Minimum distance between CAN nodes

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This article discusses a problem that is typically invisible during normal bus operation and is not easily detected. Invisible errors occur such as priority mistakes in which high priority messages receive low priority placement during arbitration and messages are transmitted out of order. Most notable is that these errors only occur when multiple dominant bits are transmitted at the same time.

CAN networks are often constructed with groups of nodes placed physically close together. When these groups of nodes are spaced, a relatively long distance from other nodes, random data errors can be generated that are not easily uncovered by a system designer. Guidelines for the spacing of CAN nodes along a bus are presented based upon the group capacitance of nodes on a system.

The CAN high-speed transceiver compliant to ISO-11898-2:2003 is a distributed parameter circuit whose electrical characteristics and responses are primarily defined by the distributed inductance and capacitance along the bus. The bus is defined here as the interconnecting cable or conducting paths, connectors, terminators, and CAN devices added along the bus.

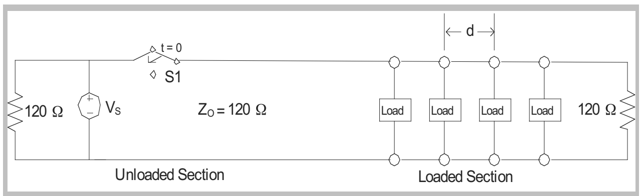

Fig. 1: CAN node spacing diagram

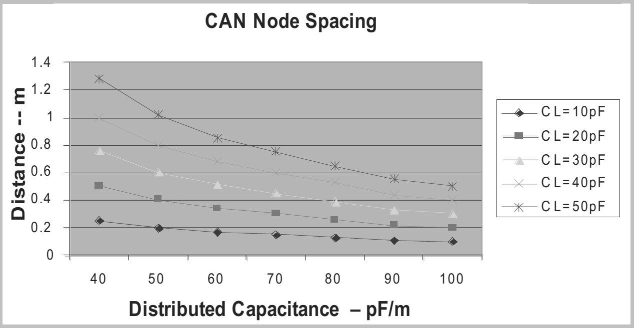

Fig. 2: Minimum CAN node spacing

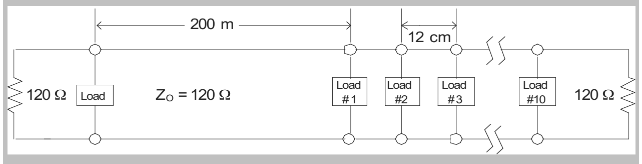

Fig. 3: Capacitive "group" load example

The following analysis reveals a trade-off between the amount of node capacitance that can be added and the node spacing on a bus while maintaining signal integrity. For a good approximation, the characteristic line impedance seen while looking into any cut point in an unloaded CAN network is defined by

$$Z = \sqrt{L/C},$$

where L is the inductance per unit length and C is the capacitance per unit length. As capacitance is added to the bus in the form of CAN transceivers and their interconnection, the bus impedance is lowered to Z'. When bus impedance is lowered, an impedance mismatch occurs between unloaded and loaded sections of the bus.

A worst-case situation occurs when multiple dominant bits are simultaneously sent from two or more nodes as occurs during arbitration or an ACK bit. Displayed in Fig. 1, as S_1 switches from a dominant state to a recessive state, the CAN driver differential output voltage (V_S), moves from a dominant voltage to a recessive steady-state 0 V differential signal on the bus. As the signal wave arrives at this mismatch, an attenuation (or amplification) of the signal occurs.

