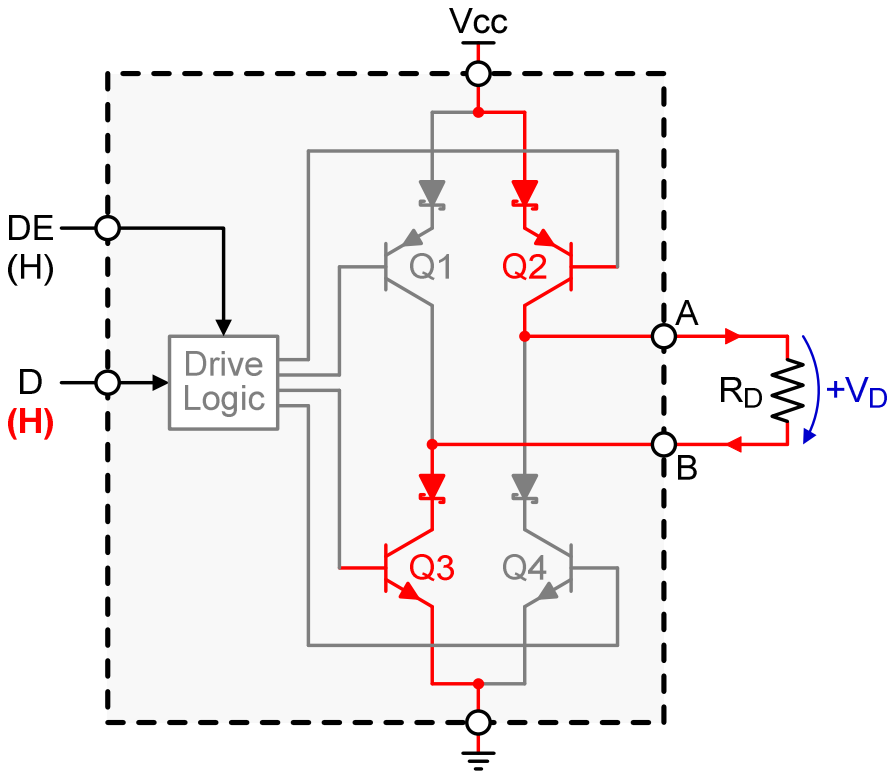
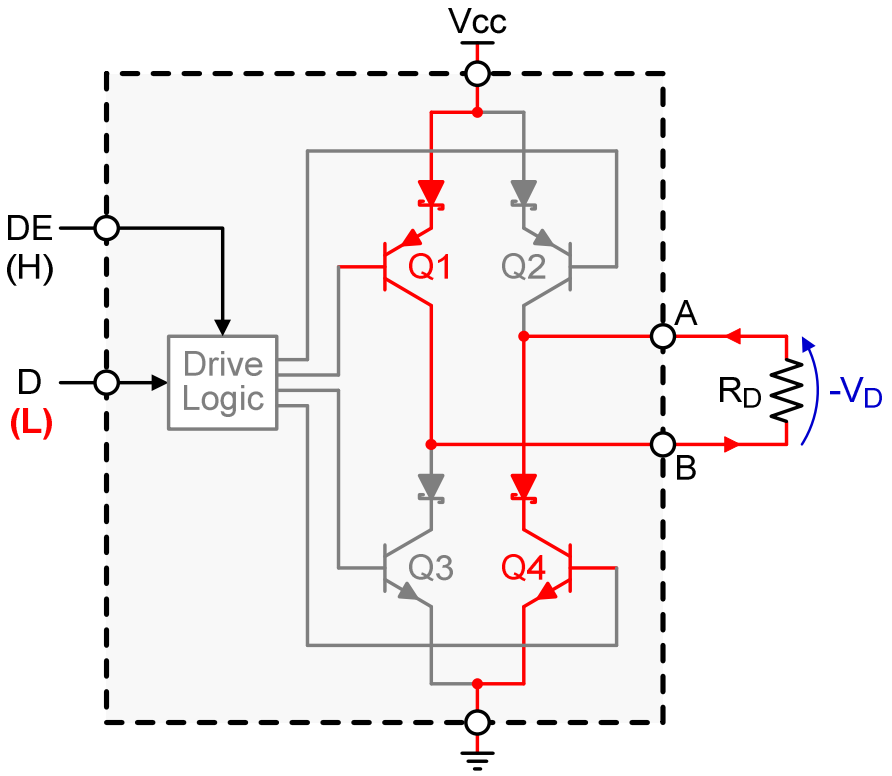
RS-485: The Industrial Workhorse's Design Guide

