On-chip 500V capacitive isolator for 1 Mbps CAN transceiver

Mutsumi Kikuchi, Takashi Sase, Masamitsu Inaba,
Atsuo Watanabe, Noboru Akiyama, Fumio Murabayashi

We have developed a single-chip network-interface LSI that integrates a 500V capacitive isolated digital coupler, a 5V / 100mA voltage regulator and a 1-Mbps CAN transceiver. The coupler uses high-voltage, on-chip-isolator technology including trench isolation with buried oxide on SOI (Silicon On Insulator). The switching-voltage regulator of a step-down DC-DC converter that is connected to the network power line (11 to 25 V) supplies a constant 5V voltage to the transceiver circuit. In addition, a network-power-supply state-monitoring function, which reports the voltage drop to a CAN controller through the insulated barrier, is provided. By connecting the SOI substrate to the network-power supply line, the electric potential that the transceiver is referenced to can follow the electric potential shift of the network by common mode noise and thus enable a dependable operation. The physical-layer interface LSI can reduce the power consumption to 20% and reduce the mounting area of the interface circuit to 50%.

Introduction

To keep up with variable market needs demands flexibilities of manufacturing plants in incremental construction and quick alteration. For this reason, field devices, such as sensors and actuators used in manufacturing plants, are being connected to field networks instead of discrete peer-to-peer connections. The purpose of this paper is to establish a circuit technology for low-power field- network transceivers and to develop a field -network-transceiver LSI based on the DeviceNet specifications [1][2][3].

In DeviceNet, e ach field device is connected to a network through a network interface that consists of a transceiver, a voltage regulator [4], an isolator, and a CAN protocol controller. The voltage regulator that is connected to the network power line (11 to 25 V) supplies a constant 5V voltage to the transceiver circuit, and all of the transceivers are referenced to V-potential of the network power line. However, when the power consumption of a network interface circuit is large, connecting many field devices obstructs communications, because the supply voltage from network power lines decreases to less than the 11V rating voltage. Therefore, the power consumption of network-interface circuits needs to be reduced to increase the number of connectable nodes and to constitute a network flexibly.

The conventional DeviceNet interface has high-speed opto-couplers for isolation and data transmission. However, the network interface needs to be less costly and smaller, to meet market requirements.

In this paper, we describe a single-chip network-interface LSI that integrates a 500V capacitive isolated digital coupler, a 5V/100mA switching-voltage regulator, and a 1Mbps CAN transceiver.

2. Isolated Transceiver

2.1 Necessity of isolation

If all network interfaces are referenced to all local grounding potentials (Fig. 1), network communications are interrupted when local grounding potentials of some transceiver as a transmitter and the others as a receiver differ more than the allowable input voltage range of the receiver (i.e., grand shift).

On the other hand, when all network interfaces have a ground isolation barrier (Fig. 2), all transceivers of the network interface are referenced to the V- potential of the power supply line, which follows a potential shift of the network, and the CAN-protocol controller of the network interface is referenced to a local grounding potential. Therefore, even if each reference potential differs, network communications are not interrupted.

This is the reason that a DeviceNet network must have a ground isolation barrier in the physical layer to prevent ground loops and to provide dependable network operations. A ground-isolation barrier forces the whole network cable system to use a single grounding point. This barrier is usually set between the transceiver and the CAN-protocol controller, or at the I/O point.

2.2 On-chip isolator

Using transceivers for long-distance construction and in a severely noisy environment requires having an isolator circuit for the network-interface circuit. Discrete devices, such as opto-couplers, magnetic isolators [5] and capacitive isolators [6], are used for the isolation. This requirement impedes reducing the cost and the mounting area of the network interface. Moreover, an opto-coupler consumes a lot of power, but a capacitive isolator consumes a relatively small amount of current when the signal changes, although it is still bulky.

Thus, we have developed an on-chip isolator technology [7]. As shown in Fig. 4(a), the signal transmission of a capacitive isolator is explained as follows.

