AN4995
Application note

Using an electromyogram technique to detect muscle activity

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Introduction

Electromyography (EMG) is a medical technique to evaluate and record the electrical activity of nerves and muscles. It allows the quality of muscular contractions to be studied using electrodes. During an electromyography, the aim is to detect the electrical potential generated by muscles to detect medical abnormalities or activation levels. Two complementary EMG techniques exist:

- Detection EMG: the goal is to measure the electrical activity of a muscle at rest and during a voluntary contraction.
- Stimulation EMG: the aim is to measure the nerve conduction speed after stimulation of the nerve with a short and small electrical current.

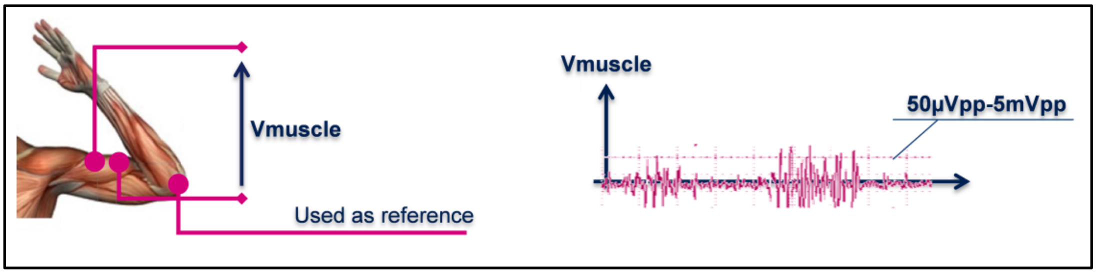
In this application note, we use the first technique to detect muscle activity using skin electrodes. Then, using signal conditioning based on operational amplifiers (op amps), we show how to amplify the muscle activity. The user can use this information to trigger a specific action e.g. light a lamp, change the TV channel, stop his alarm, etc.

Contents

1 Signal generated by muscles

To properly record a signal from a muscle (e.g. in the arm), three electrodes are required. Two skin electrodes are stuck on a muscle in the arm 2 cm apart. The third electrode is used as a reference and can be stuck close to the elbow. The electrical potential generated by the muscle between these two skin electrodes is conducted through them to the demonstration (demo) board. Normally, this signal is in the range 50 µV to a few mV and several hundred Hz. *Figure 1* highlights an example of such an input signal.

Figure 1: Example of an input signal generated by a muscle



The amplitude of the signal is related to the muscle contraction level and the overall signal is modulated in low frequency at the frequency of movement of the arm.

2 Signal conditioning chain

To analyze the muscle signal, it has to be "conditioned" i.e. the signal has to be amplified in some way so that it can be processed further. In this section, we will see how we can achieve this using four analog functions:

- Differential measurement
- Rectifier block to obtain voltage above the reference voltage
- Low-pass filter to obtain the envelope of the signal (i.e. to remove the frequency generated by the muscle and keep the frequency of the activity of the arm).
- Comparator stage to connect to the GPIO of a microcontroller such as the STM32 or STM8.

