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PPG EDUKIT SENSOR

Application Note

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1 Introduction

The PPG EduKit is used to acquire and understand the photoplethysmography (PPG) signal. The signal can be acquired using two different sensor setups:

1. Analog module with user-tunable analog conditioning stages which uses one photodetector and three different wavelenghts (green, red and IR).
2. Commercial MAXREFDES117 module which contains the MAX30102 PPG sensor together with all the additional components needed for the signal readout.

The analog module LEDs are controlled by a LED driver which uses an external 10K digital potentiometer to regulate the LEDs output current. It also has a temperature sensor (MAX30205) to measure body temperature.

The board has an additional display, a push-button (SW1) and a RGB led (NeoPixel), to be used by the user as desired. The most common application is to use the push bottom to toggle between LED wavelenghts and the RGB led to show which wavelength has been selected (particularly useful when using the IR wavelength since it is not visible by the human eye). The display is meant to be used for real-time plotting of the PPG signal together with the physiological parameter(s) calculated.

The PPG EduKit has been designed with the shape and pinout of an Arduino. It is compatible with any microcontroller/microprocessor that runs with a **logic level voltage of 3V3** and supports Arduino Shields. Additionally, it can also be used with PSOC6 with an Arduino-to-PSOC6 bridge board. A table with the pin relationship can be found in the Annex.

IMPORTANT: *DO NOT use the PPG EduKit with microcontrollers that have a logic level voltage of 5V, like the Arduino UNO. This would damage the board permanently.*

Figure 1 shows the sensor pinout as well as the different blocks present in the board. *D.CLK, D.LE, D.OE, D.SDI* correspond to the LED Driver pins. *A, B and C* correspond to the three generic (to be used) buttons on the display. *MAX.int* is the interruption pin needed to control the MAX30102. *TIA, HPF, LPF and AMP* are analog inputs corresponding to the output voltage (signal) after each conditioning stage.

Figure 2 shows the circuit diagram of the analog conditioning stages used in the analog module. The current generated by the photodetector is converted to voltage and amplified by the transimpedance amplifier (TIA) module. A 20KOhm potentiometer is placed in parallel with a resistor so that the amplification can be tuned. A 22KOhm resistor (R1) and the potentiometer set to 20K yields the best signal quality for red and IR light. For green light, the resistor used should be of 220KOhm. After the TIA, a first order band-pass filter (high pass filter followed by a low-pass filter) filters out noise and the DC component. The cutoff frequencies are 0.15Hz and 5Hz, respectively. After the filters an inverting amplifier is used to amplify and invert the denoised PPG signal. The amplification can also be tuned using a 20KOhm potentiometer in series with a 4.7KOhm (R5) resistor. R4 also has a 4.7KOhm value. This stage amplifies the signal as follows:

$$V_{AMP} = -\frac{R5 + POT2}{R4} \tag{1}$$

If the potentiometer is set to 0%, the amplification is one. A potentiometer value of 8KOhm (40%) yields the best signal quality without entering into saturation.

Each stage can be read as an analog input.

Important note: Operational amplifiers (opamps) are active electronic components. They need to be powered in order to work. The opamps used here are powered in single-supply mode (to ground at the negative supply and to 3V3 at the positive supply. This means that the opamps amplification range is from 0V to 3V3. Signals below or above this range will be seen as a 0V value or 3V3 respectively. The different conditioning stages (TIA, HPF, LPF and AMP) are not connected to GND but to a virtual ground (VG) = 3V3 / 2, which equals to 1.65V. This is done so that the PPG signal will have its 'reference' in the mid-point of the opamp amplification range. Voltage values above 1.65V are 'positive' voltages and below, 'negative'. When the inverting amplifier inverts the signal, it is 'mirrored' with respect to VG, **not with respect to GND**. This is an important consideration to understand the signals readout from the different analog stages. The signals coming from the TIA, HPF and LPF will be 'positive' (above 1.65V), while the signal after the inverting amplification will be 'negative' (below 1.65V).

For further information about the photoplethysmography (PPG) technique, please refer to this paper.