First, an original signal enters the driver circuit of the isolator, which drives a pair of the isolated barrier capacitors that withstand the high voltages. Secondly, the original signal is differentiated by the load resistance and the barrier capacitor. Then, the RC-differentiated signal pairs enter the receiver circuit of the isolator, which consists of a differential amplifier and a flip-flop circuit. The receiver circuit detects the transition timing of the differentiated signal that appears as the output voltage of the load resistance. Finally, the differentiated signal is reproduced as the original signal.

The high-voltage barrier capacitor is consists of an interlayer dielectric film and two electrodes of the wiring layer and the silicon layer. A schematic cross sectional view is shown in Fig. 4(b).

2.3 On-chip switching voltage regulator

A conventional network interface usually uses a series-dropper-type voltage regulator, which consumes a lot of power from the network-power supply line because its low efficiency can at worst be 20%. To reduce the current consumption and the mounting area, we have developed an on-chip switching voltage regulator that only requires an inductor and a capacitor for the power-output stage.

Power Supply Monitor

3.1 Problems of the monitor using the capacitive isolator

The isolation circuit in a network interface can be divided into a dynamic-pulse-signal transfer part, and a static-level-signal transfer part of the transceivers. The latter is used for monitoring the state of the network power supply. Without this part, the CAN controller cannot distinguish a network power-down from the continuous communication errors caused by other malfunctions when it cannot receive signals from the network for a long period. Thus, the state of a network power supply should be transmitted through an isolation circuit. A conventional network interface uses an opto-coupler for monitoring the power supply, but it continuously consumes current in the normal state. On the other hand, the capacitive isolator consumes a relatively small amount of current and only when a signal changes. However, the capacitive isolator cannot transmit the power supply signal in a power-down state, because the power supply to the driver circuit is simultaneously powered down. This prevents the driver circuit from transmitting correct signals.

3.2 New Detection Method

We propose a new method for the capacitive isolator that uses an oscillator to detect the power-down state. The oscillator of an on-chip switching-voltage regulator is also used to detect the power-down state. First, the input static-level signal is modulated into a dynamic-pulse signal using the oscillator's output pulse and inputted into a capacitive isolator, as shown in Fig. 5. Secondly, the pulse signal that is transmitted through the capacitive isolator is demodulated into a static level signal by a Frequency-Binary converter.

When the power supply is powered down, the pulse signal is not transmitted to the converter; the converter then resets the signal. As mentioned above, the developed method has enabled transmitting a static-level signal from the network power supply.

We transferred a static signal into the opposite direction for the transceiver standby-signal by reusing the pulse that passes through the capacitive isolator.

3.3 Power on Reset

When no regular pulse comes from the other side of the isolation barrier when the power supply starts up, the circuit is reset to standby and/or power-down mode.

4. Device Technology

We describe the technical subject for forming a transceiver, a capacitive isolator, and a switching-voltage regulator into single chip on SOI substrate.

The block diagram of the LSI is shown in Fig 3. It has a switching-voltage regulator, a CAN transceiver and four channel isolators, which are used for TX-signal, RX-signal, and standby-signal transmission, and for power-supply-state monitoring.

As shown in Fig. 4(a), the capacit ive isolator separates the LSI into two regions, a primary and a secondary side. The primary side has a transceiver circuit and a switching-voltage regulator, and these circuits include 30V devices. The secondary side has an interface circuit for the CAN controller and only constitutes of 5V devices.

A schematic cross-sectional view of the LSI is shown in Fig. 6. The silicon region is separated into a substrate and a layer for semiconductor devices by a buried oxide film. Furthermore, the semiconductor device layer is separated into two regions, a primary and a secondary side, by the trench isolation.

The capacitive isolator can couple the signals to isolate the common mode noise between the two regions. When the network-electric-potential shift occurs, the gap voltage between the network and the local-grounding potential is shared by two parasitic capacitors of a buried oxide film; one between the primary-side region and the substrate, and one between the secondary-side region and the substrate.

Since 30V devices have a deep diffusion layer, a rapid shift of the substrate potential by a surge noise can affect their electrical property. In this LSI, 30V devices are located on the primary-side circuit. Then, the SOI substrate is connected to the network potential on the primary side to eliminate the parasitic capacitor on the primary side. Consequently, the influence of the surge noise can be reduced for 30V devices.

5. Electrical properties

Fig. 7 shows an optical micrograph of the single-chip network-interface LSI with the capacitive isolator, a switching-voltage regulator, and a CAN transceiver.