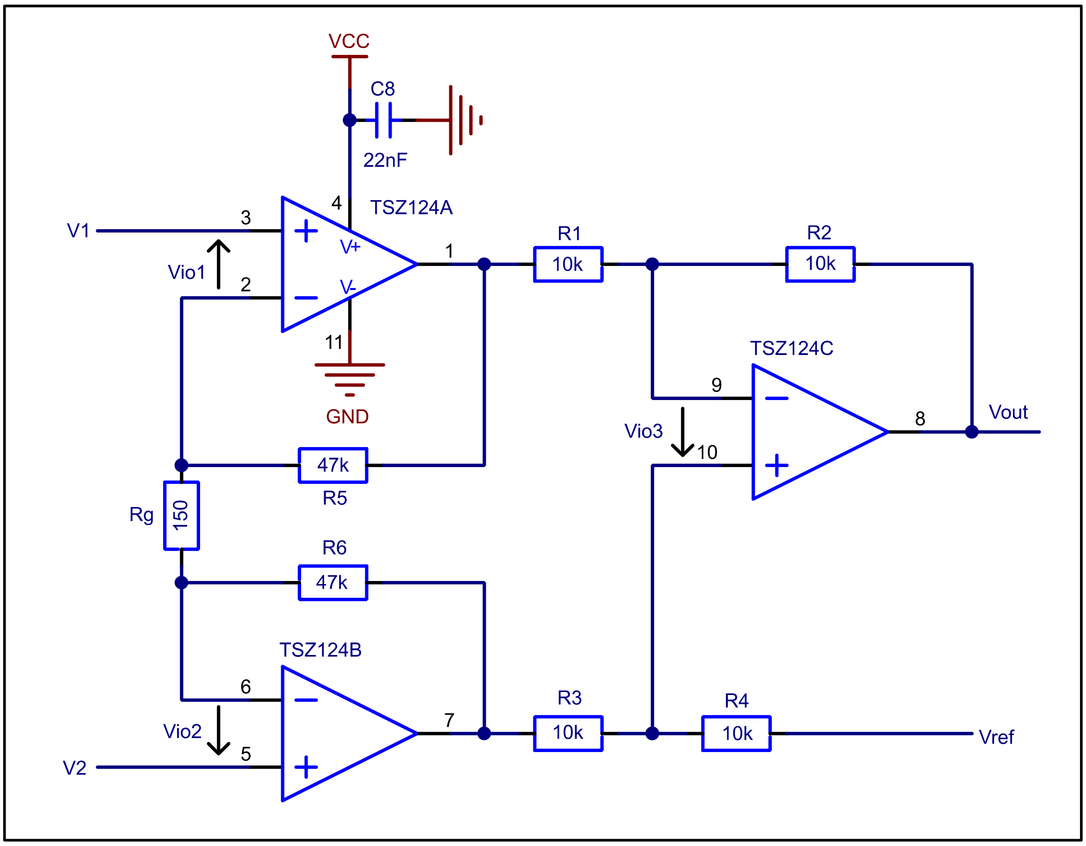
2.1 Differential measurement

What is important for this "first amplifying stage" is the voltage difference between the two sides of the muscle. To achieve a discernable difference, we have to amplify the electrical difference between the two electrodes.

Since the body is not low impedance, this first amplifying measurement has to have a high impedance. In addition, this amplifying stage needs to be very accurate because the signal is very small and thus a big amplification is required. By amplifying the signal, we also amplify the offset due to the amplifier, thus the input voltage offset (Vio) must be as low as possible.

For the above reasons, the selected structure for this stage is an instrumentation amplifier based on three op amps. *Figure 2* shows the schematic of this amplifying stage.

Figure 2: First amplifying stage based on an instrumentation amplifier structure



With R1 = R2 = R3 = R4 = R and with R5 = R6, we obtain the following output voltage formula:

$$Vout = (V2 - V1)\left(1 + 2\,\frac{R5}{Rg}\right) + Vref - (Vio2 - Vio1)\left(1 + 2\,\frac{R5}{Rg}\right) - 2 * Vio3$$

The maximum frequency generated by the muscle is 500 Hz. Considering R5 = R6 = 47 kΩ and Rg = 150 Ω, the gain of the first op amp stage is 314. Thus, the minimum required GBP without any margin is 160 kHz (314 * 500 Hz ≈ 160 kHz).

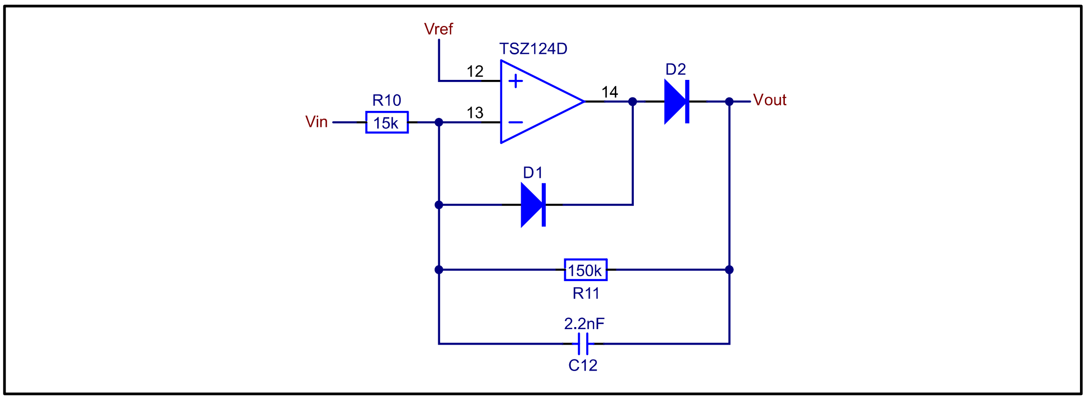
Taking into account these two main constraints, the best choice of op amp is the TSZ124 which has the following features:

- Very high accuracy and stability:
  - Input offset voltage of 5 µV max at 25 °C
  - 8 µV over full temperature range (-40 °C to 125 °C)
- Rail-to-rail input and output
- Low supply voltage of 1.8 - 5.5 V
- Low power consumption of 40 µA max at 5 V
- Gain bandwidth product of 400 kHz
- Tiny packages such as QFN16 3x3

2.2 Rectifier block

To detect the envelope of the signal, we need a signal that is just above our voltage reference. We can achieve this using a rectifier structure (*Figure 3*).

Figure 3: Rectifier schematic

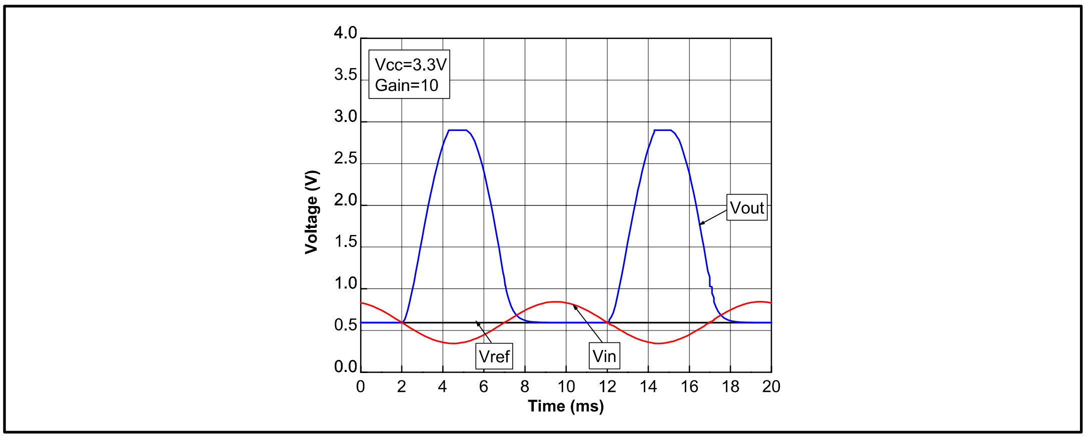


With the above schematic, when:

- Vin > Vref: Vout = Vref
- Vin < Vref: $\text{Vout} = (\text{Vref} - \text{Vin})\dfrac{R11}{R10} + \text{Vref}$

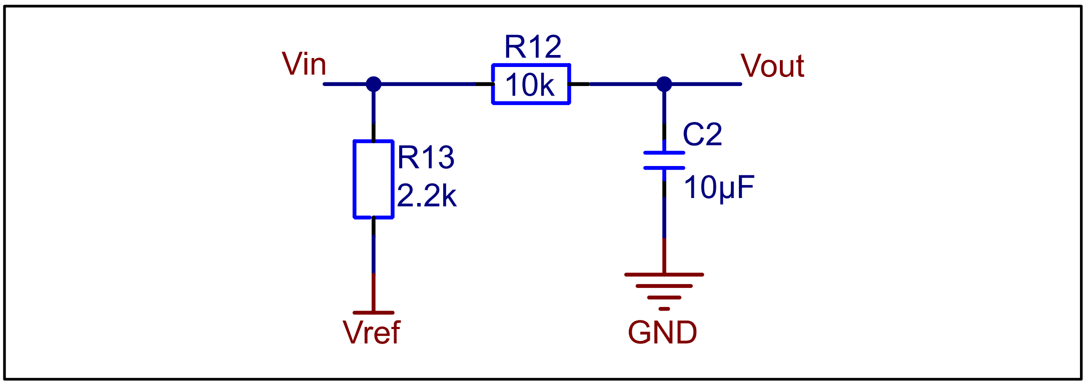
Figure 4 highlights the behavior of the rectifier with R11 = 10 * R10 and Vref = 1 V. This figure also shows that the op amp output voltage is limited due to the diode D2, which means that the maximum output voltage, Vout_max, is Vcc - Vdiode.

