OPTIMIZING SURFACE ELECTROMYOGRAPHY ACQUISITION WITHOUT RIGHT LEG DRIVE CIRCUIT

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DOI: https://doi.org/10.29121/IJOEST.v1.i1.2017.02

ABSTRACT

The right leg drive (RLD) is a circuit associated with electrocardiography acquisition circuits. For electromyography (EMG), the RLD circuit is used to a lesser degree. In general, the RLD circuit provides better noise reduction. This study compares the output of the EMG with and without the RLD circuit. The results indicate that with a good filter design, the direct grounding method can match the RLD in terms of noise reduction. As a result, EMG application, the RLD drive can be omitted.

Keywords: Circuit Design; Common Mode Noise; Electromyography; Right Leg Drive.

Cite This Article: Zinvi Fu, A.y. Bani Hashim, Z. Jamaludin, I. S. Mohamad, & N. Nasir. (2017). OPTIMIZING SURFACE ELECTROMYOGRAPHY ACQUISITION WITHOUT RIGHT LEG DRIVE CIRCUIT. *International Journal of Engineering Science Technologies*, 1(1), 13-19. doi: 10.29121/IJOEST.v1.i1.2017.02

1. INTRODUCTION

The electromyogram (EMG) is small electric potential which is generated at the neuromuscular junction just before the onset of muscle contraction. These potentials are generated as a result of an exchange of ions across muscle fiber membranes, act as a signal for the muscle fibers to contract. The EMG signal is useful, as it provides information on muscle contraction. To measure the EMG signal, two common non-invasive methods are by conductive elements or electrodes to the skin surface. The acquired signals can be used for neuro-muscular diagnostics, ergonomic studies and also machine control.

Being a biological electric signal, the EMG acquisition technic is similar to the electrocardiograph (ECG). In the ECG amplification architecture, the right leg drive (RLD) feedback sub-circuit is usually necessary[1]. The RLD is a feedback system where the common mode noise from the body is extracted and inverted, then fed back into the body[2]. On the other hand, there is no explicit rule whether or not the EMG circuit requires the RLD. For EMG circuits, the noise can be simply grounded to the circuit common. Nevertheless, there are EMG designs which adopted the RLD circuit for various applications. For instance, a general purpose EMG amplifier[3], muscle and hand grip studies [4], [5] and robotics control [6].

A pictorial comparison between the RLD and direct grounding method is presented in

Figure 1. For practical application, the most distinctive difference would be that the direct grounding method is simpler and requires fewer components. In general the additional feedback loop of the RLD provides an improved common mode rejection ratio compared to direct grounding method. However, recent findings have shown that with the help of input filters the direct grounding method can also be comparable to using the RLD [7].

