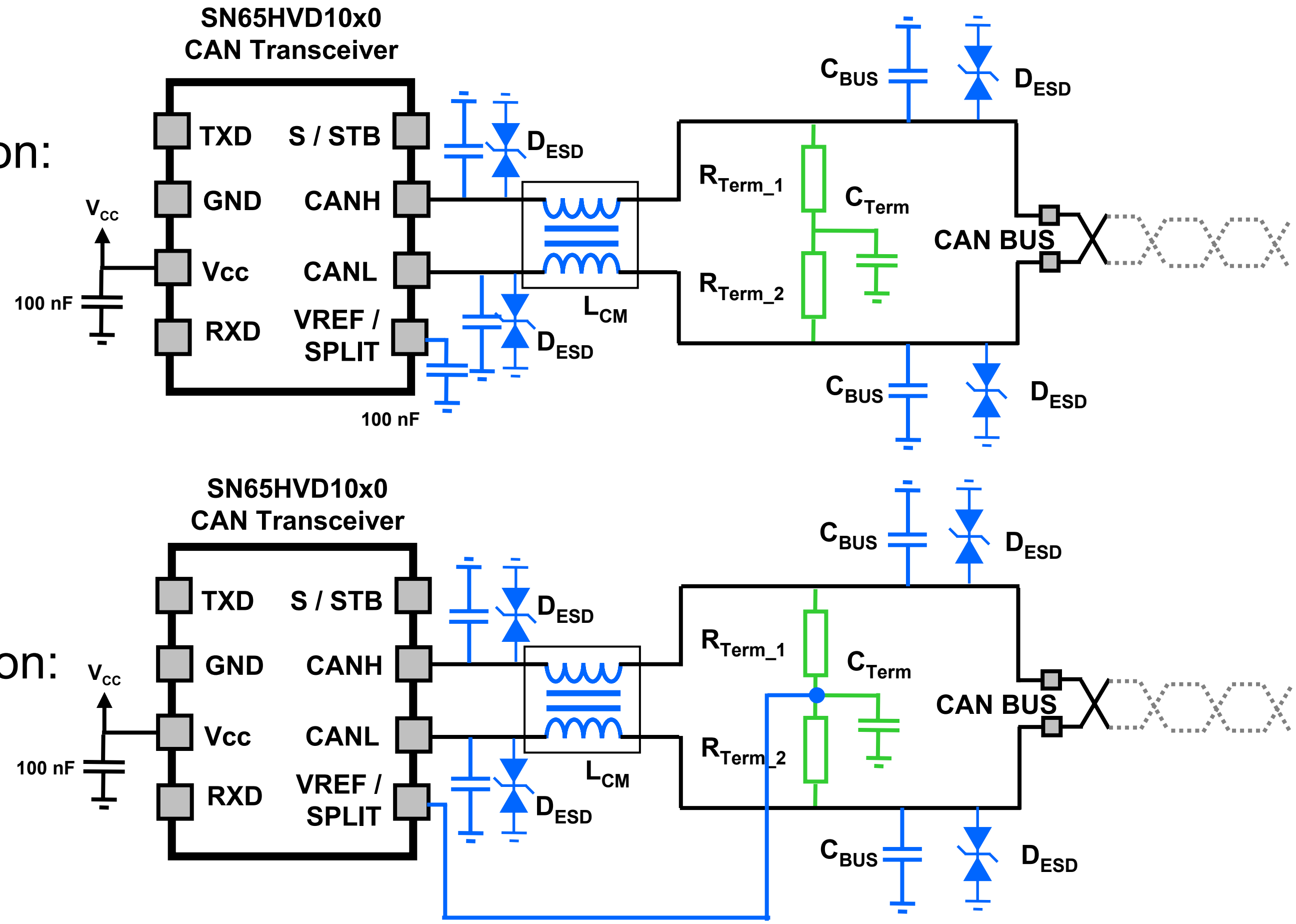
CAN: In Node Termination / Protection

Recessive stabilization:
Passive Split
Termination

Recessive stabilization:
Active Split
Termination



Optional for EMC / Protection: not all options are used together at all times. L_{CM} could be replace by series MELF resistors.