Figure 4: Rectifier behavior



In the final application, the output of the rectifier is connected to an RC network, which acts as a low-pass filter, as shown in *Figure 5*.

Figure 5: Passive low-pass filter

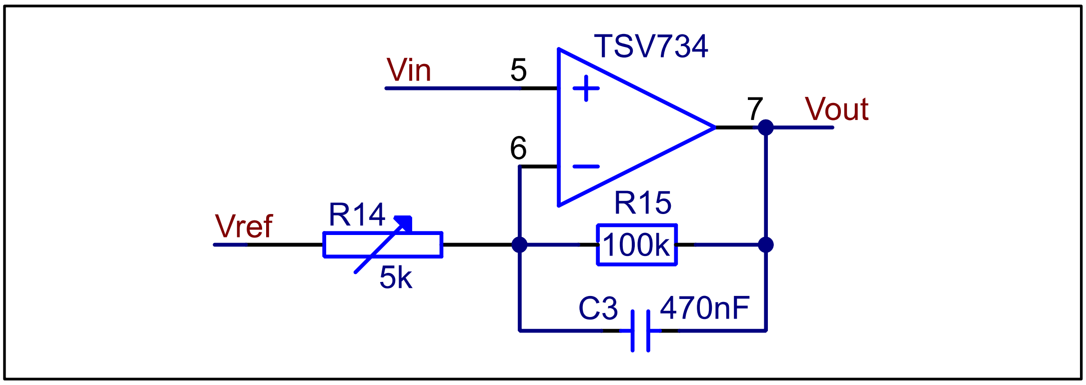


By charging the rectifier output (considering R13 << R11), the time constants R12 * C2 and (R12 + R13) * C2 are negligible compared to the muscle activity period. When we are in this configuration and when there is muscle activity, there is a rise in voltage on the Vout node. Without R13, capacitor C2 discharges into R11 (150 kΩ) and consequently the time constant (R11 + R12) * C2 becomes dangerously close to the period that we can contract/uncontract a muscle.

2.3 Low-pass filter

To detect the envelope of the signal a second time, a low-pass filter is added to the application. It is difficult to contract arm muscles more than three times per second so, we need to define the low-pass cutoff frequency at 3 Hz. To amplify the signal a second time, this low-pass filter also has a gain of at least 21 (depending on its R14 potentiometer value). The schematic of such a low-pass filter is shown in *Figure 6*.

Figure 6: Low-pass filter schematic



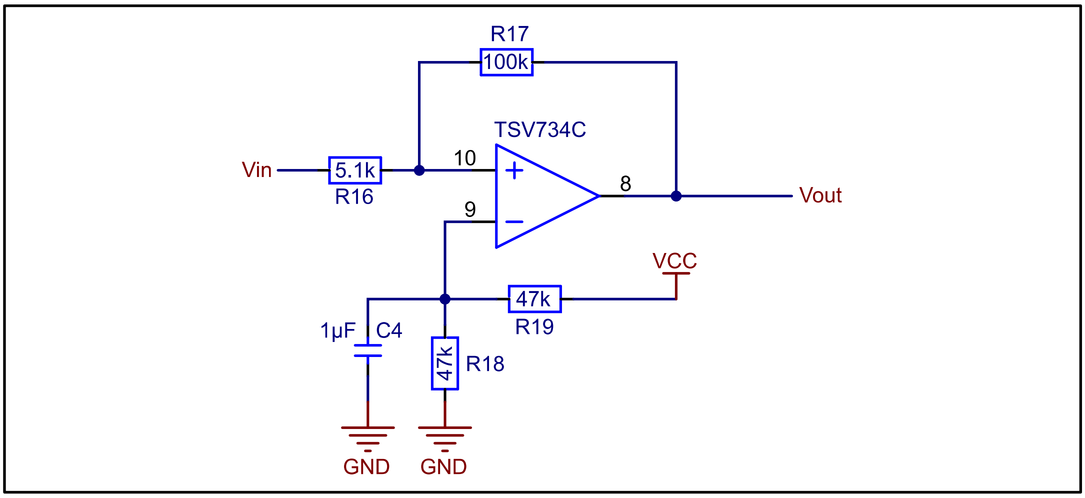
To match the low-pass filter features, we have R14 = 5 kΩ max, R15 = 100 kΩ, and C3 = 470 nF.