Minimum distance calculation

The signal voltage at the impedance mismatch is:

$$V_{L1} = V_{L0} + V_{J1} + V_{R1},$$

where V_{L0} is the initial differential voltage, V_{J1} is the input signal differential voltage transition, and V_{R1} is the reflected differential voltage. The voltage reflected back from the mismatch is

$$V_{R1} = \rho L \times V_{J1},$$

where

$$\rho L = \frac{Z' - Z}{Z' + Z},$$

and is the coefficient of reflection commonly used in transmission line analysis. The voltage equation can now be written as:

$$V_{L1} = V_{L0} + V_{J1} + \rho L \times V_{J1}$$

Assuming the bus is terminated correctly at both ends, a CAN driver creates a high-to-low differential voltage change from the standard maximum of 3 V to 0 V, or a V_{J1} of -3 V. The signal voltage at the load, V_{L1}, must go below the receiver recessive bit input voltage threshold of 0,5 V before the bit is sampled by the CAN controller.
This may be written as:

$$0{,}5 > 3 + (-3) + \rho L \times (-3)$$

$$\rho L > \frac{0{,}5}{-3} = -0{,}167$$

Now, solving for Z',

$$\rho L = \frac{Z' - Z_0}{Z' + Z_0} > -0{,}167$$

$$Z' - Z_0 > -0{,}167(Z' + Z_0)$$

$$Z'(1 + 0{,}167) > Z_0(1 - 0{,}167)$$

$$Z' > 0{,}71 Z_0$$

If the loaded bus impedance is no less than 0,71 Z_0, the minimum threshold level should be achieved on the incident wave in all situations.

In the derivation of the minimum loaded-bus impedance, the addition of CAN transceivers and their capacitance is treated as a distributed model. Therefore, the loaded-bus impedance is approximated by

$$Z' = \sqrt{L/(C + C')},$$

▶

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where *C'* is the added capacitance per unit length.

If the distributed inductance and capacitance of the media are known, *Z'* may be calculated directly, however they are not commonly specified. Manufacturers generally do specify the characteristic impedance, Z_0, of the cable and the capacitance per unit length, *C*. With these specifications known, *L* is easily solved from the relationship,

$$Z_0 = \sqrt{\frac{L}{C}}$$

as

$$L = Z_0^2 C\,.$$

Substituting this value into the equation for *Z'* and simplifying:

$$Z' = \sqrt{\frac{Z_0^2 C}{(C + C')}} = Z_0\sqrt{\frac{C}{C + C'}}$$

C' is the distributed device capacitance, C_L, divided by the distance (*d*) between devices or

$$C' = \frac{C_L}{d}\,.$$

Substituting this into the equation and solving for *d*:

$$Z' = Z_0\sqrt{\frac{C}{C + C_L/}}$$

$$\left(\frac{Z'}{Z_0}\right)^2 = \frac{C}{C + C_L}$$

$$C\left(\frac{Z_0}{Z'}\right)^2 = C + C_L/$$

$$d = \frac{C_L}{C\left(\left(\frac{Z_0}{Z'}\right)^2 - 1\right)}$$

Now substituting in the minimum *Z'* of 0,71 Z_0 yields:

$$d > \frac{C_L}{C\left(\left(\frac{Z_0}{0{,}71Z_0}\right)^2 - 1\right)}$$

$$d > \frac{C_L}{0{,}98C}$$

meters (since C is pF/m).

[given in m (since C is given in pF/m]

Therefore, the minimum allowable distance between nodes (d) is a function of the device lumped-capacitance C_L, and the cable's distributed capacitance per unit length, *C*. Fig. 2 displays this relationship graphically.

Group capacitance

Load capacitance includes contributions from the CAN transceiver, connector contacts, printed-circuit board traces, protection devices, and any other physical connection when the distance from the bus to the transceiver is electrically short.

CAN transceivers such as the SN65HVD251 used in this example, have a 10 pF typical differential capacitance. Board traces add about 0,5 pF/cm to 0,8 pF/cm depending upon construction variations. Board connector and suppression device capacitance varies widely and media distributed capacitance ranges from about 35 pF/m for low-capacitance shielded-twisted-pair cable to 70 pF/m for backplanes.

As a demonstration of this condition, Fig. 3 displays ten SN65HVD251 CAN transceivers connected to the bus with 12 cm of 120-Ω twisted-pair cable between each node. The last node on the bus is terminated with a 120-Ω termination-resistor and the first node is connected through an additional 200 m of twisted pair cable to another node and also terminated.

