Reliability Improving Approach with Opto-Based Voting System

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Abstract

Majority voting is a major approach to boost system reliability in space computers. However, voter circuit often limits operating frequency of the whole system and consumes much resource of the system.

Today, many parallel interfaces in commercial-off-the-shelf (COTS) computers are going to be serial in order to break performance limitation. As serial interface provides us many advantages and is supported by many programmable devices such as FPGAs, it will be widely used for computers in satellites in the future.

In general, such serial connection requires to be operated at very high frequency to keep bandwidth wide enough. If we want to implement serial bus into triple voting system, voter logic should operate very fast, too. In this research, high speed voting system based on optical signal is proposed to increase the reliability of serial interfaces. This is a new type of voting system based on optical signal, which is fast enough to be used in redundant high-speed serial connection. In the evaluation, both optical voting system and voltage signal based analog voting system are evaluated to discuss the feasibility and advantages of optical voting system. Our result shows that optical voting scheme has many advantages over voltage based one for the point of the easiness in implementation.

1 Introduction

1.1 Backgrounds

Traditional redundant computing system uses parallel data bus and all the output signals are voted by majority in bit by bit manner. Many hardware resources such as wire and logic circuits are consumed to keep system redundant. For example, simple triple voting system which consists of three 32-bit CPU modules, one shared 32Mbit SDRAM, one UART controller, six GPIOs consumes 279 wiring and 69 voter logics (Figure 1, Table 1), compared to original non-redundant system that requires only 93 wiring.

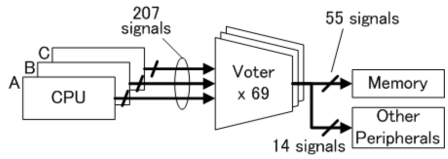

Figure 1: Parallel Memory Bus System

In general, such large number of wire connections make it difficult to synchronize signals and have limited system operating frequency.

Table 1: Example of estimated resources for a triple voting system

peripheral	signal name	width per module	total width
SDRAM	address	13 bits	39 bits
	data	32 bits	96 bits
	control	26 bits	78 bits
UART	data	2 bits	6 bits
GPIO	data	12 bits	36 bits
	control	6 bits	18 bits
CLOCK	clk	1 bit	3 bits
RESET	rst	1 bit	3 bits
total		93 bits	279 bits
signals to be voted	(all output signals)	**68 bits** = *No. of voters*	207 bits

Today, buses in COTS computers are going to be serial. Serial connection frees us from skew management or signal synchronization in the parallel bus, and this approach actually has achieved satisfactory results in some cases.

These serial bus will contribute in simplifying system configuration and saving resources of the triple voting system for space application. Here, only a few voter modules and simple wire connections are necessary. Moreover, this kind of simplification helps us to avoid many bugs or troubles that result from complicated wire connections.

In addition, some FPGAs such as Xilinx VirtexII pro begin to provide high speed serial interface, whose data rate is over 2 Gbps. These interfaces can be easily configured and implemented on FPGA by using development tools.

Being supported by these useful devices, we assume that computers for space application will also employ serial bus in the near future to simplify wiring and increase performance. For example, if the memory bus in the parallel system shown in Figure 1 is serialized, required resources decreases from 68 to 16 (voter circuits), and from 207 to 48 (wires) (Figure 2).

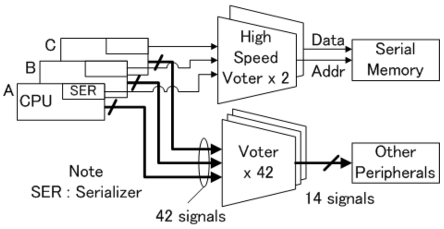

Figure 2: Serial Memory Bus System

Although serial bus in triple voting system provides such advantages, there is some problem. The bus should operate at quite high frequency to keep the transfer rate as fast as the parallel bus. A voting module should run very fast, too. For example, compared to traditional parallel bus (e.g. 32bit 100MHz), more than 3Gbps data rate is desirable for serial bus.

At such high transfer rate, traditional voting system based on synchronous digital circuits may not work properly, so we decided to design new type of voter which is suitable for high speed serial bus.

2 Optical Signal Based Voting System

2.1 System Overview

Figure 3 shows a basic concept of proposed optical voting system.