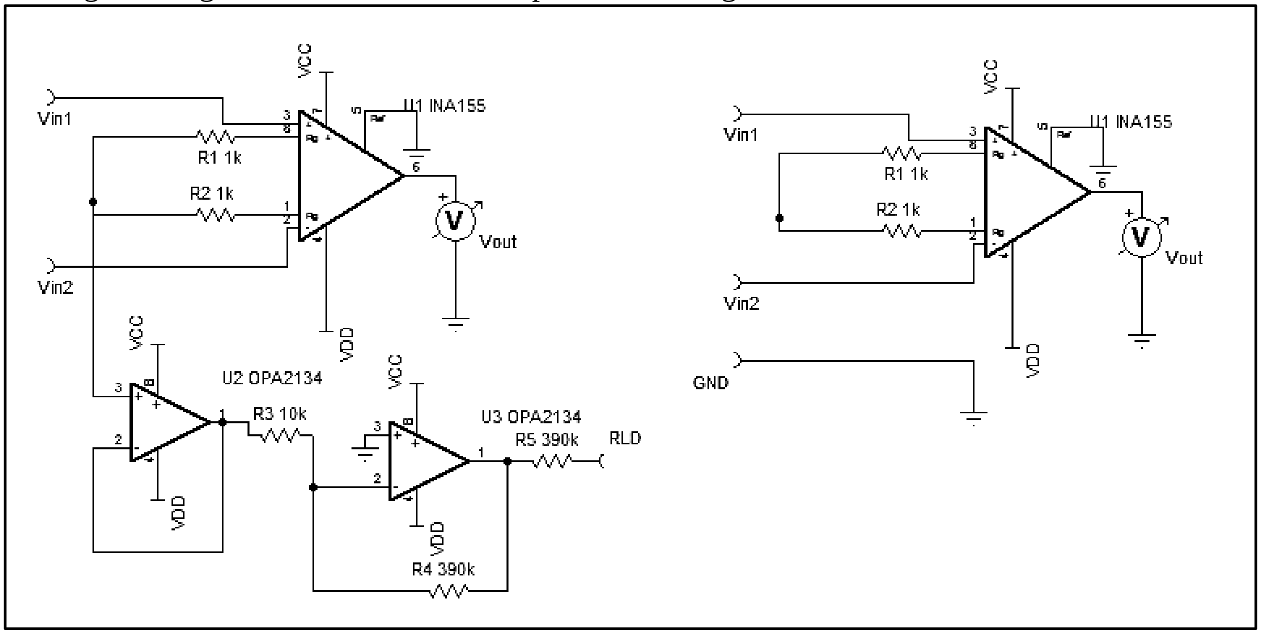

Figure 1: RLD circuit (left) and direct grounding circuit (right). The right leg drive has additional components compared to the direct grounding method.

In this study, the two methods were compared and applied for EMG acquisition. The basic design of direct grounding method was applied with the input filter proposed in [7] and the effect of cable length and shielding was also investigated.

2. MATERIALS AND METHODS

A complete EMG acquisition circuit consists of several cascaded stages of amplification and filtering. The overview of the EMG amp designed in this study is shown in Figure 2. The system consists of an input filter followed by the instrumentation amplifier. The input filter is a high pass filter, designed to remove DC offset which are caused by the body-electrode interface. It is followed by a high pass filter and low pass filter. This filter provides the bandpass region which contains the frequency spectrum of the EMG signal.

The amplitude of the EMG signal normally ranges from µVs to low mVs (0-6 mV_{pp} or 0-1.5 mV RMS). [8][9][10]The power spectrum of the EMG signal in frequency domain usually lies within the 0 to 500 Hz range, with the dominant signalslying in the 50-150 Hz range. Therefore, in an extreme case of common mode noise, a notch filter can be used to filter out the 50/60Hz noise, however at the expense of some EMG information. Beyond the 0-500 Hz bandwidth, signals with energy lower than the electrical noise level are not useful.

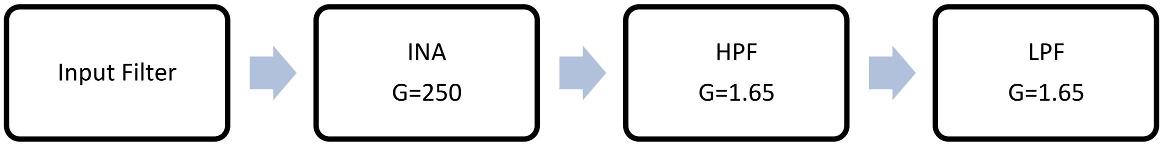

Figure 2: Block diagram of amplification stages showing the gain of each stage. The total gain desired is given as 1769

2.1.Input Filter

The input filter is an adapted designed by Wang (2010) [7]and instrumentation amplifier is shown in Figure 3. The components C2, R3 and C3, R4 form a high pass filter to block DC components from the instrumentation amplifier. C1 and R5forms another high pass filter and feedback loop whereby the common mode signal in the AC coupling and the DC bias voltage from the instrument amplifier returns into the input, which checks and filters its DC composition.

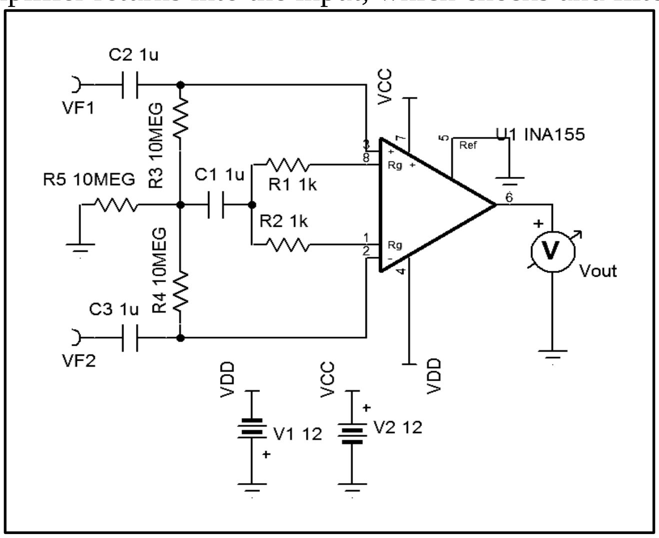

Figure 3: Design of input filter. Overall cutoff frequency is 0.0159 Hz.

