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# The Implementation of The Multi-Subject, Multi-Channel Optical Telemetry System for Physiological Signals

Cha-Hun Park*, Jong-Dae Park**, and Hee-Don Seo***


## Abstract

This paper describes the implementation of a multi-subject, multi-channel optical telemetry system for the short range measurement of electrocardiograms (EKGs) a system which receives command signals and transmits physiological signals to the external system using LED (Light Emitting Diode) and PD (Photodiode). This system decreases the dependency of power supply voltage to the CMOS IC chips and a new enforced synchronization technique using infrared bi-directional communication has also been proposed. The telemetry IC with the size of $5.1 \times 5.1 mm^2$ has the following functions: receiving of command signal, initialization of internal state of all functional blocks, decoding of subject selection signal, time division multiplexing of 4-channel modulated physiological signals, transmission of modulated signals to external system, and auto power down control.


Key words: optical telemetry system, physiological signals, LED, PD, EKG

## 1. Introduction

Non-invasive biotelemetry systems using optical link techniques are being increasingly required for specialized environments such as small experimental booths. Continuous non-invasive monitoring of physiological states is important not only for ministering the human body but also when observing the states of experimental animals. To support the studies, the following requirements have to be considered. First is the need for a small, lightweight device, which is highly reliable. Second is the need for a long-term internal power source, which often consist of a tiny primary battery. Third is a need for non-invasive monitoring [1][2]. As a transmitting media, the use of infrared rays is essential because of electromagnetic interference problems[3] and telemetry system that can get physiological from multi subjects/channels is ideal, when we consider the differences in individual animals. In this paper, we implemented a 4-channel, 4-subject optical telemetry system for the short-range measurement of the physiological signals in a system linked by optical path using LED and PD.


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## 2. Proposed Optical Telemetry System

Implemented optical telemetry system architecture is shown in figure 1. This system is divided into two areas: the experimental booth which consists of telemeter IC, LED, PD and two tiny lithium batteries on each subject and the external system which transmits command signals to the IC and receives modulated physiological signals. The latter consists of selection switches, demodulator and recorder. For the simultaneous multiple subject telemetry, a new enforced synchronization technique using infrared communication have been proposed.

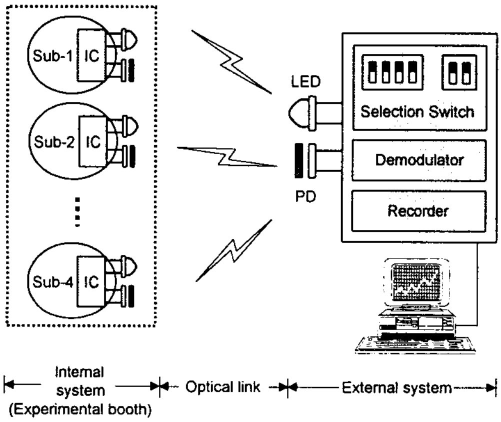


Fig. 1. The conceptual view of proposed telemetry system

When modulated physiological signals from a specific subject are demodulated in the external system, the synchronizing signals of the system have to correspond with each other. Otherwise, the modulated signal might be meaningless. Therefore, based on the enforced synchronization, an experimental telemetry system transmitting a synchronizing signal periodically was implemented. Telemetry IC and external system are linked by infrared rays using the commercial LED and PD. The telemetry is performed by bi-directional communication with a command signal and telemetry signal. The telemetry IC attached to subjects receives the command signal and reads it. The selected subject transmits physiological signals to the external system. The unit can transmit 4-channel signals simultaneously by time division multiplexing. For the small and lightweight instruments attached to each subject, a CMOS IC chip without LED and PD has been implemented as shown in figure 2. The points A, B, C~G in figure 3 are the waveforms corresponding to the same point in figure 2. Telemetry starts with transmitting command signals (figure 3. A) to telemeter IC on each subject. Command signal consists of a synchronizing signal, which enforces the initial state regulating internal states of telemeter IC, subject selection signal that means the selected subject according to the number of pulse.

