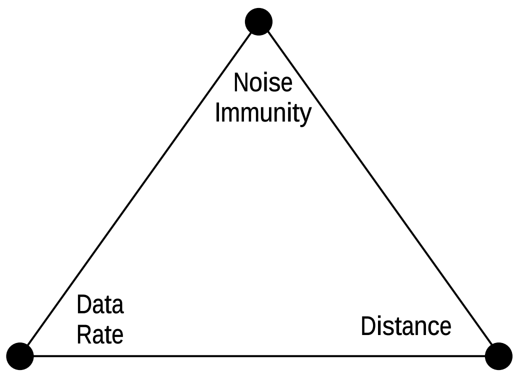
Please refer to the Glossary at the end of this paper.

DeviceNet

The goal of this white paper is to help you understand the reasoning behind the DeviceNet physical layer specifications. Armed with this knowledge, you will be able to make better design decisions and avoid costly mistakes in DeviceNet deployments.

A Fine Balance

In general, all network specifications strike a fine balance between several competing requirements including data rate, distance and noise immunity. Improving one characteristic of a network often results in the degradation of another.



Some other network features, such as media access method *(deciding who gets to talk next on a shared media)* and integrated power supply in the network cable, have side-effects which also had to be considered when defining the physical layer specifications and guidelines.

Once a network has been designed with its characteristics tuned to application requirements it will operate reliably *(providing that it is deployed according to its specification).*

CAN and DeviceNet

In the case of DeviceNet, the requirement for a low cost solution providing reasonable determinism in a potentially noisy industrial environment led to the selection of CAN *(Controller Access Network)* as the basic building block.

CAN was originally developed in the mid '80s as an on-board automotive network. On-board applications require high-speed, determinism, priority-based messaging and high noise immunity – all of which are common requirements for industrial networking applications.

The benefits that led to the selection of CAN as a foundation for DeviceNet were:

- Low Cost, commercially available off-the-shelf components
  (The automotive industry paid for the development of the technology)
- Sufficiently deterministic media access method with no loss of bandwidth during arbitration
- Error detection and recovery implemented in hardware *(interface chips)*
- Priority based media access – high priority messages go first
- Differential shared media interface defined in specification, transceivers commercially available, good noise immunity
- Producer-consumer media access supports Master-Slave, Multi-Master, and Peer-to-peer communications

The selection of CAN added the following requirements:

- CAN media access arbitration method requires tight synchronization between nodes; limiting maximum signal delay across the network is critical
- Maximum data rate 1 Mb/s or less depending on signal delay and signal attenuation
- Data rate is closely related to signal delay across the network, increasing one reduces the other
- Physical layer interface sensitive to common mode voltage, signal voltages must be maintained within specific limits

DeviceNet builds on CAN to address additional market requirements:

- Power in the wire to support basic network-powered devices *(primarily sensors)* while simultaneously supporting self-powered or externally powered devices
- Up to 64 nodes
- Isolation of network from other electrical potentials *(i.e. I/O power & line power)*

The DeviceNet specification defines a solution that addresses market requirements, considers the special requirements of CAN, and provides a range of options that trade-off data rate and network length.

Other application layer protocols that build on CAN include; CANOpen, CAN Kingdom, SDS, and NMEA2000

The CAN Specification

DeviceNet is based on the CAN protocol which defines many of the requirements for the physical layer:

CAN Feature	Physical Layer Requirements
Shared bus	- Multi-access shared media (cable). All nodes are connected to the same cable system without repeaters or hubs.
Collision based arbitration *(deciding which node gets to transmit next)* without loss of bandwidth due to arbitration	- Physical layer supports Dominant (0) and Recessive (1) bus voltage levels. If two nodes transmit at the same time, dominant levels override recessive levels and the resulting bus level is dominant. - Arbitration requires synchronization between nodes; this places restrictions on the maximum time delay between nodes, which in turn limits the maximum cable length.

The CAN specification includes a definition for a physical layer that uses two-wire differential transmission, which is adopted by DeviceNet (*with some adaptations*).