RS-485 crash course

Principles, Design-hints, Transceivers

Differential Driver

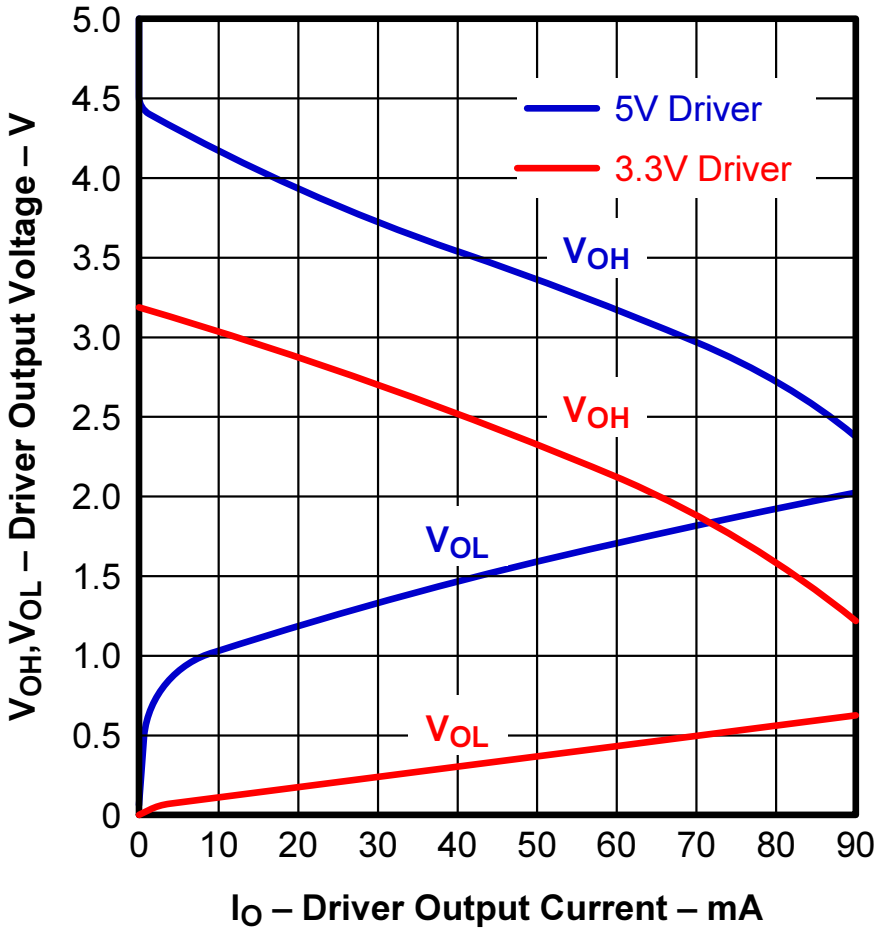


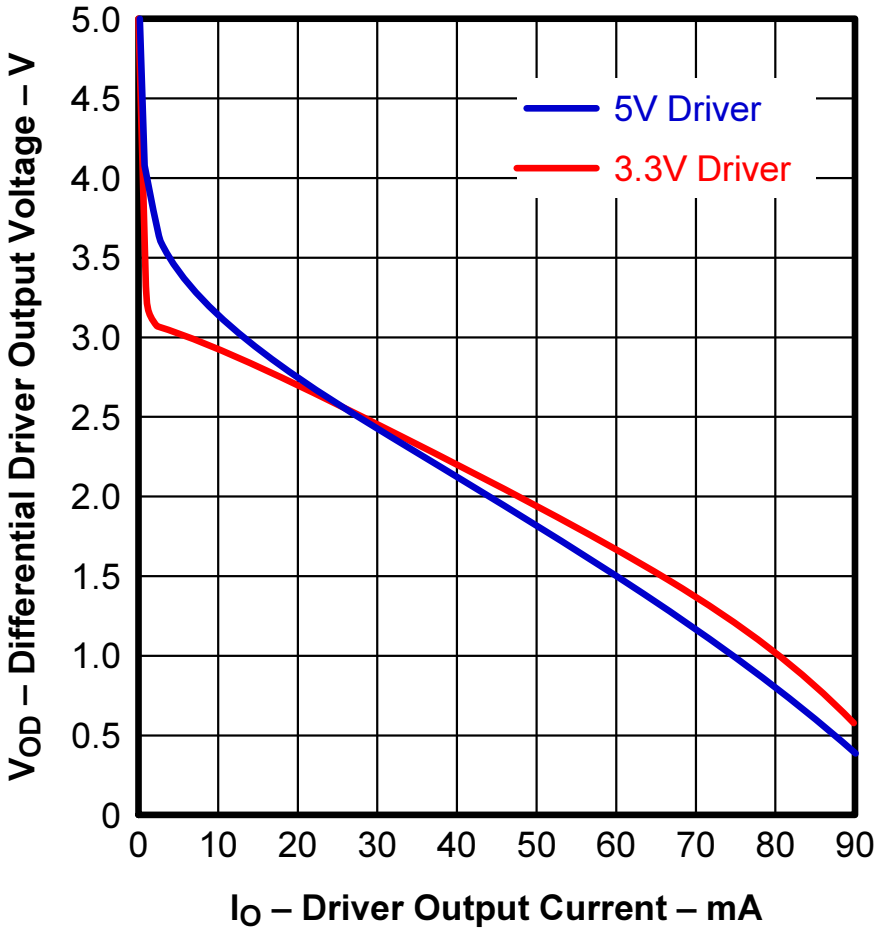


$$|V_D| = V_{CC} - 2\,(V_F + V_{R\text{-}on}) \qquad V_D = V_A - V_B$$

EIA-485 compliant drivers must produce Vdmin = 1.5V across RD = 54 Ω

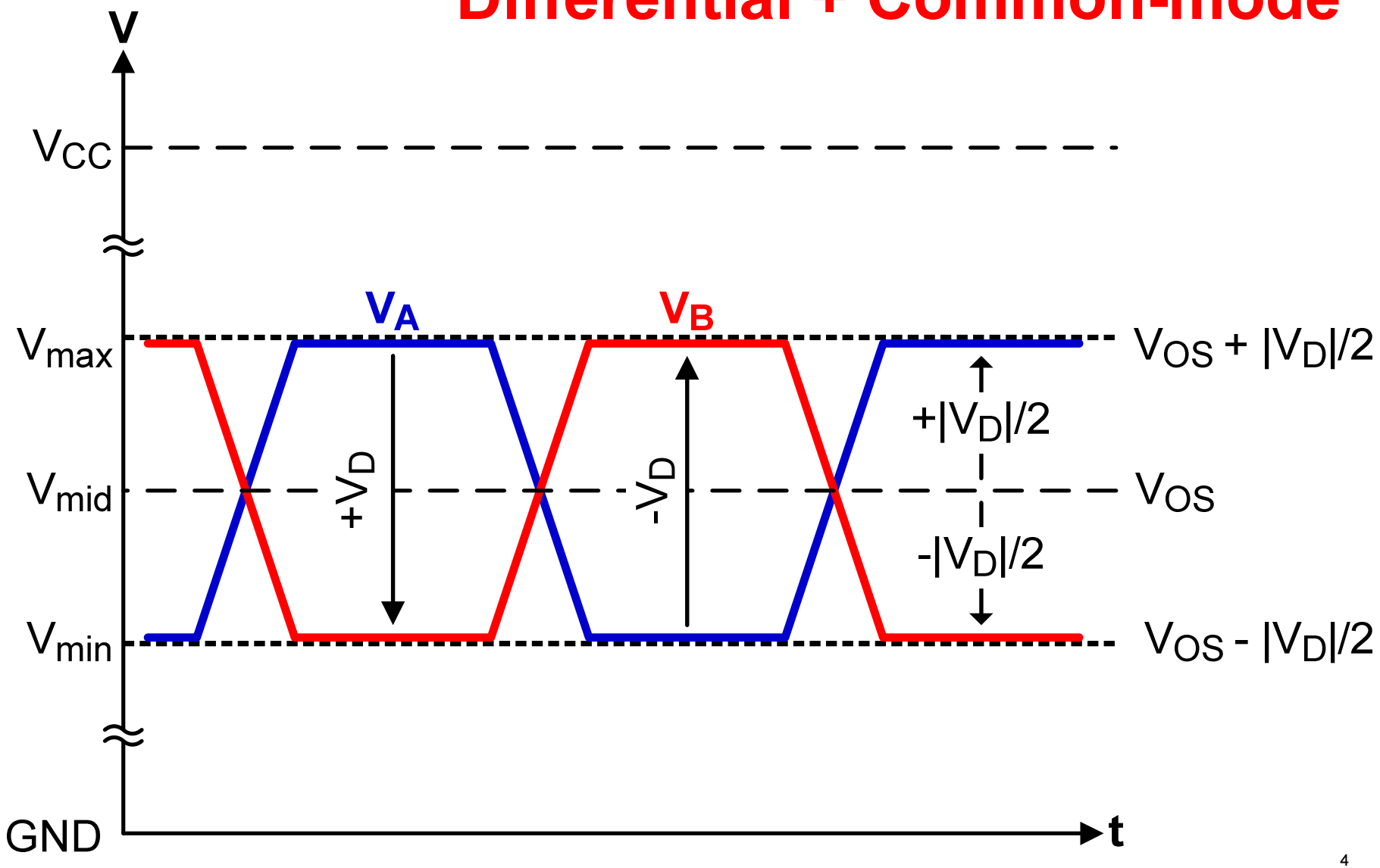
Output Characteristics



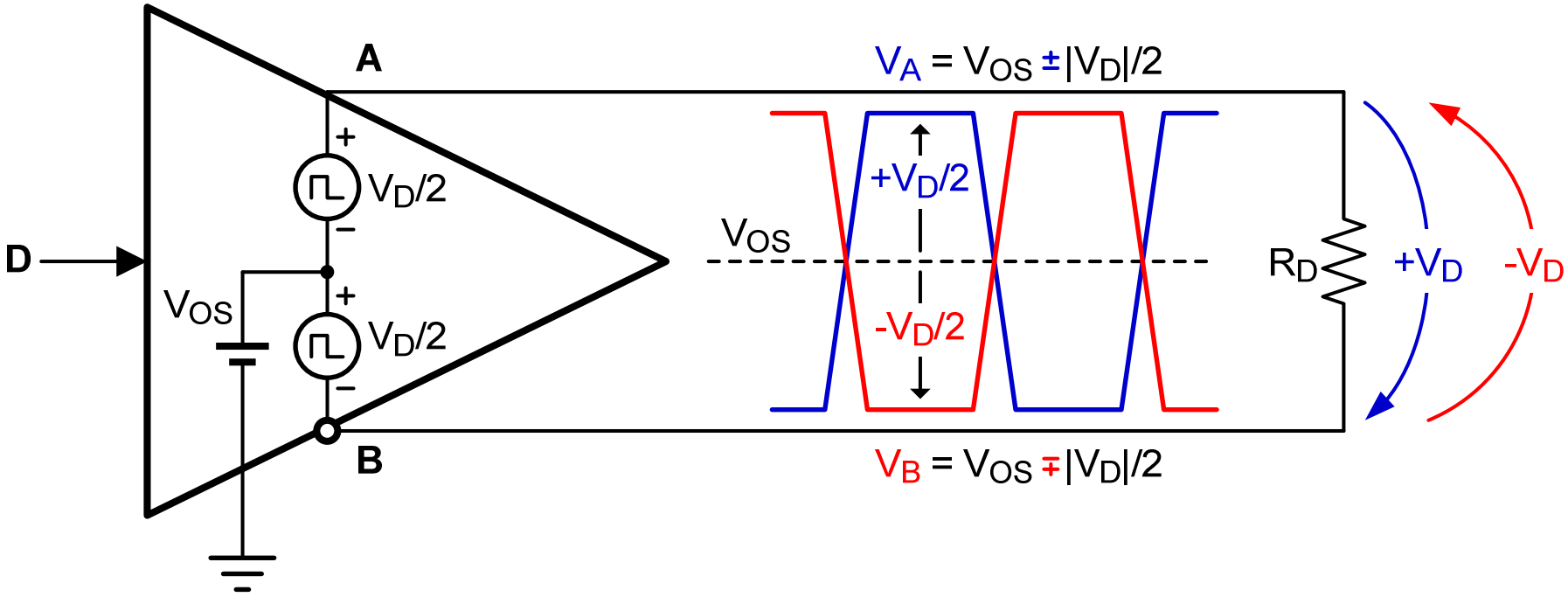


RS-485 compliant drivers must produce $V_{D\text{-}min} \geq 1.5V$ across $R_D = 54\ \Omega$

Output Signals = Differential + Common-mode

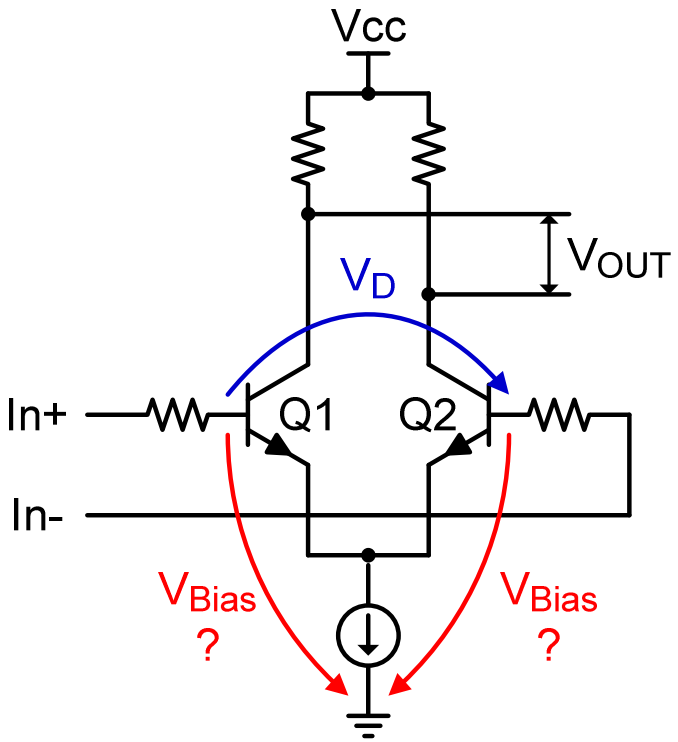


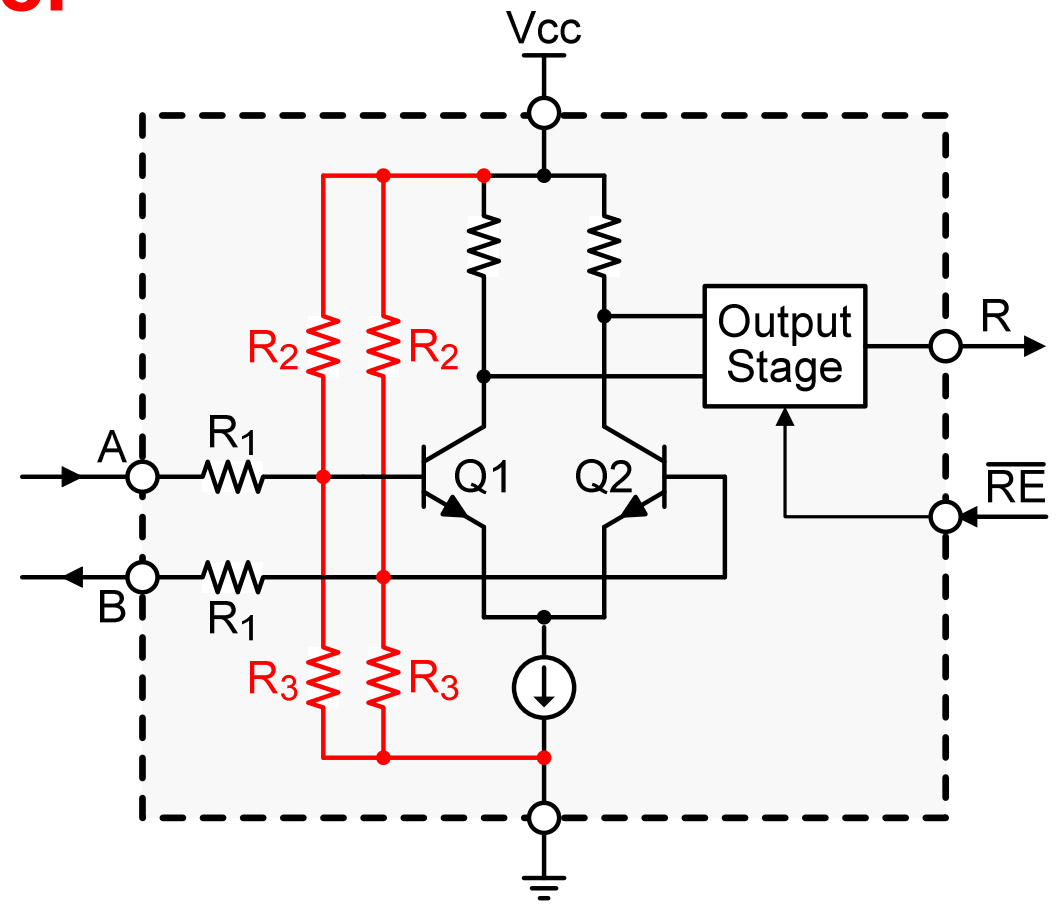
Driver Model with V_{OS} and $V_D/2$



The driver can be modelled with a bias voltage of V_{OS} superimposed by two differential voltages of $V_D/2$