Terminating Nodes: only terminating nodes have this unless termination in cable

TXD DTO Protection and Minimum Data Rate

- During normal mode, the only mode where the CAN driver is active, the TXD dominant time out circuit prevents the transceiver from blocking network communication in event of a hardware or software failure where TXD is held dominant longer than the time out period t_{TXD_DTO}. The dominant time out circuit is triggered by a falling edge on TXD. If no rising edge is seen before the time out period of the circuit expires, the CAN bus driver is disabled. This keeps the bus free for communication between other nodes on the network. The CAN driver is re-activated when a recessive signal is seen on TXD pin, thus clearing the TXD dominant time out. The receiver and RXD pin will still reflect the CAN bus and the bus pins will be biased to recessive level during a TXD dominant time out.

- **APPLICATION NOTE:** The minimum dominant TXD time allowed by the TXD dominant time out limits the minimum possible transmitted data rate of the device. The CAN protocol allows a maximum of eleven successive dominant bits (on TXD) for the worst case, where five successive dominant bits are followed immediately by an error frame. This, along with the t_{TXD_DTO} minimum, limits the minimum data rate. The minimum transmitted data rate may be calculated by: Minimum Data Rate = $11/ t_{TXD\_DTO}$

Terminology, Features, Protocols and Applications

CAN Features and Terminology

CAN: Controller Area Network

ISO11898: General ISO specification for CAN. The original 1993 version was ISO11898, but in subsequent updates & revisions the standard has been divided into parts (ISO11898-x). For a "***High Speed*** Medium Access Unit" (PHY or transceiver) the applicable parts are -2 and -5. -5 is a superset of -2, thus if -5 is met -2 is met or exceeded. Parts -2 and -5 are generally called "High Speed" even though the data rate per the standards is ~0 to 1mbps.

Loop Time / Round Trip Delay / Propagation Delay: The time it takes a bit to propagate through the entire CAN system from TXD input to RXD output. Critical to arbitration working and allowable data rate in a given CAN network topology. Lowering the CAN transceivers loop time lowers the system loop time and means higher data rates in the same network may be achieved. See article at: http://www.eetimes.com/design/industrial-control/4014279/Signaling-rate-versus-cable-length-the-CAN-bus-timing-trade-off?pageNumber=0

TXD Dominant Time Out (DTO): The TXD DTO circuit prevents the driver from blocking network communication during a hardware or software failure. TXD DTO minimum time will limit the lowest data rate the transceiver will successfully transmit. Balance must be used in choosing a transceiver based on planned operating data rates vs how tight the TXD DTO protection of the bus may be.

Silent Mode: A diagnostic mode of a transceiver where the device receives data but is silent, ie cannot transmit even if data is put on TXD pin. Some times called receive only mode.

CAN: Features and Terminology (2)

Bus Wake Up: Ability to operate in a very low power mode (usually called standby mode) to save system power and wake up when dominant bit greater than 5μs is passed to the receiver output (RXD) by the bus monitor circuit. Edge triggered interrupt tied to RXD wakes the rest of the system up.

Diagnostic Loopback: The loopback function forces the driver into a recessive state and redirects the data (D) input at pin 1 to the received-data output (R) at pin 4. This allows the host controller to input and read back a bit sequence to perform diagnostic routines without disturbing the CAN bus.

Autobaud Loopback: In autobaud, the *bus-transmit* function of the transceiver is disabled, while the *bus-receive* function and all of the normal operating functions of the device remain intact. This function is used to detect the correct autobaud. Once the correct autobaud is determined, the *bus-transmit* function of the transceiver is enabled. Autobaud detection is best suited to applications that have a known selection of baud rates.

