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Design of Multichannel Telemetering IC for Physiological Signals

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생체 신호처리를 위한 다채널 텔레미터용 IC 설계

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Abstract

This paper describes the design of implantable 8-channel telemetering system to get physiological signals. The internal circuits of this system are designed not only to achieve as small size and low power dissipation as possible, but also to enable continuous measurement of physiological signals. Its main functions are to enable continuous measurement of physiological signals and to accomplish on-off power switching of an implantable battery by receiving appropriate command signals from an external circuit. To integrate implantable biotelemetry system, we performed layout of internal system using Lambda based 2μm n-well design rules. This system, used together with appropriate sensors, is expected to be capable of measuring and transmitting such significant parameters as pressure, pH, and temperature.

요 약

본 논문은 생체 신호를 얻기 위한 생체삽입형 8-채널 바이오텔레메트리 시스템을 설계하였다. 본 시스템의 내부회로는 가능한 한 소형이고 저소비 전력화하였을 뿐만아니라 synchronization gap을 주기로 생체신호의 연속측정을 가능하도록 설계하였다. 본 시스템의 주된 기능은 생체신호 연속측정과 외부회로의 적절한 명령에 의해 생체 삽입 전지를 On, Off하여 소비전력을 줄일 수 있도록 하였다. 또한 체내 삽입시스템을 집적화하기 위해 람다룰을 기본으로 한 2μm n-well 설계규칙에 의해 레이아웃을 수행하였다. 그러므로 국내에서 개발되고 있는 압력센서나 ISFET 등을 본 시스템과 함게 삽입하여 생체신호, 즉 심전도, 혈류량, 혈압 등을 측정해 외부로 전송하는 의용 텔레메트리 시스템이 기대된다.

Ⅰ. Introduction

Implantable biotelemetry system is useful tool in both research and clinical medicine, because such system does not restrict the object and there is no risk of infection from percutaneous wires which are sometimes used for measuring deep body parameters.[1] The use of implantable biotelemetry system, however, entails several stringent demands.[2] First is the need for relatively small size and light weight, together with high reliability. Second is the need for long-term use of the internal power source which often consists of tiny primary batteries. Finally the implantable parts of the system must be encapsulated in a biocompatible material. Unfortunately, commercial integrated circuits seem to be mostly unsuit-

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able for implantable systems, because these are designed for a broad range of application. Consequently, in subcutaneous electronics, more than in any other forms of medical electronics, it is necessary to design custom integrated circuits to fulfill unique medical requirements.

This paper presents a design of implantable biotelemetry system of a CMOS IC which fulfills the above mentioned requirements. Its internal circuit is as small size as possible and is designed not only to accomplish low power dissipation by On-Off the power switching of an implantable battery by receiving appropriate command signals from an external circuit, but also to enable continuous measurement of physiological signals using the synchronization gap. The external system, receiving physiological signals measured from 7 implanted sensors, is composed of a receiver and external recorders.

The objects of this system is to transmit physiological signals obtained from 7 implanted sensors, and to receive physiological signals on external recorder.

II. Design of biotelemetry system

A biotelemetry system is designed with an implantable system and an external system as shown in Fig. 1. By examining the operation of the implantable system we may know the following.

The sequential outputs of the 8-state ring counter from Q0 to Q7 are connected to sensors. When a Q is turned on, the output of voltage level (physiological signals) measured from 8-channel sensors is made to be a sequential output. The first channel is connected to GND, therefore, it works as a synchronization gap.

The time sharing signal comes from the 8-to-1 multiplexer and the signal generator yields the triangular wave. As these signals are fed to the comparator, PWM (pulse width modulation) waves are generated.

This PWM waves are transmitted to the external circuits by FM transmitter. To minimize power dissipation, the internal circuits of this system are designed by using CMOS circuits, which are little power consumption when the digital parts of system do not work. By using command receiver circuit, we also designed that the power supply has to be turned Off when the implantable system is not in use. There are a variety of methods for supplying power for the biotelemetry system such as using a primary battery, supplying power by inductive coupling, and bio-battery using bio-energy. However the power supply used in this system is a primary lithium battery.

The external system consists of a command transmitter and a receiver. The command transmitter generates the signals that turn on or off the internal power supply. The receiver transmits measured physiological signals to an external recorder.