Differential Receiver



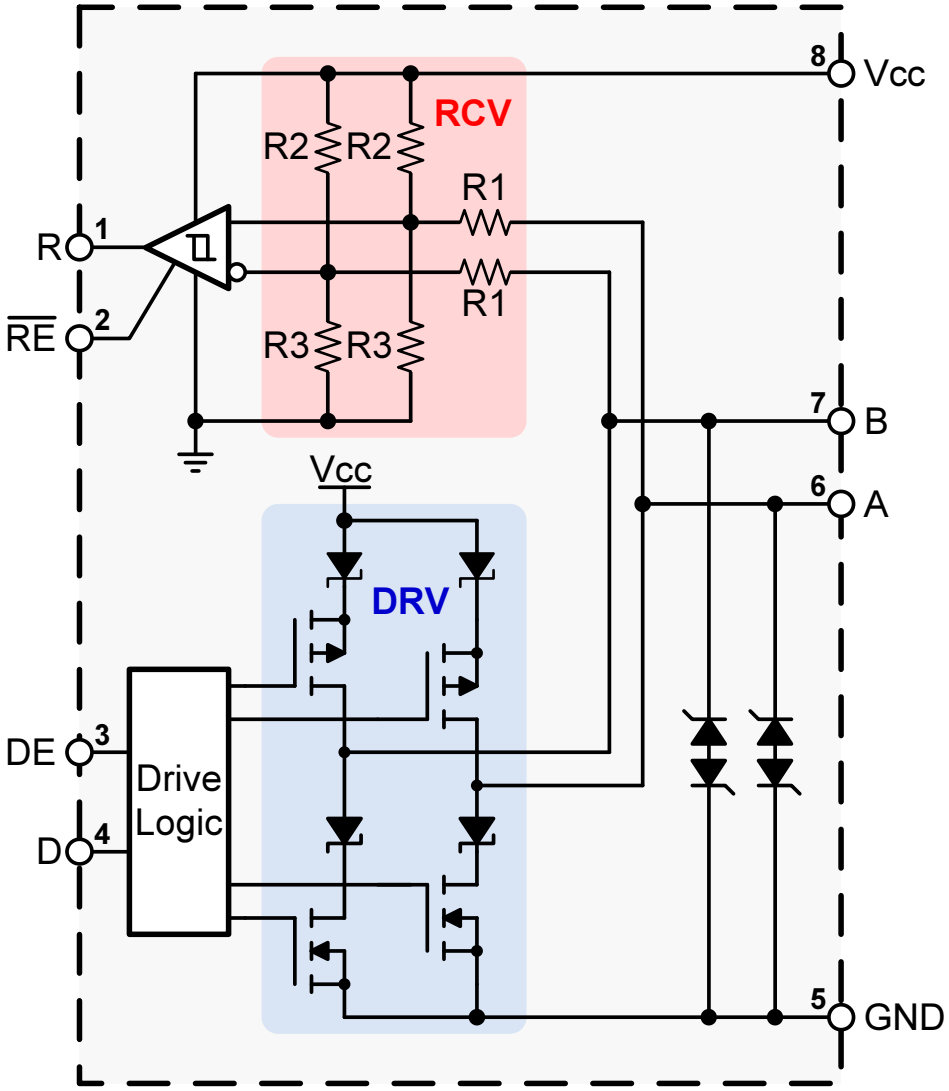


Without biasing the differential input stage will not work without a ground wire.

Therefore every RS-485 receiver has internal biasing through R_2 and R_3.

Hence, no ground wire is needed !

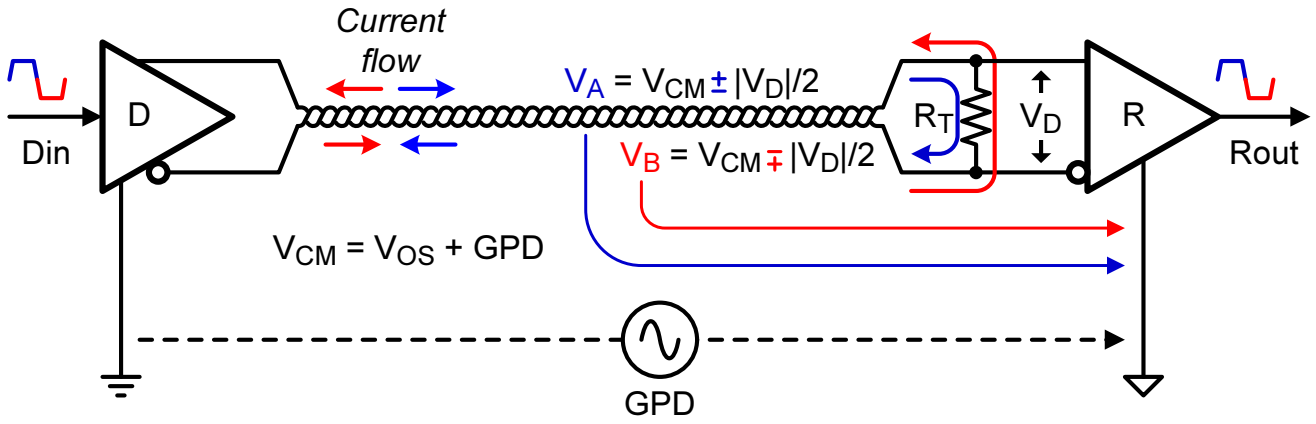
Bus Terminals Equivalent Circuit Diagram



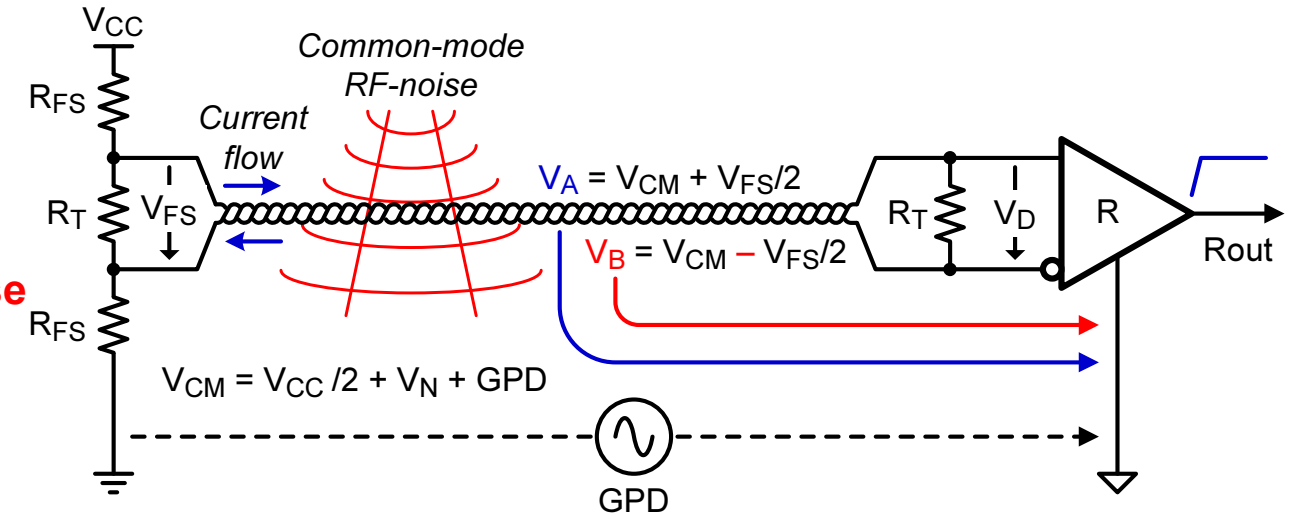
The protection diodes, shown separately in data sheets, are in fact one and the same SCRs.

Balanced Data Link

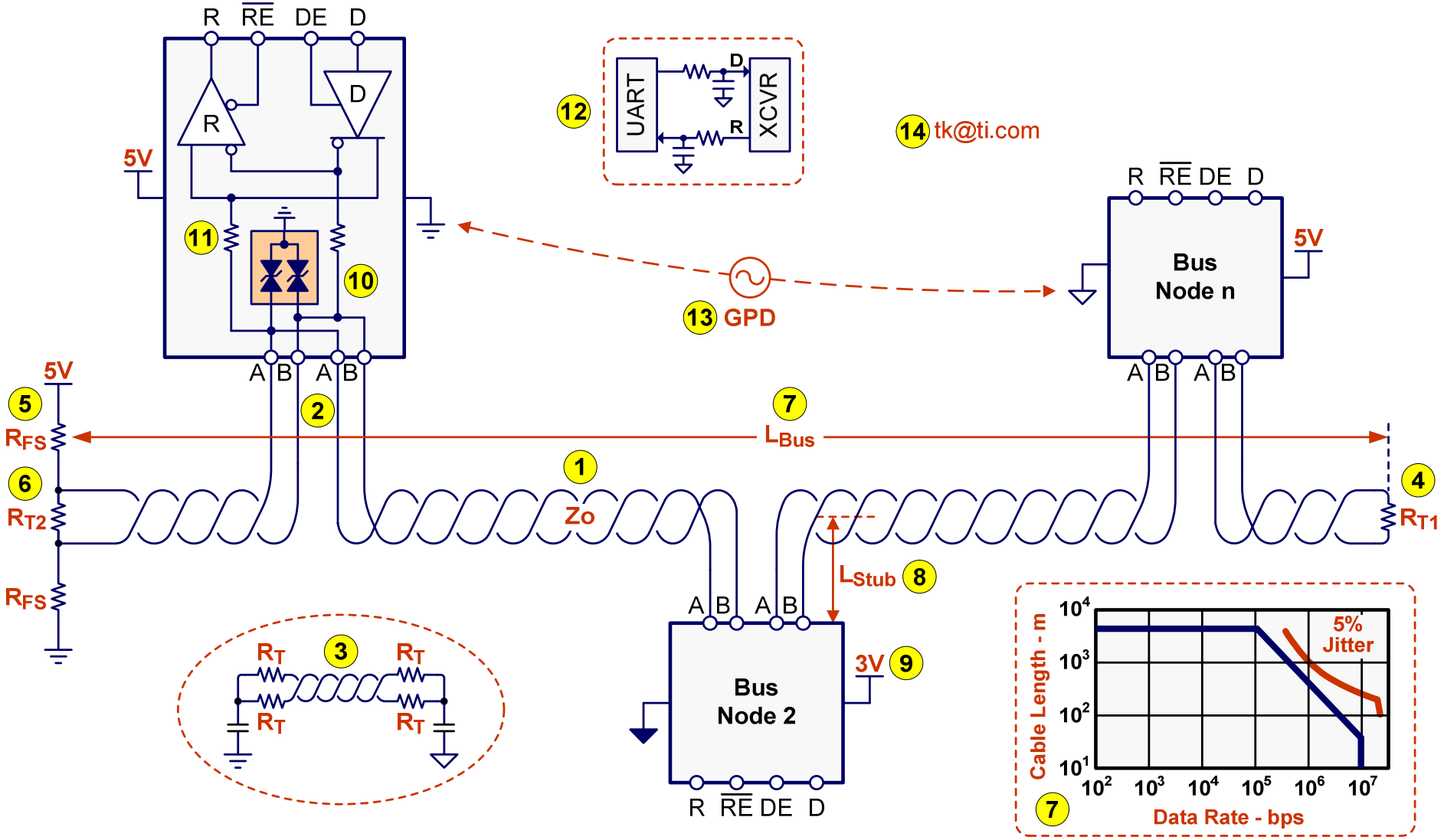
Active bus:
Driver must provide symmetrical signals to avoid causing EMI towards other circuits.



Idle bus:
Cable, traces must have symmetrical geometries to convert EMI from other circuits into common-mode noise that is rejected by the receiver.



The 14 Commandments of RS-485 ….