CAN Physical Layer Parameter	Min	Typical	Max
Number of nodes			30
Recessive Differential Bus Voltage	-120mV	0.0V	12mV
Dominant Differential Bus Voltage[1]	1.2V	2.0V	3.0V
Common Mode Voltage *(difference between ground reference of transmitting and receiving transceivers)*			2.5V
Signal Voltage Range *(including common mode voltage effects)*	-2V		7V

Shaded values are superseded by the DeviceNet specification

1 May be higher during arbitration when multiple nodes are transmitting

The DeviceNet Physical Layer

DeviceNet builds on the CAN specification and defines the remainder of the requirements for the physical layer:

DeviceNet Feature	Physical Layer Requirements
Maximum 64 nodes	- Improved transceiver specifications
24VDC Power in wire	- Power conductors in network cable - Extended common mode voltage *(to 5V)* to tolerate voltage drop in power conductors - Controlled voltage drop in power conductors to meet 5V common mode voltage limits, which requires control over both cable length and load current
125, 250, 500 Kb/s	- Pre-defined maximum cable length for each baud rate

By examining the DeviceNet Specification, and applying the extended requirements to the original limits in the CAN specification we can derive the fundamental DeviceNet physical layer limits:

DeviceNet Physical Layer Parameter	Min	Typical	Max
Number of Nodes			64
Recessive Differential Bus Voltage	-120mV	0.0V	12mV
Dominant Differential Bus Voltage[1]	1.2V	2.0V	3.0V
Common Mode Voltage *(difference between network common of transmitting and receiving nodes)*	0V		5V
Signal Voltage Range[2] *(including common mode voltage effects)*	-4.5V		10V
Shield Voltage *(Relative to the network common wire, shield is not present in flat media)*	0		-5V

1 May be higher during arbitration when multiple nodes are transmitting

2 Includes allowance for voltage drop across protection diode present in many devices

Explaining the DeviceNet Specification

The following table lists various aspects of the DeviceNet specification and explains the reasoning behind the limits.

Specification	Limits	Why?
Electrical Isolation	500VDC	The transceiver chips have a limited working voltage range *(see differential transmission and common mode voltage in the glossary)*, which requires careful control of signal levels. External voltage sources *(including earth ground)* can affect signal levels and must therefore be isolated. Contrary to common belief, the 500VDC isolation specification is in place for network functional purposes and not safety considerations. Products that control or use hazardous voltages require a higher isolation voltage for safety reasons.
Number of Nodes	64	Each node has a transceiver circuit that interfaces it to the network cable. Due to the laws of physics and current technology each transceiver is a load on the network, which affects signal strength. Commercially available transceivers exceed the original CAN specification by a significant margin, permitting the DeviceNet to allow more nodes on the network than the 30 specified by CAN. The DeviceNet messaging protocol has support for 64 node numbers, so further improvements in transceiver design will not increase the maximum number of nodes permitted.
Topology	Trunk-Drop	Ideally, shared media networks are connected in a daisy-chained fashion with the nodes strung-out along a common cable. Shared media networks with junctions and branches result in signal distortion and are usually avoided. Trunk-drop topology is a trade-off that permits the nodes to be connected to the main "trunk" cable by short "drop" cables. This provides for enhanced cable system flexibility and easier installation, but the drop lines must be carefully managed to avoid excessive signal distortion.

Specification	Limits	Why?
Maximum Trunk Length	Depends on baud rate and Cable Type ↓	The maximum trunk length is limited by the greater of two factors: signal delay, and signal attenuation.
@ 125Kb/s	Thick Cable 500m (1640')	Thick cable has lower signal attenuation and therefore can carry a signal over long distances limited by maximum signal delay.
	Thin Cable 100m (328')	Thin cable has higher signal attenuation and reaches the attenuation limit at distances less than would be limited by signal delay alone.
	Flat Media 420m (1378')	Flat Media has the same signal attenuation as thick cable, but due to the characteristics of the cable signals pass through it more slowly and the maximum distance is reduced to meet the same maximum signal delay limit.
@ 250Kb/s	Thick Cable 250m (820')	At 250 Kb/s the maximum permissible signal delay is less than at 125 Kb/s, as a result the maximum trunk length for thick cable is reduced.
	Thin Cable 100m (328')	Thin cable reaches the attenuation limit at distances less than would be limited by signal delay alone as with 125 Kb/s operation.
	Flat Media 200m (656')	The higher signal delay of flat media requires a reduced maximum trunk length to meet the maximum signal delay limit.
@ 500Kb/s	Thick Cable 100m (328')	Just as with 250 Kb/s, the maximum trunk length at 500 Kb/s is limited to meet a reduced maximum tolerable signal delay.
	Thin Cable 100m (328')	Thin cable is limited equally by signal attenuation and signal delay to a maximum of 100m. *(Since thin and thick cables have the same signal delay, they have the same length limit at 500 Kb/s.)*
	Flat Media 75m (246')	Flat media, with its higher signal delay, has a reduced trunk length limit to meet the same signal delay requirements as thick and thin cable.
Maximum Single Drop Cable Length	6m (20')	All drop lines create localized changes in the impedance *(see glossary)* of a network trunk cable. As signals pass through the trunk, the impedance variations cause signal distortion proportional to the size of the variation. By limiting the maximum length of each drop line the magnitude of the impedance variation and the subsequent level of signal distortion can be limited to a tolerable level.