The output frequency is determined by the formula

$$fc = \frac{1}{2\pi RC}\ Hz. \ (1)$$

With C=1 uF and R=10 MΩ, the corner frequency is 0.0159 Hz. This frequency is low enough to filter out DC components. The gain is set by the relationship:

$$G(s)_{INA} = \frac{V_0}{V_{in}} = \left[1 + \frac{50k}{R_G}\right]. \ (2)$$

With R_G = 200 Ω, the gain is set at approximately 250.

2.2.Bandpass Filter

In this research, a second order Sallen-Key active filter topology was used. The filter stages include a low pass (LPF and high pass filter (HPF). The notch filter, commonly used to filter the

50/60Hz power line noise was omitted, because a majority of EMG energy exists near that frequency. The bandpass filter consists of two filters, shown in Figure 4.

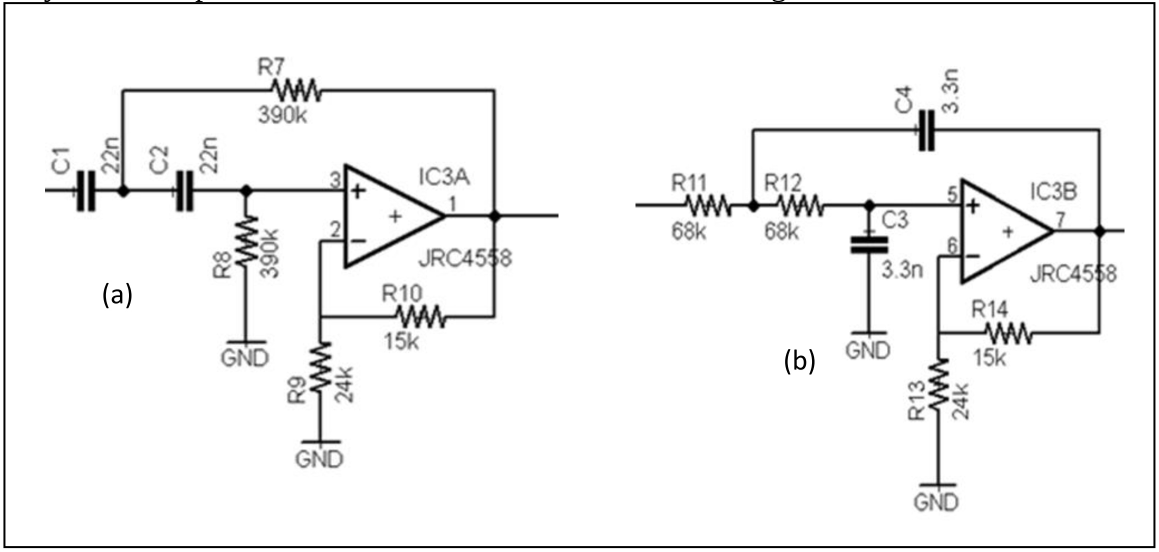

Figure 4: High pass filter (a) and low pass filter (b)

The corner frequency, passband gain and Q factor of the second-order Sallen-Key filters are given in (4), (5) and (6) respectively:

$$\boldsymbol{f_c = \frac{1}{2\pi\sqrt{R_1R_2C_1C_2}}} \quad (2)$$

$$\boldsymbol{G_{pass} = 1 + \frac{R_4}{R_3}} \quad (3)$$

$$\boldsymbol{Q = \frac{1}{\sqrt{\frac{R_1C_1}{R_2C_2}} + \sqrt{\frac{R_1C_2}{R_2C_1}} + (1-k)\sqrt{\frac{R_2C_2}{R_1C_1}}}} \quad (4)$$

Basing on the resistor and capacitor values in the schematics, the corner frequency, passband gain and Q factor for the filter stage are computed in Table 1.

Table 1: Filter design parameters

	HPF	LPF
Corner frequency, f_c	18.97Hz	709Hz
Passband gain, K	1.625	1.625
Q factor, Q	0.727	0.727

The gain value was set as such to obtain a Q factor in between 0.7 to 1.0 in order to achieve the steepest rolloff possible. Keeping a higher Q factor in conjunction of a gain greater than 1 can also reduce circuit noise.

