The CAN Repeater with Optical Fiber Link

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Abstract

We have developed optical CAN repeaters that connect two electrical buses with a pair of optical fibers. The repeater has a circuit that propagates the states of one bus to the other through the optical fibers and vice versa. Since a pair of repeaters can equalize the states of the two buses within a single bit time, the CAN network maintains real-time communication.

Because of the translation overhead between electrical and optical signals, the transfer distance is shorter compared to that of an electrical CAN network at the same transfer rate. However, the CAN network maintains compatibility with the electrical CAN network. Further, the optical fibers can isolate the CAN network from noise due to high voltage lines and lightning surges.

1 Introduction

During the past few years, many industrial facilities have been adopting field networks to connect controllers and equipment because serial connections by field networks lead to fewer connections between the controllers and equipment and the field networks can be made as multi-vender systems through specification standardization.

The Controller Area Network (CAN) is based on several well-known industrial field networks, DeviceNet, SDS, etc. and it has quick response and real-time transfer. But when installed in the field, the CAN tends to be affected by power line noise and lighting surges. As a concrete example, we offer a water treatment plant which has a control center and many water tanks that use pumps with motors driven by high voltage power supplies. DeviceNet connects the equipment at the water tanks and the controller at the control center. In this plant, DeviceNet is placed in the same under-floor-pit as the high voltage power links, leading to the problem of power line noise. Furthermore DeviceNet is laid underground to connect the control center and the water tanks, causing the problem of lightning surges. So, we developed an optical CAN repeater that physically replaces a part of DeviceNet cable by optical fibers so as to solve these problems.

First, this paper describes the structure of the optical CAN repeater, and then it describes problems faced when implementing the repeater. Next the architecture to solve the problems is given, and finally an evaluation of the repeater is made.

2 Structure of a Repeater or Bridge

Optical fibers are free from power line noise and lightning surges. Since optical connectors are very expensive, it is more practical to replace only a part of the CAN cables by optical fibers than to use

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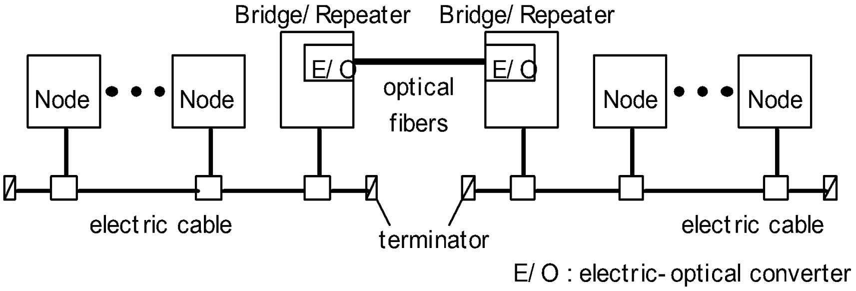


Fig 1 Repeater/bridge system

optical fibers for all of them.

Fig 1 shows the repeater/bridge system structure Each repeater/bridge has electric-optical converters and connects two electric cables through optical fibers. The bridges have CAN chips and the two electric cables are in another arbitration area. Therefore, the transfer distance is long and real-time transfer is not guaranteed. The repeaters bring the statuses of the two cables into agreement within one-bit transfer time. Then, the two electric cables are in the same arbitration area. Therefore, real-time transfer is guaranteed and the transfer distance is shortened because of the electric-optical converter overhead.

For industrial facilities, real-time transfer is one of the most important factors, so, we decided to develop an optical CAN repeater.

3 Design Issues for Optical Repeater

3.1 CAN/DeviceNet protocol

A CAN cable whose topology is a bus has two statuses, Dominant and Recessive. When output of all the nodes is Recessive, the status of the bus becomes Recessive because Dominant overrides Recessive.

Fig 2 shows the one bit format which consists of three segments, SYNCSEG, TSEG1, and TSEG2, according to the CAN protocol. The segments TSEG1 and TSEG2 are data output periods. At the end of TSEG1 each node compares the status of the electric bus with the status which it has outputted to the electric bus and determines whether the data should be continuously outputted to the electric bus or not. According to the DeviceNet protocol, the segment TSEG1 period occupies about 80% of a one-bit period.