For further questions you can send an email to **angelsm@etrovub.be**

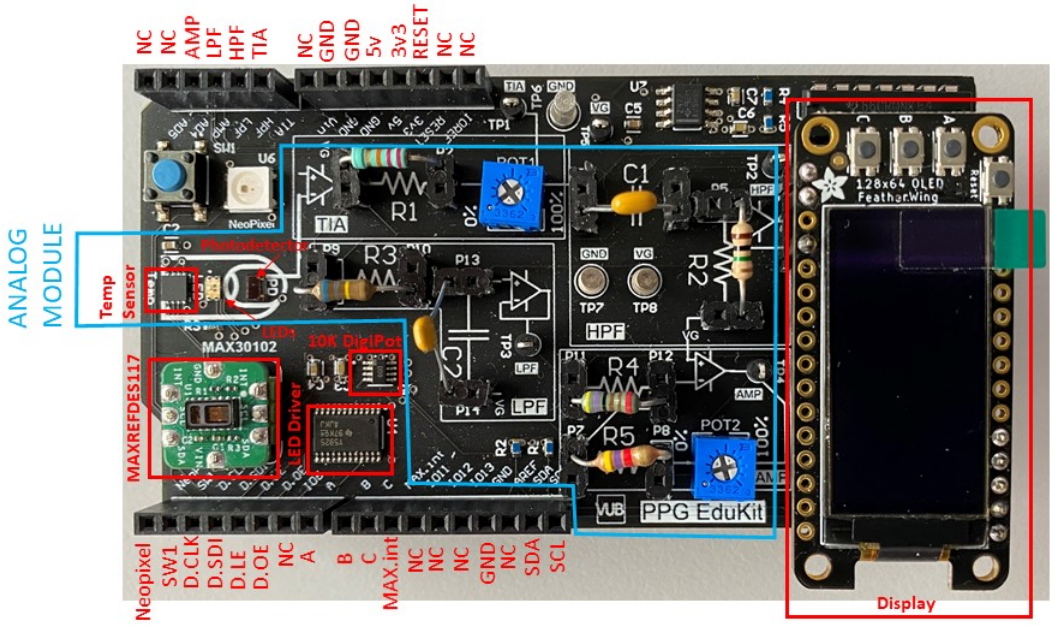


Figure 1: PCB image of PPG EduKit depicting each of its building blocks and the pinout. NC is a not connected, unused microcontroller pin by the EduKit.

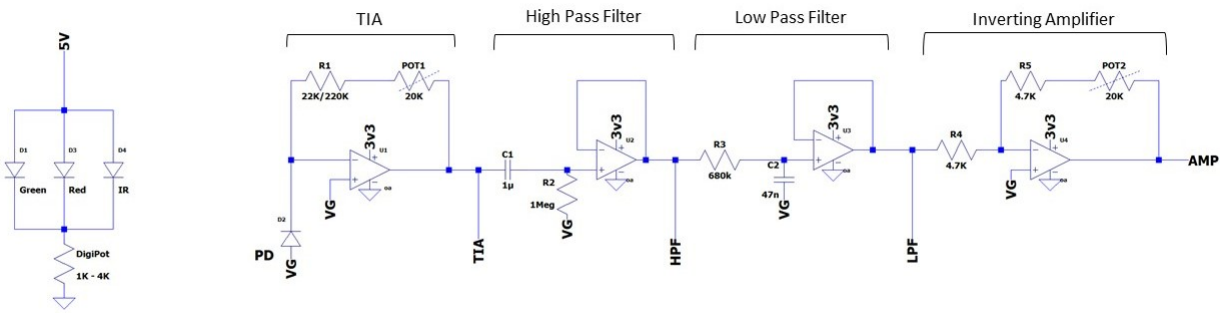


Figure 2: Analog conditioning stages of the analog module.

2 LEDs & LED Driver

2.1 LEDs

The SFH7013 chip is used for the green, red and infrared (IR) wavelengths. Check the datasheet for the optimal driving currents (20mA is the normal value).

Maximum driving currents for each wavelength:

- Blue: 30mA
- Green: 30mA
- Red: 40mA
- IR: 60mA

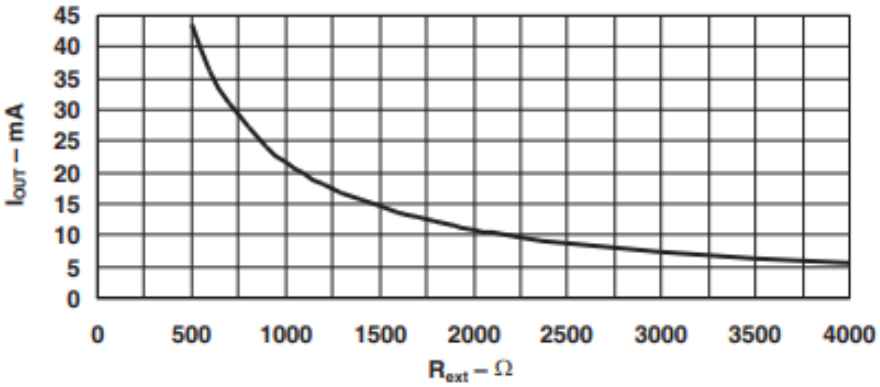
2.2 LED Driver TLC5925

The LED Driver TLC5925 is used to drive the LEDs. An external resistor (Rext = 10k DigiPot) is used to modify the driving current. Figure 3 shows the current vs resistance relationship.

