Sorbonne University

Report

Heartbeat Measuring Electronic Circuit

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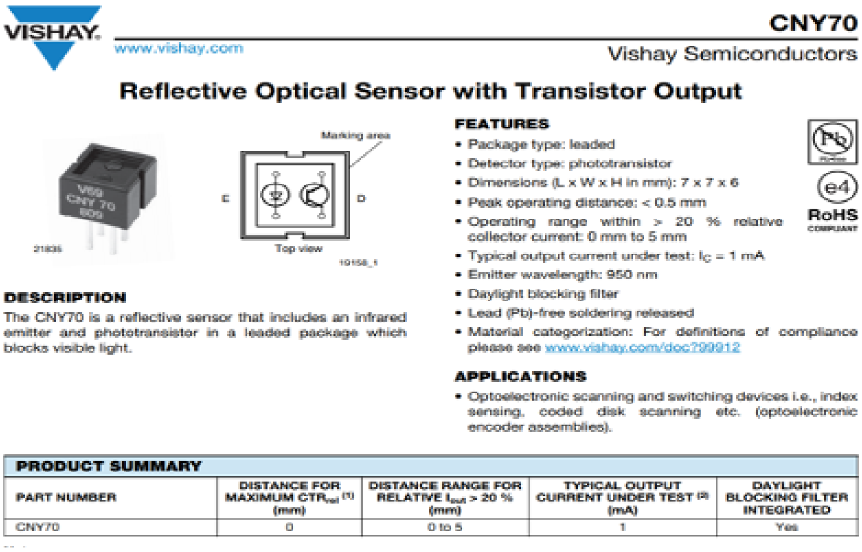
Report for the UE 2EE203 project

Contents

Principle of the Heartbeat Sensor

The principle of the sensor is simple; it is based on the phenomenon of light reflection. An LED emits infrared light (infrared penetrates the skin better without damaging it) into the finger. With each heartbeat, blood is pumped into the vein, thus the finger becomes more or less reflective depending on the blood flow. The reflected light is absorbed by a phototransistor inside the sensor (see Figure 1).


VISHAY.

CNY70

www.vishay.com

Vishay Semiconductors

Reflective Optical Sensor with Transistor Output

DESCRIPTION

The CNY70 is a reflective sensor that includes an infrared emitter and phototransistor in a leaded package which blocks visible light.

FEATURES

- Package type: leaded
- Detector type: phototransistor
- Dimensions (L x W x H in mm): 7 x 7 x 6
- Peak operating distance: < 0.5 mm
- Operating range within > 20 % relative collector current: 0 mm to 5 mm
- Typical output current under test: I_C = 1 mA
- Emitter wavelength: 950 nm
- Daylight blocking filter
- Lead (Pb)-free soldering released
- Material categorization: For definitions of compliance please see www.vishay.com/doc?99912

e4

RoHS COMPLIANT

APPLICATIONS

- Optoelectronic scanning and switching devices i.e., index sensing, coded disk scanning etc. (optoelectronic encoder assemblies).

PRODUCT SUMMARY

PART NUMBER	DISTANCE FOR MAXIMUM CTR_{rel} [1] (mm)	DISTANCE RANGE FOR RELATIVE I_{out} > 20 % (mm)	TYPICAL OUTPUT CURRENT UNDER TEST [2] (mA)	DAYLIGHT BLOCKING FILTER INTEGRATED
CNY70	0	0 to 5	1	Yes

Figure 1: CNY70 Sensor

Chapter 1

The Sensor

1.1 Theoretical Study of the Sensor

The output of the sensor is around 400 mV, each peak represents a heartbeat (see Figure 1.1).

