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| NMRA Technical Note | |
|----------------------------|-----------------------|
| NMRANet[®] | |
| Physical Layer | |
| All Scales | |
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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 Intended Use

- 5 There is no intention that devices that connect more than on CAN segment (e.g. bridges) have to electrically interconnect those separate segments.

We don't discuss CAN terminators, because they're discussed in detail in the CAN documentation that the standard references. A simple resistor on a RJ45 plug can be used, or more complex devices can be created and sold that e.g. contain diagnostic readouts. So long as it provides in-spec termination, they're all fine.

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3 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.

15 4 Physical Interconnection

We're trying to enable two basic kinds of nodes: Board with 2 connectors and box with a pig-tail cable, e.g. a handheld throttle. But we don't want to 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.

- 20 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. If you're 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.

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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.

- 30 We want all 8 wires present so people can add power later, or we can define the reserved conductors later, and still use them. The 1A 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."

- 35 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 your product is providing power and has e.g. two jacks, you 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
40 that this means that your product has to provide power, however; if providing power is an option, not always present, you should connect conductor 8 across the board to ensure that downstream nodes aren't cut off from power when it's not provided by your board.

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

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

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

5 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.

6 Supply of Power

- 55 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. We expect that nodes will 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
60 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's not required that it comes from a NMRAnet node itself.

- Note that the standard permits, but does not require, connecting the CAN signal ground on
65 conductors 3 & 6 with the PWR_NEG power distribution ground on conductor 7. We expect that most power-supplying and power-consuming boards will 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

70 connection is within the letter of the requirement. An alternative to connecting them directly is e.g. a 10 ohm resistor and a 0.1uF capacitor in parallel.

75 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.

7 Consumption of Power

80 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.

8 Termination

85 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.

8.1 Methods

8.1.1 Passive single resistor:

90 This consists simply of a 120 ohm connected between CAN-H and CAN-L, and is the commonest termination scheme. Its main advantage is simplicity.

8.1.2 Passive split resistors 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 is simple but also helps balance the two lines.

95 8.1.3 Passive split resistors to fixed voltage:

As in (2), but common is also tied to a fixed voltage. This can be to nominal 2.5V via a voltage divider (ref xx), or by other means, by using a voltage reference. Unfortunately, this may lead to problems if there is a large ground offset between two nodes.

8.1.4 Active termination:

100 This termination is accomplished by using active elements, such as transistors or op-amps to actively drive the bus to its active state. Although theoretically possible, this has not been used on CAN. Note: active termination requires power.

8.1.5 Distributed termination:

This is not appropriate for MRR, since it requires a fixed number of nodes.

105 8.2 Placement:

Any termination can be supplied as a on-board option, or as a terminator- connector. Obviously, this is based on the preferences of the manufacturer and users. Using terminator-plugs 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 that as well as providing passive or active termination, also provides some indication of bus health.

110 Termination should, generally, 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."

9 Repeaters, Bridges and Gateways

120 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.

125 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.

130 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.

9.1 Repeaters

135 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.

140 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

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

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

9.2 Bridges

150 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.

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.

155 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.

160 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

165 <http://www.matric.com/canbridge.html>

9.3 Gateways

170 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>

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

10 References

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

10.1 Standards

180 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
185 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.

190 10.2 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.

10.2.1 Anixter

195 “ANSI/TIA/EIA-568-B Standards Reference Guide”
([http://www.anixter.com/AXECOM/AXEDocLib.nsf/\(UnID\)/8F2E0839A6190F4986257309005757CC/\\$file/ANSI-TIA-EIA-568-B.pdf](http://www.anixter.com/AXECOM/AXEDocLib.nsf/(UnID)/8F2E0839A6190F4986257309005757CC/$file/ANSI-TIA-EIA-568-B.pdf))

10.2.2 Mohawk.com

200 “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>)

10.2.3 Microchip Corp

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

205 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>)

10.2.4 Philips

AN96116 “PCA82C250 / 251 CAN Transceiver”

210 (http://www.nxp.com/documents/application_note/AN96116.pdf)

10.2.5 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)”

215 (<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>)

220 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>)

10.3 Component data sheets

225 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 drawn from a component or data sheet being or not being included in this section.

10.3.1 Microchip

230 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>)

10.3.2 NXP Electronics (Philips)

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

10.3.3 STMicroelectronics

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

10.3.4 Texas Instruments

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

240 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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Table of Contents

| | |
|-------------------------------|---|
| Introduction..... | 1 |
| Physical Interconnection..... | 1 |
| Power Supply..... | 2 |

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