Table 1 lists the characteristics of the interface LSI. The isolation voltage is higher than 500Vdc, and we obtained a maximum brake-down voltage of 1900Vdc. The delay time of the TX to CAN and TX to RX is 30-35 ns and 60-80 ns, respectively. The waveforms of TX to RX (loop back) are shown in Figs. 8 and 9.

As shown in Fig. 10, the interface LSI can reduce the power consumption to 20%, and the mounting area of the interface circuit to 50%.

6. Conclusion

We have developed a single chip network interface LSI that integrates a 500V capacitive isolated digital coupler, a 5V/100mA switching voltage regulator, and a 1 Mbps CAN transceiver. The isolation voltage of the coupler is higher than 500Vdc, and we obtained a maximum brake-down voltage of 1900Vdc. The delay time of the TX to CAN and TX to RX is 30-35 ns and 60-80 ns, respectively. We also developed a power-supply monitoring function, which reports the voltage drop for the CAN controller through the insulated barrier. We found that the interface LSI can reduce the power consumption to 20% and the mounting area of the interface circuit to 50%.

Acknowledgement

This work is financially supported by a national project: "Optimal Control System for Energy Conservation in Factories, Shops, Buildings, and Houses" of the joint research among New Energy and Industrial Technology Development Organization (NEDO), and Energy Conservation Center, Japan (ECC).

References

[1] BOSCH: CAN specification 2.0 (1991-9)
[2] ISO11898:1993,Amd.1:1995
[3]ODVA: DeviceNet specifications Volume I,II Release 2.0 Errata 1-4 (2000)
[4] Francesco Colandrea et al., “Triple Voltage Regulator with Fault-Tolerant Low-Speed CAN-Transceiver for Car Body Applications," Proceedings of the 5th international CAN Conference (iCC '98), pp.02-07 - 02-13 (1998-11)
[5]C.H.Smith, R.W.Schneider, "The Growing Role of Solid-State Magnetic Sensing" Proceedings of the Sensors Expo Boston, pp.139-149 (Helmers,Peterborough, NH,1997).
[6] Burr-Brown: ISO150 Product Datasheet (1994-8)
[7] Y.kojima, et al. ,”A Novel Monolithic Isolator for a Communications Network Interface IC”, The 11th Annual IEEE International ASIC conf. ,1998,pp.255-258