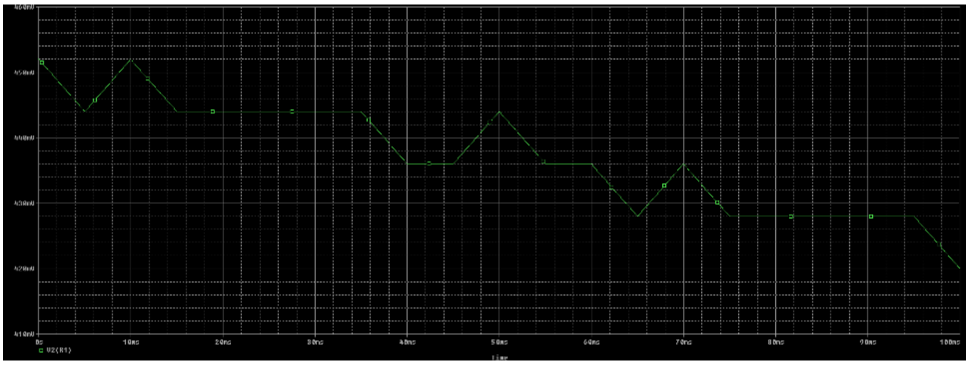


Figure 1.1: Output voltage of our sensor, with R=100 ohm

Since this signal can be distorted in real life (we are not in a perfect world), we need to determine the bandwidth where our signal lies. To do this, we perform an FFT (Fast Fourier Transform), which gives the voltage value as a function of frequency (see Figure 1.2).

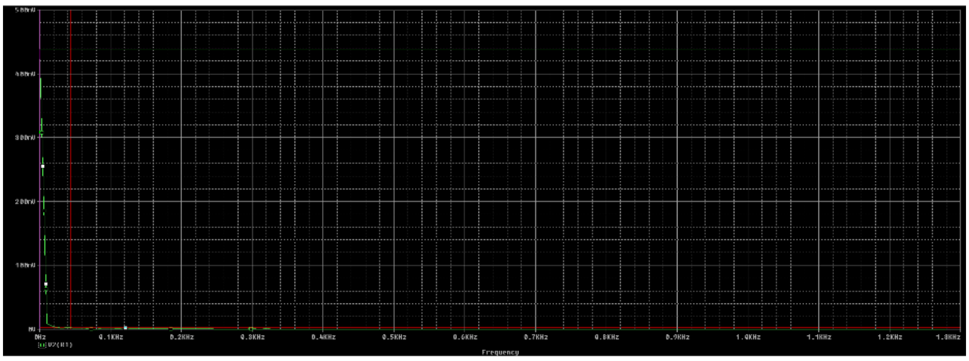


Figure 1.2: FFT of our signal

The frequency band is in the range [0.1Hz, 10Hz] (see Figure 1.3).

	Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2	
		X Values	9.559	0.000	9.559		Y1 - Y1(Cursor1)	Y2
	CURSOR 1,2	V2(R1)	27.503m	438.978m	-411.475m		0.000	0.0

Figure 1.3: Frequency band of the sensor signal, tending towards 10Hz

1.2 Practical Study of the Sensor

To use the sensor, we need to bias the phototransistor to make it work linearly. To do this, we use a potentiometer (blue) on the physical circuit, turning the screw until we obtain a VCE voltage at the phototransistor terminals of 6V. This voltage is the x-intercept of the load line and one of the I(V) curves, providing us with a linear operation (see Figure 1.4 with R=4000 ohms).

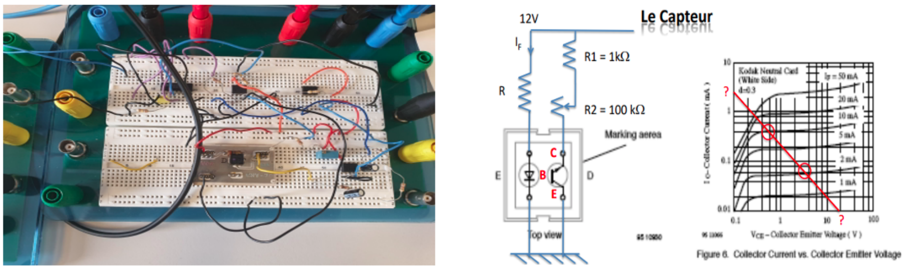


Figure 1.4: Physical sensor and its schematic

To determine the VCE bias, we use the characteristic curve of the phototransistor. First, we find IC: $IC = E/R_{eq} = 12V$, thus $IC = 1.18mA$.