Specification	Limits	Why?
Maximum Total Drop Cable Length @ 125Kb/s @ 250Kb/s @ 500Kb/s	Depends on baud rate ↓ 156m (512') 78m (256') 39m (128')	Any two conductors in close proximity *(such as the wires in a network cable)* form a capacitor. The effects of capacitance increase with the signal frequency and the tolerance of a network to the effects of capacitance reduces with data rate. The maximum cumulative drop length is calculated for each bit rate *(signal frequency)* to limit the effects of capacitance to tolerable levels.
Terminating Resistors	120Ω *(One at each end of the trunk cable)*	Just as a drop cable creates localized changes in the impedance *(see glossary)* of a network trunk cable, the end of a cable represents a sharp impedance change. Electrical signals tend to reflect off the sharp impedance change at the end of a cable resulting in significant signal distortion. Placing the appropriate terminating resistor at the end of a cable eliminates the impedance change, eliminating signal distortion due to signal reflection. In the case of DeviceNet the terminating resistor also serves to ensure that the recessive state of the bus *(when no nodes are transmitting)* has a zero volt differential. Omitting one or both terminating resistors can render DeviceNet inoperable.
Power Supply	24V ±1% 0.3% Line Regulation 0.3% Load Regulation 0.6% Temperature Drift 1.05% Time Drift 250mV P-P Ripple	The minimum voltage delivered to a device at the end of a network is the voltage at the power supply less voltage drop in the network cable. In order to specify a guaranteed minimum voltage that each device is designed to operate with it is essential to control both the voltage from the power supply and the voltage lost in the cable system.
Power Tap	Optional Shottky Diode at power supply input. Thick Trunk: Optional 8A Fuses or circuit breakers Thin Trunk: Optional 3A Fuses or circuit breakers	The power tap is an optional component that connects a power supply to the network via a T fitting. The optional fuses or circuit breakers protect each of the two network connectors on the tap to individually protect each "leg" of the network. The optional shottky diode *(see glossary)* provides for load sharing of multiple power supplies and for redundant power supplies on a network. Power taps are not needed when power supplies designed specifically for DeviceNet are used as they commonly include the fuses and protection diode internally.
Network Power	12.69V – 24.53V *(At installation)* 12.44V – 24.78V *(Including drift over time)*	Devices are required to operate with as little as 11V power. The power supply specifications and cable system design guidelines ensure that under normal conditions the bus voltage is maintained above the device minimum including an allowance for ripple. The cable system design guidelines allow for up to 10V drop in the cable; 5V in each power conductor.

Specification	Limits	Why?
Network Load Current	Thick Trunk 8A (or less) Thin Trunk 3A (or less) Drop Cable 3A (or less) Flat Media 8A (or less)	The maximum load current in a segment of DeviceNet cable is limited by the lower of three factors; cable rating, local electrical codes and voltage drop budget. Each DeviceNet cable type has a maximum load current rating, but in the case of thick cable and flat media, it is often limited by local electrical codes to less than 8A. In designing the power system for a network it is necessary to control the maximum voltage drop between the power supply and each mode. This involves determining the maximum load current for each device and placing one or more power supplies on the network to limit the maximum voltage drop in each conductor to less than 5V (10V total). For example, with 500m (1640') of thick cable, while the cable is rated for 8A, local electrical codes limit the current to 4A, but the voltage drop budget limits current to around 0.63A.
Common Mode Voltage (CMV)	5VDC	*See Common Mode Voltage and Differential Transmission in the glossary.* DeviceNet allows for up to 5VDC difference between the network common connections of any two nodes. The voltage at the network common connection is different for each node due to voltage drop in the network common conductor. The maximum voltage drop in the network common conductor is 5VDC according to the cable system design guidelines. The DeviceNet specification does not have a specified limit for AC common mode voltage (noise). AC CMV is primarily caused by external interference, but can also be caused by transients or spikes in the power conductors. A practical limit based on the capabilities of commonly used transceivers is 6.5V including 5V DC common mode and up to 1.5V (peak, 3V peak-peak) AC common mode noise. *In cases where a significant amount of common mode noise is expected it is prudent to reduce the DC common mode budget to increase the allowable noise margin – this is especially helpful with flat media.*