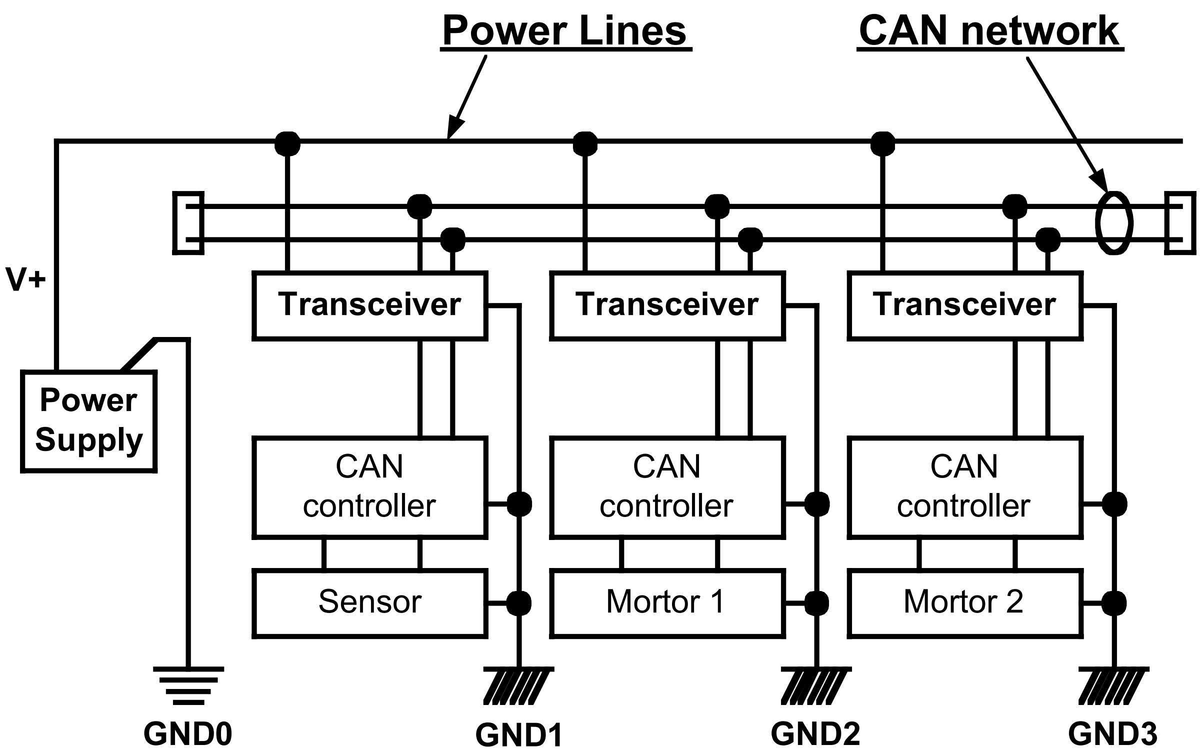

Fig. 1. Non-Isolated Network.

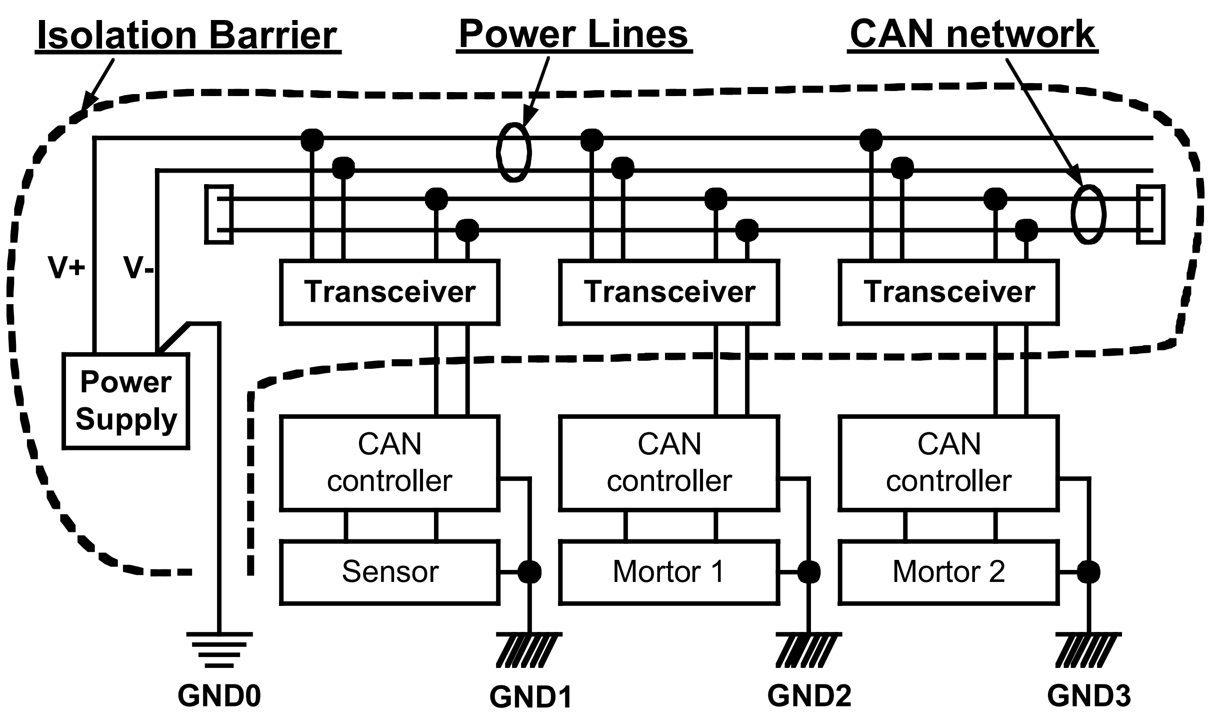

Fig. 2. Isolated Network.