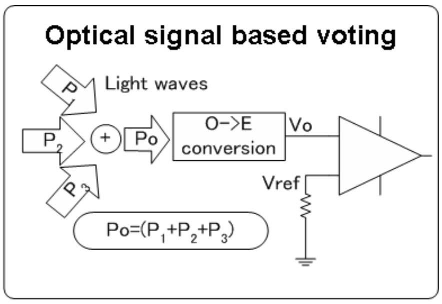

Figure 3: Basic concept of optical voting system

In this optical voting system, three light waves are modulated their amplitude by using each serial signal from triple redundant CPU modules. After modulation, three optical signals are input into a photo detector to sum up their optical power. The photo detector outputs logical "High" signal when the input optical power exceeds threshold, otherwise outputs logical "Low" signal (Figure 4).

In order to achieve high speed transfer rate, laser diode is used as a light source here because it can be modulated very fast. However, light wave generated by laser light source is coherent itself and three modulated lights in Figure 4 may interferes each other. This coherency may prevent us from summing up the power of light waves properly. So, we decide to evaluate this coherency of laser diodes.

2.2 Experimental Setup

The experimental setup is illustrated in Figure 5.

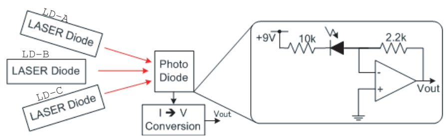

Figure 5: Experimental setup of optical voting system

As a light source, three laser diodes (LD-A,B,C wavelength:650 [nm], optical output power :2.7$\pm$0.2 [mW]) are used. A photo detector is consists of a photo diode and outputs absolute value of voltage in proportion to the power of input optical signal. The distance between each LD and photo detector is set to 260 [mm], and each light travels this distance through air.

In this experiment, it is evaluated how the output voltage changes as the number of lighted LD increases. The result is summarized in Table 2

Table 2: Output voltage of photo detector versus lighted LD

ON/OFF Status	Output voltage
All OFF	92mV
LD-A ON	-766mV
LD-B ON	-772mV
LD-C ON	-828mV
LD-A,B ON	-1.63V
LD-B,C ON	-1.61V
LD-C,A ON	-1.63V
All ON	-2.48V

Table 2 shows that the absolute value of output voltage increases linearly as the number of "ON" LD increases. This result indicates that the lights from different laser diodes can be summed up without interference between them. When the threshold voltage is set to around -1200 [mV] to convert analog output voltage into digital signal, majority vote can be done by this circuit.

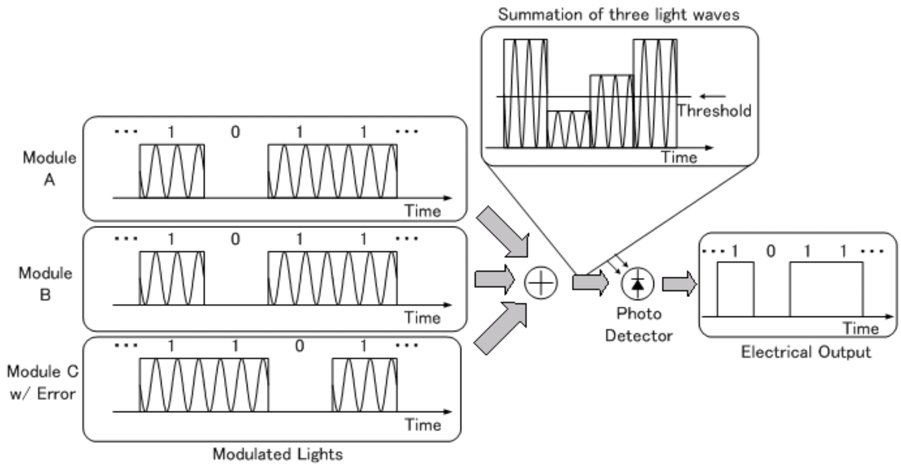

Figure 4: Basic operation of optical voting system

3 Electrical Signal Based Voting System

3.1 System Overview

Figure 6 shows an basic concept of voltage voting system.