…. and how to apply them

1. Use twisted pair cable with
   $Z_O = 120\Omega$ or 100Ω
2. Connect bus nodes via
   Daisy-chain
3. Terminate unused conductors with
   $R_T = Z_0/2$ to their local grounds
4. Terminate one cable end with
   $R_{T1} = Z_0$
5. Apply failsafe biasing to the other end

$$R_{FS} = \left(\frac{V_{CC\text{-}min}}{V_{AB\text{-}Idle}} + 1 \right) \cdot k$$

k = 27.8Ω for Zo = 120Ω
k = 23.4Ω for Zo = 100Ω

6. Terminate this end with

$$R_{T2} = \frac{2R_{FS} \cdot Z_0}{2R_{FS} - Z_0}$$

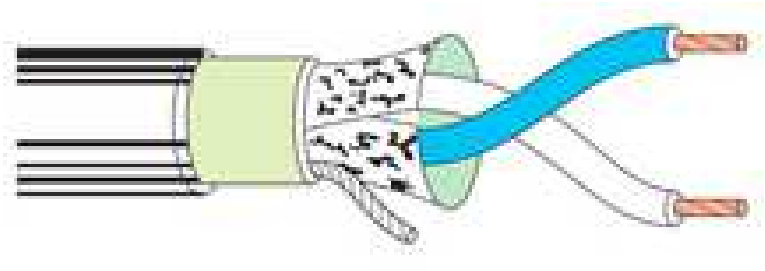
7. Determine maximum Cable-Length
   with chart bottom right
8. Make stub length no longer than

$$L_{Stub} < 3 \cdot 10^{-4} \cdot tr \cdot v$$

L_{Stub} = stub length (m)
tr = driver rise time (ns)
v = signal velocity (%)

9. You can operate 3V and 5V devices on the same bus
10. For ESD, EFT, and surge protection use SM712
11. Limit clamping current into the transceiver with 10 Ω pulse-proof or MELF resistors
12. Filter signal noise between transceiver and UART with R-C low-pass filters (fc ≥ 5 x DR)
13. For ± 7V GPDs use standard transceivers
    For ± 20V GPDs use SN65HVD17xx
    For higher GPDs use isolated transceivers
14. Pose further questions to tk@ti.com

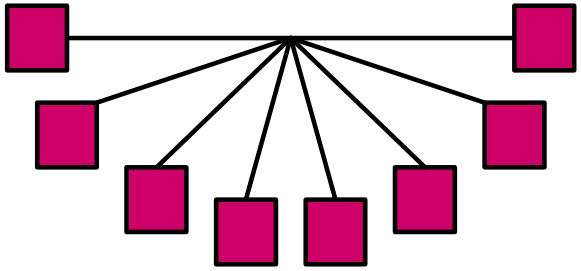
1) Use twisted pair cable



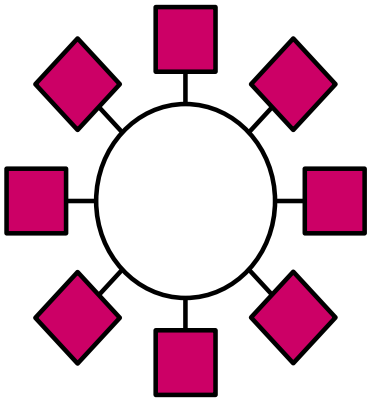
Cable:	Belden 3105A
Type:	1-pairy, 22 AWG, PLCT/CM
Impedance:	120 Ω
Capacitance:	11 pF/ft
DC-Resistance:	14.7 mΩ/ft
Velocity:	78% (1.3 ns/ft)

- Belden Wire and Cable Company, www.belden.com
- CommScope, www.commscope.com
- General Cable Corporation, www.generalcable.com
- Madison Cable Corporation, www.madisoncable.com
- Handbook of Wiring, Cabling, and Interconnecting for Electronics, Charles A. Harper, ed., McGraw-Hill, New York, 1972.
- Introduction to Copper Cabling, John Crisp, Newnes (Elsevier Science), Oxford, 2002.

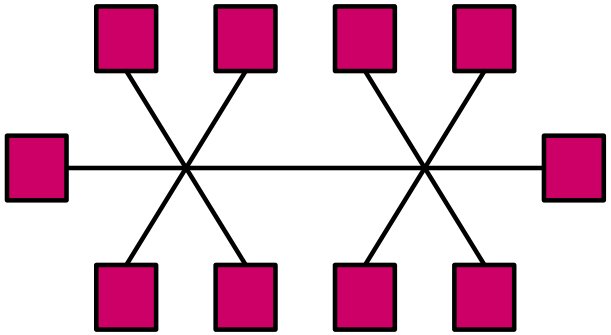
2) Connect bus nodes via daisy-chain



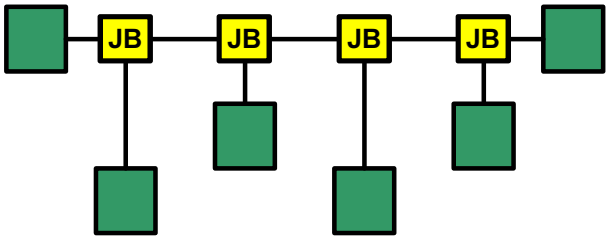
Star network **(avoid)**



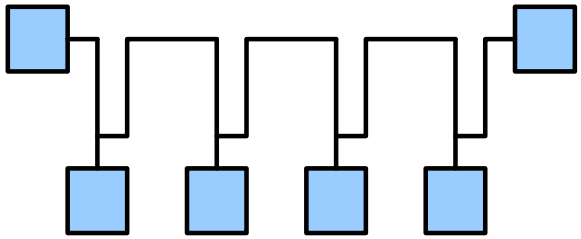
Ring network **(avoid)**



Backbone with stars **(avoid)**



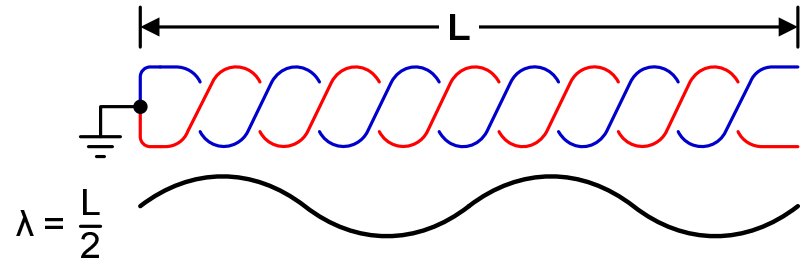
Backbone with junction boxes (works)



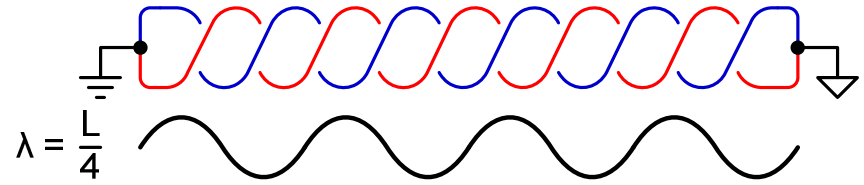
Daisy chain (best)

3) Terminate unused conductors

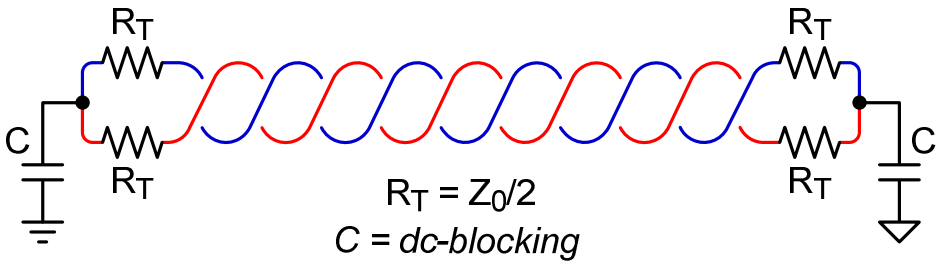
Unused conductors self resonate and couple noise into data wires.
If left open, they resonate at all sorts of strange frequencies.



If grounded at one end, they resonate at L/2.

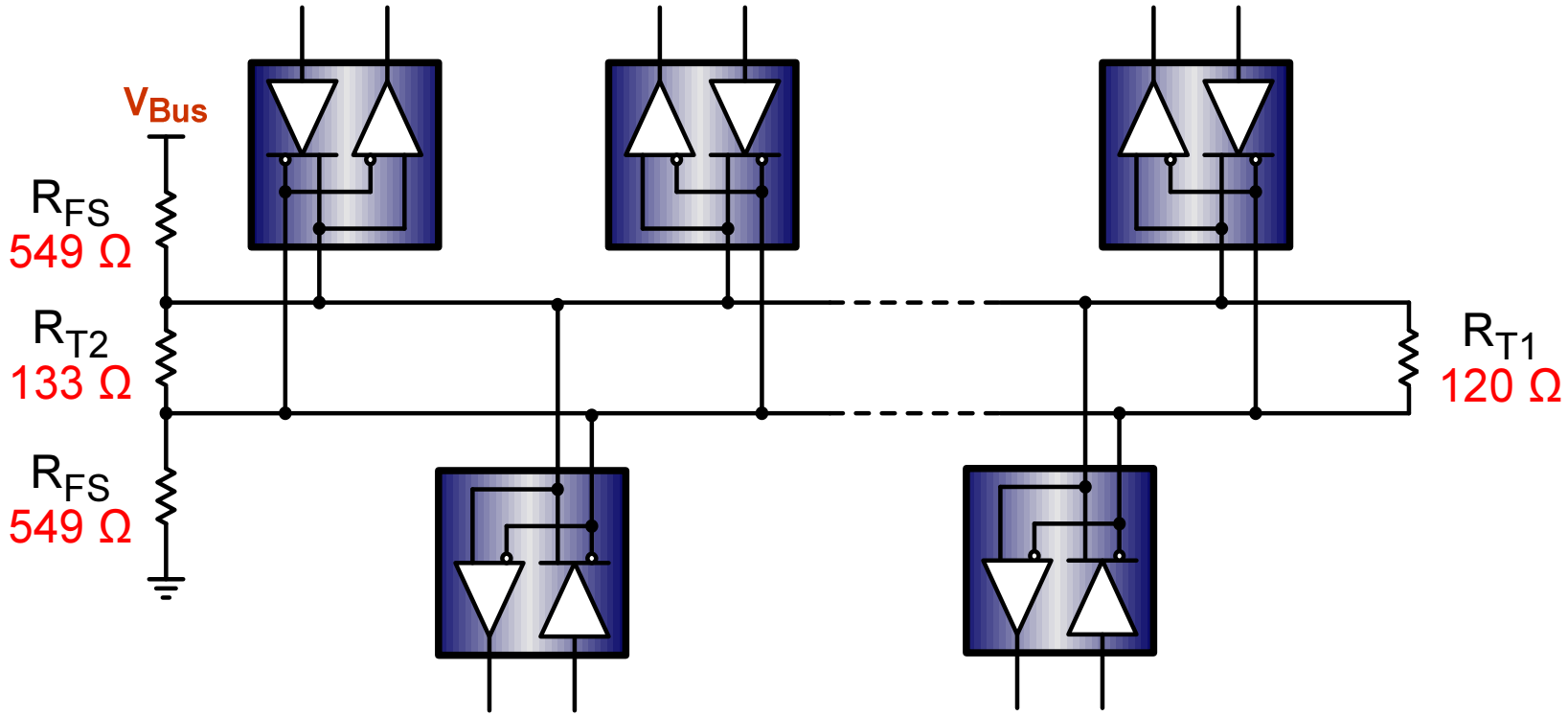


If grounded at both ends, they resonate at L/4.



The best method for minimizing energy on unused conductors is to dissipate it as heat. Hence, terminate both ends to ground with resistors equal to half the characteristic line impedance.