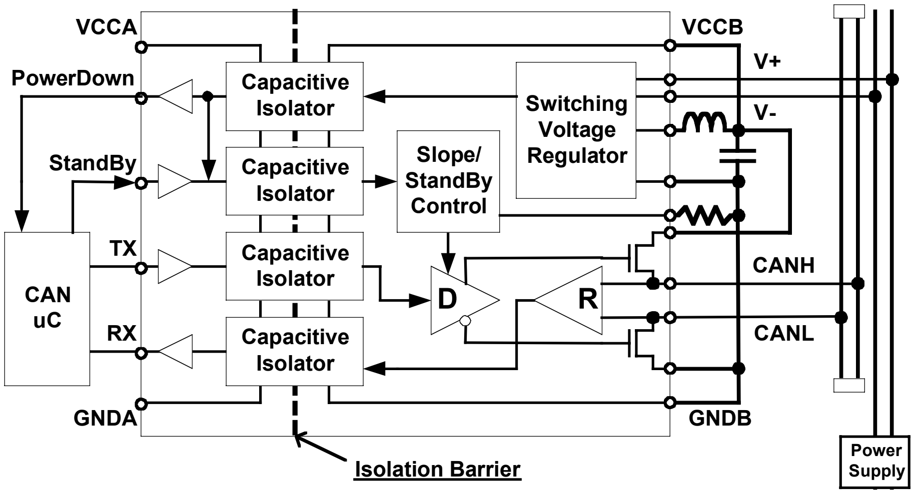

Fig. 3. Block Diagram.

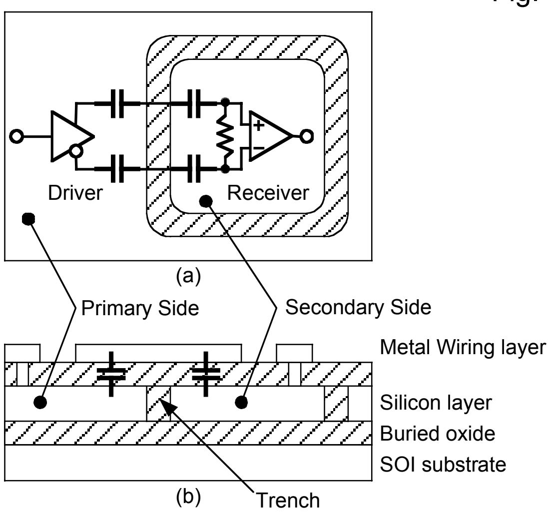

Fig. 4. Capacitive Isolator.

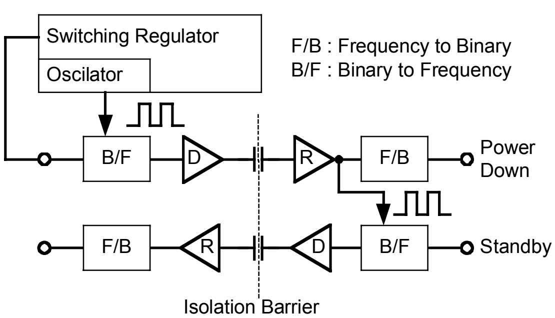

Fig. 5. Power Supply Monitor.

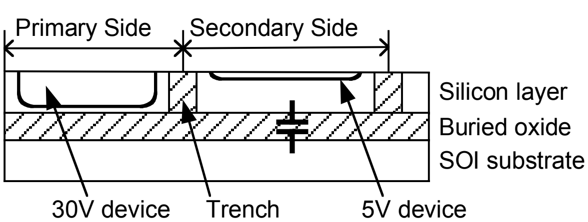

Fig. 6. 30V device.

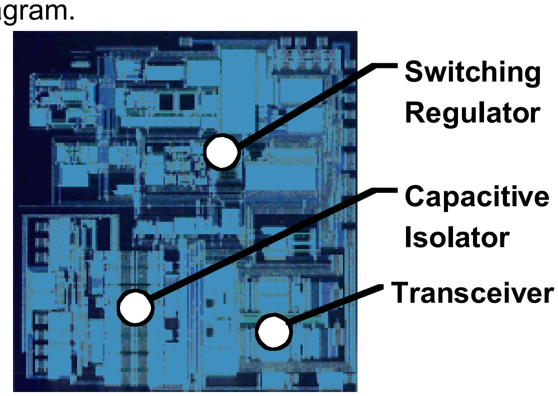

Fig. 7. Chip Micrograph.