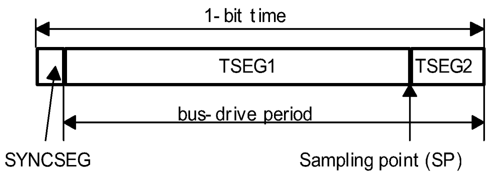


Fig 2 One-bit format

Next, we look at the conditions under which data are transferred correctly. Each node always observes the CAN bus status so as to check if packets are being transferred and to fetch bit data. The propagation delay between nodes connected at each end of the bus, node 1 and node 2, is called T_p. The time from node 1 outputting to the bus to that from node 2 doing it is called $T_{delay12}$. The conditions are shown as follows.

$$T_{delay12} < T_P \quad (1)$$

$$T_{delay12} + T_P < TSEG1 \quad (2)$$

Inequality (1) shows the condition to allow node 2 to output data, and inequality (2) shows the condition that node 1 can receive the node 2 output at the end of TSEG1.

So, inequality (3) shows the condition of T_p between node 1 and node 2. Here, T_p is not only the CAN cable propagation delay time, but the CAN driver delay time, etc. and B is the CAN transfer rate (bps) (500kbps, 250kbps, and 125kbps according to DeviceNet).

$$T_p < \frac{1}{2} TSEG1 = 0.4 \times \frac{1}{B} \quad (3)$$

3.2 Dominant transfer for two repeaters

So that the statuses of the two electric buses connected through optical fibers are brought into agreement, the transfer between the developed optical repeaters adopts the Dominant transfer in two directions because Dominant overrides Recessive. The optical fibers consist of a fiber for transmitting and one for receiving.

The Dominant transfer is done as follows. (1) When one repeater observes that the bus status becomes Dominant, it transmits the light through the optical fiber so as to report this to the other repeater. (2) On receiving the light, the second repeater outputs Dominant to the second bus, that is, it drives the second bus. In this way, Dominant is transferred to the second bus. (3) When the first bus status goes back to Recessive, the first repeater stops transmitting the light. (4) When there is no light, the second repeater stops driving the second bus and the statuses of both buses become Recessive.

3.3 Problems of the repeater

The first optical repeater was made of a CAN driver and an electric-optical converter and it had three problems.

(a) Deadlock: once one bus has become Dominant, both buses become Dominant and remain so. Because the CAN driver consists of a bus transmitter and a bus receiver and they operate independently, then, when the repeater drives the bus because of optical input from the other repeater, Dominant of the bus is fed back by a bus receiver and the repeater transmits the light. Then, the other repeater drives the other bus. Therefore, a loop appears which is composed of two optical fibers and two CAN drivers.

(b) Transient Dominant transfer: the CAN bus starts to go from Dominant to Recessive after stopping driving. So as soon as the repeater has stopped driving, if it restarts to observe the CAN bus, it misjudges the bus being driven as transient Dominant.

(c) Crossing situation: in the same transfer cycle, if both CAN buses are to be Dominant, both repeaters are transmitting the light and both CAN buses are Dominant at the instant just after the cycle ends.

Then we developed another optical repeater to solve these problems.

4 Optical Repeater Architecture

4.1 Strategies to solve the problems

(a) Avoiding deadlock: a repeater has a state machine inserted between an electric-optical converter and a CAN driver. This state machine divides the bus drive and the optical transmission by states. Therefore, the repeater does not observe the bus while it is driving the bus.

(b) Re-observing bus timer: by combining a timer with the state machine, the repeater does not observe the bus until the bus becomes stable after it drives the bus. The CAN driver determines the waiting time.

(c) Parent-child modes: an optical repeater has a transition mode switch which determines whether to continue the optical transmission or not when both repeaters are transmitting the light. Then, one of the repeaters stops transmitting the light. The mode to continue the optical drive is called the “parent mode”, and the other is called the "child mode".

4.2 System structure

Fig 3 shows the developed optical repeaters connected by an optical cable. Each repeater can connect a CAN cable. Fig 4 shows the configuration of the optical repeater, which consists mainly of a CAN driver 80C250, an E/O converter DC9104L, a programmable array logic PALCE22V10 which has a state machine and a timer block, a clock generator (20MHz), and a mode switch. The state machine inputs RxD from 80C250, DOUT from DC9104L, CNTup from the timer block, and mode from the mode switch and outputs TxD to 80C250, DIN to DC9104L, and CNT_ENB to the timer block.