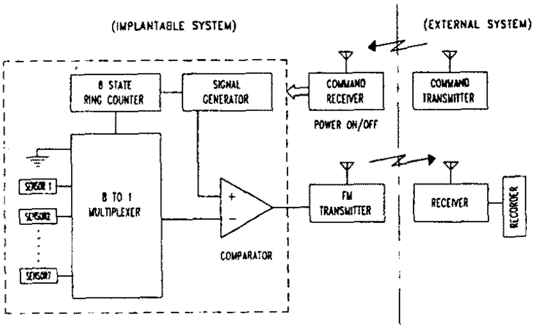


Fig. 1. Block diagram of 8-channel biotelemetry system.

2.1 Implantable system

The implantable system consists of command receiver, FM transmitter, 8-state ring counter, signal generator, 8-to-1 multiplexer, and comparator. Since the command receiver of the implantable system had already been manufactured as an IC chip, the remainder circuits (inside of dash) except the command receiver and FM transmitter(Fig. 1) are made to be an IC chip by using CMOS process technology.

2.1.1 *Pulse powered command receiver*

The function of command receiver is to connect or disconnect the battery to the sensors and implantable telemetry system on demand.[3]

Therefore, the command receiver should be continuously connected to the power source. In order to keep its power dissipation as low as possible, a pulse powered circuit has been designed for the command receiver.[4,5]

The pulse powered circuit concept involves intermittent gating of the power supply. A block diagram of pulse powered command receiver which performs this function is illustrated in Fig. 2, and this receiver operates according to the pulse width of the command signal. That is, when an On signal is received from external command transmitter, the output level(Q_2 and Q_3) of the second and third stages of the counter become high. This connects the power to the sensors and digital systems in the implantable system. After receiving physiological signals, an Off signal is transmitted and the power source to the sensors and digital circuits is switched Off, as the output level of the second and third states of counter becomes high, respectively. Even if an Off command signal is not received, the power switch toggles Off automatically after a time t($C_2 \cdot V_{DD}/2 I_R$) has elapsed. Here, I_R is the reverse bias leakage current of the diode(D_2) in Fig. 2.

2.1.2 *8-state ring counter*

In order to provide the sequential signal to TGs (transmission gate) of the 8-to-1 multiplexer, 8-state ring counter using D flip-flops is designed.

2.1.3 *Sensor interface circuit*

For obtaining voltage level output of 7 implantable sensors, sensor interface circuit is needed. In this section, we studied sensor interface circuit of a capacitive pressure sensor and ISFET.

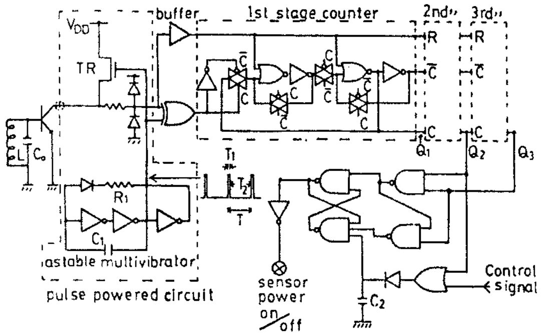


Fig. 2. Schematic diagram of pulse powered command receiver.

Fig. 3 is the example of circuit[6] that convert the capacitance value of the pressure sensor into a voltage level. The capacitive pressure sensor has a better sensitivity than a piezoresistive pressure sensor and is less sensitive to the variation of temperature. However, the capacitive pressure sensor has less linearity than the piezoresistive pressure sensor and we cannot ignore the effect of parasitic capacitance due to miniaturization. Thus, in order to complement these defects in this paper, we designed the interface circuit converting the variation of capacitance into voltage by using SC integrator and low pass filter. The functioning is as follows.

During clock phase FI1, the on-chip capacitors C1 are charged to a reference voltage Vo, while the sensor capacitor Cx and the reference capacitor Cref are discharged. Cref is a micromachined capacitor of the same type as Cx, but insensitive to pressure changes. During phase FI2, the charge on C1 is transferred to the sensor Cx and to the reference capacitor Cref, to yield voltages Vx and Vref after low-pass filtering. The clock phases were chosen to be asymmetrical in order to enable their removal from the output by a simple filtering technique. Consequently, a d.c. voltage level is present at the output of the filters. Fig. 4 is another example of ISFET interface circuit.

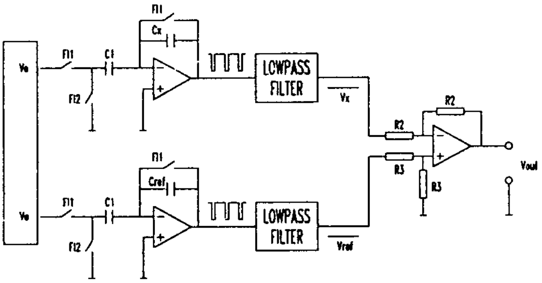


Fig. 3. Schematic diagram of C-V interface circuit.

