

# Multi-sensor Wireless Physiological Monitor Module

C. H. Ko, H. L. Chen, C. C. Kuo, G. Y. Yang, C. W. Yeh, B. C. Tsai, Y. T. Chiou, C. H. Chu  
Industrial Technology Research Institute  
No. 31, Gongye 2nd Rd., Annan District, Tainan City 709, Taiwan, R.O.C.  
Email: kurt@itri.org.tw, Phone: 886-6-3847138

## Abstract

A wearable, wireless, multi-sensor module for long-term, continuous physiological signal monitoring is presented in this paper. The multi-sensor wireless physiological monitor module, called a "tag," is attached to a wrist and a fingertip for monitoring skin temperature and beat-to-beat pulsation respectively, and the data is sent to a host computer, called a "reader," via a radio-frequency transmitter. Two major design issues are addressed: one is to combine the two sensors in one tag, and the other is to develop the low power consumption ASIC. It was verified through experiments that the tag module can monitor both the temperature and the pulse simultaneously in a long period, and the wireless transmission distance between the tag and the reader could be successfully extended to 6 meters.

## Introduction

Because of coming into a geriatric society, physiological signal monitoring is increasingly important for securing their independent lives. On-line, continuous monitoring allows us to detect emergencies and abrupt changes in the patient conditions. Especially for cardiac patients, on-line, long-term monitoring plays a pivotal role. It provides critical information for long-term assessment and preventive diagnosis for which long-term trends and signal patterns are of special importance. Such trends and patterns can hardly be identified by traditional examinations. Those cardiac problems that occur frequently during normal daily activities may disappear the moment the patient is hospitalized, causing diagnostic difficulties and consequently possible therapeutic errors.

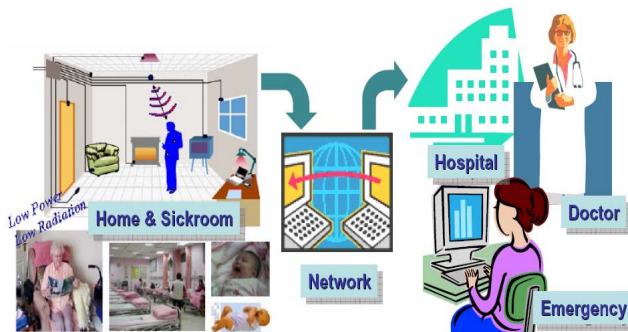


Fig 1 Wireless physiological application scenario

In general, long-term, ambulatory monitoring systems have not yet reached a technical level that is widely accepted by both clinicians and patients. Such long-term, ambulatory devices must be compact, lightweight, and comfortable to wear at all times. They must be designed for low power consumption for long-term use. Furthermore, they must be

able to detect signals reliably and stably in the face of motion artifact and various disturbances. Unlike traditional monitoring systems, these devices are used under no supervision of clinicians. Data is collected from daily lives of patients in an unstructured environment. Recently, a variety of vital sign sensors have been developed that are compact and easy to wear.

Yamashita et al. [1] attempted to develop a simple telemetry device for monitoring pulse at a finger. This was the first attempt to implement analog photoplethysmographic (PPG) measurement on the finger base. The device can send pulse data through an analog signal transmitter. On the other hand, wristwatch-type pulse oximetry and blood pressure sensors have been developed and commercialized by several companies including Casio (BP-100 and JP200W-1V) and Omron (HEM-608 and HEM-609). A prototype miniaturized, telemetric, PPG sensor for long-term, continuous monitoring was presented in [2]. It was shown that the device meets diverse and conflicting requirements, including compactness, motion artifact reduction, minimum loading effects, and low power consumption.

The goal of this paper is to develop wireless multi-sensor technology for reducing power consumption and obtaining reliable measurements of physiological signals for long-term use. A wearable, wireless, multi-sensor module was designed and built based on the power budget analysis and the artifact-resistive attachment method.

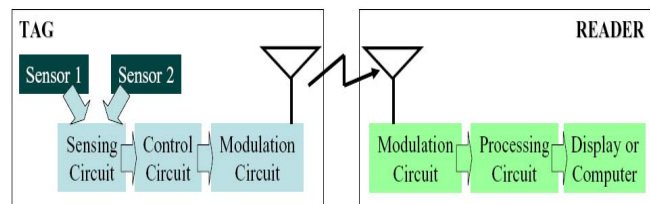


Fig 2 Wireless physiological monitor system

## Smart Sensor Circuit

### ■ PPG & Thermal Sensor

In this paper, we use photoplethysmograph (PPG) sensor to monitor the arterial pulsation non-invasively and continuously. The light emitting and sensitive parts are located side by side in one probe. The photo-sensors detect the light, which is backscattered from the tissue of the skin as shown in Fig 3. Due to the body's anatomy, the PPG sensors can only detect the pulse waves in areas that contain many arterio-venous anastomoses such as the fingers, toes, earlobes, or some regions of the face.