4,5,6) Apply termination and failsafe biasing



$$R_{FS} = \left(\frac{V_{bus\text{-}min}}{V_{AB}} + 1 \right) \cdot \frac{1}{(1/375 + 4/Z_0)}$$

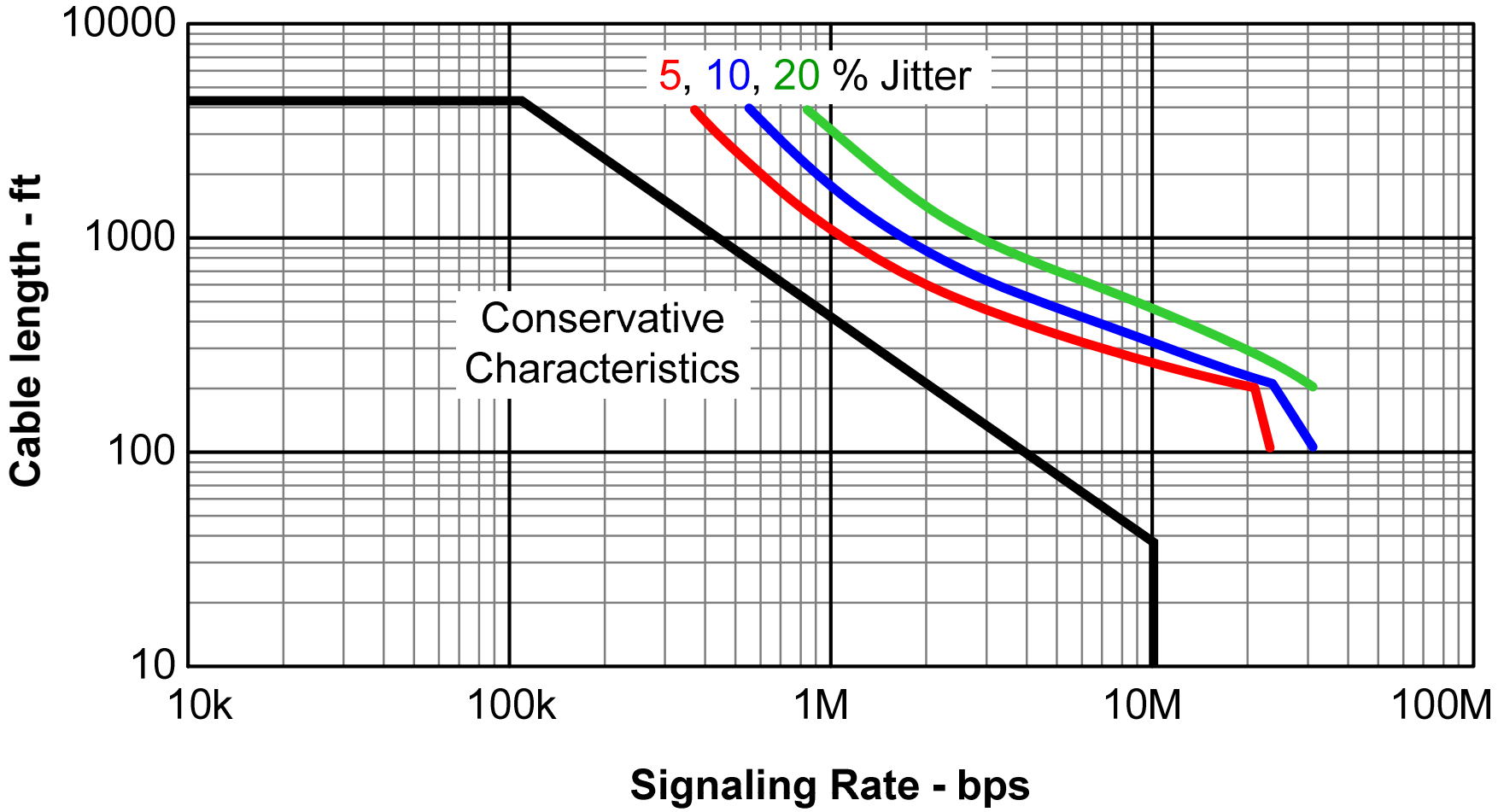
$$R_{T2} = \frac{2\,R_{FS} \cdot Z_0}{2\,R_{FS} - Z_0)}$$

$V_{Bus\text{-}min}$ = minimum bus supply voltage

$V_{AB} = 200mV + V_{Noise}$

$Z_0 = 120\Omega$

7) Determine cable length or data rate



8) Minimize stub length

A stub is a piece of unterminated transmission line, whose electrical length *(signal propagation time)* should be less then 1/10 the fastest signal transition on the bus *(the driver rise/fall time)*.

$$L_{Stub} \leq \frac{t_r}{10} \cdot v \cdot c$$

L_{Stub} = maximum stub length (ft)

t_r = driver (10/90) rise time (ns)

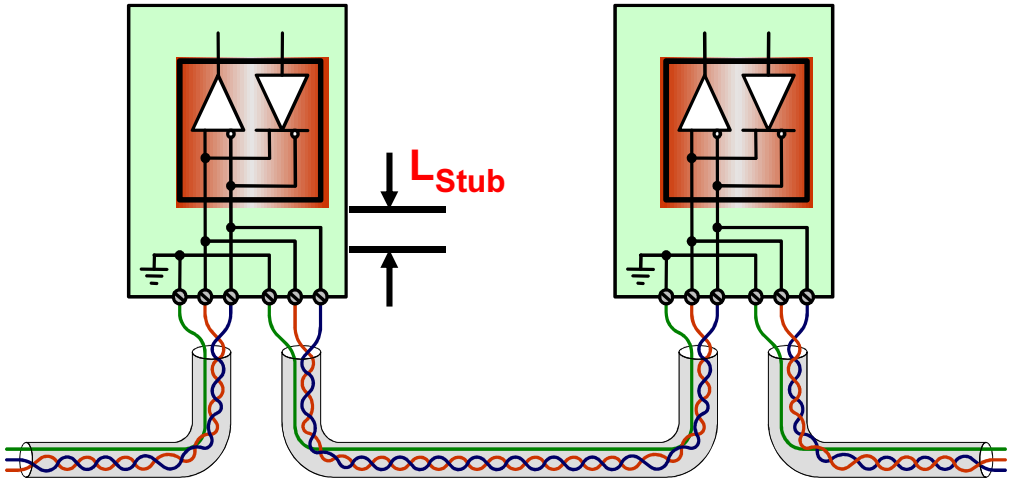
v = signal velocity of the cable as factor of c

c = speed of light ($9.8 \cdot 10^8$ ft/s)

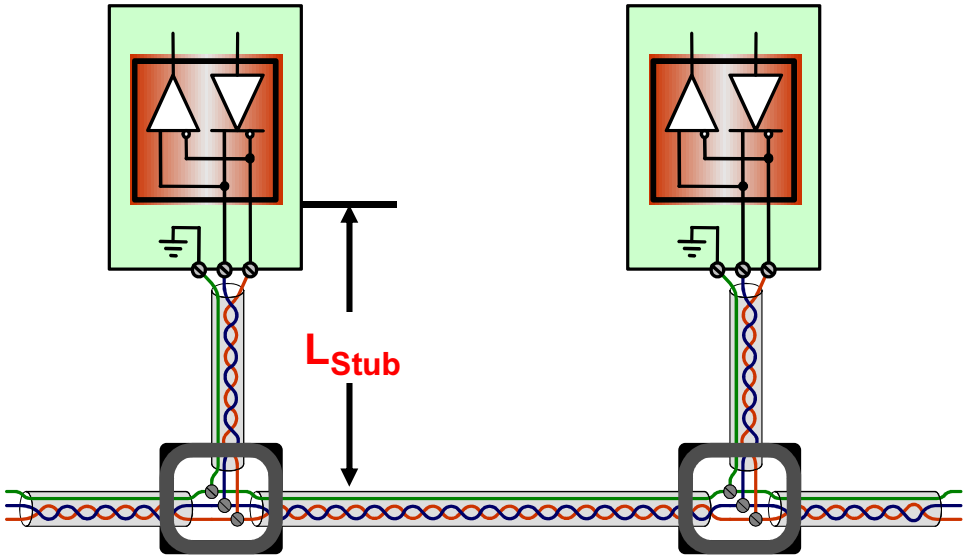
Device	Signal rate [Mbps]	Rise time tr [ns]	Max. Stub length [ft]
SN65HVD1176	40	2	0.15
SN65HVD21	5	20	1.5
SN65HVD12	1	100	7.6
SN65LBC184	0.25	250	19
SN65HVD3082E	0.2	500	38