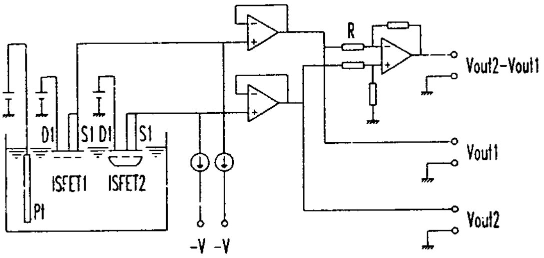


Fig. 4. Schematic diagram of ISFET interface circuit.

2.1.4 *8-to-1 multiplexer*

In order to obtain the sequential outputs generated by time-sharing method from the outputs generated by 7 sensors, the multiplexer using TGs is designed as shown in Fig. 5. In the multiplexer, the power supply of the sensors is derived by logical ending of outputs from the command receiver and the counter. Therefore, when the internal system is not in use, the power supply of the sensor is turned Off and the power consumption decreases.

2.1.5 *Operational amlifier and comparator*

The operational amplifier used in the circuit (Fig. 3, 4) detecting capacitance and pH from the capacitive pressure sensor and ISFET, is designed as 2-stage amplifier structure by using CMOS devices. It consists of differential amplifier, bias circuit, output stage, and one capacitor. The comparator generates PWM waveform using the output of the signal generator, that is, triangular wave, and the output of multiplexer as inputs of comparator.

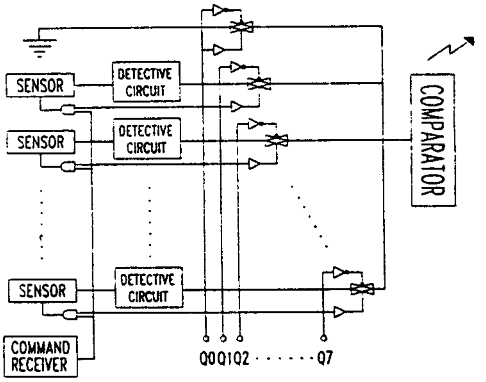


Fig. 5. 8-to-1 multiplexer circuit.

2.1.6 *Signal generator*

The signal generator provides a clock used in 8-state ring counter and triangular wave used in the input of a comparator. The signal generator consists of schmitt trigger, capacitor, and inverter as shown in Fig. 6. Referring to the circuit, the oscillator frequency is determined by charge current(I_C) and discharge current(I_D) in the capacitor of circuit. Thus in the circuit of the signal generator, we can obtain triangular wave in Voutl, and clock pulse in Vout2. Vout2 is used as the clock of the 8-state ring couter in the implantable system.

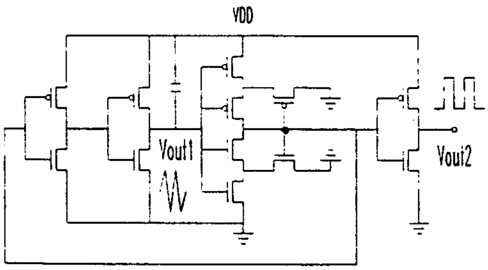


Fig. 6. Signal generator (produce clock & triangular wave).

2.1.7 FM transmitter

Fig. 7 shows comparator circuit which consists of a bias stage, a diffential amplifier stage and a cascode amplifier stage using CMOS devices.

Fig. 8 is a block diagram of a transmitter and a receiver, where the transmitter modulates the physiological signals measured in the implanted sensors and transmits to the receiver.

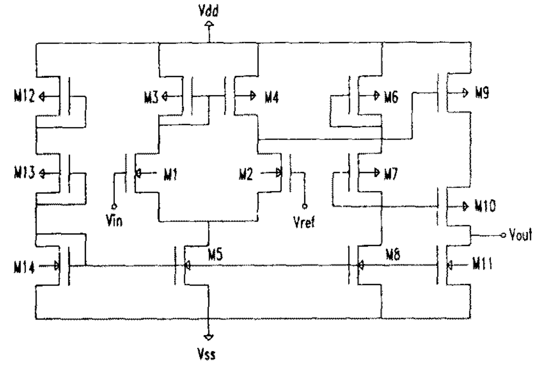
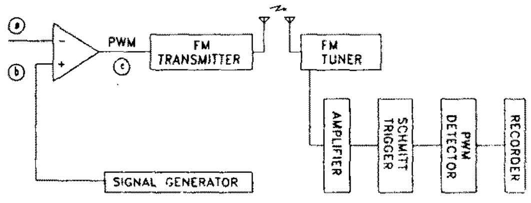


Fig. 7. Configuration of compartor circuit.