The state machine has 4 states, Opt-drive which is only to transmit the light, Bus-drive which is only to drive the CAN bus, Idle which is only to observe the CAN bus status and optical input, and Wait which is to observe neither CAN bus status nor optical input. Fig 5(a) shows a parent mode state transition graph, called STG. Fig 5(b) shows a child mode STG. The table in Fig 5(c) lists outputs of each state. Opt-drive state and Bus-drive state avoid deadlock. Timer block and Wait state solve the problem of transient Dominant transfer. The state transition from Opt-drive to Bus-drive in child mode STG solves the problem of crossing.

4.3 Time chart example

Fig 6 shows repeaters' behavior when buses A and B are Dominant in the same transfer cycle and only bus A goes back

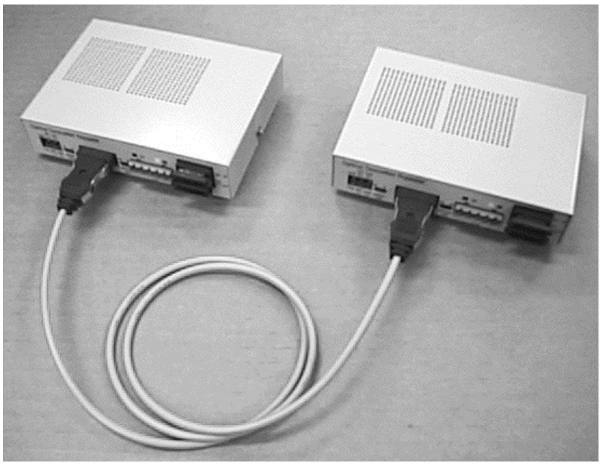


Fig 3 Developed optical repeaters

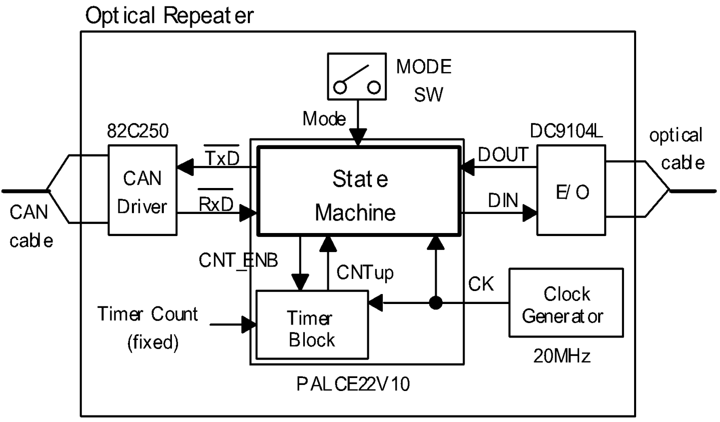
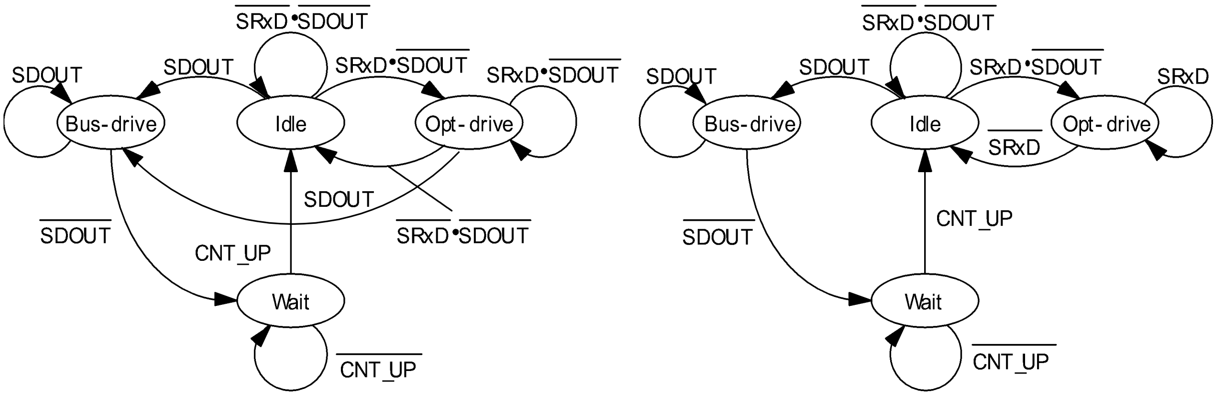