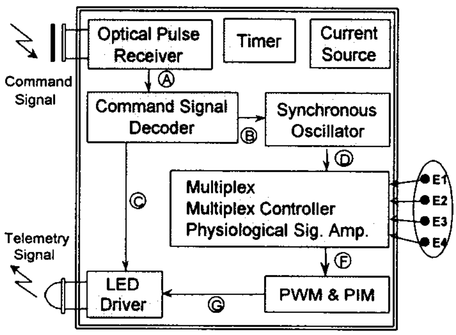


Fig. 2. Block diagram of telemeter IC

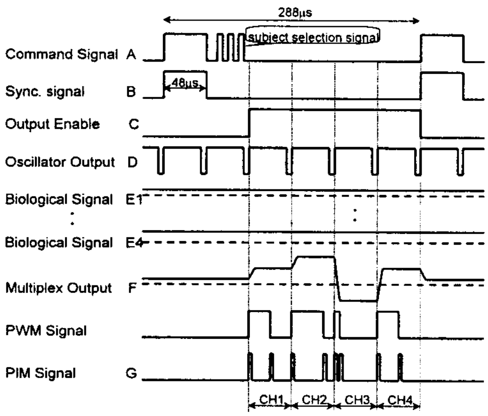


Fig. 3. Waveforms of telemetry system

The selected subject gives rise to the output enable signal (figure 3. C) to activate the LED driver. The selection of each subject is decided according to the pulse count. If a specific subject is selected, physiological signals of a selected subject transmitted as modulated signals. In our study, the physiological signal was modulated by PWM (Pulse Width Modulation) and PIM (Pulse Interval Modulation). The functions and characteristics on the each telemeter IC blocks are as follows;

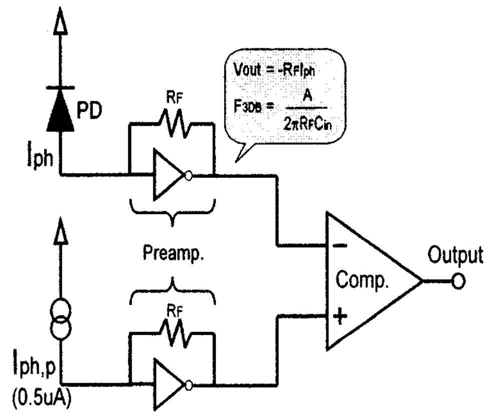


Fig. 4. Block diagram of optical pulse receiver

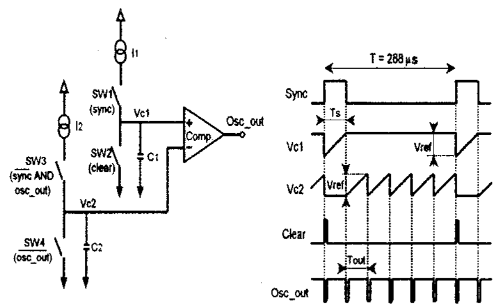


Fig. 5. Schematic diagram of synchronized oscillator and its waveforms.

A CMOS optical receiver is designed for a building block of the telemeter IC to receive command signals from external system. The receiver has to operate at a high pulse frequency and have wide dynamic range on optical power level [4]. The received optical power is dynamically changed due to the possibility of receiving both direct and indirect signals. In order to meet the above requirements, a non-linear feedback impedance with MOSFET is used in the transimpedance type receive as shown in figure 4. Regarding the CMOS optical receiver, the operation pulse frequency of 250kHz with dynamic range of 60dB was achieved. For the purpose of highly functional telemeter, it is ideal that complete synchronization between the external system and telemeter IC is made. We designed a synchronized oscillator without sensitivity of power source variation as shown in figure 5. We can write the following relationships for the Ts and Tout:

$$V_{C_1} = \frac{I_1 T_s}{C_1} \quad (1)$$

$$T_{out} = \frac{C_2 V_{C1}}{I_2} \; (\text{where } I_1 = I_2 \, , \; C_1 = C_2) \quad (2)$$

$$T_s = T_{out} \quad (3)$$

The advantage of this schematic is its flexibility that can adjust Ts(pulse width of synchronous signal) from the external system. Yet there are cases of mismatching between Ts and Tout (output of oscillator) because of IC process variation.