8b) Distinguish between stub types

Daisy Chain



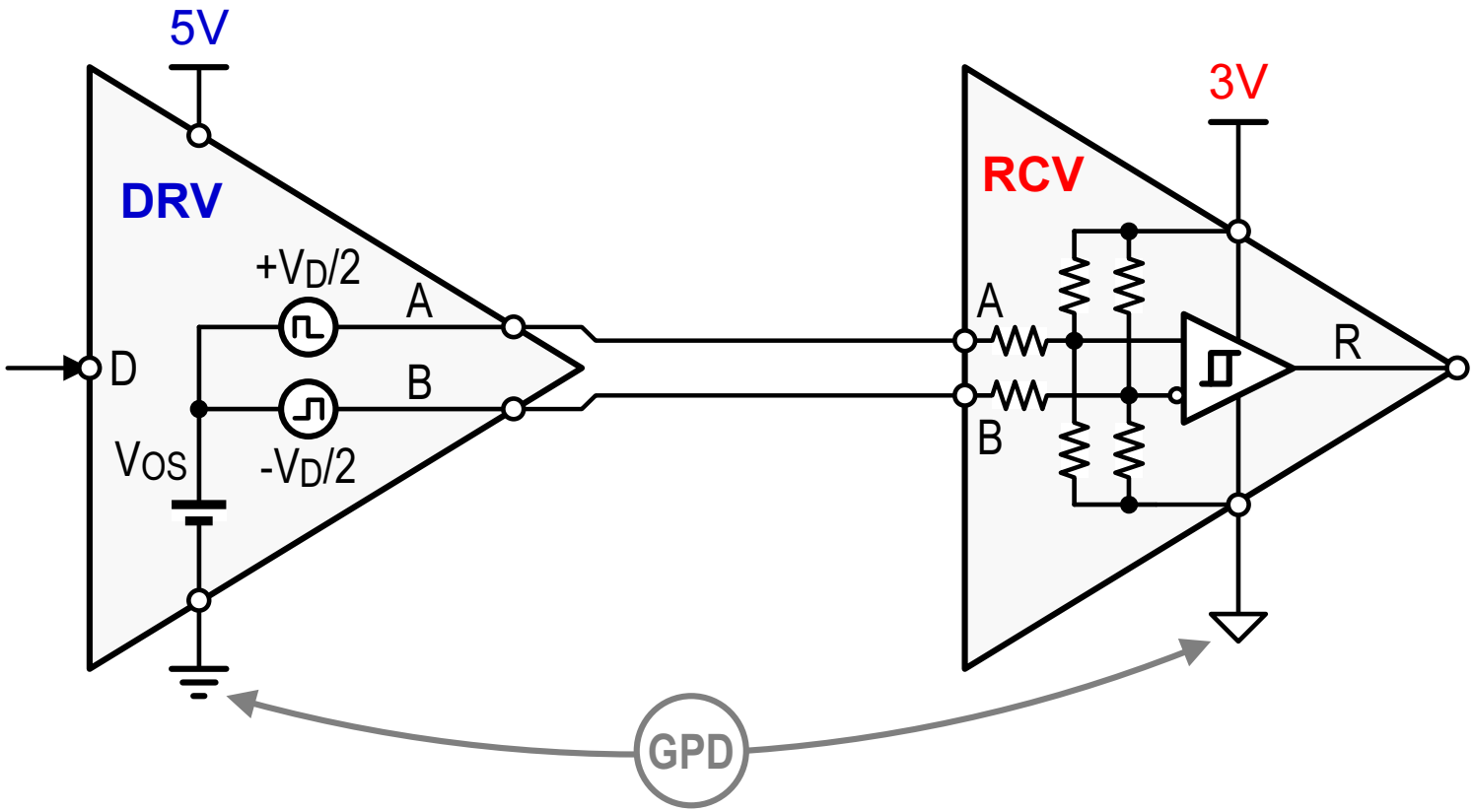
Junction Boxes



9) You can mix 3V and 5V transceivers

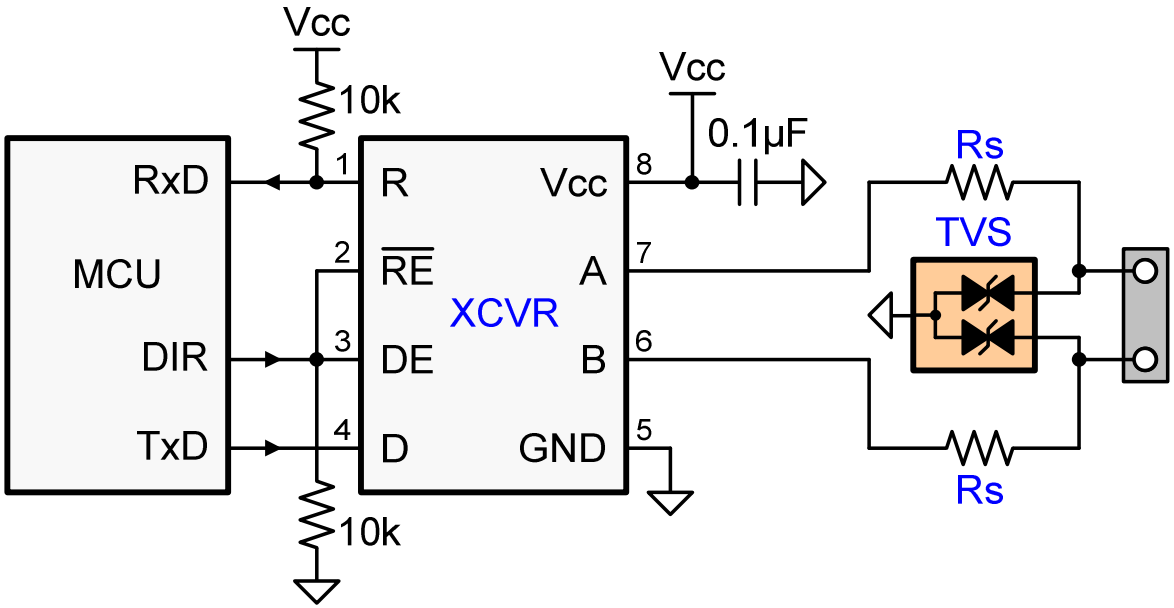
By referencing the receiver inputs to receiver ground, the receiver processes differential signals only.

It does not care whether the differential bus signal comes from a 3V or 5V driver.

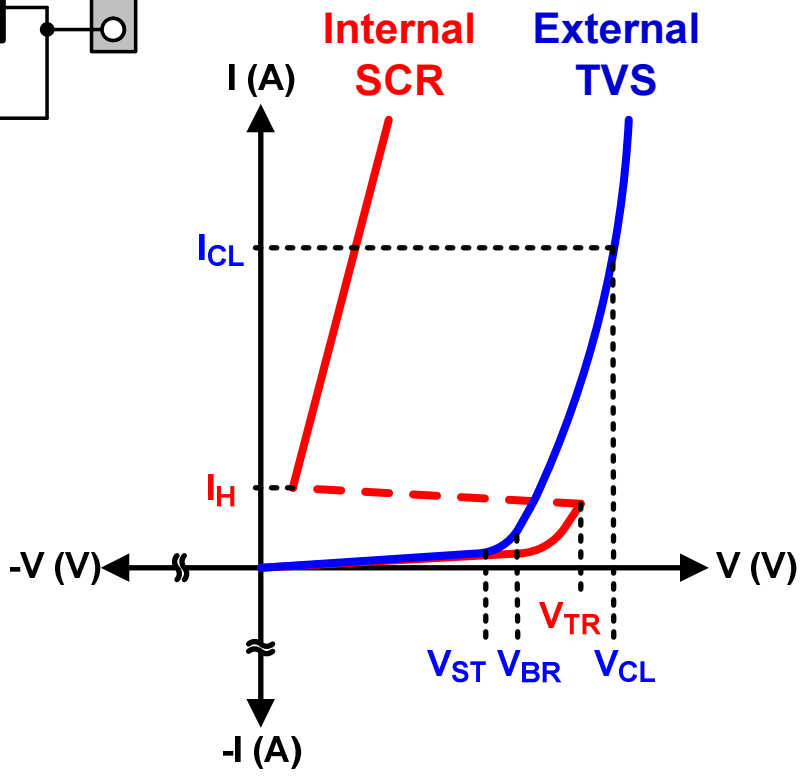


Independent of their supply technology, EIA-485 compliant transceivers must provide a minimum output of V_{OD} = 1.5V across a differential load of 54Ω.

10,11) Apply transient protection



Without Rs the SCR can shunt the TVS and turn it off!



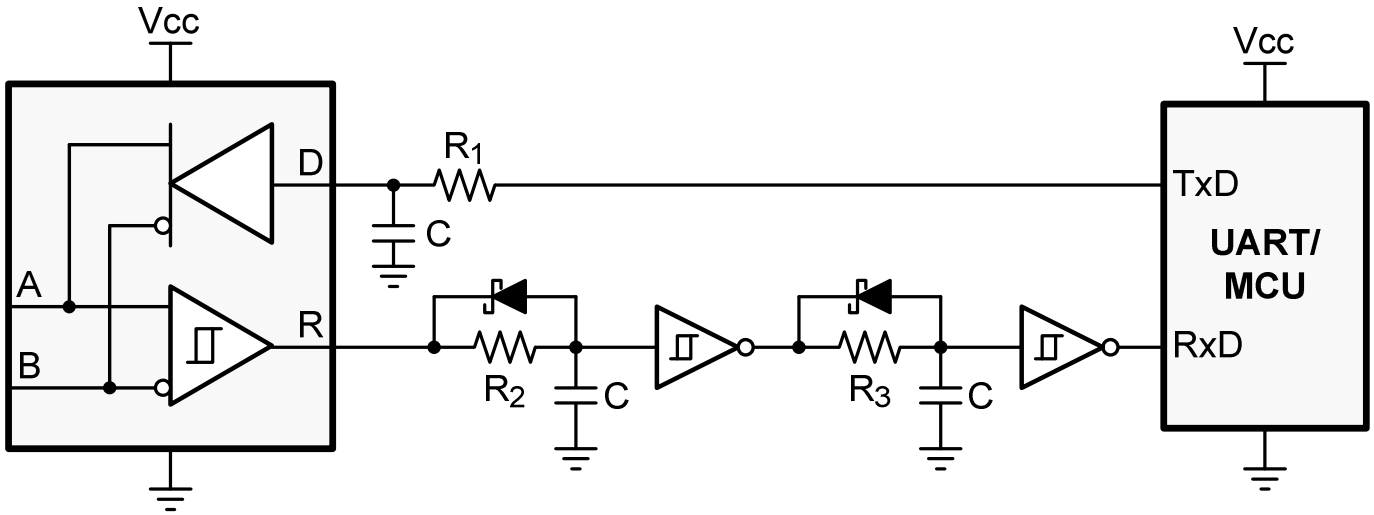
The preferred TVS is SM712 with breakdown voltages from -7V to +12V (EIA-485 compliant).

(available from Semtech, Bourns, Protek Devices)

Rs should be 5Ω to 10Ω MELF or pulse-proof thickfilm resistors.

(available from Vishay)

12) Filter signal noise on control side

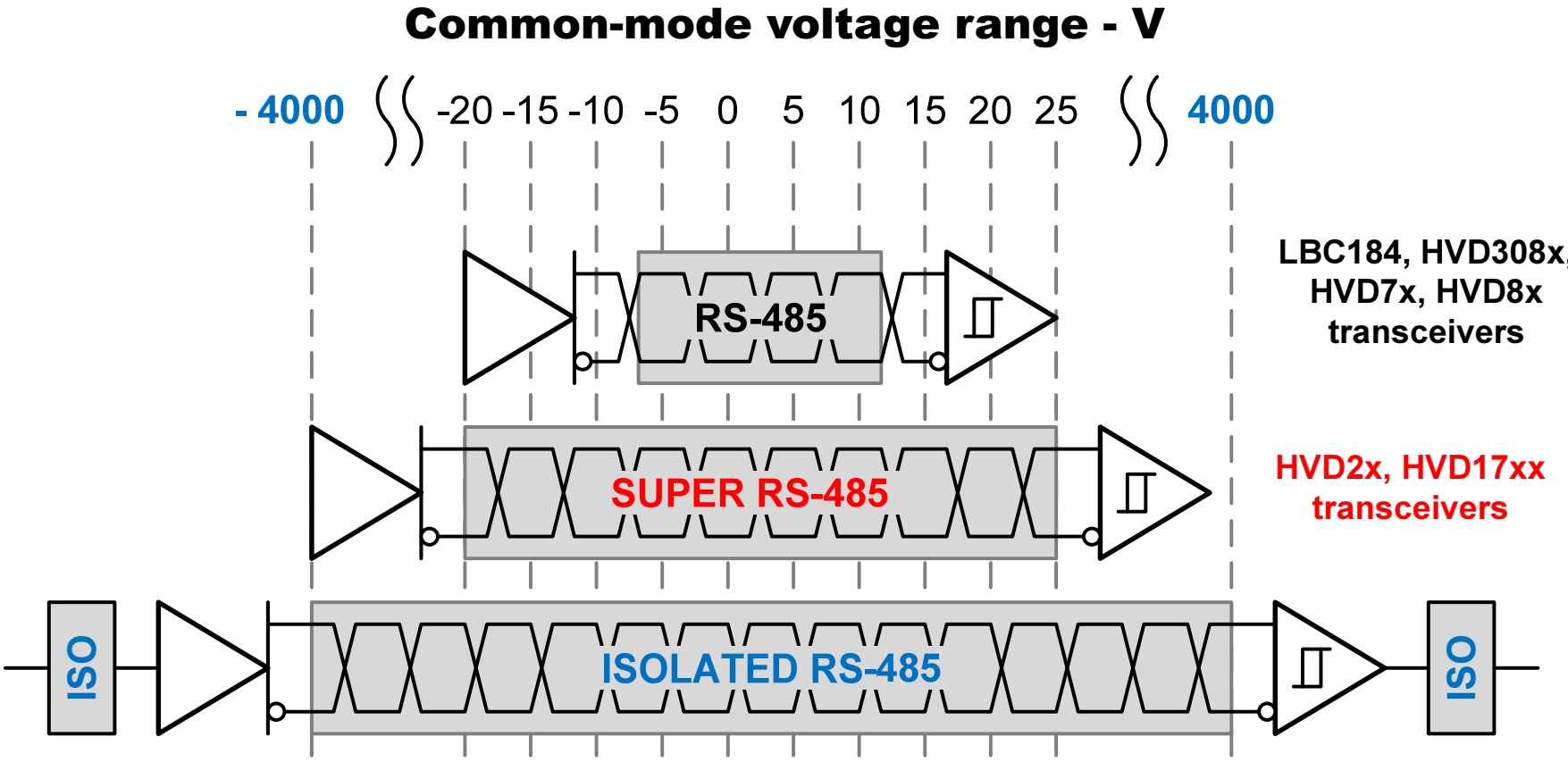


For long traces between controller and transceiver apply low-pass filtering.
In the transmit path, simple R-C filter might suffice.

In the receive path apply debounce filters to block transient remnants from EFT events.
The first R-C stage filters positive, the second stage negative transients.

Example: T_{EFT} = 400ns (positive and negative transients), Inverter = SN74LVC2G14, Diode = BAT54, C = 100pF, R_2 = 4.7kΩ, and R_3 = 12kΩ.

