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NMRA Technical Note

NMRANet®

Physical Layer

All Scales

9/12/2010 | Draft TN-9.x.1

1 Introduction

This Technical Note contains informative discussion and background for the corresponding S 9.x.1 Standard. This Technical Note is not normative in any way.

2 Annotations to the Standard

This section provides background information on corresponding sections of the S 9.x.1 Standard document.

2.1 Intended Use

The Standard discusses single CAN segments, and is silent on interconnecting multiple segments. For more discussion of options for interconnection, see the “Repeaters, Bridges and Gateways” section below.

The Standard does not discuss CAN terminators because they're discussed in detail in the CAN literature. See the “Termination” section below for more discussion.

2.2 References and Context

NMRA conformance testing is simplified when it can be done by referring to vendor documentation, rather than requiring specific tests of parameters. The Standard therefore refers to other to existing standards, where possible, instead of repeating the information here.

2.3 Physical Interconnection

The Standard envisions two basic kinds of nodes: Board with 2 connectors and box with a pig-tail cable, e.g. a handheld throttle. At the same time, the Standard should not rule out e.g. a board with two connectors and three pig-tails for attaching throttles, or anything else, hence the somewhat complex wording in this section.

The assignments to particular colors are for information only. These are the colors that users will encounter in the two popular ways of wiring commercial cables. When building a product using commercial cable, using one of these two color codes will reduce confusion, but most NMRAnet users will never need to refer to the colors in their cables.

The signal names refer back to the signal definitions in the CAN specifications. UTP is unshielded cable, so the CAN_SHIELD conductor is being used as a second conductor for the CAN ground reference, CAN_GND.

The discussion of connecting in parallel is to make sure that all 8 wires go through a board, whether it's got connectors, pig-tail cables or a combination of the two, so long as it's got more than one connection to other nodes.

The requirement to have all eight wires present is so people can add power later, or an updated Standard can define the reserved conductors later, and still use them. The 1A requirement on interconnects is to make sure they're at least as robust as the connectors and cable.

For information on sizing circuit board traces to carry the required interconnection current, please see "IPC-2152 — Standard for Determining Current-carrying Capacity in Printed Board Design, 2009."

All 8 wires don't have to go through the board if there's only one connection, e.g. a throttle with a single jack or pig-tail cable with plug. In that case, only two pairs are required.

If a conforming device is providing power and has e.g. two jacks, the device can either connect them together and provide a max of 0.5A to both combined, or separately power them up to 0.5A each. This is the only case where a conductor doesn't have to pass through the board as a continuous electrical circuit. Note that this means that the device has to provide power, however; if providing power is an option, not always present, the device should connect conductor 8 across the board to ensure that downstream nodes aren't cut off from power when it's not provided by the device.

The 100V requirement on the reserved conductors is also there to make sure that when a use if defined for them late, it doesn't blow up existing installations. The goal is to have all existing installations be able to move to newly-defined uses without having to retrofit cables nor non-involved nodes.

To use the reserved conductors for experimental purposes, consider using jumpers (fixed or movable) for making connections to the conductors and/or splitting the reserved conductors between connectors so that the user can restore normal usage later, should some other use be defined for the reserved conductors.

The 27V requirement comes from the S9.1 limitation on track voltage.

2.4 Data Transport

A 4V/microsecond slew rate is preferred to reduce the effect of stubs on the network.

This standard is silent on the use of specific CAN frame formats or features.

2.5 Supply of Power

The power supply section is meant to define a 12V nominal system with wide margins on production and consumption of power over the UTP cable. The Standard is written to allow nodes to use this power in a range of ways, including having local power regulation ranging from simple analog regulators through more advanced supplies that increase current and/or voltage. 12V was chosen to reduce heat loads when using the simplest regulators. The current limit was required by use of 1 conductor in UTP wiring.

Power can be injected into the cable by simple "mid-span injector" devices, essentially just two RJ45 connectors and a 2.1mm jack for a wall-wart. It is not required that power comes from a NMRAnet node itself.