Fig 4 Optical repeater configuration



(a) STG of the state machine (Child mode)

(b) STG of the state machine (Parent mode)

state	DIN	$\overline{\text{TxD}}$	CNT_ENB
Idle	0	1	0
Bus-drive	0	0	0
Opt-drive	1	1	0
Wait	0	1	1

(c) Outputs of the state machine

Fig 5 State transition graph

to Recessive in the next cycle. The mode of repeater A is parent and that of repeater B is child. First of all, both repeaters A and B are in the Idle state since buses A and B are stable to Recessive. Then, buses A and B are driven to Dominant (RxD=L) in the same cycle and repeaters A and B go from Idle to Opt-drive states and both repeaters A and B transmit the light.

Conventionally, this would cause a crossing situation. With both repeaters A and B receiving light (DOUT=H), repeater A is stable in the Opt-drive state because of the parent mode, but repeater B goes from Opt-drive to Bus-drive states because of the child mode, it stops transmitting the light, and starts to drive bus B, thus the crossing situation can be avoided. At the sampling point, SP1, all of the nodes connected to buses A and B observe Dominant.

Since bus A is Recessive in the next cycle, repeater A goes to the Idle state and stops transmitting the light. Then, repeater B goes to the Wait state and makes the timer in the timer block operate in order to avoid the transient Dominant transfer. After the timer is overflowed (CNT_UP=Hi), repeater B goes from Wait to Idle states and resumes observing the status of bus B and optical input. However, bus B remains Dominant, and repeater B goes to the Opt-drive state. Repeater A goes from Idle to Bus-drive states, and both buses A and B become Dominant. At the sampling point SP2, all nodes observe Dominant.

As described above, the statuses of buses A and B are brought into agreement by the state transitions of both repeaters A and B.