Specification	Limits	Why?
Grounding & Shielding	Thick & Thin Cable DC Common and Shield grounded at one power supply	The signal conductors in a cable act as antennas, which pick up electrical, magnetic and electromagnetic interference (EMI) from the environment, adjacent equipment and cables. The interference takes the form of an alternating voltage, which is added to the data signal in the conductor. This unwanted signal is commonly called "noise". With twisted pair cable, noise is generally induced equally in both signal conductors. Noise common to both signal conductors is cancelled when the receiver *(part of a transceiver)* subtracts one signal voltage from the other to extract the differential data signal *(see Differential Transmission in the glossary)*. (Signal_A + Noise) – (Signal_B + Noise) = Signal_A – Signal_B Even though the receiver cancels noise by subtraction, each input of the receiver sees a signal range that includes the data signal, DC common mode voltage *(CMV)*, and the noise. This can be a problem if the signal + DC CMV + noise exceeds the common mode range *(signal range)* the receiver is designed to handle. DeviceNet, due to its power system, already has up to 5VDC of common mode voltage – before adding any noise. Shielded cable reduces the level of noise induced in a cable with varying degrees of effectiveness for different types of noise. Limiting the level of noise induced in the cable increases the total level of ambient noise that can be tolerated before the receiver's common mode range is exceeded and errors are more likely to occur. A good practical limit based on the capabilities of commonly used transceivers is 3V AC (peak-peak) common mode noise. **The protection offered by a shield is significantly reduced or eliminated if the shield does not fully enclose the signal conductors or is not properly grounded.** If the shield is connected to ground at more than one place *(forming a ground loop)*, differences in ground voltage *(ground is never exactly the same in two places)* causes a current *(with AC and DC components)* to flow in the shield, which develops a voltage across the resistance of the shield. The AC voltage and current can couple into the signal conductors and actually contribute to common mode noise. **Grounding both the shield and the DC common at the power supply is important for shield effectiveness.**

Specification	Limits	Why?
Grounding & Shielding *(continued)*	Flat Media DC Common grounded at one power supply	Flat media was designed for ease of use and rapid attachment of connectors. In order to meet the design goals several compromises were necessary; flat media is unshielded and the signal conductors are not twisted. Since flat media is unshielded a higher level of noise is induced in the data conductors than shielded cable for a given ambient noise level. While this does mean that flat media has a higher susceptibility to noise, field-testing has proven that it remains immune to the types and levels of noise commonly experienced in industrial settings. Drop cables in flat media systems are also unshielded. **Avoid using shielded drop cables with flat media as the result is a "floating" shield which can, in some cases, increase the level of noise induced in the signal conductors.** In order to support "clamp-on" cable connectors the power and data conductors must be in the same position throughout the length of the cable. While this does mean that the data conductors are not twisted, they are located close to each other, which approximates the effect of twisted pair cable. The lack of twists does increase noise-susceptibility compared to twisted cable, but the negative effect is related to the distance from the cable to the noise source and can be minimized by observing proper cable routing practices.

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Glossary

Arbitration	A process that determines which node has the right to transmit on a network at a given time.
CAN	Controller Area Network, originally developed in the mid 80's as an on-board network for automotive applications. Adopted for use in several industrial networks including DeviceNet.
Common Mode Voltage	Please read *Differential Transmission* first… Differential transmission encodes data as a difference in voltage between two signal conductors. Any voltage, which is common to both signal conductors and therefore not part of the data signal, is called common mode voltage. There are two types of common mode voltage, AC and DC, which have different origins. In a DeviceNet network each node's transceiver chip is referenced to the DC common power conductor in the network cable. The transceiver evaluates all signal voltages relative to the network common voltage at the point where the node is connected. As a result of voltage drop in the power conductors, each transceiver has a different reference point. These differences cause an *apparent* DC shift in the signal voltages from the *point of view of the receiving nodes*. This apparent DC shift is *common to both signal wires* and is the primary contributor to DC common mode voltage. Network interface and other circuitry inside the node can also contribute a small DC offset. External interference induces an AC voltage in a wire. Since the data wires in the network cable have equivalent characteristics and are twisted together they tend to pick up the same noise signal. The noise *common to both signal wires* is AC common mode voltage. Differential receivers subtract the voltage on one signal wire from the other in order to extract the data signal. Any AC or DC voltage, which is *common to both signal wires,* is eliminated by the subtraction leaving only the data signal. Transceiver chip designs are limited by physics and by the current state-of-the-art in semiconductor manufacturing. Transceivers reject DC and AC common mode voltage very well, but only within a limited common mode range the chip can be designed for. Signal voltages outside the common mode range can cause the transceiver to incorrectly decode data bits on the network resulting in communication errors.
Determinism	The relevant dictionary definition is "Describes a system whose time evolution can be predicted exactly". The antonym of deterministic is probabilistic, which describes a system whose performance cannot be predicted exactly. Both of these terms are absolute: A given system is either deterministic or probabilistic. No network is deterministic in a pure sense, but if the level of non-determinism is managed to an acceptable level, a system can be considered deterministic from a practical point-of-view. With respect to industrial networks, "determinism" is used to describe a network's ability to <u>consistently</u> deliver data within a <u>reasonably predictable</u> amount of time. The target application for the network is a major factor in defining what is considered "reasonably predictable", hence the wide range of networks describing themselves as deterministic even though their performance varies widely.