The drawback of the general PPG sensor is its high power consumption due to large driving currents of LEDs. To manage the power system more effectively, we adopt the optical modulation technique and reduce each duty cycle of the pulses. In 1kHz frequency and 0.1% duty cycle conditions, the tag can save more 1000 times power consumption than the traditional driving method. [2]

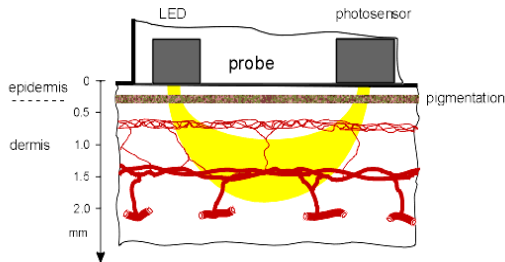


Fig 3 PPG sensor diagram [4]

On the other hand, the skin temperature is readout by a thermistor with a RC oscillating circuit (Fig 4). When the temperature changes, the thermistor  $R_t$  and its oscillating frequency  $fR_t$  changes, too. To compensate the environmental variation, we add a reference resistance  $R_{ref}$  and record the oscillating frequencies of  $R_t$ ,  $R_{ref}$  and the ratio of  $R_t / R_{ref}$  as Tab 1.

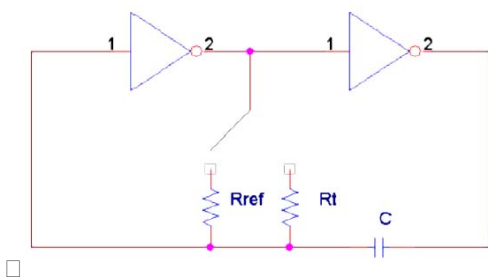


Fig 4 A RC oscillating circuit

Tab 1 Ref. parameters of the thermal compensated circuit

Temp. (deg. C)	$R_t$ (kOhms)	$R_{ref}$ Freq.	$R_t$ Freq.	Ratio $R_t / R_{ref}$
16	14.16	990	423	0.427
17	13.61	990	440	0.444
18	13.09	990	542	0.456
19	12.59	989	467	0.472
20	12.11	989	483	0.488
21	11.65	989	499	0.504
22	11.21	988	512	0.518
23	10.79	988	530	0.536
24	10.38	987	544	0.551
25	10.00	987	560	0.567
26	9.630	987	578	0.585

#### ■ ASIC (SP9400) Design

The SP9400 is an application specific integrated circuit (ASIC) for long-term, continuous physiological signal monitoring applications. It integrates a PPG and thermal analog front-end (AFE) circuit, an analog-to-digital converter

(ADC), and a modulated circuit. Fig 5 and Fig 6 are the function block and layout of the SP9400 respectively.

The other features of the SP9400 are as follows:

- Build-in high gain, low noise amplifier for low voltage sensor.
- Typical operation frequency: 433 MHz.
- Long range application more than 3 m.
- Ultra low power operation.
- 3V supply battery.
- Modulation type: OOK/ASK.
- Code type: Manchester.
- Chip size: 1.4\*1.5 mm<sup>2</sup>