13) Handle ground potential differences



ISO3080/82, ISO35/15, ISO3086/88, ISO1176
ISO35T, ISO3086T, ISO1176T
transceivers

T = integrated transformer driver

Applications and suggested transceivers

Tolerating cross-wire faults : *(E-metering and longhaul networks)*	**SN65HVD888**
High-speed data over long distance: *(Encoders, seismic, traffic monitoring)*	**SN65HVD23 / 24**
High-speed data, high ESD/EFT: *(Backplanes)*	**SN65HVD75 / 78**
High ESD/EFT, long distance: *(Factory and building automation)*	**SN65HVD72 / 82**
Lightning protection: *(Industrial networks)*	**SN65LBC184**
Running data adjacent to power cable: *(Factory and building automation)*	**SN65HVD17xx**
Selecting low/high data rates at 1.8 Vcc: *(Telecom linecards)*	**SN65HVD01**
Isolated bus nodes: *(Profibus networks)*	**ISO1176T**

SN65HVD888

5V, 250kbps, RS485 w/ automatic polarity correction

Features

- Automatic polarity correction
- IEC ESD protection
  - ±16kV HBM protection
  - ±12kV IEC61000-4-2 Contact Discharge
  - +4kV IEC61000-4-4 Fast Transient Burst
- Low quiescent supply current (<1 mA) & Low Standby Supply Current: (< 1 uA typ)
- Large Receiver Hysteresis (60 mV)
- Up to 256 Nodes on a Bus
- Standard SOIC-8 package

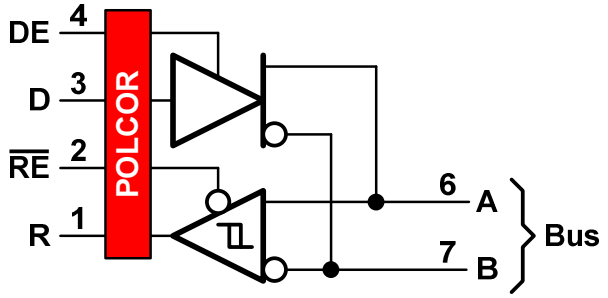
Benefits

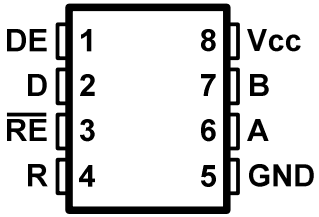
- Prevents system failure in case of mis-wiring
- Reliable in high noise environments
- Enables system power savings → suitable for low power applications.
- Immunity to noise signals on the bus lines
- Allows many nodes on a single network
- Drop-in replacement for industry standard parts

Applications

- E-Metering Networks
- Industrial Automation
- HVAC Systems
- DMX512-Networks
- Process Control
- Battery-Powered Applications

Part #	Data Rate	Duplex	Package
SN65HVD888	250kbps	Half	SOIC-8





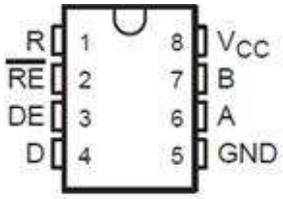
SN65HVD23/24

Wide Common-mode transceivers with receiver Equalization

Features

- **Low EMI Receiver Equalization**
- Common-mode voltage range (-20V to +25V)
- Bus I/O protection to over 16kV HBM
- Failsafe receiver (open / short / idle)
- More than 100mV receiver hysteresis
- Standby current ≤ 1 µA

Part #	Data Rate	Cable Length	Nodes	Package
SN65HVD23	25Mbps	160m	Up to 64	SOIC-8/PDIP-8
SN65HVD24	3Mbps	500m	Up to 256	SOIC-8/PDIP-8

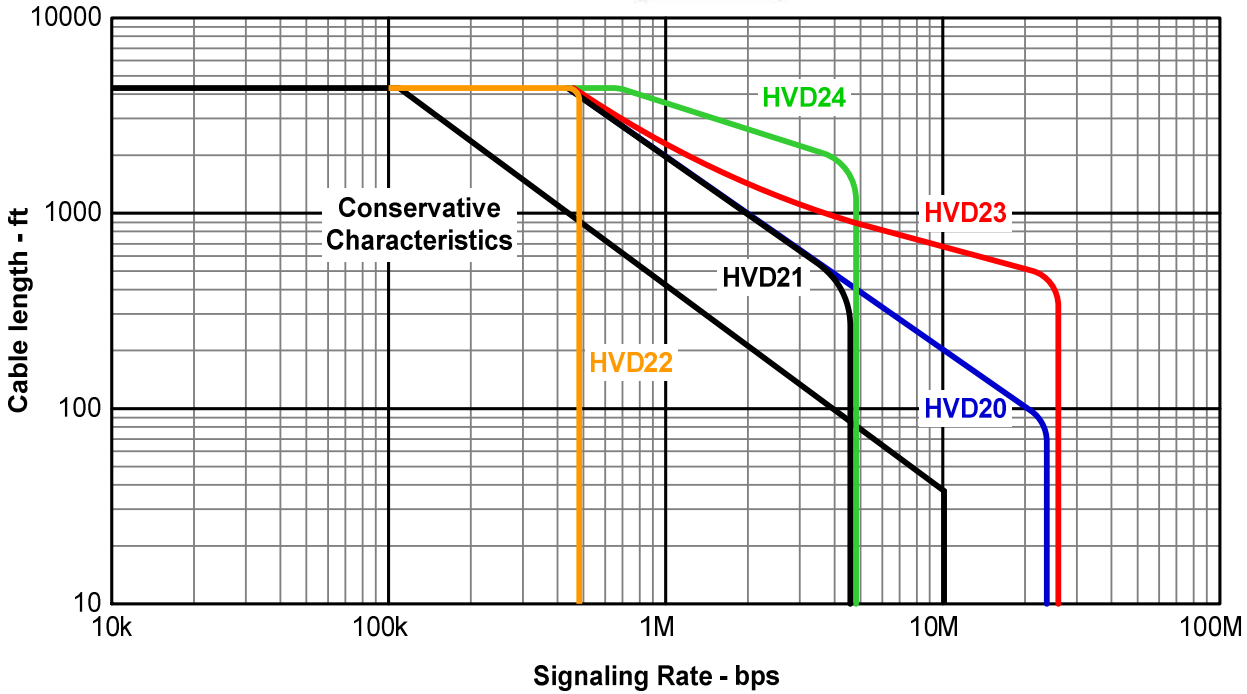


Applications

- Long-cable solutions
  - Building automation
  - Security networks

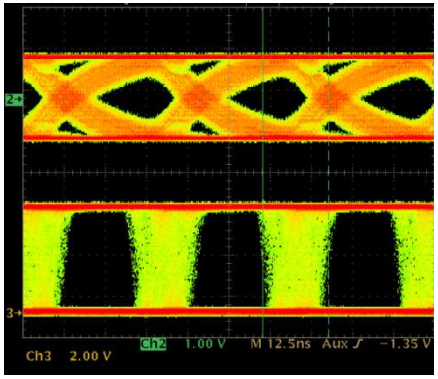
Benefits

- Improves jitter performance on longhaul bus
- Low-cost Network extension
- Low-cost Bandwidth increase

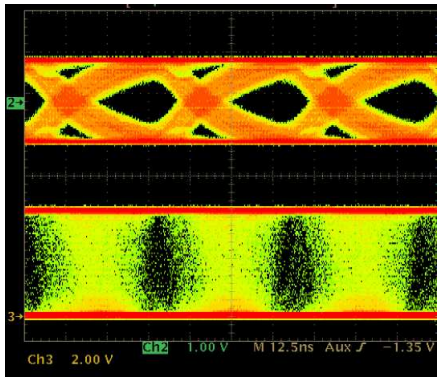


SN65HVD23/24 with Receiver Equalization

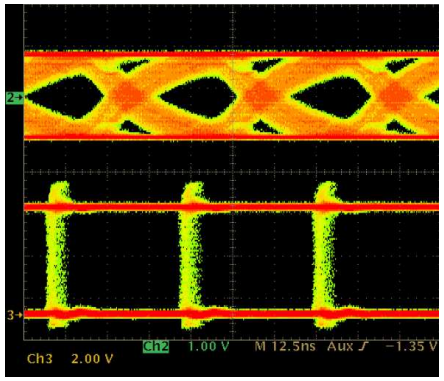
Transceiver Performance over 500 ft at 25 Mbps



LTC1485

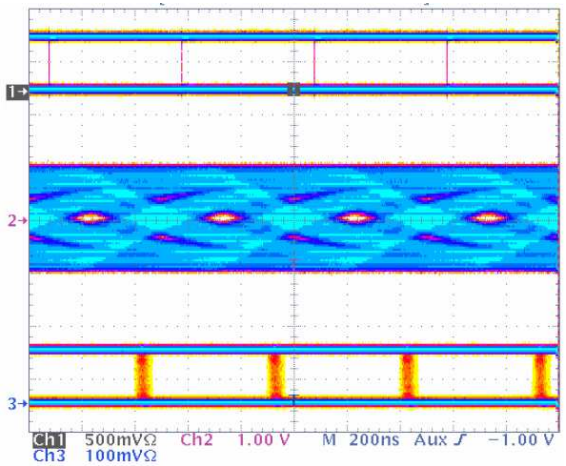


MAX485

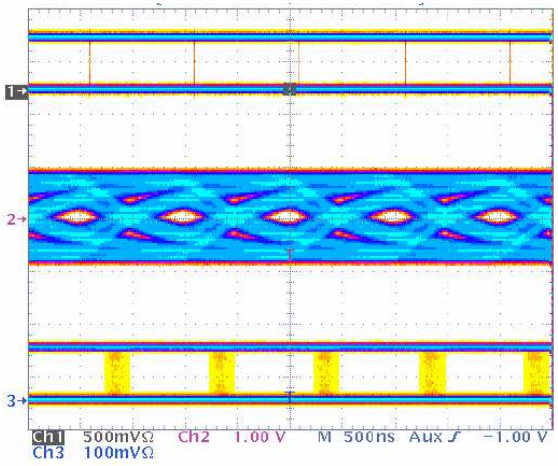


SN65HVD23

Look at these beautiful eyes of SN65HVD24



3300 ft, 2 Mbps



5000 ft, 1 Mbps

SN65HVD7X Transceivers

3.3V RS-485 with IEC ESD protection

Features

- IEC ESD protection
  - > ±15kV HBM protection
  - > ±12kV IEC61000-4-2 Contact Discharge
  - > ±12kV IEC61000-4-2 Air-Gap Discharge
- Low quiescent supply current (<1 mA)
  & Low Standby Supply Current: < 2 uA
- Large Receiver Hysteresis (80 mV)
- 5V-tolerant D, DE, RE inputs
- Standard SOIC-8 package, Small-size MSOP-8 and SON-8 packages

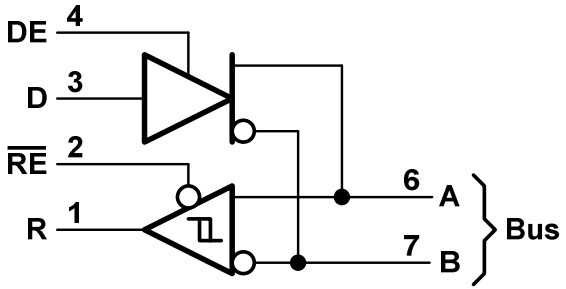
Applications

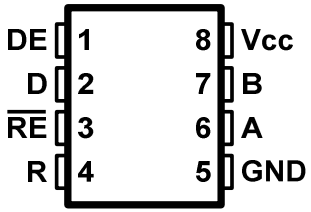
- ANY Application needing high performance in small size
- Factory Automation
- Telecomm Infrastructure
- Motion Control
- Drop in Upgrade for Standard RS-485

Benefits

- Reliable in high noise environments
- Power savings
- Immunity to noise signals on the bus lines
- Compatible with 5V controllers
- Drop-in replacement for industry standard parts
- Smaller packages provide space savings

Part #	Data Rate	Duplex	Package
SN65HVD72	250kbps	Half	SOIC-8, MSOP-8, SON-8
SN65HVD75	20Mbps	Half	SOIC-8, MSOP-8, SON-8
SN65HVD78	50Mbps	Half	SOIC-8, MSOP-8, SON-8