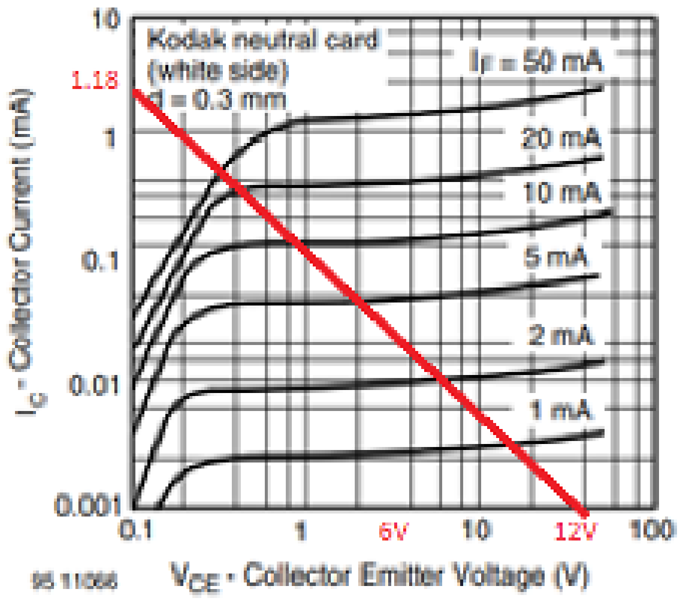


Figure 1.5: Load line of the phototransistor

After biasing our phototransistor, we can visualize the pulsations on the oscilloscope (AC coupling is used to remove the DC component of the signal) (see Figure 1.6).

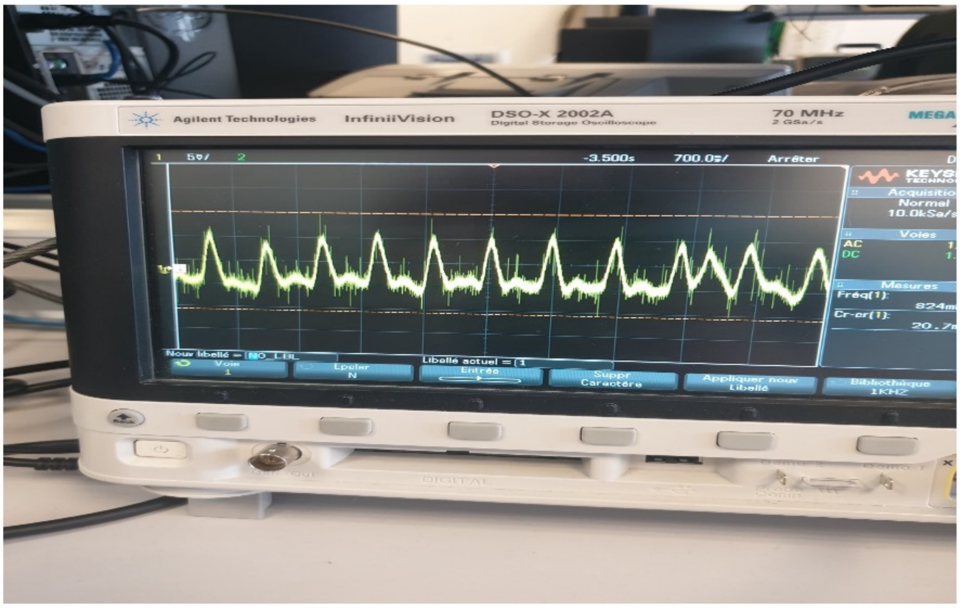


Figure 1.6: Unfiltered heartbeat signal

The signal in real life is noisy due to multiple sources (neons, voices, etc.). To solve this, we will use a filter to remove all this noise.

Chapter 2

Band-Pass Filter

2.1 Theoretical Study of the Band-Pass Filter

To remove noise from the signal, we use a band-pass filter. The high-pass filter already present within the band-pass filter will remove the DC component.

The respective transfer functions of the low-pass and high-pass filters are demonstrated using a voltage divider.

The cutoff frequency for each filter is determined, and by connecting the two stages, we obtain a band-pass filter.

Using Kirchhoff's law on the nodes:

$$\frac{V_E - V_A}{R} + \frac{0 - V_A}{\frac{1}{jC\omega}} + \frac{V_S - V_A}{R} = 0$$

Where: - V_E is the input voltage - V_A is the voltage at the first capacitor - V_S is the output voltage

We obtain the resulting transfer function:

$$H_3(\omega) = \frac{1}{1 + \frac{1}{H_1 H_2}}$$

However, in reality, this function does not directly tend towards $H_1 H_2$ because the filters are coupled. To isolate them, we need impedance matching (using a high-value resistor $R_2 \gg R_1$ or a buffer stage).