Note that the standard permits, but does not require, connecting the CAN signal ground on conductors 3 & 6 with the PWR_NEG power distribution ground on conductor 7. Power-supplying and power-consuming boards can connect PWR_NEG and the 3/6 grounds to simplify their internal structure. Designers should carefully consider noise immunity, the possibility of ground loop, and voltage offsets when doing this. A straight copper connection is within the letter of the requirement. An alternative to connecting them directly is a filtered connection, e.g. a 10 ohm resistor and a 0.1uF capacitor in parallel.

The power provisions are for low-power uses that can be conveniently handled over short lengths of cable. Boards are welcome to have other connectors for power. These other connectors can be anything not otherwise forbidden by some other standard, including terminal blocks, 2.1mm jacks, Anderson PowerPole connectors, or whatever else is considered useful for the specific market.

Note the effect of the “must withstand” requirement is that power supply boards must be able to be connected to each other, even if their output voltages are not exactly the same. One way to handle this is an isolating diode on the PWR_POS output.

2.6 Consumption of Power

For their thermal calculations, node designers must assume that power is supplied at 15V.

For their power calculations, node designers must assume that power is supplied at 7.5V.

3 Termination

The CAN specification (ISO11898-2 section 7.1 and section 7.5.2) specifies using a bus termination of 120±10 ohms located at each end of the bus.. Several alternate termination schemes have been proposed in the literature (see references), and these alternatives are discussed below.

3.1 Methods

3.1.1 Passive single resistor:

A single 120±10 ohm resistor of ¼ watt or more capacity can connected between CAN-H and CAN-L. This approach has the advantage of simplicity.

3.1.2 Passive split resistors bypassed to ground:

This consists of the CAN-L and CAN-H lines being connected by two 60 ohm resistors in series, with their common connected via a capacitor to ground. This provides a bypass to ground for common mode noise. The tolerance on the individual resistor values is significantly tighter than on their total resistance. (http://focus.ti.com/lit/an/slla270/slla270.pdf)

3.1.3 Biased split termination:

As in (2), but the common of the resistors is also tied to a fixed voltage. This can be to nominal 2.5V via a voltage divider (http://ww1.microchip.com/downloads/en/AppNotes/00228a.pdf), or by using a voltage reference (http://focus.ti.com.cn/cn/lit/an/sloa101a/sloa101a.pdf). If there is a significant offset of ground between two nodes, then this offset will be transmitted to the CAN lines and subsequent degradation of common-mode rejection.

3.1.4 Active termination:

This termination is accomplished by using active elements, such as transistors or op-amps, to actively drive the bus to its proper state. Because of the recessive component of the ISO 11898-2 CAN signal, this form of termination is not appropriate.

3.1.5 Distributed termination:

This technique requires a fixed number of custom-impedance nodes, and is therefore not suitable for model railroad applications that are based on multiple ad-hoc networks made from standard components.

3.2 Placement

Termination can be supplied as an on-board option, or as a terminator housed within an RJ45 plug, or as a separate terminator device, depending on the preferences of the manufacturer and users. Using plug-resident terminators would seem to provide the maximum flexibility. However, as long as on-board termination is de-selectable, flexibility is maintained. Manufacturers may want to provide a special termination node to provide some indication of bus health as well as providing passive termination.

Termination should only occur at the two distant ends of the bus. Termination in the middle of a significant-length CAN bus is very disruptive because it causes reflections. The one downside to on-board termination is that it makes it much easier to have multiple terminators (customers think more must be good, and mistakenly turn them all on).

Note that ISO11898-2 states "The locating of the termination within a CAN node should be avoided because the bus lines lose termination if this node is disconnected from the bus line."

4 Repeaters, Bridges and Gateways

A CAN segment is a set of directly-connected cables that is shared by multiple nodes with directly-connected transceivers. Any node on the segment can communicate with any other node. A CAN segment has limited length, number of nodes and stub connections due to timing and electrical properties of the cables and transceivers.