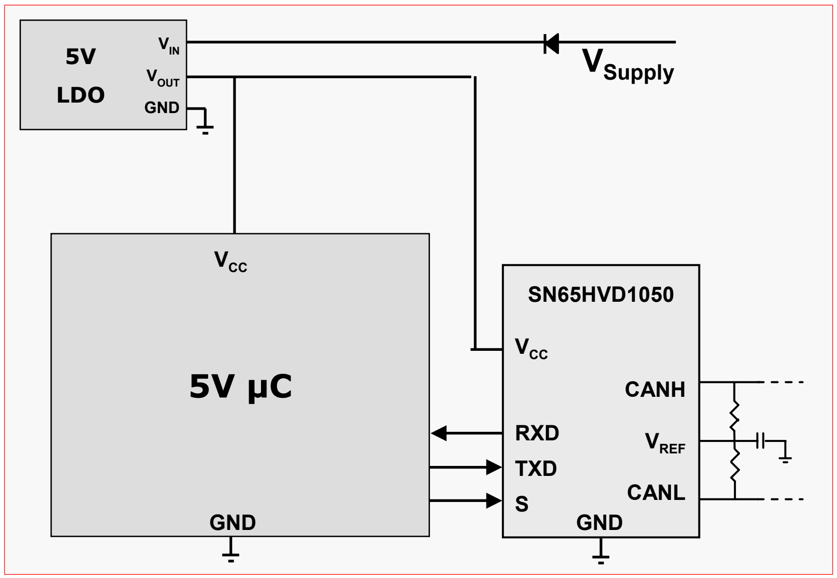
SPLIT / V_{REF}: A pin that outputs a reference $V_{CC}/2$. May be used to actively drive the center tap on split termination to stabilize the common mode voltage of the network.

Slope Control: To optimize the electromagnetic interference, the rise and fall slopes can be adjusted by connecting a resistor to ground at a certain pin, since the slope is proportional to the pin's output current. Slowing the slopes down also slows the loop times down impacting possible data rates (see above on loop time).

5V Typical Applications

5V system with 1050 type transceiver

Normal and Silent Modes



Optimized system 5V with no CAN Wake

•No extra components

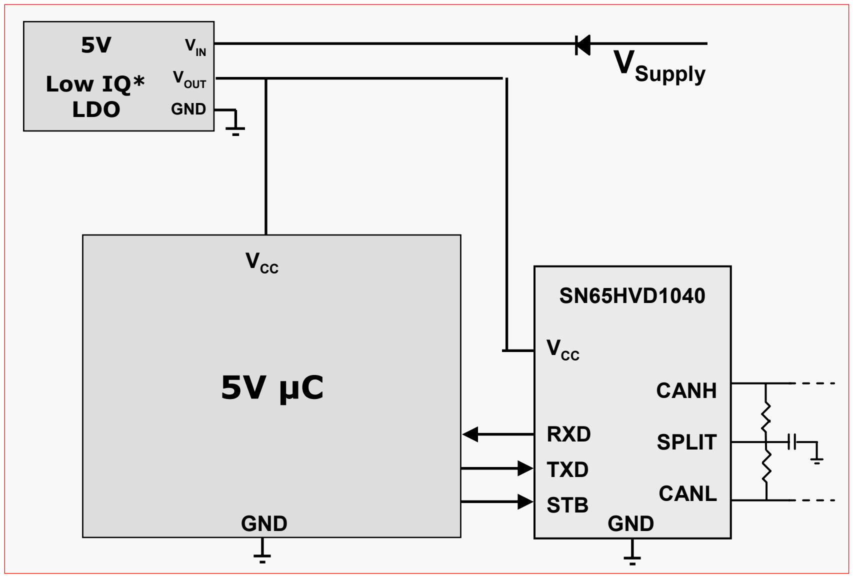
•Lower cost Vreg (Systems normally powered so no low power mode or low IQ requirements)

•Silent (receive only) mode for software diagnostics on CAN bus

•Vref may be left open or connected with bypass cap to GND if un-used for driving split termination.

5V system with 1040 type transceiver

Normal and Low Power Standby (with CAN wake) Modes



Optimized system 5V with low power CAN Wake

•No extra components

•Low power Standby Mode (5µA typical) with wake from CAN bus.

•Low quiescent current (IQ) Vreg needed to keep system current (power) low if wake from CAN in low power standby mode is used.

•Split may be left open or connected with bypass cap to GND if un-used for driving split termination.