Impedance Adaptation: By ensuring the first filter has an open output (since input current to the op-amp is nearly zero), we can connect the filters without mutual influence.

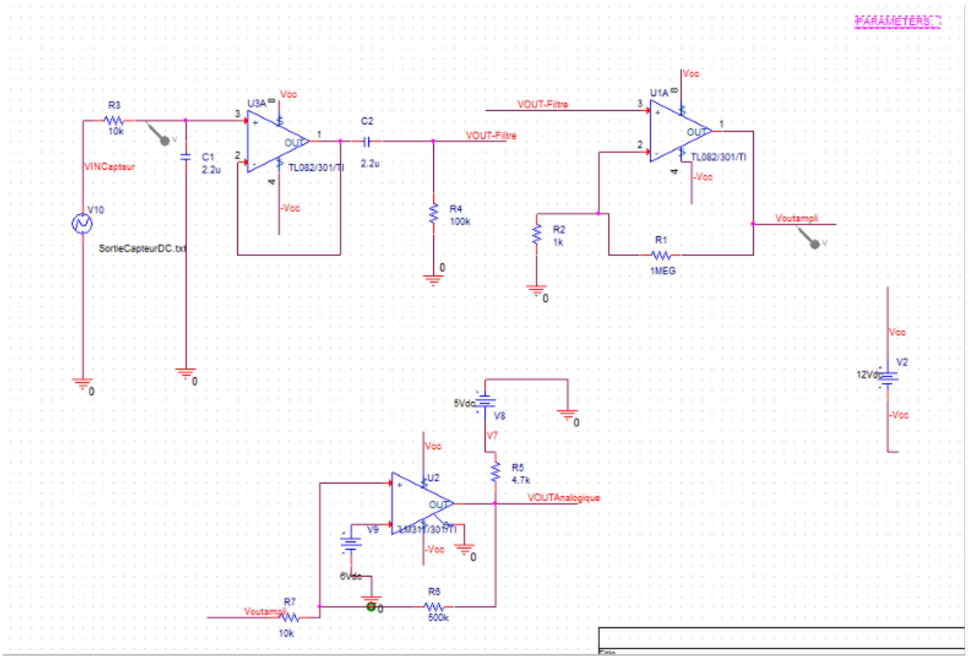


Figure 2.1: Filter with impedance adaptation

The gain of the RC-CR filter with $R3 = 10k\Omega$ (low-pass) and $R4 = 100k\Omega$ without a follower stage gives a band between 0.7Hz and 7Hz:

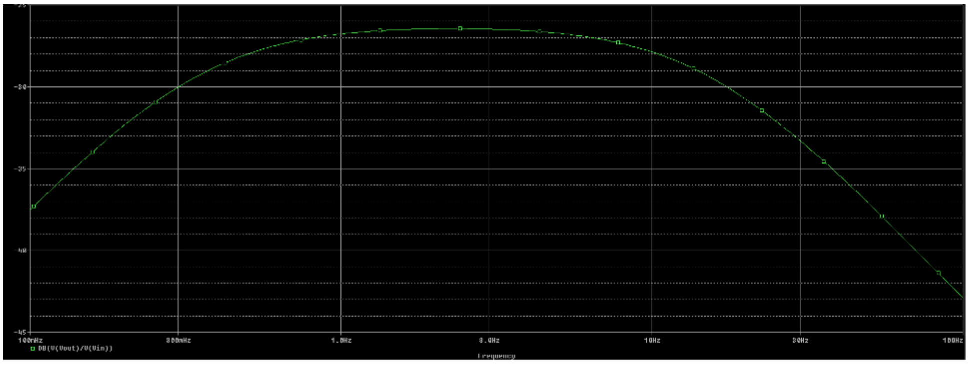


Figure 2.2: Band-pass filter response between 0.7Hz and 7Hz

With impedance adaptation, the pass-band remains identical:

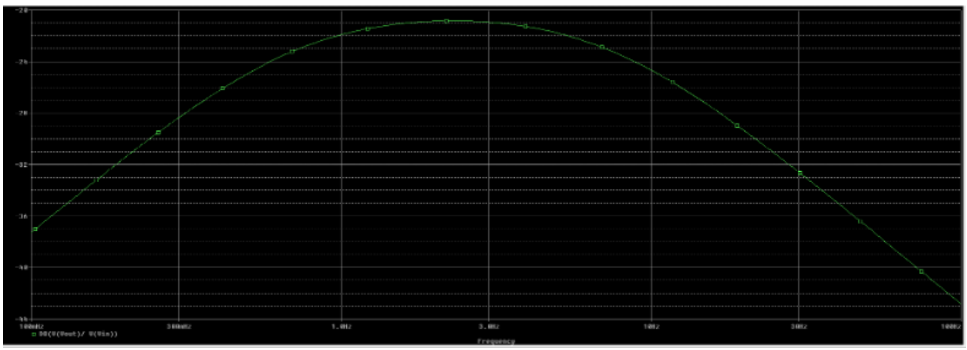


Figure 2.3: Filter with impedance adaptation, same pass-band

Simulation: We simulated in MATLAB and confirmed that the ideal response $H_3 = H_1 \cdot H_2$ matches the follower circuit response:

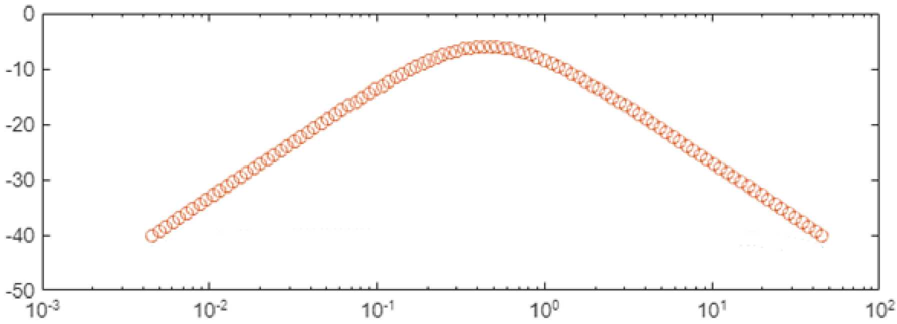


Figure 2.4: MATLAB simulation of ideal vs. practical band-pass filter

Conclusion: The most efficient design uses a follower (buffer) for impedance matching.

2.2 Practical Study of the Band-Pass Filter

In practice, we applied the filter circuit and observed the signal. The green trace is the raw signal before filtering, and the yellow trace is the filtered heartbeat signal.

