AN2944
Application note

Plethysmograph based on the TS507

Introduction

This application note provides a method to make an analog front-end plethysmograph (from the ancient greek plethysmos, which means increase), which is an instrument for measuring changes in volume within an organ or whole body, usually resulting from fluctuations in the amount of blood or air it contains. In this context, we refer in particular to the fluctuations in the quantity of blood in blood vessels.

Contents

List of figures

1 Description

1.1 Purpose

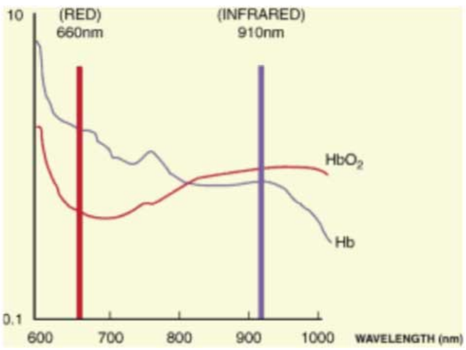
This application note describes a demonstration board which is designed for demonstration purposes only, and shall not be used as a medical instrument, nor for domestic installation. The technical data included in this document shall be taken as a guideline.

1.2 Theoretical background

The contraction of the heart causes a pressure wave which moves along the arteries producing, as a consequence, their expansion during the positive peak. The wave is faster than the blood flow and its speed reaches a few meters per second. The pulse wave can be sensed at a limb as well as the wrist or a finger.

The two possibilities for sensing the pulse wave are via a pressure sensor or through an optoelectronic plethysmograph which uses the physical mechanism of light absorption. Hemoglobin present in the blood absorbs the light emitted in a particular wavelength range (see figure below). In this system infrared light can be used with no distinction between oxyhemoglobin and deoxyhemoglobin.

Figure 1. Light absorption by hemoglobin at different wavelengths



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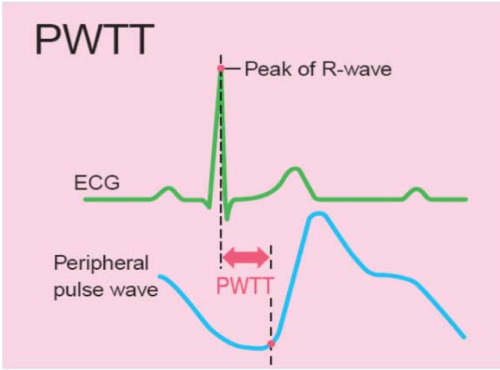
For this reason, the light which is able to pass through the body at a wavelength of 600-900 nm depends on the quantity of hemoglobin flowing in the blood vessels. Therefore, since the quantity of hemoglobin at a given time is proportional to the pulse wave at that time, it is possible to calculate the pulse wave from the transmitted light.

The information from the pulse wave is often used in conjuntion with a three-lead electrocardiogram (ECG or EKC) with the differential electrodes placed on the thorax. In fact, from the two measurements, it is possible to calculate the PWTT (pulse wave transit time) which is the time interval between the R wave peak of the ECG and the positive peak of the plethysmography (see *Figure 2*) and can be correlated with blood pressure.

Figure 2. Schematic representation of the pulse wave transit time (PWTT)



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2 Model for creating a plethysmograph

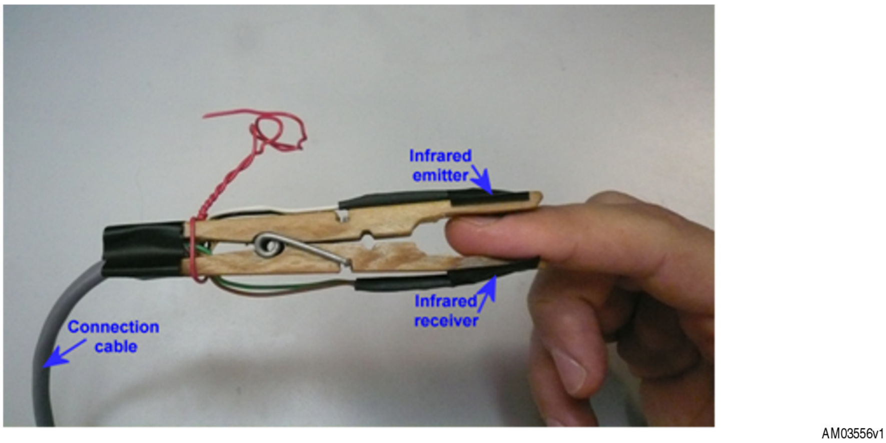
2.1 Getting started

The construction of the board described in the following sections has been inspired from other projects already developed in an educational and scientific context [see *1* and *2* in *Section 5: References*]. However, in order to prevent accidents, the electrical installation of the power supply shall be completed in accordance with safety requirements (e.g. by assuring a satisfactory cross-section of the conductors, by using a fuse, etc.).

2.2 Sensors

The sensor consists of an infrared (800 nm) light emitter diode, the SFH309FA, and an NPN phototransistor light receiver, the SFH487. The source and detector have to be mounted side by side on a finger. The light passes through the tissues and the amount of light captured by the photodetector depends on the quantity of hemoglobin. Timed samples of the photodetector output allow us to reconstruct the pulse wave. An easy way to mount these two components to have steady contact with the finger is to use a wooden clothespin to hold them in a fixed position (see figure below). The infrared filter of the phototransistor reduces the interference from the fluorescent lights, which exhibit a large AC component in their output.