2.3. Final Stage Amplification

The final stage is a non-inverting amplifier, shown in Figure. The gain of the amplifier is given as:

$$G = 1 + \frac{P_1}{R_1} \quad (5).$$

With R_1 and $P_1$is 1 kΩ and 10 kΩ respectively, the potentiometer P_1 provides a 1 to 10 gain.

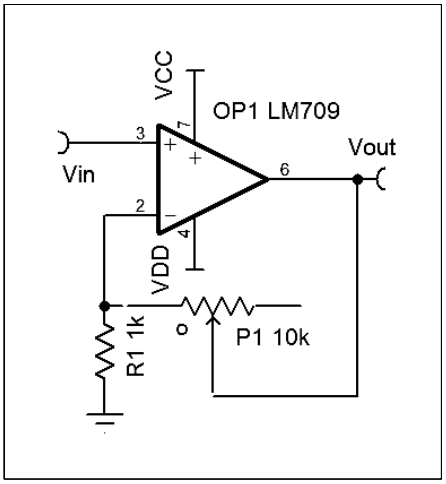

Figure 5: Non-inverting amplifier

3. RESULTS AND DISCUSSIONS

The final design was produced on a printed circuit board, shown in Fig. 6(a). The mains filter is a low pass filter, designed to suppress high frequency noise from the power line of above 1 MHz. The rectifier is a LM317/LM337 pair which provides the ±12 V DC supply. The DC power supply is further filtered by a symmetrical capacitor bank.

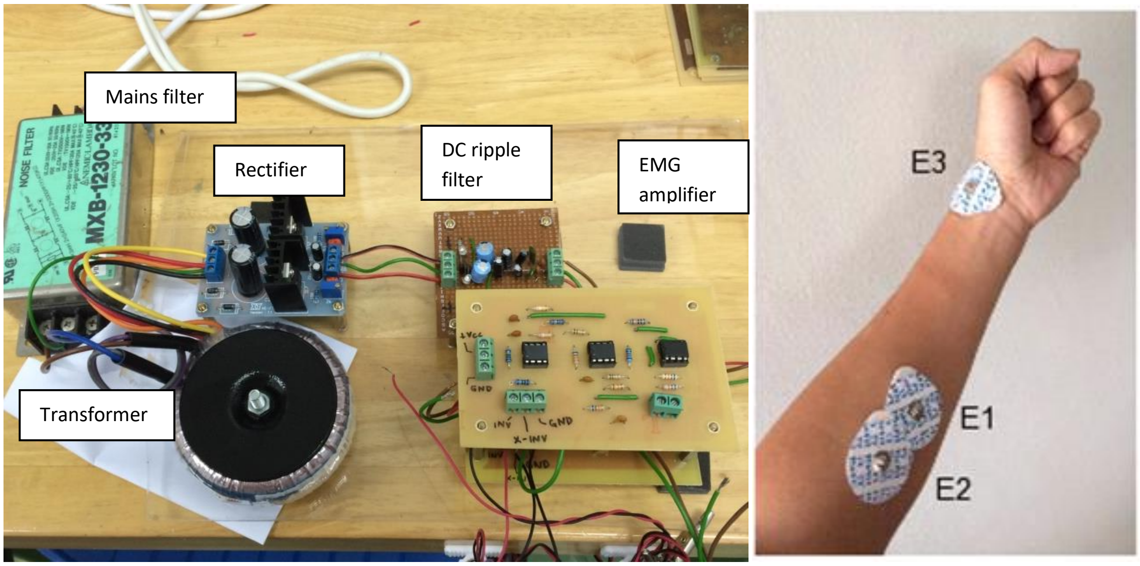

Figure 6: Final product of the EMG amplifier design (a) and setup of electrode on forearm (b)

The electrode setup is shown in Fig. 6B. E1 and E2 were placed over the flexor digitorum superficialis (FDS) muscle. The ground electrode, E3 was alternated between RLD and direct grounding. The FDS contraction was recorded with the National Instrumentation NI-9708 DAQ and Labview PC interface. Three readings were acquired, shown in Fig. 8 through Fig. 10.