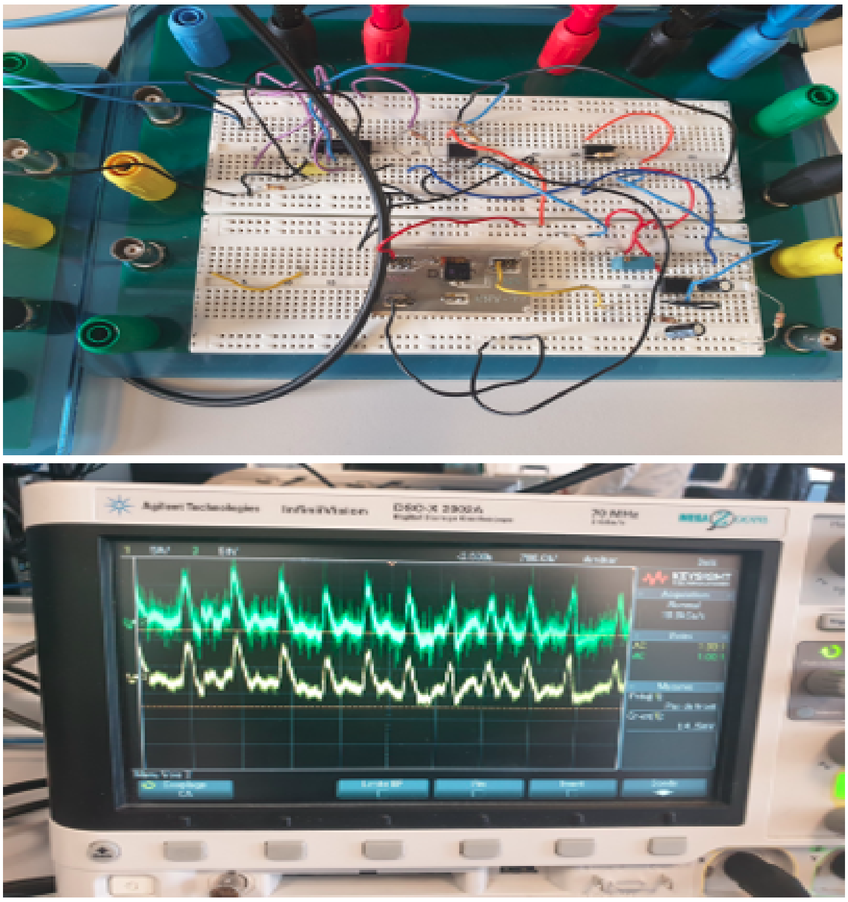


Figure 2.5: Practical filter implementation and oscilloscope output

Chapter 3

Amplifier

3.1 Theoretical Study of the Amplifier

As seen previously, the signal amplitude is very low (tens of mV). To study the signal precisely, we need to amplify it.

We use a non-inverting amplifier based on the TL082 operational amplifier. The gain is defined by:

$$Gain = 1 + \frac{R_2}{R_1}$$

Note that an op-amp has a gain-bandwidth product:

$$Gain \times Bandwidth = \text{constant}$$

So higher gain reduces bandwidth, which must be balanced.

We tested different resistor values $R_2 = 10^2, 10^3, 10^4, 10^5, 10^6, 10^7 \Omega$.

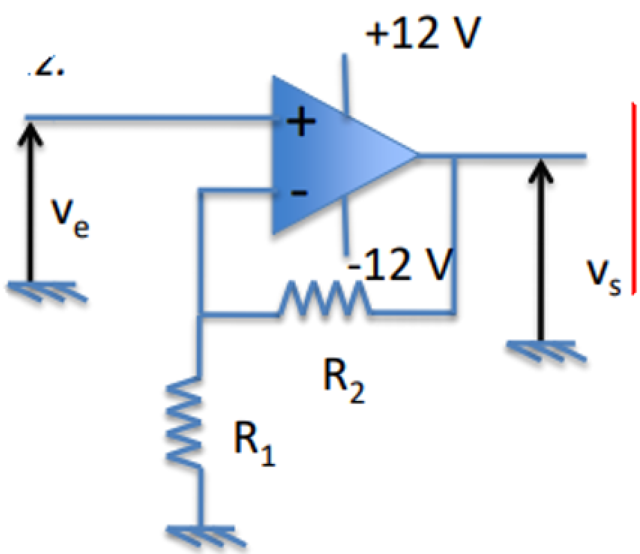


Figure 3.1: Non-inverting amplifier TL082

Simulation shows that increasing gain narrows the bandwidth:

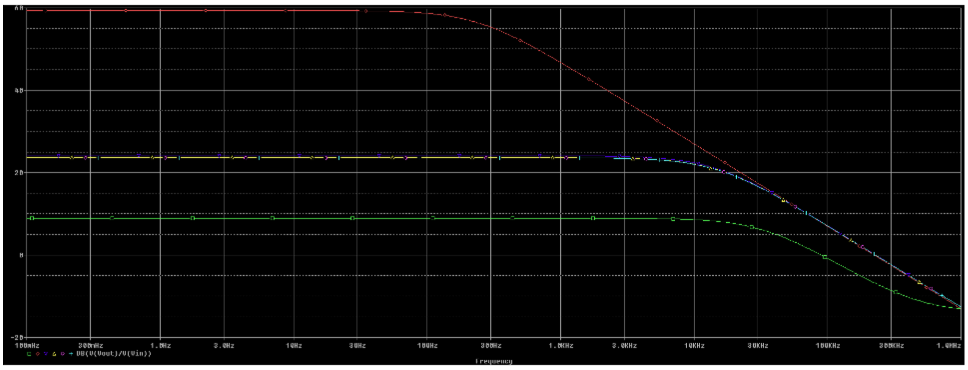


Figure 3.2: Gain-bandwidth relationship in simulation

We chose a gain of 100, which provides a sufficiently wide bandwidth for this application.

3.2 Practical Study of the Amplifier

The amplifier was built in PSpice with gain = 100. This configuration gave a wide enough pass-band.