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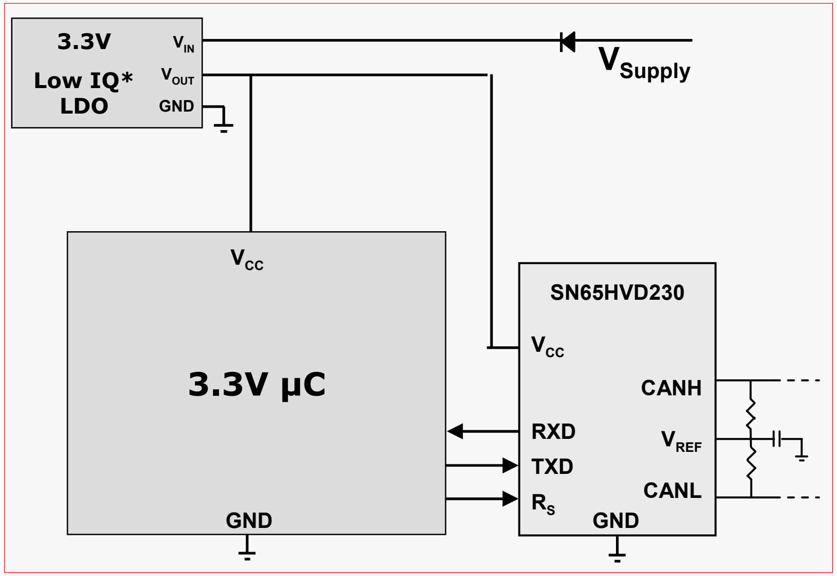
3.3V Typical Applications

3.3V system with HVD230 3.3V transceiver

Normal and Standby Modes

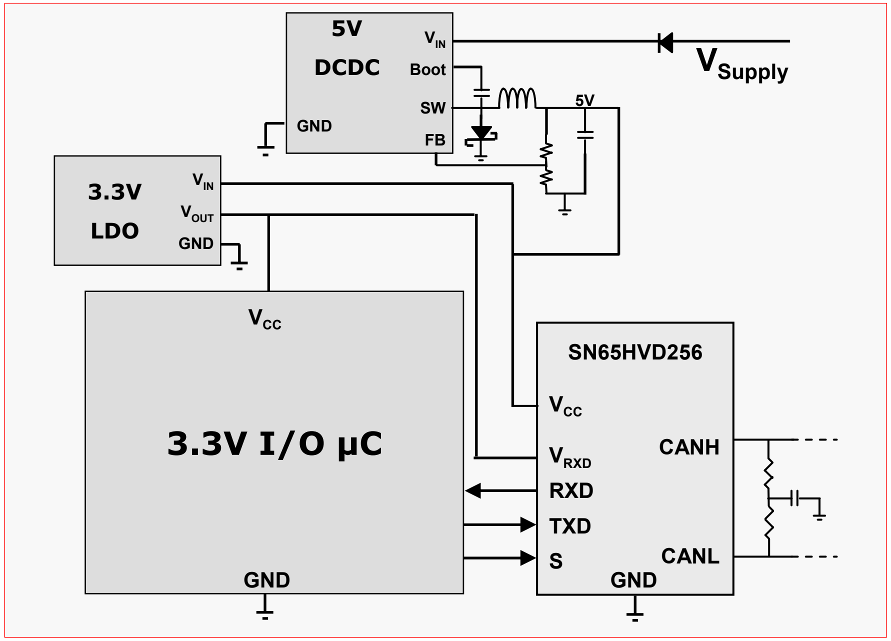


Optimized system 3.3V including low power CAN Wake

- No extra components
- Low power Standby Mode (370µA typical) with wake from CAN bus.
- *Lower cost Vreg used for systems not requiring low power wake up, if low power wake up needed then a low quiescent current (IQ) Vreg is needed to keep system current (power) low.
- V_{REF} may be left open or connected with bypass cap to GND if un-used for driving split termination.

3.3V I/O MCU with 5V HVD256 transceiver

Normal and Silent Modes



3.3V I/O MCU with 5V CAN PHY

- Drop in to other 5V CAN PHYs with I/O level shifter if pure 3.3V optimization isn't desired.
- Can be used with various power supply rail and I/O voltage level schemes.
- Silent (receive only) mode for software diagnostics on CAN bus