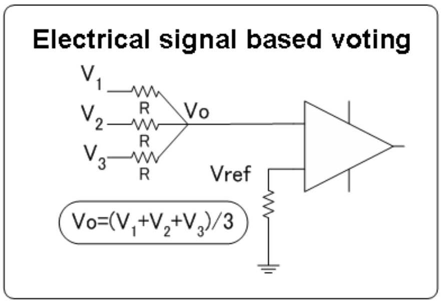

Figure 6: Basic concept of voltage averaging system

Voltage voting system is a kind of analog voting system which votes by averaging input voltage signals. Input voltage signals from three redundant modules go through resister to be averaged. The comparator decides logical "High" or "Low" by comparing the average result and a reference voltage.

Here, two types of experiment is conducted for the voltage voting system: functional test and loss measurement at high frequency. In the former test, we built an evaluation board which consists of resisters and input three arbitrary digital signals around 100MHz to check if this scheme can vote by majority. The latter test measures the loss of this circuit at very high frequency (2GHz).

3.2 Function Test

Evaluation circuit of voltage voting system for function test is shown in Figure 7.

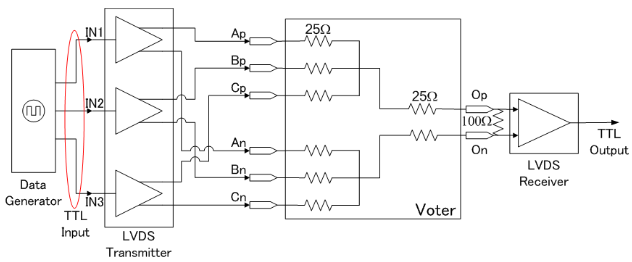

Figure 7: Evaluation circuit of Voltage Voting System for differential signal

The test circuit is designed for differential signal because high speed serial signal is usually transferred by using differential signal. For differential inputs, LVDS signals are used for this evaluation. LVDS transmitter and receiver on the test board are TI DS90C051B and DS90C052B (Max transfer rate: 155Mbps), respectively. LVDS transmitter generates differential signal of +340/-340 [mV] when the input TTL signal is "High"/"Low". LVDS receiver outputs TTL "High"/"Low" signal if the input differential signal is over +100 [mV] / under -100 [mV].

The circuit is built by mounting chip resisters on glass epoxy board. The value of these registers are set to 27 Ω to match the circuit impedance as 50 Ω.

The calculated value of output voltage against three TTL inputs of this circuit is summarized in Table 3.

Table 3: Calculated value of output voltage of voltage voting system versus three input TTL signal

TTL inputs	Differential voltage [mV]
All High	198
1 Low, 2 High	65.9
2 Low, 1 High	-65.9
All Low	-198

As is shown in Table 3, when all of the input signal is equally "High" or "Low", the absolute value of differential output voltage exceeds 100 [mV], which is a threshold voltage of LVDS receiver. On the other hand, if one input is different from other two, the output voltage becomes 65.9 [mV], which may result in data conversion error at a LVDS receiver.

We input an arbitrary digital signal for one TTL input (IN2), and another different digital signal for the rest (IN1, IN3) and tested if receiver votes them by majority and outputs the same digital signal as input signal of (IN1, IN3). The result of this function test is shown in Figure 8. Here, all the input signals (IN1-IN3) and output signal (OUT1) are shown. The data rate of input signals is set to 120Mbps.

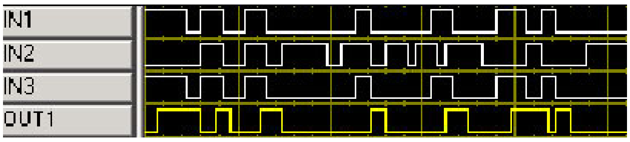

Figure 8: Result of function test (Voltage Voting System)

The waveform of OUT1 in Figure 8 indicates that this circuit does not work well. The output signal OUT1 is different from input signal IN1 and IN2 at the end of the waveform.

The main reason of this is that the averaged voltage does not meet the requirement of LVDS receiver when one of the three input signal differs from others. As long as input signals are averaged by resisters, this voltage drop is inherently inevitable in this scheme. In order to make this circuit always work properly, it is necessary to amplify the LVDS signal before receiver or to lower the value of resisters in averaging circuit. However, the former way needs additional circuit such as amplifier and the latter changes an impedance of the circuit, which causes signal reflection and prevent high speed signal from propagating. For these reason, this voltage voting technique is not suitable for high speed voting circuit.