Repeaters, bridges and gateways are methods for connecting two or more CAN segments so that any node can communicate with any node on any of the connected segments. This section provides some background information on the three technologies. Note that the terminology is somewhat flexible, and not all manufacturers refer to their products in the same way.

In each section, URLs are provided for a few example devices. Inclusion of a device in this section is not a recommendation, positive or negative, for the device. No inferences should be draw from a device being or not being included in this section.

4.1 Repeaters

A short CAN segment with many nodes may run out of electrical drive without reaching the timing limitations of the CAN protocol. In this case, a repeater may be used to connect a second segment containing more nodes. The repeater effectively boosts the electrical signals moving from one segment to the other, so that the nodes on one side appear as only a single electrical load on the other.

Doing this takes a small amount of time, so use of repeaters reduces the total possible end-to-end length of the combined CAN segments, typically around 30 m / 100 ft. Under certain circumstances, they can be used to add long stubs to a CAN network; doing this successfully requires detailed understanding of CAN characteristics.

Repeaters are sometimes referred to as “working at the bit level”. The CAN transmission is delayed by less than a bit time, and the CAN arbitration process still works between nodes on the two segments.

http://www.softing.com/home/en/industrial-automation/products/can-bus/more-can-bus/high-speed/iso-11898-2-repeater.php

http://www.ixxat.com/introduction-repeater_en.html

http://www.esd-electronics-usa.com/shared/datasheets/repeat-e.pdf

http://www.ixxat.com/can_cr200_en.html

4.2 Bridges

A bridge looks like an independent CAN node on each of two or more CAN segments, receiving frames on a segment and sending them independently on the others. As such, it allows connection of two or more full size, full node-count CAN segments.s

Bridges are sometimes referred to as “working at the frame level”. The CAN transmission is delayed by more than a bit time, usually a frame time or longer.

The CAN arbitration process takes place on each segment independently, and is not shared between the separate segments; frames will appear in different order on the various segments. The protocol(s) running on the CAN segments must be compatible with this reordering.

Because bridges break the timing connection between the connected segments, they can also be used for remote connections via non-CAN cables, wireless, etc. In this case, a bridge device is usually used at each end of the remote link, and the protocol between the two devices is specific to the CAN bridge function.

http://www.ixxat.com/introduction_bridges_en.html

http://www.ieee-icnp.org/1996/papers/1996-21.pdf

http://doi.ieeecomputersociety.org/10.1109/ISPAN.1996.509033

http://www.ixxat.com/can_bridge_en.html

http://www.wrcakron.com/devicenet/CAN_Bus_Applications.pdf

http://www.matric.com/canbridge.html

4.3 Gateways

Gateways connect a CAN segment to another communication technology, such as IP over wireless, Ethernet or some other. In the process, they may reformat or translate the CAN frames as needed. For example, a USB-CAN adapter may convert the CAN frame bytes into some form of human-readable text.

This reformatting may be independent of the CAN frame content information, or specific to some protocol that defines meaning for the CAN frames.

http://www.phytec.com/products/can/pc-can-interfaces/CAN-Ethernet-Gateway.html

http://news.thomasnet.com/fullstory/Gateway-converts-from-CAN-into-Ethernet-529941

http://www.icpdas-usa.com/products.php?PID=3075

5 References

This section provides references, and when possible URLs, that may be of use to NMRAnet implementors.

5.1 Standards

The S 9.x.1 standard references ISO 11898-1 and ISO 11898-2 for CAN specifications. The ISO (http://www.iso.org) sells PDF and paper copies of these. Copies can generally be found in engineering libraries.

Note that ISO 11898-3, 11898-4 and 11898-5 specify different variants of the CAN standard that are not relevant to S 9.x.1 compliant implementations. The original 1995 Bosch CAN standard, which can be found online, is similar to IS 11898-1 and -2, but not identical.