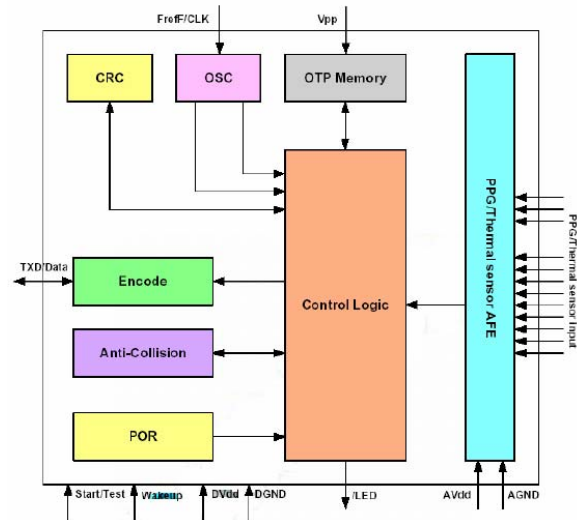


Fig 5 A SP9400 functional block diagram

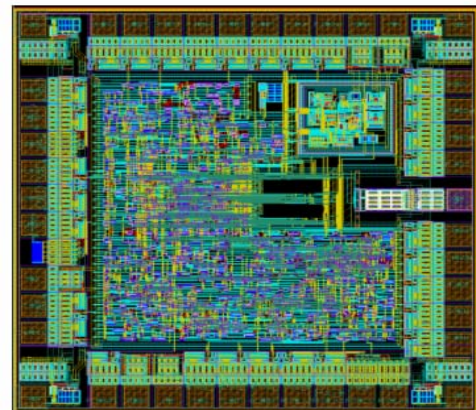


Fig 6 The SP9400 layout

#### Wireless Transmitter and Reader Module

After sensing and processing the physiological signal, we need a wireless transmitter to deliver the data to the reader. A wireless transmitter includes two parts: a RF front-end circuit and a printed loop antenna.

#### ■ RF Front-end Circuit

A hybrid front-end integrated circuit, TX5000, is chosen to simplify the circuit and reduce the volume of the tag

module. All critical RF functions are contained in the hybrid, simplifying and speeding design-in. The TX5000 includes provisions for both on-off keyed (OOK) and amplitude-shift keyed (ASK) modulation. It employs a SAW filter to suppress output harmonics, facilitating compliance with ETSI I-ETS 300 220 and similar regulations. Fig 7 shows that the transmitter chain consists of a SAW coupled-resonator oscillator followed by a modulated buffer amplifier. The SAW coupled resonator output filter suppresses transmitter harmonics to the antenna. [6]

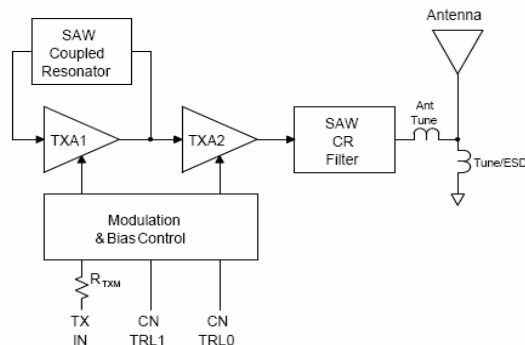


Fig 7 Transmitter block diagram [6]

#### Printed Loop Antenna

Because of the requirements of small size, low cost, and UHF band application, we chose a printed loop antenna as the best solution of the tag module. A printed loop antenna owns strong points, like small, easy to design, and tunable. Though this type antenna has less than 20 percent radiation efficiency generally, it is still a superior choice. Therefore, we adopt and design a printed loop antenna with center frequency, 433.92 MHz, in the wireless sensing system. The inductance of the printed loop antenna is determined upon the size of the loop, the width of the trace, the PCB thickness and the location of the ground plane. The loop itself is an inductive element and the value shall be determined by the formulas that follow.

$$L_{ANT} = 0.2 \times Length \times \ln\left(\frac{Length}{d} - 1.6\right) \times 10^{-9} \times k$$

Where:

Length is the total antenna length in mm.

d is the trace width in mm.

k is a frequency correction factor.

$L_{ANT}$  is the approximate antenna inductance in henries.

Then, we need a specific capacitor that is tuned to the inductance of the antenna to ensure the resonance at the transmit frequency. Calculate the value of the parallel capacitor  $C_T$  using the following equation.

$$C_T = \frac{1}{4\pi^2 f^2 \times L_{ANT}}$$

Where:

$C_T$  is the value of parallel capacitance in farads.

f is the carrier frequency in hertz.

$L_{ANT}$  is the inductance of the antenna in henries.

According to the method described above, the 433 MHz printed loop antenna can be produced as shown in Fig 8. The S11 and SWR were measured by a VNA as shown in Fig 9,

and the measuring results are -23.65dB and 1.14 @ 433.92 MHz respectively. It was also verified through experiments that the antenna transmission distance between the tag and the reader could be successfully extended to 6 meters.