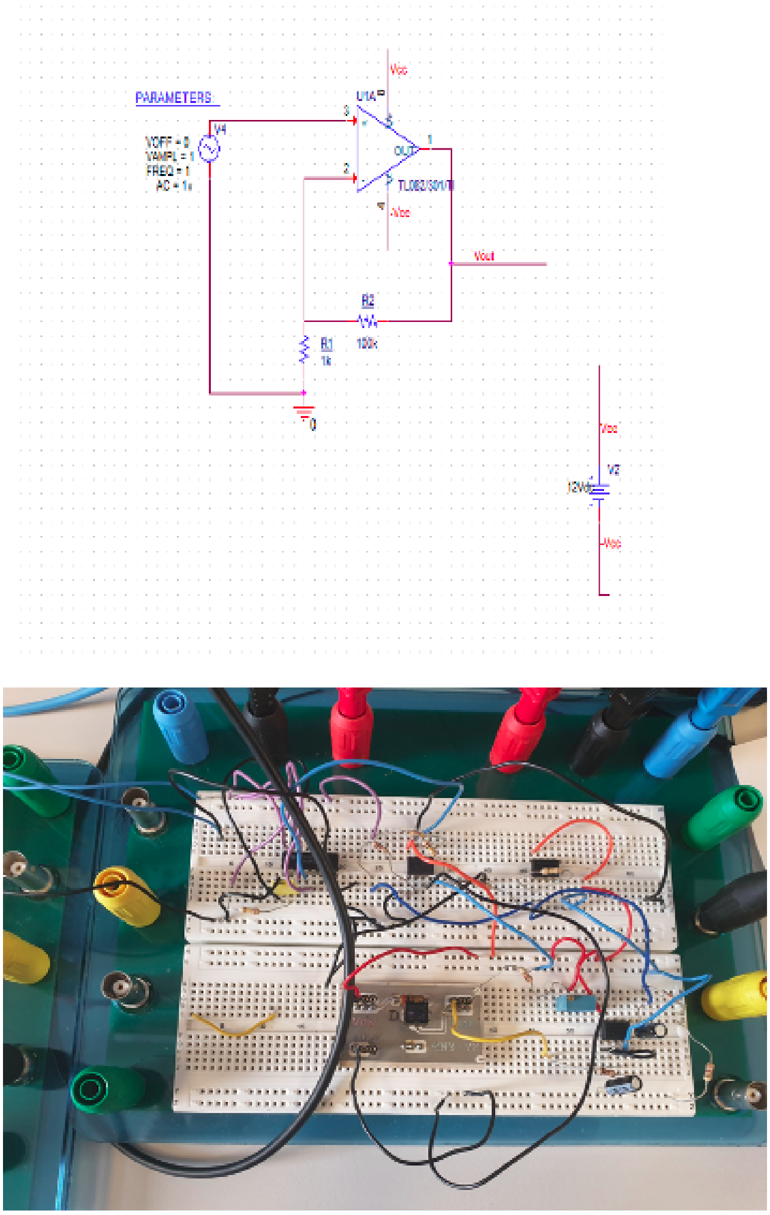


Figure 3.3: Amplifier implementation in PSpice

On the oscilloscope, the amplified heartbeat signal is clearly visible (yellow trace).