The S 9.x.1 standard references TIA/EIA-568-B or the successor TIA/EIA- 568-C for unshielded twisted pair (UTP) cable, and TIA-968-A for RJ45 modular plugs and jacks. The TIA (http://www.tiaonline.org) sells PDF and paper copies of these. Copies can generally be found in engineering libraries.

5.2 Application Notes

A number of component manufacturers have written application notes that may be useful to NMRAnet developers. A list is provided here for reference, but please note that none of these are normative; for specific values, etc, please refer to the standards listed above.

5.2.1 Anixter

"ANSI/TIA/EIA-568-B Standards Reference Guide" (http://www.anixter.com/AXECOM/AXEDocLib.nsf/(UnID)/8F2E0839A6190F4986257309005757CC/$file/ANSI-TIA-EIA-568-B.pdf)

5.2.2 Mohawk.com

"ANSI/TIA/EIA-568-B (B.1, B.2 and B.3) Commercial Building Telecommunications Cabling Standard" (http://www.mohawk-cable.com/support/ansi-tia-eia-568-b.html)

5.2.3 Microchip Corp

AN713 “Controller Area Network (CAN) Basics” (http://ww1.microchip.com/downloads/en/AppNotes/00713a.pdf)

AN228 “A CAN Physical Layer Discussion” (http://ww1.microchip.com/downloads/en/AppNotes/00228a.pdf)

AN853 “PIC18XXX8 CAN Driver with Prioritized Transmit Buffer” (http://ww1.microchip.com/downloads/en/AppNotes/00853a.pdf)

5.2.4 Philips

AN96116 “PCA82C250 / 251 CAN Transceiver” (http://www.nxp.com/documents/application_note/AN96116.pdf)

5.2.5 Texas Instruments

Analog Applications Journal, August 1999, TI SLYT197 “TIA/EIA-568A Category 5 cables in low-voltage differential signaling (LVDS)” (http://focus.ti.com/lit/an/slyt197/slyt197.pdf)

Application Report SLOA101A “Introduction to the Controller Area Network (CAN)” (http://focus.ti.com.cn/cn/lit/an/sloa101a/sloa101a.pdf)

Application Report SLLA270 “Controller Area Network Physical Layer Requirements” (http://focus.ti.com/lit/an/slla270/slla270.pdf)

Application Report SLLA298B “Isolated CAN Reference Design” (http://focus.ti.com/lit/an/slla298b/slla298b.pdf)

Application Report SLOU262 “Isolated CAN Transceiver EVM” (http://focus.tij.co.jp/jp/lit/ug/slou262/slou262.pdf)

Analog Applications Journal, 3Q 2006, TI SLYT249 “Improved CAN network security with TI’s SN65HVD1050 transceiver” (http://focus.ti.com/lit/an/slyt249/slyt249.pdf)

5.3 Component data sheets

This section lists component data sheets that may be of value to the NMRAnet implementor. Inclusion of a component data sheet in this section is not a recommendation, positive or negative, for the component. No inferences should be draw from a component or data sheet being or not being included in this section.

5.3.1 Microchip

MCP 2551 High-Speed CAN Transceiver (http://ww1.microchip.com/downloads/en/DeviceDoc/21667f.pdf)

MCP2515 Stand-Alone CAN Controller With SPI Interface (http://ww1.microchip.com/downloads/en/DeviceDoc/21801e.pdf)

5.3.2 NXP Electronics (Philips)

PCA82C250 CAN controller interface (http://www.nxp.com/documents/data_sheet/PCA82C250.pdf)

5.3.3 STMicroelectronics

L9615 transceiver (http://www.st.com/stonline/products/literature/ds/5637.pdf)

5.3.4 Texas Instruments

ISO1050 Isolated CAN Transceiver (http://focus.ti.com/lit/ds/symlink/iso1050.pdf)

SN55HVD251, SN65HVD251 Industrial CAN Transceiver (http://focus.ti.com/lit/ds/symlink/sn55hvd251.pdf)

SN65HVD1050 EMC Optimized CAN Transceiver (http://focus.ti.com/lit/ds/symlink/sn65hvd1050.pdf)

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