Table 1. Characteristics.

Isolator	
Rated Voltage, Continuous	>500 Vdc
Transceiver	
Bit Speed	1 Mbps
Delay TX to CAN dominant	35 ns
Delay TX to CAN recessive	30 ns
Delay TX to RX low	80 ns
Delay TX to RX high	60 ns
(TX to RX include isolator's delay)	
Switching-Voltage Regulator	
Input Voltage	11 to 25 V
Output Voltage	5 V
Maximum Load Current	100 mA

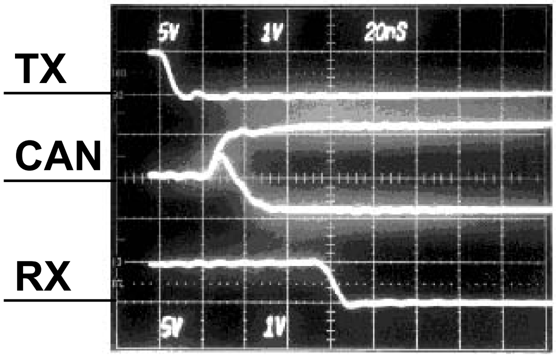

Fig. 8. TX to RX Loopback Waveform (Dominant).

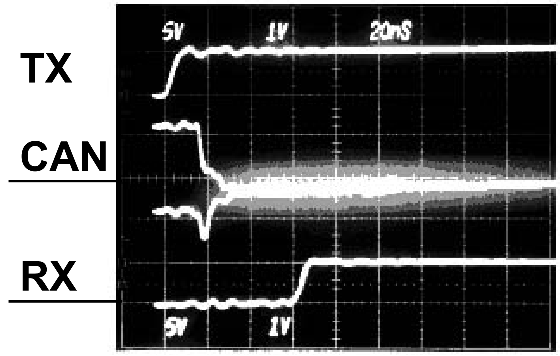

Fig. 9. TX to RX Loopback Waveform (Recessive).

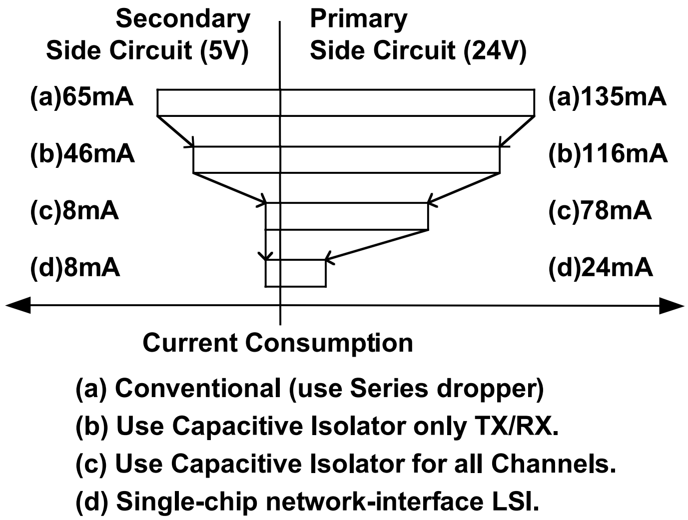

Fig. 10. Current Consumption.

Mutsumi Kikuchi
Company : Hitachi, Ltd.
Address : (MD#230) 1-1, Ohmika-cho 7, Hitachi-shi, Ibaraki-ken, 319-1292 JAPAN
Phone : +81-294-52-5111
Fax : +81-294-52-7613
E-mail : kikuchim@gm.hrl.hitachi.co.jp

Takashi Sase
E-mail : tsase@gm.hrl.hitachi.co.jp

Masamitsu Inaba
E-mail : minaba@gm.hrl.hitachi.co.jp

Atsuo Watanabe
E-mail : awatana@gm.hrl.hitachi.co.jp

Noboru Akiyama
E-mail : nakiyama@gm.hrl.hitachi.co.jp

Fumio Murabayashi
E-mail : murabaya@gm.hrl.hitachi.co.jp