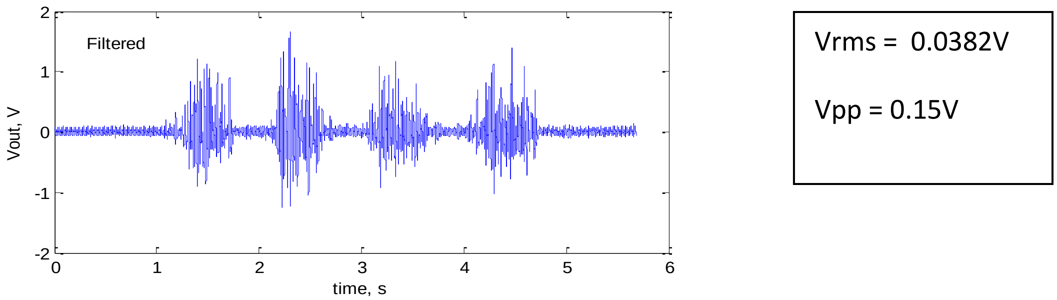

Figure 7: Direct grounding, with no input filter

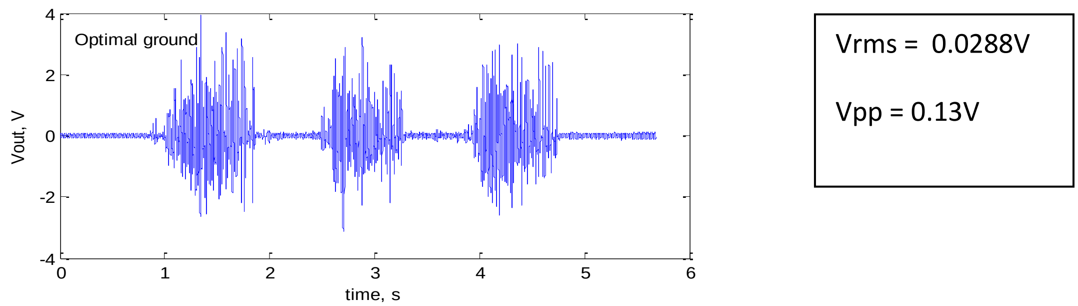

Figure 8: Direct grounding, with input filter

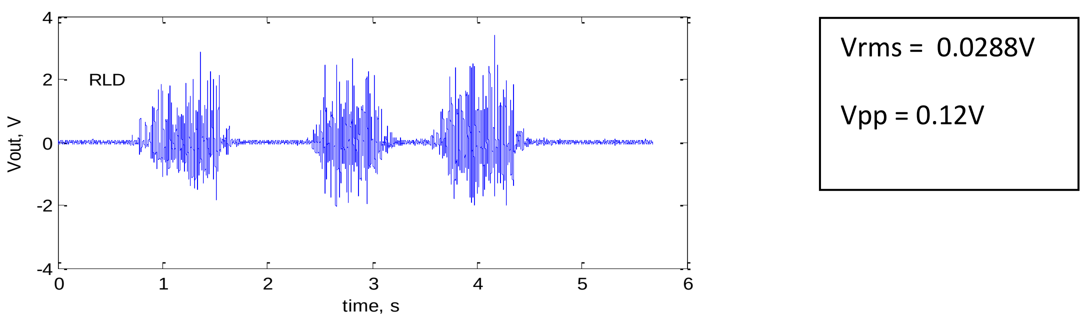

Figure 9: RLD placed on wrist

To evaluate the effectiveness of the EMG amplifier, the RMS value of the noise is a convenient indicator, as it gives the averaged DC magnitude of the signal. The lower the RMS value, the better the noise rejection. In Fig. 8, the FDS flexion was taken without any filter. The resulting baseline noise was the highest. Fig. 9 shows that the input filter did reduce the common mode noise.. Finally, the result of the RLD application is shown in Fig. 10. The RLD circuit only provides marginal improvement in the common mode rejection. This result concurs with that of [7].

4. CONCLUSIONS & RECOMMENDATIONS

As a summary, this study has shown that the direct grounding method can match the common mode noise reduction of the RLD method. Given the low level of baseline noise, the bandstop filter can also be omitted from the amplifier citcuit. Considering the simple implementation of the direct grounding method over the RLD, EMG amplifiers can be designed without the RLD circuit.

However, the ground electrode adhesion is critical for low noise. Any degradation in the electrolyte and the skin contact can cause the common mode noise to increase considerably.

ACKNOWLEDGEMENTS

This research is supported by the Malaysian Ministry of Education, research grant identification number FRGS/2/2013/SG02/FKP/02/2/F00176.

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