R14 is a potentiometer which allows the signal to be amplified depending on the "contact" quality between the electrode and the skin. To achieve a similar contact quality, this gain can be adjusted to arrive at a solution that works for everybody, whatever their skin characteristics.

2.4 Comparator stage

The final phase of muscle signal analysis is the comparator stage which allows a digital input on a microcontroller to be used instead of an ADC. This function can be performed using a comparator, but since this comparative function does not require high performance, we can also use an unused op amp channel for greater cost effectiveness. *Figure 7* shows the application set up: the trigger voltage is set thanks to a divider bridge composed of resistors R18 and R19.

Figure 7: Comparator function schematic



In our application:

$$\text{Vtrig} = \text{Vcc}\,\frac{\text{R18}}{\text{R18} + \text{R19}}$$

To avoid unwanted toggling, an external hysteresis has been designed with resistors R16 and R17:

$$\text{Vhyst+} = \text{Vtrig}\,\frac{\text{R16} + \text{R17}}{\text{R17}}\ -\text{Vccn}\,\frac{\text{R16}}{\text{R17}}$$

$$\text{Vhyst-} = \text{Vtrig}\,\frac{\text{R16} + \text{R17}}{\text{R17}}\ -\text{Vccp}\,\frac{\text{R16}}{\text{R17}}$$

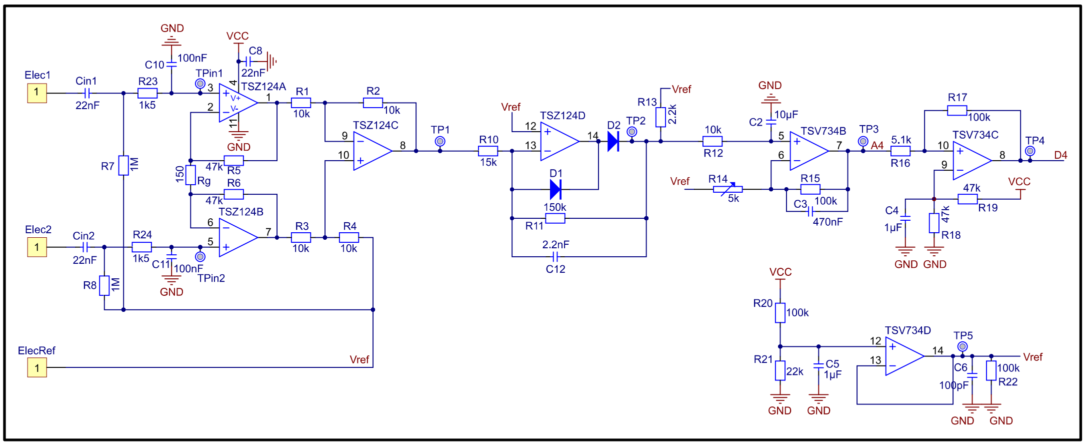
Thus, R16 = 5.1 kΩ, R17 = 100 kΩ, R18 = 47 kΩ, R19 = 47 kΩ, Vccn = 0 V, and Vccp = 3.3 V. Consequently, we have:

- Vtrig = 1.65 V
- Vhyst+ = 1.73 V
- Vhyst- = 1.57 V

3 Global signal conditioning chain

Figure 8 shows the schematic of all four analog functions (differential measurement, rectifier block, low-pass filter, and comparator stage). To perform the voltage reference (Vref), one channel of the TSV734 is used. It is a unity gain stable and accurate op amp with a minimum output current of 20 mA which is adequate in our application.

Figure 8: Global signal conditioning chain schematic



4 Consumption considerations

EMG is a low-power application thanks to the use of micro-power op amps and appropriate resistance values.