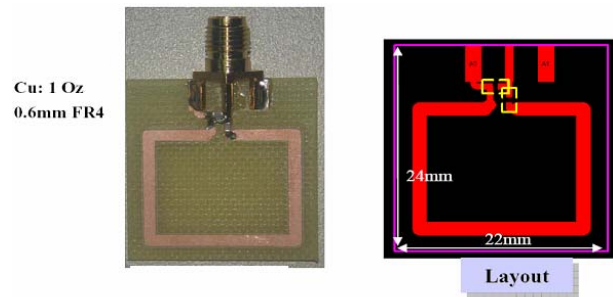


Fig 8 The 433 MHz printed loop antenna

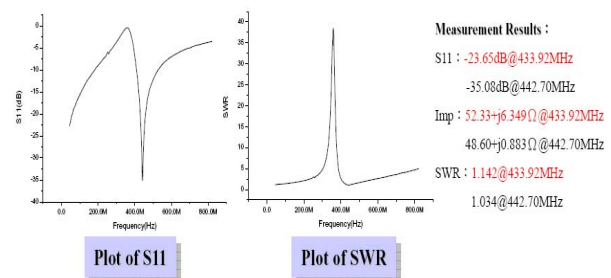


Fig 9 The S11 and SWR measurement

Finally, the complete tag module of the wireless physiological monitor system is shown in Fig 10. It integrated PPG and thermal sensors, the low power consumption ASIC, a RF transmitter, a battery and a case. The thermistor was placed on the bottom of the case in order to measure the skin temperature. The PPG sensor, placed on the fingertip, was connected to the PCB by a wire. The module was fixed on the people's wrist belt after assembling PCB and battery.

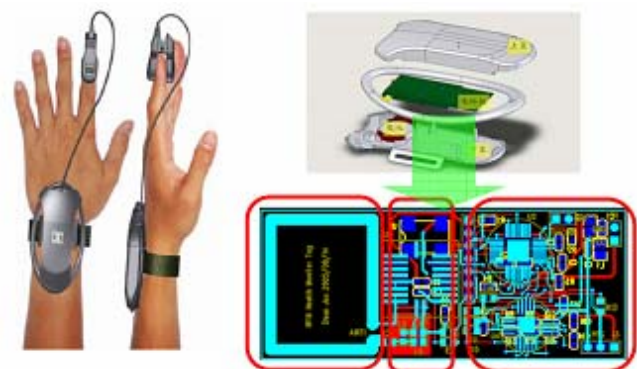


Fig 10 A tag module structure

#### Reader

In this system, we also need a reader to receive the wireless physiological signal from the tag. The complete reader includes a RF receiver, a FPGA, the 8051 controller, a SRAM and a LCD display. The operation process of the reader is shown in Fig 11. After receiving the wireless signal,

the RF receiver demodulates the high-frequency signal to the baseband signal. Then the baseband signal was synchronized, decoded, and processed by the FPGA. At the same time, the PC will inquire whether the packet sent back from the FPGA through the RS-232 cable or not. Finally the measuring results will appear on the PC monitor as shown in Fig 12.

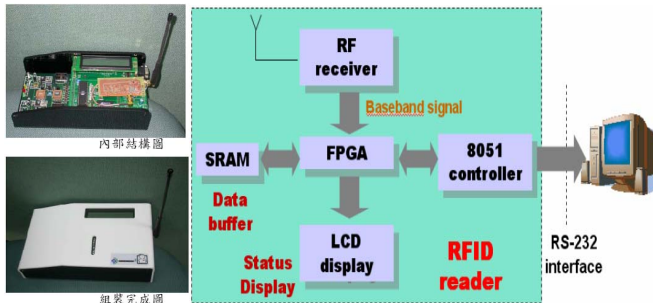


Fig 11 The operation process of the reader

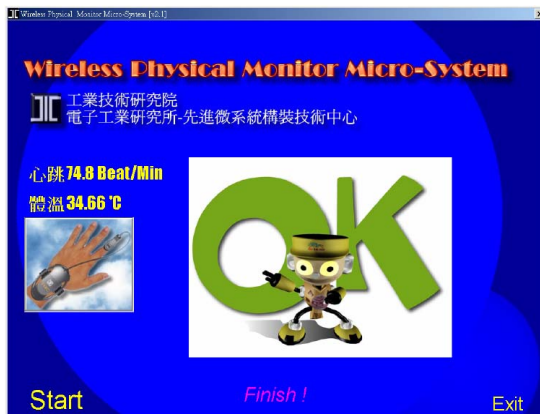


Fig 12 The user window of the wireless physiological monitor system

## Conclusions

In this paper, we developed a wireless physiological monitor module. It integrated PPG and thermal sensors, the low power consumption ASIC, and a RF transmitter. It can monitor both the temperature and the pulse simultaneously in a long period, and the wireless transmission distance between the tag and the reader can be successfully extended to 6 meters. However it still takes time to improve the performance, including the stability of dynamic measurements and the anti-collision capability. Furthermore, we plan to integrate other physiological sensors, such as the respiration, blood pressure, and electrocardiogram (ECG) into this module in the future.

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