Differential Transmission	This technique uses pairs of wires to transmit electrical signals and is highly immune to electrical interference. Data bits *(1's and 0's)* are encoded as differences in voltage on the two wires. Receiving nodes subtract the voltage on one wire from the other to decode the data bits. Any electrical or magnetic interference induces the same noise voltage in both wires, especially when the wires are twisted together and shielded as a pair. When the receiver subtracts the voltage on one wire from the other, the noise voltage is canceled out. For example: if the transmitter sends 3V on wire A, and 2V on wire B, the difference is 1V *(3V – 2V)*. If 0.5V of noise is induced in both wires, the receiver sees 3.5V on wire A and 2.5V on wire B, the different is still 1V *(3.5V – 2.5V)*. The actual differential voltages used to encode data bits varies for each network, but the fundamental concept remains the same.
Drop Cable	A section of network cable that links a node to the trunk *(i.e. through a tee connector or multiport splitter)*. Drop cables are always short *(maximum 20 feet for DeviceNet)*.
Impedance	Impedance is a combination of resistance, capacitance and inductance. Where resistance is an opposition to the passage of a DC signal, impedance can be considered an opposition to the passage of both DC and AC signals. Since impedance is related to the frequency of the signal, it is usually specified for network cables in ohms *(just like resistance)* at a particular frequency.
Kb/s	Kilobits per second, thousands of bits per second
Mb/s	Megabits per second, millions of bits per second
ms	Millisecond, one thousandth of a second
mV	Millivolt, one thousandth of a volt
µs	Microsecond, one millionth of a second
ns	Nanosecond, one billionth of a second
Physical Layer	Networks are often described as a series of layers. The physical layer is the lowest layer that handles transmitting 1's and 0's on the network. The physical layer includes the media (wire), specifications for signal levels on the wire, and specifications for the electrical interface to the media.
Recessive	A bus condition on a CAN network representing a logical value of 1. This is the idle state of the bus (when no nodes are transmitting). Any dominant bits transmitted override recessive bits resulting in a dominant bit on the wire.
Shottky Diode	A diode is a semiconductor device that permits current flow in one direction only. A shottky diode is a specific type of diode that features very low voltage drop when conducting in the forward direction, and offers faster on/of switching times than "standard" diodes.
Signal Delay	Even though electric signals travel through a cable very quickly (about 70% of the speed of light, or 4.77 ns per meter) the small amount of time it does take is significant, especially at higher data rates. For example: at 500 Kb/s one bit of data occupies 2µS (1/500,000) of time on the wire. It takes that signal 0.47µS or 24% of the bit-time to travel through 100m of cable.

Signal Attenuation	When an electrical signal passes through a cable, the impedance of the cable causes a small reduction in the signal strength. The amount of signal attenuation is a factor of cable impedance and cable length. Larger cables typically have lower impedance and lower signal attenuation.
Tee Connector	A cabling device installed in-line with the trunk to facilitate the connection of a drop cable.
Terminator	The terminator is a resistor connected between the network data lines. Two terminators are required for DeviceNet, one at each end of the trunk. The purpose of the terminator in a DeviceNet network is twofold: to prevent signal distortion due to reflections, and to define the recessive state of the bus.
Transceiver	A circuit that **trans**mits and re**ceive**s data on a network. A transceiver circuit is designed to encode digital data *(1 and 0)* as voltages on the media and decode voltages on the media as digital data *(1 and 0)*. The encoding method and voltage specification varies for each network.
Trunk	The section of network cable between the network terminators. The trunk cable is typically *(but not always)* the longest section of cable in a network.
VDC	Volts DC, a measure of constant electrical potential.
VAC	Volts AC, a measure of an alternating electrical potential.