5 Evaluation

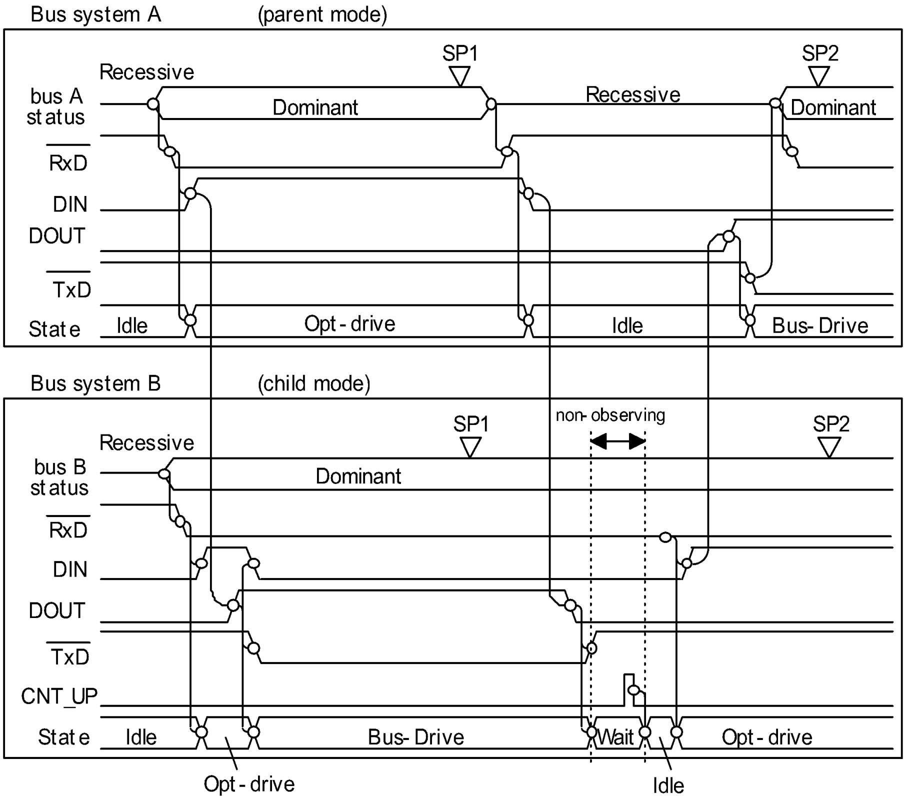


Fig 6 Time chart

All CAN-based field networks can use the optical repeaters. We made some evaluations based on the DeviceNet specifications.

5.1 Propagation delay

Fig 7 shows the delay evaluation of the developed repeaters that connects two buses, bus 1 and bus 2, through optical fibers. Here, T_{ecd}, the delay time of CAN drivers 82C250 from TxD to RxD, is 170ns and T_{oe}, the delay time of E/O converters DC9104L from DIN to DOUT, is 150ns. The delay time of the photo-coupler HCPL7101 is 40ns. And the time that the general CAN chip starts to observe RxD from changing the output TxD is 50ns. The clock period T_{ck} in which the state machine and the timer block are operated in synchronization, is 50ns according to 20MHz. The lengths of bus 1, bus 2, and the pair of optical fibers are L_{e1}, L_{e2}, and L_o, respectively. The propagation speed of the electric cables, δ_e , and that of the optical fibers, δ_o, are 5ns/m. Then, the overhead time of the pair of optical repeaters T_{orp} equals 580ns. And the time T_{tm}, which the timer block counts to stay in the Wait state, is long enough for the state machine to observe the change of RxD from stopping TxD output. Therefore, T_{tm} is more than 260ns and the timer block has a 4bit-width timer to count 300ns, because of sampling by T_{ck}.

Table 1 The overhead ratio of the repeater

bit rate(kbps)	500	250	125
T_{orp}/T_p	73%	36%	18%
L_{max} (m)	0	144	464

At each of the bit rates defined in

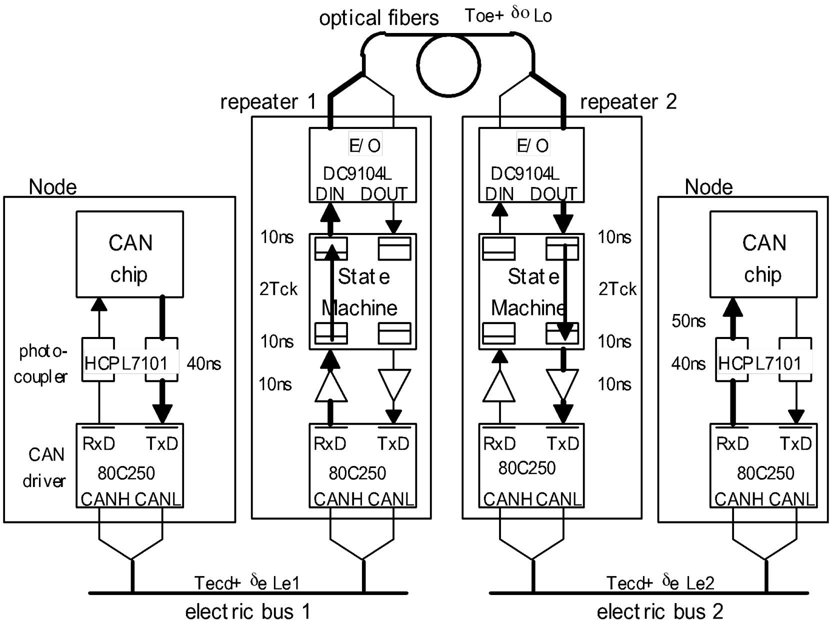


Fig 7 DeviceNet communication structure using optical repeaters

DeviceNet, we see the ratio T_{orp}/T_p and the logical maximum transfer distance $L_{\max}$. $L_{\max}$ can be led to divide it by the propagation speed, $\delta_e = \delta_o$ =5ns/m, that T_p minus all the overhead time, including T_{orp}, two photo-couplers, a CAN driver, and a CAN chip equals T_p-880ns. DeviceNet can transfer within 100m at 500kpbs, 250m at 250kbps and 500m at 125kbps, respectively. The optical repeater is practical except at 500kbps, and is very good at 125kbps because T_{orp} has nothing to do with bit rates.