(a) (b)

Fig. 8. Block diagram of transmitter and receiver.
(a) transmitter (b) receiver.

In order to transmit the measured physiological signals at low power as well as possible, the transmitter is designed with a double modulation which is pulse width modulation(PWM) with high noise immunity and frequency modulation (FM). The first stage modulation(PWM), referring to Fig. 8, performs pulse width modulation. That is, the signal that comes from the sensors is applied at the inverting input of the comparator and the triangular wave made in the signal generator is connected to the noninverting input. The second stage modulation as well as the transmitter circuit is colpitts oscillation circuit using one transistor and transmits about 80MHz through FSK(frequency shift keying).

2.2 External system

The receiver is assembled by a commercial FM tuner and PWM demodulation circuit.[7] To realize demodulated PWM waveform, we use schmitt trigger circuit in the first stage of receiver system for the shaping of waves.

III. Simulation results and discussions

The measurement results of a command receiver circuit which had already been made as an IC chip are shown in Fig. 9. To reduce power dissipation, it is important to decrease the ratio of pulse width(T_1) and period(T), T_1/T(duty ratio), in the command receiver circuit. Here, the duty ratio is related to intermittent operation of the pulse powered circuit. In Fig. 2, when the resistance R1 and the capacitance C_1 were 10 KΩ and 50 pF, respectively, we were able to get the duty ratio to 1/7000. That is, it causes the command receiver circuit to operate for only 6 μsec per 42.5 msec.

In the case of logical operation in the command receiver, when the command signal that makes the power of the internal turn On is transmitted from the external, as designed, both Q_2 and Q_3 become "H" level and the power switch is turned On. When the Off signal is transmitted, Q_2 is low, Q_3 is high, hence we may know that the power switch is Off.

Assuming that the outputs of sensors were different frequencies, we verified the operation of the 8-to-1 multiplexer with a logic simulator (EDAS-P) in Fig. 10. As shown in Fig. 10, we may know that, after the synchronization gap, the outputs of 7 sensors are sequential. Fig. 11 is a SPICE simulation result of PWM wave, through a comparator whose input is voltage level physiological signals and triangular wave of signal generator. The overall waveforms of the implantable biotelemetry system are also shown in Fig. 12. The output of the comparator, namely PWM wave, using the output of the multiplexer(time-sharing signal) and of the signal generator(triangular wave) as inputs is indicated here. The points ⓐ, ⓑ, ⓒ in Fig. 12. are the waveforms corresponding to the same point in Fig. 7.

The CMOS IC chip of the implantable system is designed as shown in Fig. 13 using lambda based 2μm n-well design rule of ISRC(inter-university of semiconductor research center).

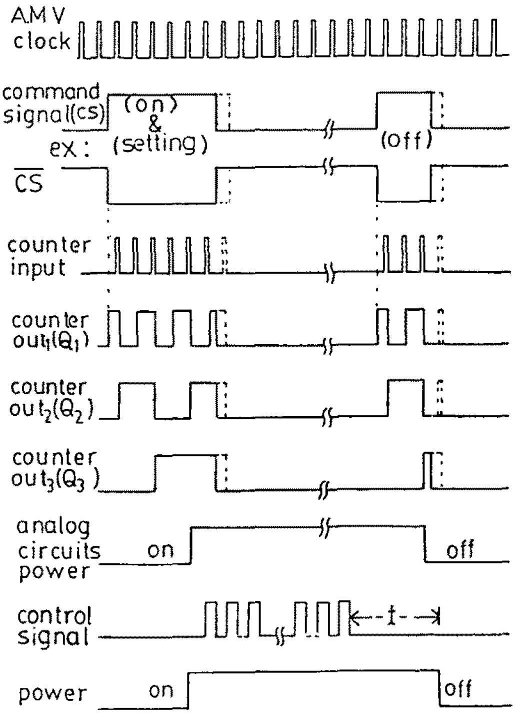


Fig. 9. The measurement result of command receiver.