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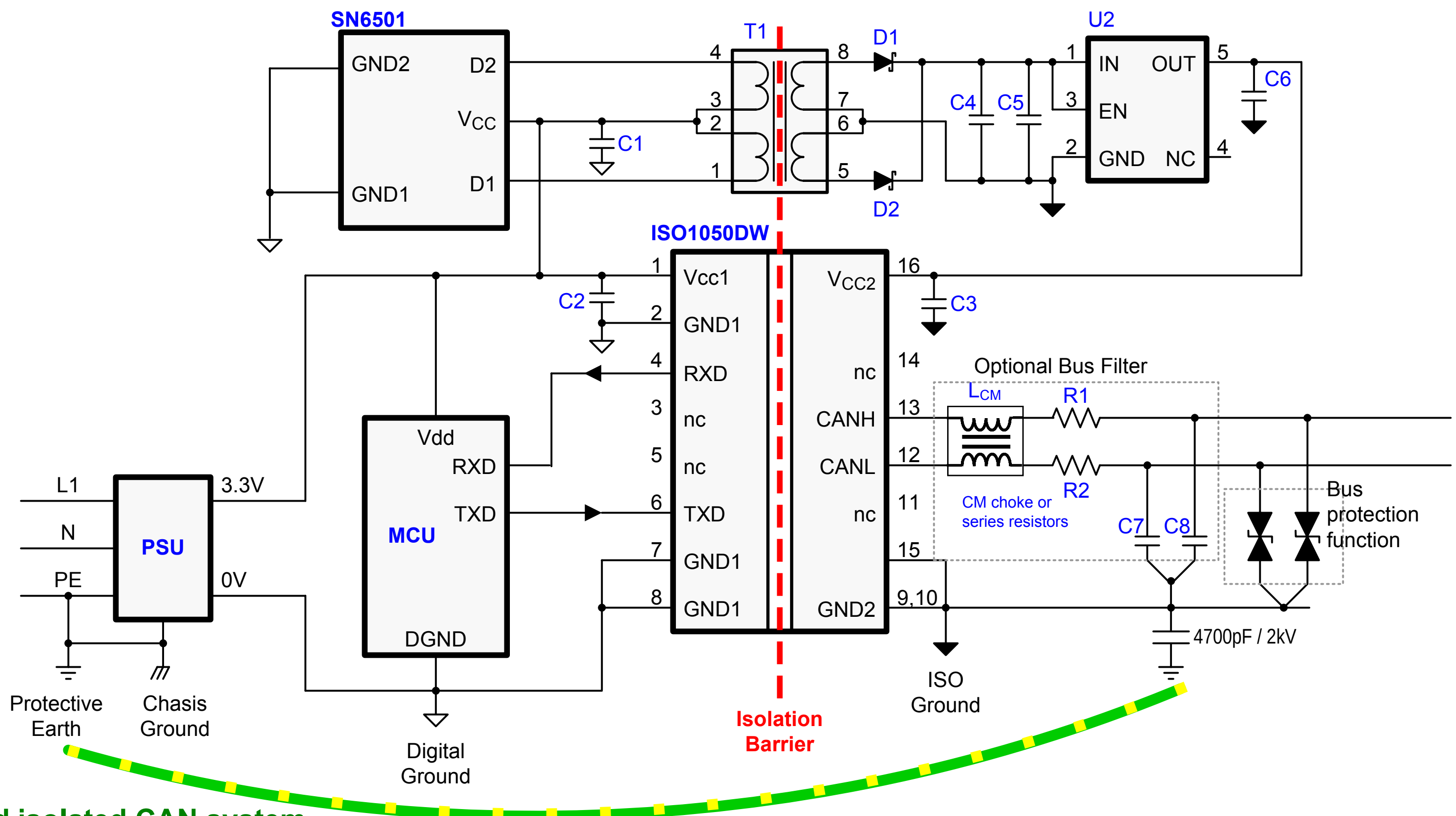
Galvanic Isolated Typical Application

Isolated power from digital to transceiver side



Optimized isolated CAN system

- Easy system integration
- Optimized isolated CAN transceiver:
  - Meets ISO11898-2 including galvanic isolation
  - Isolated CAN with fast loop time, offsets loop delay from isolation layer allow high data rate isolated CAN networks, no need to calculate various maximum loop times for CAN network timing calculations. One value from ISO1050.
- High efficiency transformer driver to power CAN transceiver (or reverse if power from bus side) to minimize power losses

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Thank You