The waveform problem

Fig. 4 displays the waveforms of the normal 250 kbit/s data being transmitted on the bus. However, Fig. 5 displays what happens when more than one node sends a dominant bit onto the bus such as happens during an arbitration. Clearly there is a higher voltage magnitude when more than one node is simultaneously placing a dominant bit on a bus. Note that the typical propagation delay of 5 ns/m for 200 m is 1 000 ns, or 1 µs, and is clearly evident in each of the waveforms.

The negatively charged waveform is reflected back and attenuates the waveform at the impedance miss-match of nodes. Fig. 6 displays a higher resolution of this reflected condition. ▶

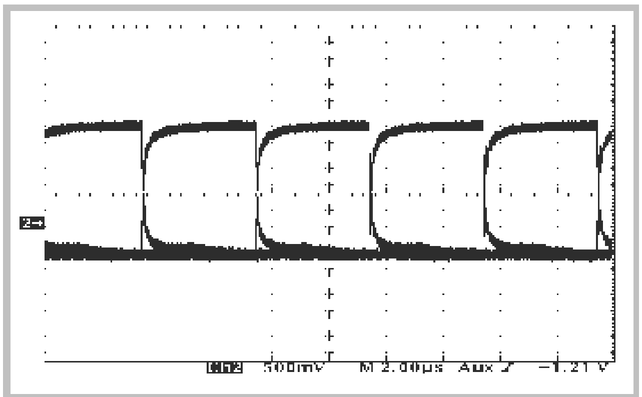

Fig. 4: Normal data transmission

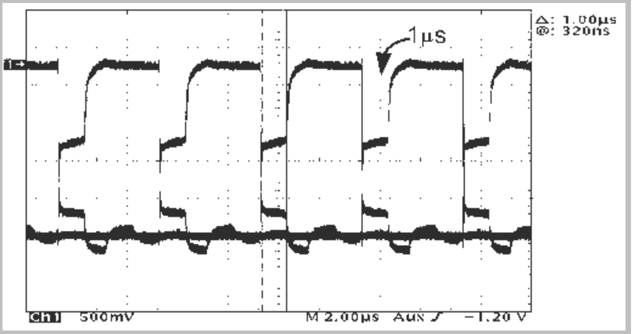

Fig. 5: Multiple dominant-bit reflected wave

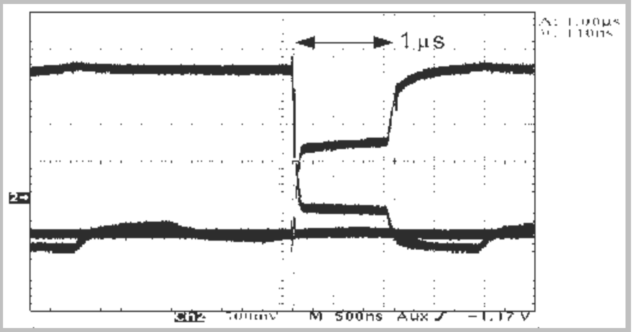

Fig. 6: The multiple dominant bit reflected wave close-up

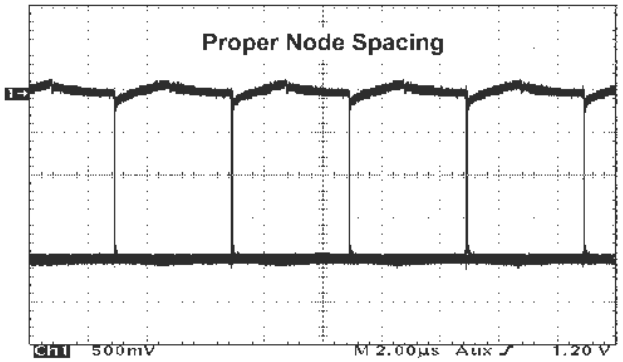

Fig. 7: CAN node spacing correction

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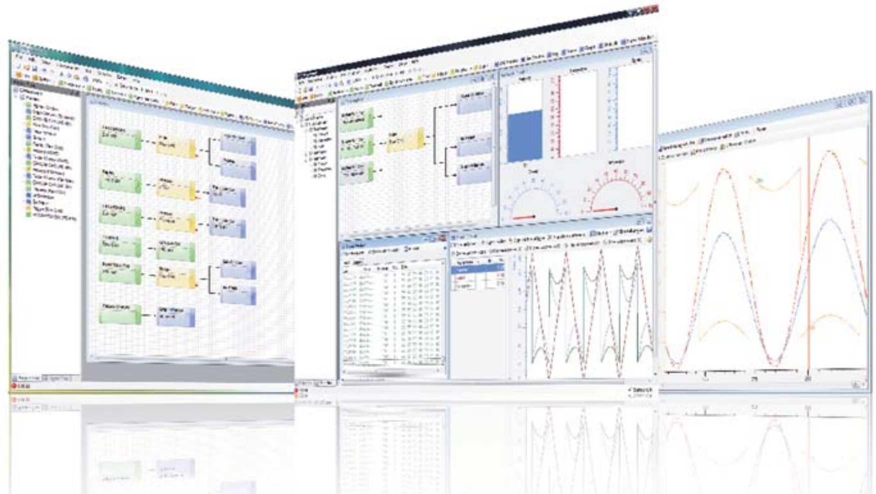

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Fig. 5 and Fig. 6 exemplify possible problems since the waveform voltage magnitude obviously falls below the 900-mV dominant bit threshold for a large percentage of the wave. The dominant threshold may or may not be reached for 1 µs into the bit's width. Should the signaling rate be increased to 500 kbit/s, this reflection would consume more than half of the 2-µs waveform.

CAN node spacing solution

The lumped load capacitance, CL for each CAN transceiver, board trace and Berg connector amounts to approximately 20 pF per node in this example, while the distributed capacitance per unit length, C, is about 40 pF per meter. The calculations presented in Fig. 2 for a CL of 20 pF and C of 40 pF indicate that a half meter of cable added between each of the ten group nodes in place of the 12 cm cable is required to correct the problem.

Fig. 7 displays conclusive evidence that the calculations prove correct, and the reflected wave is almost completely corrected. The half-meter of twisted-pair cable rolls up neatly out of the way next to each node. Invisible multiple dominant-bit errors no longer occur on the test bus.