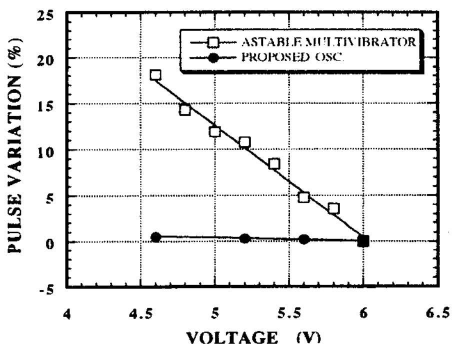


Fig. 6. Pulse variation rate of astable multivibrator and proposed oscillator as a function of power supply voltage

Figure 6 showed the text result of the pulse variation rate of the stable multi-vibrator and proposed oscillator as a function of power supply voltage. We confirmed that our proposed circuit works well in the voltage source range of 4.6V~

6.0V. For a stable amplification of low voltage physiological signals, the amplifier needs to be a high impedance, low voltage driving circuit. A BJT amplifier was used for signal processing of physiological signals conventionally. However, it causes a lot of power dissipation compared to a CMOS process technology. In our system, CMOS switched capacitor (SC) amplifier circuits[5] including buffers and time division multiplexing was designed as shown in figure 7. The principle operations of SC circuit consist of sampling and charge transfer.

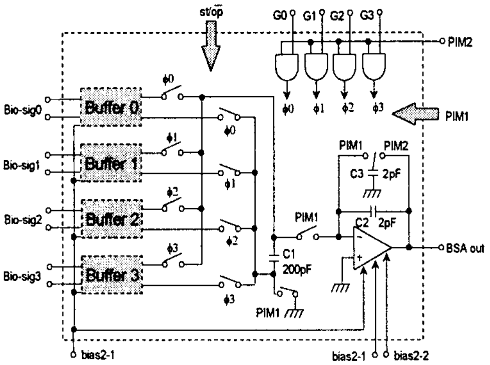


Fig. 7. Schematic diagram of time division multiplexing SC amplifier

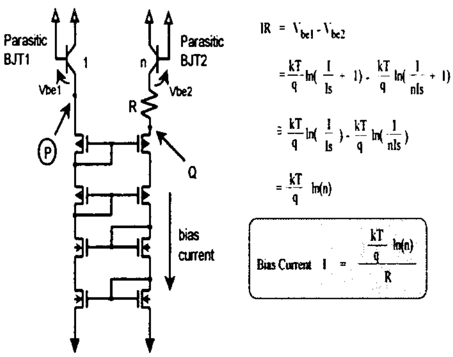


Fig. 8. Self-biasing current reference and current equations

The gain of proposed SC amplifier is 100 times (C1/C2). For the stable operation of the telemeter IC, a supply-independent biasing circuit is required. We designed the supply voltage independent circuit using a so-called self-biased current[6], as shown in figure 8. In most of the self-biased circuits, there are not one, but two stable operating points. The second operating point, which is not desirable, normally occurs at zero current state. This problem, which is common to self-biased circuits, is often referred to as the startup problems. This problem can be avoided by eliminating the undesired zero-current state. This can be done by supplying a very small amount of start-up current.

For a supply-independent circuit using CMOS technology, we designed parasitic bipolar junction transistors using the parasitic effects of CMOS process technology [7] as shown in figure 9.