The LED driver contains a 16-bit shift register to load which outputs are activated (pulled low). The 16-bit register must be loaded using the CLK signal at the SDI input. Once the loading is complete, the LE pin must be toggled to latch in the data. Finally, when OE pin goes low the outputs are activated and current flows through them. Check section 9 in the datasheet for more detailed information.

The IR led is connected to two different inputs since its maximum driving current is 60mA and each output has a maximum output current of 45mA.

The LED driver outputs the same current to all outputs simultaneously, so be careful to set the right current to drive the desired wavelength.



re 10. Default Relationship Curve Between $I_{OUT,target}$ and R_{ext} After Power Up

Figure 3: Relationship curve between output current and Rext. TLC5925

For more information refer to the TLC5925 datasheet

2.3 10K Digital Potentiometer AD5273

As explained in the previous section, a 10K digital potentiometer (AD5273) is used as Rext. It is a 64 position (0 = 60 Ohm; 63 = 10K) digipot which uses I2C communication. A value (D) between 0 and 63 must be written in the digipot.The relationship between D and resistance is:

$$R_{WB} = \frac{D}{63} \cdot R_{AB} + R_W \tag{2}$$

According Figure 3 on the LED driver datasheet, a LED driving-current of 20mA is obtained with a 2KOhm resistance. This value is obtained by setting the potentiometer to a value of 15. Nevertheless, a value of 25 set the potentiometer to 4KOhm (5-10mA driving current), which enough

For further information check *'VARIABLE RESISTANCE AND VOLTAGE FOR RHEOSTAT MODE* in the datasheet. In the PPG EduKit, the wiper is connected to A.

3 MAXREFDES117

The MAXREFDES117 is a built-in module that generates PPG signal by using red and infrared light. It communicated with I2C together with and interrupt pin.

There is a lot of documentation on the internet about the MAXREFDES117. The main reference can be found on the company's site.

There are many project examples that can be used as a reference when implementing your own application:

Example 1

Example 2

Example 3

4 Temperature sensor MAX30205

The MAX30205 temperature sensor is designed to measure human body temperature. It communicates using I2C. For the correct configuration refer to the datasheet. An arduino library already exists to use the sensor with Arduino compatible MCU. For non-compatible MCU, this library can be used as a reference.

5 Adafruit 128x64 OLED Feather Wing

The display on the PPG EduKit board is an Adafruit 128x64 OLED Feather Wing, It has 3 configurable push-buttons and it communicates via I2C. Use the display guide to configure it.

Appendix: Pinout Relationship

Function	NAME on PCB	Arduino Pin	PSOC6 pin
Analog output TIA	TIA	AD0	P5.2
Analog output HPF	HPF	AD1	P5.3
Analog output LPF	LPF	AD2	P5.4
Analog output AMP	AMP	AD3	P5.5
NC	AD4	AD4	P5.6
NC	AD5	AD5	P10.0
RGB Led NeoPixel	NeoPixel	D0	P5.0/RX
Generic push-button	SW1	D1	P5.1/TX
Led Driver Clock (CLK)	D.CLK	D2	P12.7
Led Driver SDI	D.SDI	D3	P12.6
Led Driver Latch Enable (LE)	D.LE	D4	P0.5
Led Driver Output Enable (OE)	D.OE	D5	P7.2
NC	IO6	D6	P6.2
Display button A	A	D7	P9.6
Display button B	B	D8	P9.5
Display button C	C	D9	P9.4
MAX30102 interruption pin	MAX.int	D10	P9.3
NC	IO11	D11	P9.0
NC	IO12	D12	P9.1
NC	IO13	D13	P9.2
-	3V3	3V3	P6.VVD
-	5V	5V	P5LP.VDD
-	RESET	RESET	RESET
-	GND	GND	GND
-	SCL	SCL	SCL
-	SDA	SDA	SDA