www.kvaser.se

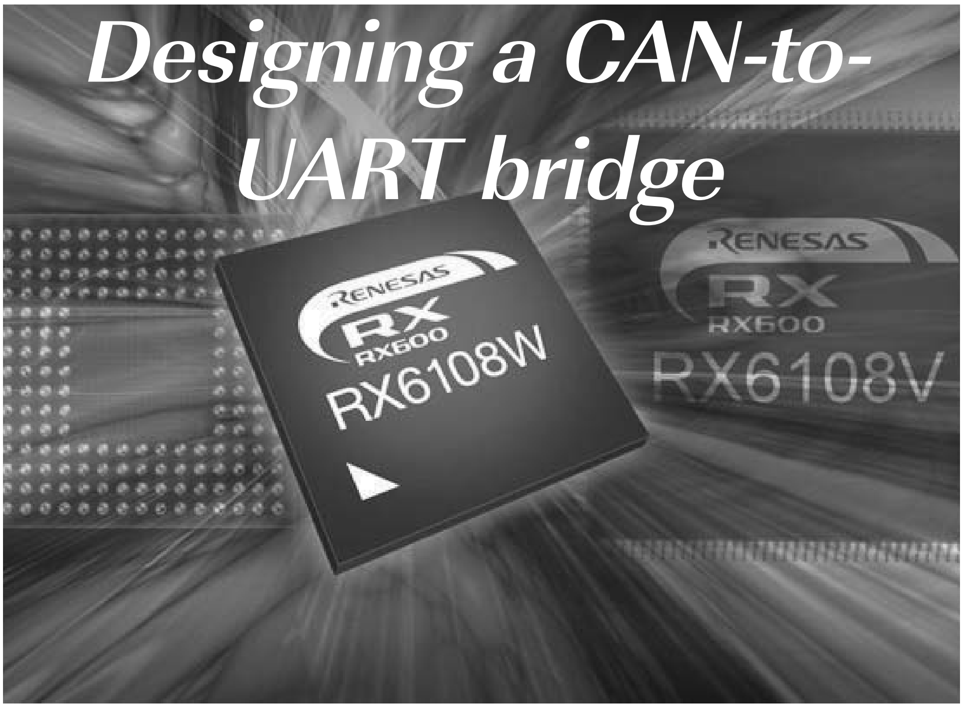
References

[1] Wolfhard Lawrenz, "CAN System Engineering: From Theory to Practical Applications" 1997, Springer-Verlag, ISBN 0-387-94939-9

[2] Howard W. Johnson, "High-Speed Digital Design", 1993, Prentice-Hall Inc., ISBN 0-13-395724-1

[3] Henry W. Ott, "Noise Reduction Techniques in Electronic Systems", 1988, John Wiley and Sons, Inc., ISBN 0-471-85068-3

Designing a CAN-to-UART bridge



Renesas has released an application note that describes how to implement a CAN-to-UART bridge with its RX/600 micro-controllers. The chips provide integrated asynchronous serial port (UART) peripherals as well as on-chip CAN modules. Commands and data entered on the terminal are sent to the MCU over the EIA-232 serial link. The MCU's software interprets those commands and the data is encoded into CAN frames, which are transmitted via the CAN network. Conversely, the MCU receives CAN frames and decodes them, then passes the data on to the terminal over the EIA-232 serial link.

A simple demonstration program serves as an effective example of how the MCU, with its UART peripheral and CAN module, becomes a communication link between the two interface standards. The bridge application will act as a CAN 'sniffer' by listening to the CAN network and transmitting any data it sees on the CAN bus over to the serial port (UART). The serial data can be viewed on a PC with the use of a generic terminal program such as "HyperTerminal". You can also send messages from the PC terminal program over the bridge onto the CAN network.

Typically, the CAN interface will operate at a higher bit rate than the UART. For example, the CAN may be operating at 500 kbit/s, while the UART is running at 115,2 kit/s. This raises the possibility of the CAN data transmissions overrunning the capacity of the UART to forward them, resulting in lost data frames. To handle the speed differences between the CAN network and the serial interfaces, incoming CAN data is buffered. CAN transmissions tend to occur in bursts rather than being continuous. Therefore, buffering of the CAN data frames in RAM provides the UART time to send the data from the MCU. In case of a buffer overflow, a message will appear in the serial data stream.

This demonstration runs on a Renesas RX development board, but can be readily used for custom applications. The provided CAN API (application programming interface) can be configured to use CAN interrupts or to operate in a polled mode. To be able to run the CAN-to-UART bridge, the demo-application must be configured to use CAN interrupts. If you use a polled configuration you will only be able to send commands from the PC (EIA-232) terminal. With CAN interrupts enabled, the remote CAN device will be able to asynchronously send and receive CAN messages and they will be forwarded to the serial terminal on the UART side of the bridge.

The CAN data-rate is, by default, configured for 500 kbit/s. This can be adjusted if necessary to your wished CAN speed.

A way to demonstrate the bridge application is with the aid of a CAN diagnostic tool, such as CAN analyzer by Systec. This "CAN sniffer" comes with the Renesas CAN development kits for R8C and R32C (YRDKR8C and YRDKR32C), but it can be ordered separately, too. It connects to the PC-USB host and to a CAN network. On the CAN side the tool acts as a CAN node. On the PC side, a GUI monitors received data and can also send CAN data frames to the CAN network. (hz)

www.renesas.com

Reference

Renesas, RX600 Series – CAN-UART Bridge (AN0721EU0100)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