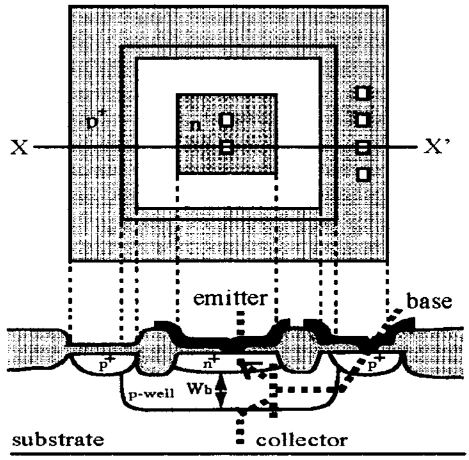


Fig. 9. Top and cross-sectional view of parasitic bipolar junction transistor.

Transmission of physiological voltage signal of figure 3. F using a time division multiplexing technique is susceptible to noise. We converted this signal into PWM waveforms. However, PWM waves have only information at the falling and rising edge of its signals. Other points, outside the falling and rising edges provide no data information. Therefore, the physiological signal converted into PIM of figure 3. G technique to save power consumption. This PIM signal is transmitted to the external system. In addition, we designed a timer circuit, which cut off the power source of the CMOS IC without receiving command signals for a specific period. Finally, the proposed telemeter IC has a timer circuit for auto power down control during the periods when commanding signals are not received(figure 10). Photomicrograph of a telemetry IC chip with size of 5.1×5.1㎟ is shown in figure 11. It has been fabricated by 5㎛ p-well CMOS process technology at Toyohashi University of Technology. For the confirmed stable operation of telemeter IC, we tested a synchronized oscillator block as shown in figure 12. This measurement result shows that the period of synchronized signal and each channel is 288㎲ and 48㎲, respectively, so that stable operation can be expected even if the supply voltage and temperature fluctuates. To transmit command signals and receive modulated physiological signals, an external system has been assembled with commercial ICs as shown in figure 13.

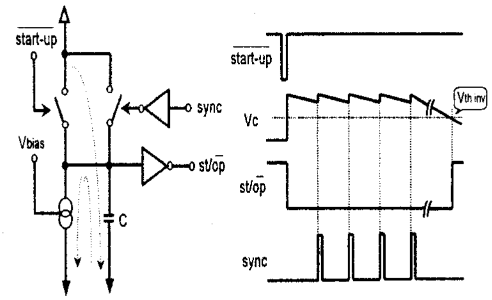


Fig. 10. Block diagram of timer and its waveforms.

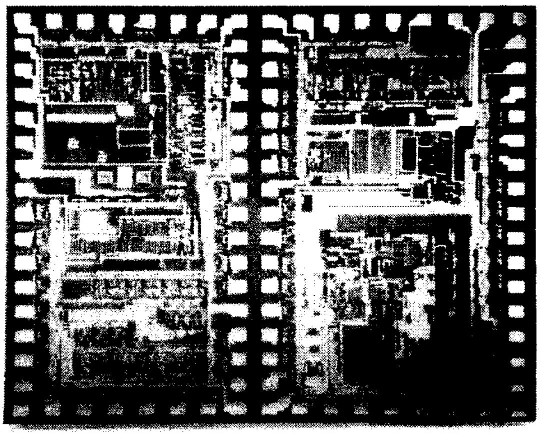

Fig. 11. Photomicrograph of CMOS telemete IC

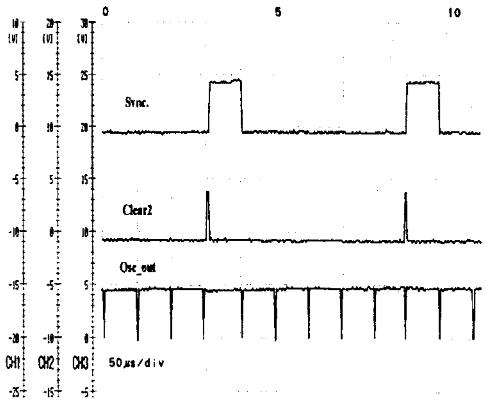


Fig. 12. Measurement result of a synchronized oscillator.