3.3 Loss measurement test

The loss of voltage averaging circuit is evaluated as a transmission characteristic at high frequency. Since the effect of parasitic capacitance becomes significant as the operating frequency grows, the voting circuit is designed carefully, taking transmission characteristic into consideration. The loss is measured by 2 [GHz] sign wave using network analyzer. The transmission line is designed as micro strip line, whose characteristic impedance of single line and differential line are 58.87 Ω and 100.7 Ω , respectively. This microwave circuit is designed with Micro Wave Office. The substrate used here is glass epoxy board, whose dielectric constant, tanδ and thickness are 4.7, 0.0175 and 1.6 [mm], respectively. To emulate differential signal, the input signal from network analyzer is divided into two signal by 3dB coupler. One of the divided signal goes through $\lambda/2$ longer cable than other signal to generate antiphase signal.

The experimental setup is shown in Figure 9.

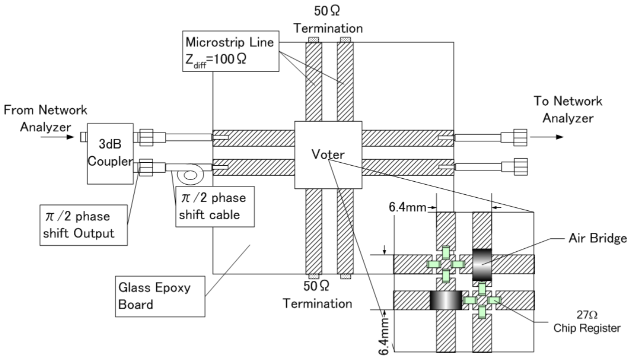

Figure 9: Experimental setup for loss evaluation

The result of this evaluation is that the total loss of this voltage voting circuit turned out to be -13.93 [dB]. On the other hand, theoretical loss is -13.43 [dB] (3.44 [dB] at coupler, -9.99 [dB] at voter), so the loss in transmission line is -0.5 [dB]. This result indicates that, if designed carefully, unexpected loss in the voting circuit can be suppressed around -0.5 [dB], while 75% (-10.5/-13.93) of total loss is originated from voting circuit itself.

4 Discussion

Voltage voting system needs additional circuits such as amplifier because a signal essentially attenuated by resisters for voltage averaging. The unexpected loss of transmission line can be kept low enough by designing properly, but the loss in voting circuit reaches -10.5 [dB] at 2 [GHz]. For this reason, this kind of voltage voting scheme is not suitable for high speed signal.

Optical voting system utilizes optical signal and optical fiber to vote and transmit signal, so there is no distortion of signal wave form and it has little loss even if the signal frequency is several GHz. In addition, as optical signal has electro magnetic compatibility, it will not affected by outer noise.

In order to keep the loss low enough, transmission line in voltage voting circuit needs to be specially designed for the frequency it will be operated at. On the other hand, optical voting circuit can be used in wide range of signal frequency without changing its design.

As laser light is usually coherent and interferes each other, there is a problem that optical voting system may not work properly with laser light source. However, the evaluation result shows that laser light from multiple laser module can be summed up. The output voltage from a photo detector changes linearly as the number of active laser diodes changes, so by setting proper threshold level, this system can work as voter.

Optical voting system has another advantage that is has wider noise margin. If voter input voltages is the combination of (”High”,”High”,”Low”) or (”High”,”Low”,”Low”), the output voltage of the circuit becomes 2V/3 and V/3 in optical voting circuit (Table 2) and voltage voting one (Table 3), respectively. Here, the maximum voltage a voter outputs is assumed to be V when three inputs are (”High”,”High”,”High”) or (”Low”,”Low”,”Low”).

5 Summary

Many parallel interfaces in COTS computers are going to be serial today because of the performance limitation. As serial interface provide us many advantages, it will be widely used for computers in satellites in the future. In addition to performance advantage, if memory bus is serialized, much resource for wire connection and voting circuits can be saved.

In this research, high speed voting system based on optical signal is proposed to increase the reliability of serial interfaces. The evaluation result shows that even optical signal produced by laser diode can be summarized. This means that optical voting system can be built with optical communication devices which utilizes laser diode as a light source and already achieves over Gbps transfer rate.

Voltage based voting system is also introduced and evaluated, but its transmission loss turned out to be inherently too high to transmit high speed signal precisely.

Our future work is to implement optical voting system into the triple voting system and validate its feasibility.