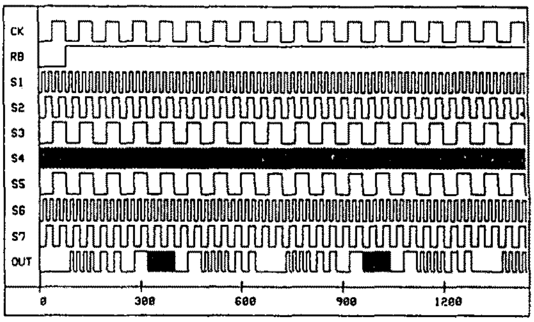


Fig. 10. Simulation result of 8-to-1 multiplexer circuit.

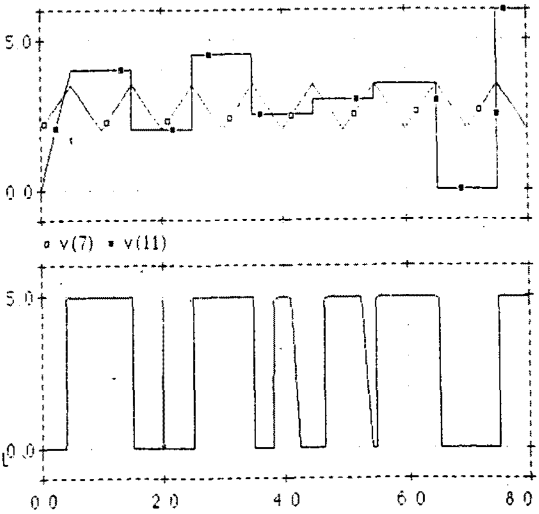


Fig. 11. Simulation result of PWM waveform.

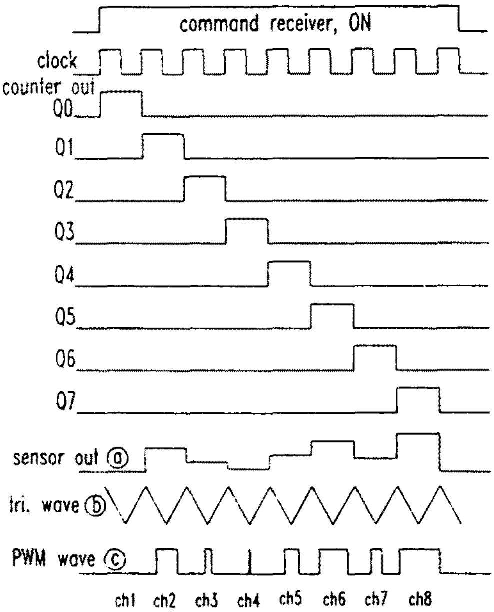


Fig. 12. Waveforms of total implantable system.

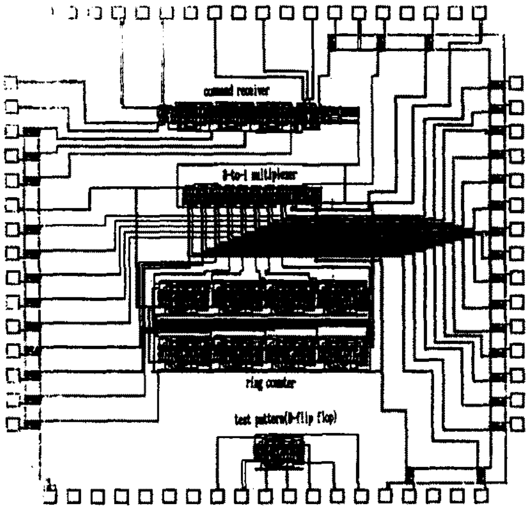


Fig. 13. The layout of implantable system(3×3㎟).

Ⅳ. Conclusion

This paper presents the design of a multichannel telemetering IC for physiological signals. The designed system can get physiological signals from 7 implantable sensors sequentially, using synchronization gap as a period. By tuning On or Off the power source of the implantable system, this system is designed to increase the lifetime of implanted primary battery as much as possible. From the results of simulation, we may obtain the signals measured from 7 sensors continuously. The PWM waves are generated from these signals through the comparator, hence the total biotelemetry system is confirmed to work as well as designed. In order to make such a biotelemetry system available for wide applications in medicine, (1) small size, (2) low power dissipation, and (3) high reliability are required. The first two are satisfied by implantable system developed here.

The last will be satisfied by further development of biocompatible packaging and of implantable sensors for different physiological parameters such as pressure, pH, temperature and bioelectrical activity.

In the future, by implanting this system with a pressure sensor and ISFET that has been developed in our country, we will be able to measure useful physiological signals in the situation which a patient doesn't know, and stimulate a certain parts of the internal living body from the external electrically. Thus thanks to the development of the medical telemetry system, it is expected to contribute to the medical electronics.

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