SN65HVD82 Transceiver

5V RS-485 with IEC ESD protection

Features

- IEC ESD protection
  - ±16kV HBM protection
  - ±12kV IEC61000-4-2 Contact Discharge
  - +4kV IEC61000-4-4 Fast Transient Burst
- Low quiescent supply current (<1 mA)
  & Low Standby Supply Current < 1µA typ
- Large Receiver Hysteresis (60 mV)
- Standard SOIC-8 package

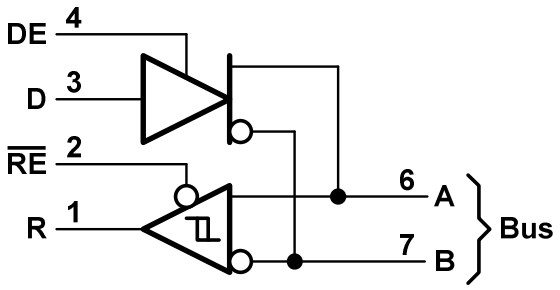
Benefits

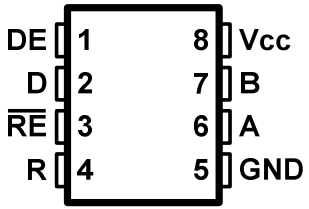
- Reliable in high noise environments
- Enables system power savings
- Immunity to noise signals on the bus lines
- Drop-in replacement for industry standard parts

Part #	Data Rate	Duplex	Package
SN65HVD82	250kbps	Half	SOIC-8

Applications

- Electrical Meters
- Building Automation
- Industrial Networks
- Security Electronics





SN65LBC184 Transceiver

5V RS-485 with integrated TVS diodes

Features

- IEC ESD protection
  - ± 30kV HBM protection
  - ± 15kV IEC61000-4-2 Contact Discharge
  - ± 15kV IEC61000-4-2 Air Discharge
  - ± 4kV IEC61000-4-4 Fast Transient Burst
  - ± 500V IEC61000-4-5 Surge Transient
- Low Standby Supply Current (< 300 uA)
- High Output Drive (90 mA @ 1.5V / 54Ω)
- Standard SOIC-8 package

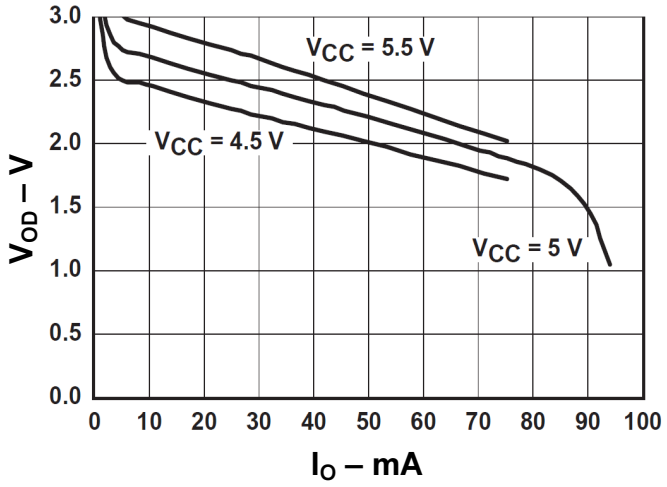
Applications

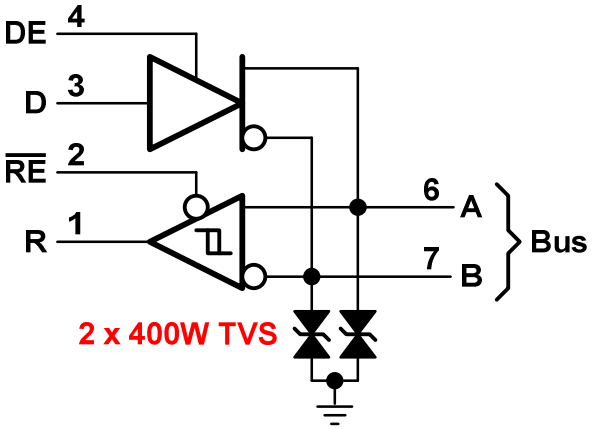
- Longhaul Networks
  (Industrial, Building, Security)
- Repeater Nodes

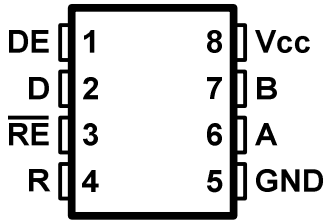
Benefits

- Ultra robust in high noise environments
- Drives long bus lines > 4000 ft
- Provides high noise - immunity
- Drop-in replacement for industry standard parts

Part #	Data Rate	Duplex	Package
SN65LBC184	250kbps	Half	SOIC-8







SN65HVD17xx

Wide Common-mode transceivers with ±70V Stand-off

Features

- Bus-pin fault protection up to ±70V
- -20V to +25V Common mode operation
- ~~3V to~~ 5V VCC operation
- Bus ESD Protection +16kV JEDEC HBM
- Up to 256 or 320 Nodes
- Failsafe Receiver (Open, Shorted, Idle)
- Low Power - 6 mA Active / 5 µA Shutdown
- Glitch−Free Power−Up/Down

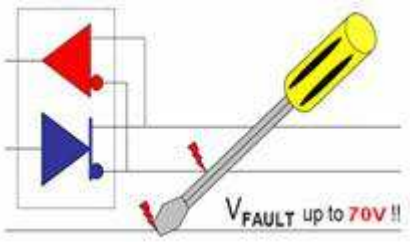
Benefits

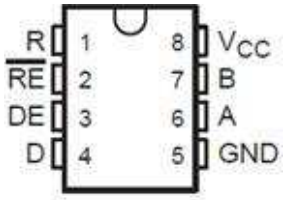
- Ultra High reliability Harshest conditions
  - Over voltage protection to ±70V
  - No termination needed for protection!!
- Wide Common for large ground differences
- Wide VCC Range of operation
- High ESD Protection added survivability
- Hot pluggable without data Corruption
- Versions for all Applications

Applications

- ANY Application with potential to shorten up to ±70 V to bus lines!

  Drop in Upgrade for Standard RS485





Part #	Data Rate	Duplex	Features	Package
SN65HVD1780	115kbps	Half	3V to 5V VCC	SOIC-8/PDIP-8
SN65HVD1781	1Mbps	Half	3V to 5V VCC	SOIC-8/PDIP-8
SN65HVD1782*	10Mbps	Half	3V to 5V VCC	SOIC-8/PDIP-8
SN65HVD1785	115kbps	Half	5V VCC, -20V to 25V CM	SOIC-8/PDIP-8
SN65HVD1786	1Mbps	Half	5V VCC, -20V to 25V CM	SOIC-8/PDIP-8
SN65HVD1787*	10Mbps	Half	5V VCC, -20V to 25V CM	SOIC-8/PDIP-8
SN65HVD1791	115kbps	Full	5V VCC, -20V to 25V CM	SOIC-14
SN65HVD1792	1Mbps	Full	5V VCC, -20V to 25V CM	SOIC-14
SN65HVD1793*	10Mbps	Full	5V VCC, -20V to 25V CM	SOIC-14
SN65HVD1794	115kbps	Half	5V VCC, -20V to 25V CM, Cable Invert	SOIC-8

SN65HVD01: 3.3V RS-485 with Low-Voltage I/O and Switchable Signaling Rate

Features

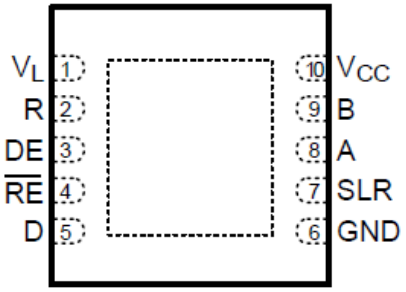
- Low-voltage Input/Output supply
- Small package (3mm x 3mm SON)
- Switchable signaling rate (250 kbps or 20 Mbps)
- High receiver hysteresis (50 mV minimum)
- Low-power standby mode (100 nA typical)
- V_L = 1.65V – 3.6V, V_{CC} = 3.0V – 3.6V

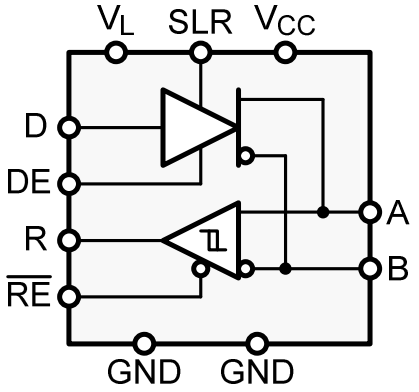
Benefits

- Interface with low-voltage micro-controllers
- Saves board space
- Optimize for slow & long network, or fast network
- Immune to differential-mode noise
- Use in battery-powered systems, or wherever power consumption is critical

Applications

- Telecommunications equipment
- Point-of-sales terminals
- Portable industrial equipment





ISO RS-485 with Transformer Driver

Features

- **Integrated Design**
  - SiO_2 Dielectric Capacitor and Transformer Driver
  - IBus-Pin ESD Protection:
    - >10kV GND2
    - 6kV GND1
  - 1Mbps / 20Mbps / 40Mbps
  - 1/8 Unit load – 256 nodes on a bus
  - Glitch-Free & Failsafe (Open, Shorted, Idle)
- **Immunity and Certifications**
  - Meets or Exceeds TIA/EIA RS-485
  - 2500Vrms Withstand, 560Vpk Working Voltages
  - UL1577, IEC 60747-5-2 (VDE 0884, rev. 2), IEC 61010-1 & CSA pending

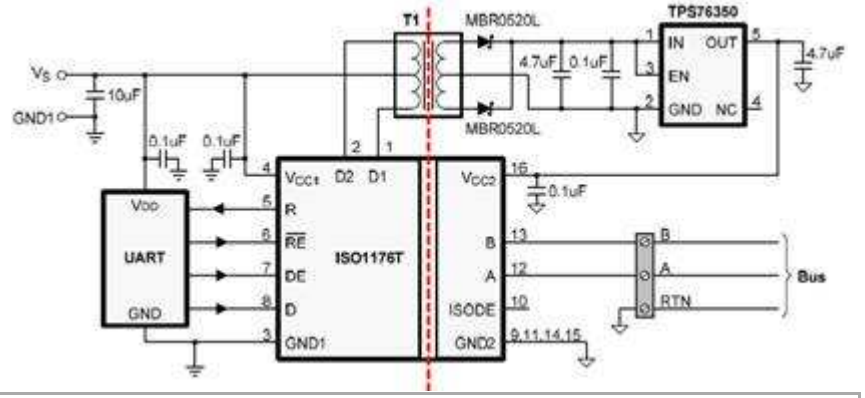
Benefits

- Ease of isolated power design
- Fully compliant to RS-485 Standard
- High Reliability in Harsh Environments
- Optimized for Long Cables Or High Speed
- Large buses
- Hot pluggable & Protected in all situations
- Proven Reliability of SiO2 Insulation, Stable over Time, Temperature & Moisture
  - Life Span > 25 years @ 125°C

Applications

- Energy Meter Networks
- Power Inverters
- Industrial Automation
- Building Automation Networks
- Motor Control
- HVAC

Part #	Duplex	Function	Speed	Package
ISO1176T	Half	Profibus	40Mbps	SOIC-16 (DW)
ISO35T	Full	3.3V RS485	1Mbps	SOIC-16 (DW)
ISO3086T	Full	5V RS485	20Mbps	SOIC-16 (DW)



EVM – ISO1176TEVM / ISO35TEVM / ISO3086TEVM


Thank You!