The current contribution of the op amps is:

- TSV734: 240 µA
- TSZ124: 120 µA

The current contribution of the resistors is:

- R20 and R21 on the divider bridge of the voltage reference: 27 µA
- R18 and R19 on the divider bridge of the comparator: 35 µA

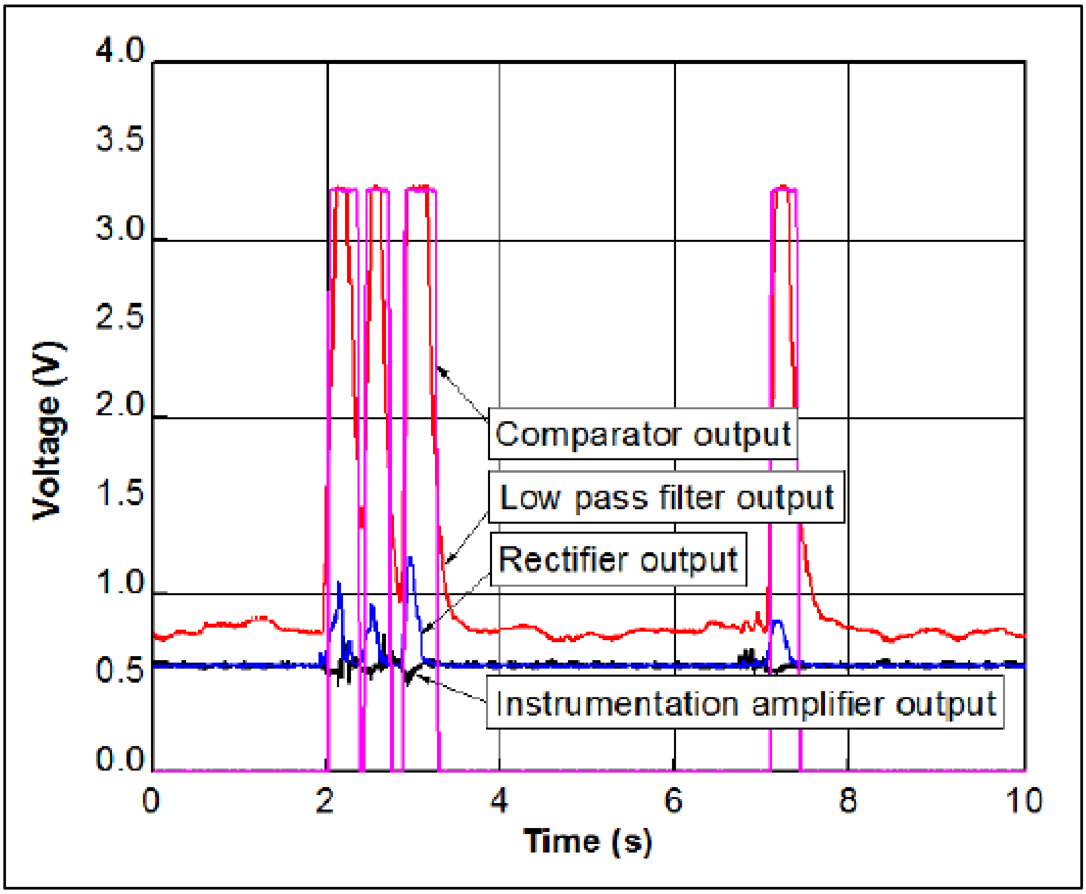
Thus, in DC, this application only consumes approximately 420 µA.

5 Practical measurements

This section highlights the functionality of the schematics presented in *Section 2: "Signal conditioning chain"*. *Figure 9* below shows the signal at the output of the:

- Differential amplification
- Rectifier block
- Low-pass filter
- Comparator stage