Figure 3. Sensing system

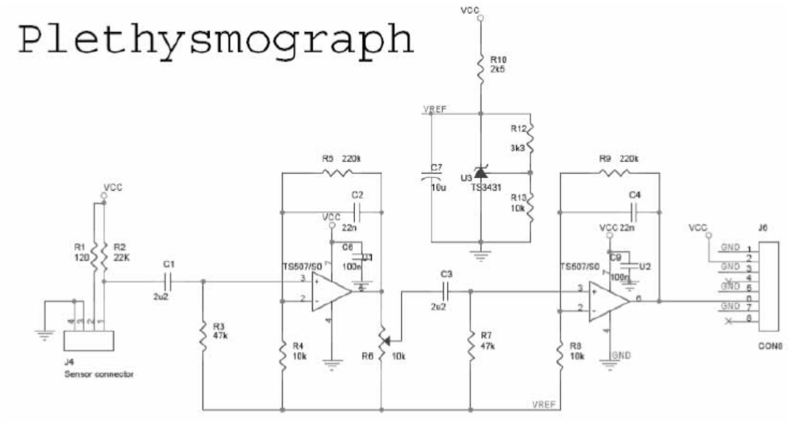


2.3 Analog front-end

The analog front-end, used for conditioning the output signal of the phototransistor, is made of two high-precision rail-to-rail operational amplifiers (TS507) and a programmable shunt voltage reference (TS3431AILT) with a small number of passive components.

The schematic, shown in *Figure 4*, consists of an amplification and a filtering block. The signal received from the phototransistor is high-pass filtered to remove the DC voltage offset and then amplified by 100 and low-pass filtered with a cutoff frequency of 10 Hz. The power supply voltage is set to 3.3 V while the VREF signal is set to 1.65 V through the resistors R12 and R13.

Figure 4. **Schematic diagram for the analog front-end plethysmograph**



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In order to acquire the pulse wave measurement, we suggest connecting the output pin of the analog board (pin 6 of J6 in figure above) to a digital subsystem where the input of a microcontroller (e.g. STM32) can be acquired through an A/D converter. The board that implements the analog front-end and a picture showing the measurement setup are presented in *Figure 5* and *6*.

Figure 5. **Analog front-end demonstration board**

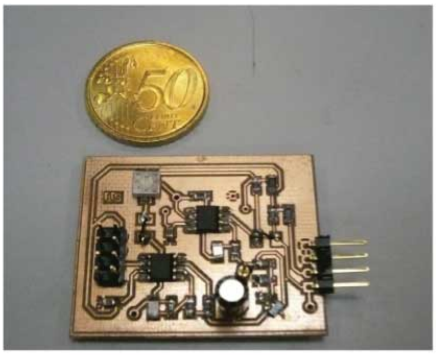

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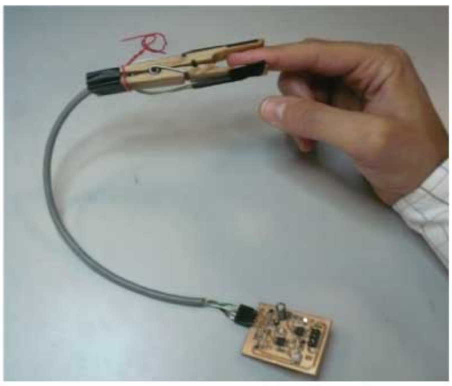
Figure 6. **Entire system**



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3 Bill of material

Table 1. BOM

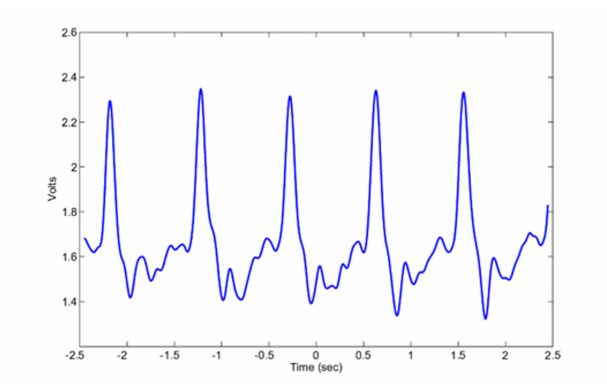
Item	Quantity	Value	Part reference
1	1	2.2 µ	C1
2	1	22 n	C2
3	1	2.2 µ	C3
4	1	22 n	C4
5	1	100 n	C6
6	1	10 µ	C7
7	1	100 n	C9
8	1	CON4	J4
9	1	CON8	J6
10	1	120 Ω	R1
11	1	22 kΩ	R2
12	1	47 kΩ	R3
13	1	10 kΩ	R4
14	1	220 kΩ	R5
15	1	10 kΩ	R6
16	1	47 kΩ	R7
17	1	10 kΩ	R8
18	1	220 kΩ	R9
19	1	2.5 kΩ	R10
20	1	3.3 kΩ ±1%	R12
21	1	10 kΩ ±1%	R13
25	1	TS507ID	U1
26	1	TS507ID	U2
27	1	TS3431AILT	U3

4 Results

An example of the pulse wave measurement as recorded by the plethysmograph is shown in *Figure 7*. The experiment was carried out on a healthy subject at rest because movement of the finger causes additional compression of the blood volume which varies the DC component of the measurement. The peaks in the signals correspond to a maximum in the blood flow because the greater the voltage, the lesser the light which is received by the phototransistor and the greater the voltage between the phototransistor collector and ground.

The time interval between two consecutive peaks can be easily measured by combining the A/D converter with a triggered timer of the microcontroller which computes this interval.

Figure 7. Five seconds recording by plethysmograph of a healthy subject



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5 References

1. The PicoTech project on calculating the heart rate
2. Proceeding of the 2006 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS2006), pp. 2620 - 2625 (2006)

6 Revision history

Table 2. Document revision history

Date	Revision	Changes
28-Jan-2010	1	Initial release