Therefore, we define the equivalent distance of the repeater L_{orp} in order to check easily if the optical repeater system can communicate correctly. L_{orp} is the length of an electric cable whose propagation delay is the same as T_{orp} and L_{orp} = T_{orp} / δ_e =116m. $L_{\max}$ plus L_{orp} is longer than the DeviceNet specification because $L_{\max}$ involves no margins.

5.2 The evaluation of clock frequency

To reduce the overhead of a pair of repeaters T_{orp}, the clock frequency must be faster and a faster E/O converter or faster CAN driver should also be used.

Fig 8 shows the transfer and equivalent distances versus clock frequency at bit rates 500kbps, 250kbps, and 125kbps. The logical maximum of transfer distance, $L_{\max}$, is linear to the clock frequency up to 20MHz, but it saturates over 20MHz. Conversely, the equivalent distance decreases linearly with the clock frequency up to 20MHz, but it saturates over 20MHz. Conventionally, high clock frequency causes problems of high power dissipation and a large size of the timer block because the timer block counts to the time to stay in the Wait state, T_{tm}, synchronously with the clock. Therefore, the developed repeater is practical

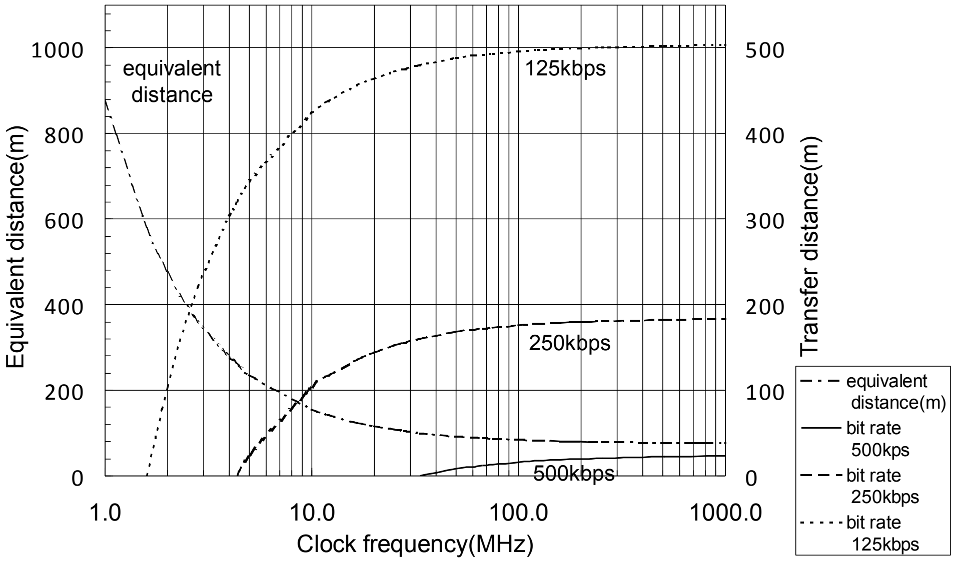


Fig 8 Transfer/equivalent distance versus clock period

around 20MHz.

Finally, using the equivalent distance L_{orp}, the optical repeater system can be checked regarding correct data transfer. We compare the DeviceNet specifications with L_{conv}, which is calculated, as follows.

$$L_{conv} = L_{orp} + L_{e1} + L_{e2} + \frac{\delta_o}{\delta_e} \times L_o$$

This is more practical than using $L_{\max}$ because the specification already involves margins.

6 Conclusion

We developed a practical optical CAN repeater. A pair of repeaters physically replaces part of the CAN electric cable by optical fibers, eliminating susceptibility to power line noise and lighting surges. The repeater adopts Dominant transfer and has a state machine, a timer, and a mode switch. It realizes real-time data transfer.

Evaluation of the repeater showed that the clock frequency is best around 20MHz. Further, the equivalent distance of the repeater overhead allowed easy judgement of correct data transfers.

7 References

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