Figure 9: EMG measurements

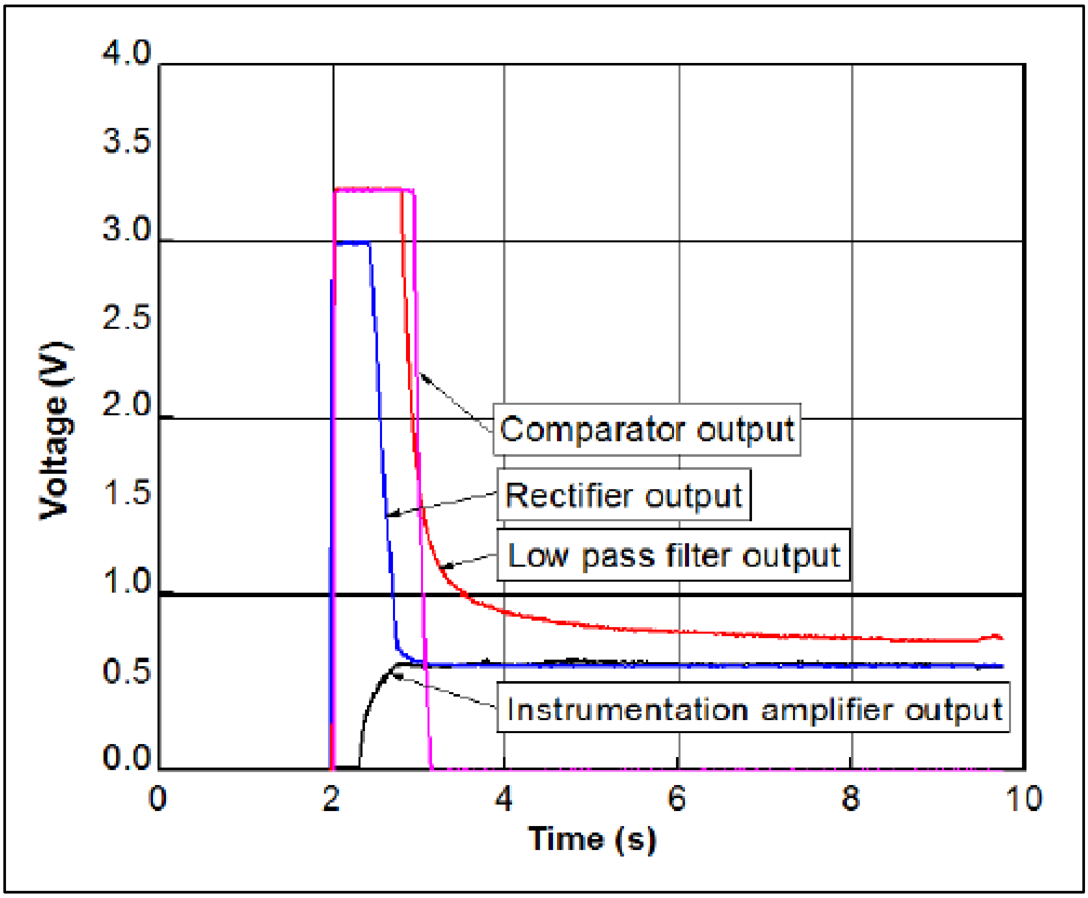


In this figure, we can see that three consecutive muscle contractions were made, followed by a single arm contraction.

6 Initialization time

At power-up, the 100 nF capacitors at the input of the instrumentation stage need to charge through the 1 MΩ resistor to set the input common-mode voltage to Vref. This constant time is huge and indicates the need for a blank period. Based on the waveforms of *Section 5: "Practical measurements"*, we have an initialization time of 2 s (see *Figure 10*).

Figure 10: Initialization time



7 Conclusion

Electromyogram applications are well known in the medical business field, but are also becoming more common in daily life. With this application note, we have shown how you can monitor your muscle activity to trigger a specific action, for example, related to fitness, healthcare, video games, or other activities.

Thanks to the analog signal conditioning chain, micro-power and accurate op amps have been used to give a portable application. Note that an alternative setup is to directly connect the ADC of an STM32 to the output of the first stage and to use an FIR filter.

For op amps and comparators with different performances such as a higher bandwidths or higher power supply voltages, you can have a look at the ST catalog. You may also benefit from its wide portfolio of analog switches, voltage references, temperature and pressure sensors, or microcontrollers to develop your applications, making STMicroelectronics your one-stop shop.

8 Revision history

Table 1: Document revision history

Date	Revision	Changes
15-Mar-2017	1	Initial release