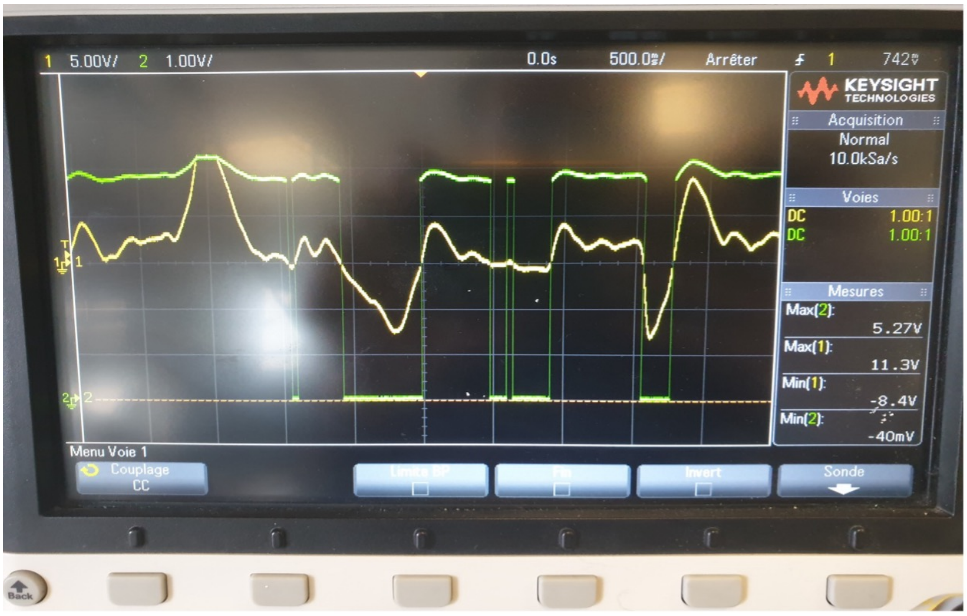


Figure 3.4: Amplified heartbeat signal on oscilloscope

Chapter 4

Counter

4.1 Theoretical Study of the Counter

To calculate the heartbeat rate (BPM), we use a digital counter triggered by the comparator output (square pulses representing each heartbeat).

We designed a 4-bit counter in PSpice:

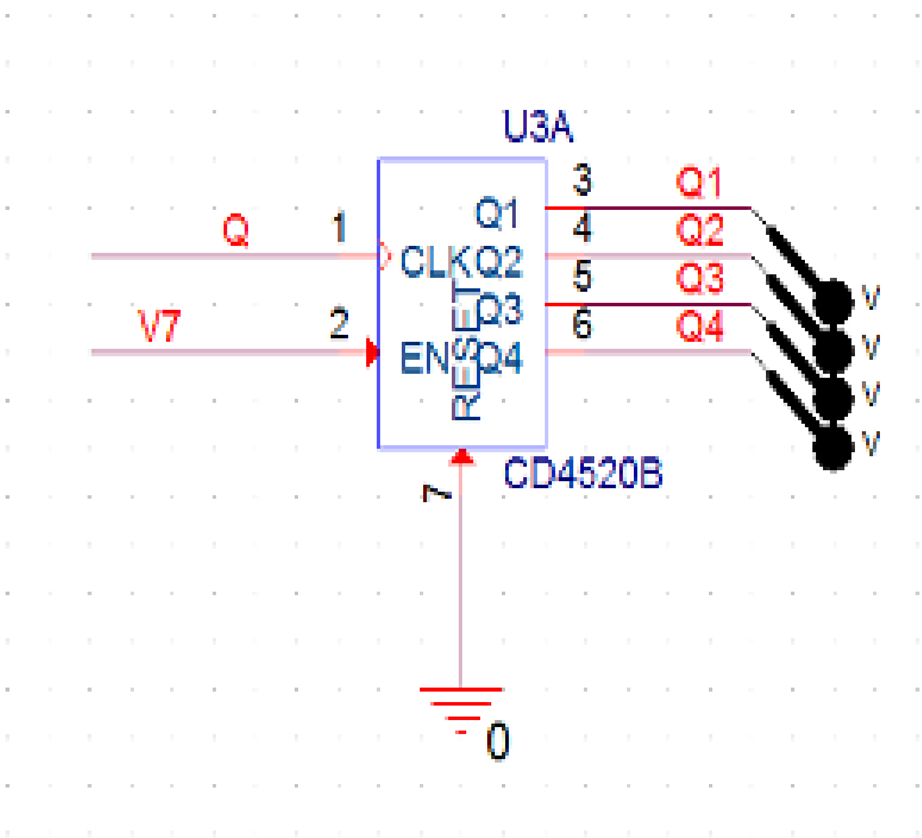


Figure 4.1: 4-bit counter schematic in PSpice

Next step: Comparator A comparator will be used to convert the amplified analog signal into a digital square wave. This comparator circuit must: - Have a reference threshold (adjustable) - Reject noise by adding hysteresis (Schmitt trigger)

Once the comparator is tuned, the clean pulses can be fed to the digital counter, and BPM can be computed.

Bibliography

- Vishay Semiconductors – CNY70 Datasheet: https://www.vishay.com/docs/83751/cny70.pdf
- Texas Instruments – TL082 Operational Amplifier Datasheet.
- MATLAB and PSpice simulations for filter and amplifier validation.