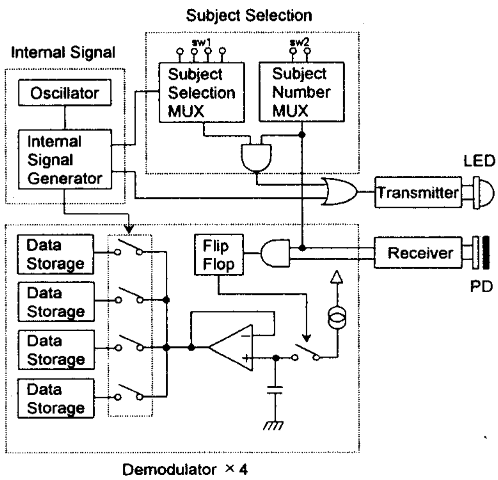


Fig. 13. Block diagram of external system.

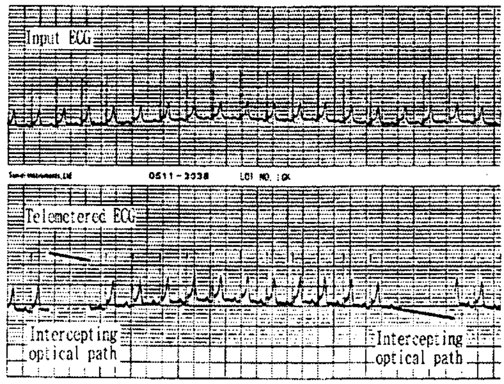


Fig. 14. Recordings of EKG by telemetry system with optical link

Table 1. Specifications of optical telemetry system.

| Specifications | Values |
|---|---|
| Power source | Two 3V lithium battery (120mAh × 2) |
| Power dissipation | Below 10mA |
| Infrared rays wavelength | 850nm for command<br>950nm for telemetry |
| Optical link | 50cm |
| IC technology | 5μm p-well CMOS |
| Die size | 5.1×5.1mm² |
| Max. subject number | 4 |
| Max. channel number | 4/subject |
| Channel period | 48μs |
| Synchronous signal | 288μs |
| Subject selection signal pulse | 5μs |
| Oscillator operation | 4.6V~6.0V |
| Current source operation | 4.3V~6.0V |
| Amplifier gain | 30dB~70dB |
| CMRR | 60dB |
| Input impedance | $10^{10}\Omega$ |
| Modulation | PWM-PIM |
| PIM nonlinerarity | 1.2%F.S |
| Recorder speed | 2.5cm/sec |
| EKG voltage level | 3mV |

An experimental telemetry system has been developed with implemented chips and the external system. The experiments of telemetry using EKG were performed. Two kind of wavelength of infrared rays, 850nm and 950nm are used for command and telemetry signals, respectively. In our system, there is a maximum of subjects and channels because of the requirements in practical use. We have demonstrated the principle operations of 1-subject, 1-channel EKG telemetry as shown in figure 14. We use the commercial EKG electrodes to detect a human body's EKG, by which output of EKG electrodes is connected to the physiological amplification circuit in CMOS IC. In recordings of EKG, the upper figure shows the test result of the output to the amplification circuit.

The lower one is the measurement result of demodulated EKG data in the external system and also shows that the optical path was intercepted by a thick material. The experimental distance of optical link to demonstrate a human body's EKG operation was 0.5m. We can successfully recover the modulated EKG data that has the range of the 0mV to 3mV without interference from transmitter to receiver. Finally, we summarized the features of our proposed optical telemetry system in table 1.

## 3. Conclusions

This paper presents an improved circuitry for reducing noise and dependency of power supply in CMOS one-chip short monitoring telemetry system for use in EKG by optical link. For simultaneous 4-subject 4-channel telemetry, a new enforced synchronization technique using infrared bi-directional communication has been proposed. The newly designed synchronized oscillator with low supply voltage dependency operates at a supply voltage from 4.6V~6.0V and the nonlinearity error of PIM modulator was less than 1.2% F.S. The power saving block operates at the period of 2.0ms even if the telemetry IC does not receive a command signal from the external system for a constant time. There are several problems to be solved for practical use. However, the possibility of the telemetry system within a specific area has been confirmed by the experimental telemetry system we have developed.

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