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# DEVELOPMENT OF LINEAR ENVELOPED SURFACE ELECTROMYOGRAPHY CIRCUIT BASED ON FOREARM MUSCLE

**[1]MUHAMMAD ALIF NORIZAN, [2]FARIZ ALI, [3]NORAFIZAH ABAS, [4]HERMAN JAMALUDDIN, [5]WAN MOHD BUKHARI, [6]MUHAMMAD ANAS BORHAN, [7]MOHAMAD FAIZAL BAHAROM, [8]ARFAH SYAHIDA MOHD NOR**
[1, 2,3,4,5,6,7,8] Universiti Teknikal Malaysia Melaka, Faculty of Electrical Engineering, Melaka, Malaysia
E-mail: [1]alifnorizan@gmail.com, [2]fariz@utem.edu.my, [3]norafizahabas@utem.edu.my,
[4]herman@utem.edu.my, [5]bukhari@utem.edu.my, [6]anasborhan@yahoo.com.my,
[7]mohamad.faizal@utem.edu.my, [8]arfahsyahida@utem.edu.my

## ABSTRACT

A linear enveloped circuit for processing of EMG signal has been designed and presented in this paper. The circuit acquires EMG signals from forearm muscle namely Flexor Digitorum Superficialis (FDS) using surface electrode and processed in into linear enveloped form. EMG can be defined as the electrical potential produced due to the contraction of muscle. EMG signal requires processes of preamplification, band limiting, rectification and smoothing in order to gain output signal in enveloped form. The output signal can be used for application in robotic such as prostheses or exoskeleton.

Keywords: *EMG, Flexor Digitorum Superficialis, Signal Processing, Preamplifier, Driven Right Leg, Band pass filter, CMMR, Linear Enveloped EMG Signal, Sallen Key*

## 1. INTRODUCTION

Human hand is an indispensable organ of human structure, function and expression. It is capable of producing complex and expressive articulation. It is a daunting challenge for robotic engineer to emulate human hand in the applications of prosthetics and exoskeleton due to the complex neurophysiology of human hand. There are a total of thirty five muscles which are responsible for the complex movement of human hands[1].

Physiological variations in the membranes of muscle fiber cause myoelectric signals. A technique used for reading and analyzing the myoelectric signal is called Electromyography (EMG). Electromyography (EMG) is a method used for recording the electrical activity on skeletal muscles. EMG signals can be acquired by using invasive electrodes or more commonly non-invasive electrodes. Surface electrodes are a non-invasive approach used to measure an electrical concentration that can be analyzed through signal processing.

As been discussed in many journals, the surface EMG signals are within the range of +/- 500 microvolts, and the ranges of frequency content are from 6 Hz to 600 Hz which the dominant frequency range is from 20 Hz to 150 Hz [2,3,4,5,6,7]. Two types of noises are contained by this signal; ambient noise come from the electromagnetic devices and it has a wide range of frequency component, however 50 or 60 Hz is the dominant frequency component. Transducer noise generated at the skin electrode junction. Electrode converts ionic current from the muscles into the electric current and during the process two types of transducer noises are produced. Direct voltage potential is generated due to the difference in the impedance between the electrode surface and the skin, and the alternating voltage is generated due to the fluctuations in impedance between the skin and the electrode. To reduce it, Argentum Chloride (AgCl) surface electrode is selected[8].

To remove these noises, the EMG signal is required to be processed either by using software such as Matlab or using instrumentation technique. In this paper, instrumentation technique is selected and the process include preamplification, band pass filtering, rectification and smoothing. The output from these process is linear enveloped EMG signal and it can be used for further analysis.

In this paper, one subject is selected and the muscle used is Flexor Digitorum Superficialis (FDS). FDS muscle is selected to measure hand grip strength while the subject grip an object at different wrist angles. From [9], FDS muscle was chosen because it is the forearm muscle responsible for finger flexion and the clenching of fists.

## 2. EXPERIMENT DESCRIPTION

The experiment consists of designing an electronic circuit to measure EMG signals from the FDS. The EMG measurements are recorded using GW Instek GDS-3000 digital oscilloscope while the subject is gripping a hand dynamometer with force levels and different wrist angles.

## 3. METHODOLOGY

### 3.1 Sensors placement

To determine the location of the FDS we placed the palm of our hand on the medial epicondyle and extended our thumb and fingers down the forearm as shown in Fig 1. Each of the fingers and thumb will be above a particular muscle; thumb – pronator teres, index finger – flexor carpi radialis, middle finger – palmaris longus, ring finger – flexor digitorum superficialis, and pinky finger – flexor carpi ulnaris[10]. AgCl electrodes then placed in FDS muscle as shown in Fig 2.

*Fig 1: Hand Palm On Medial Epicondyle*

*Fig 2: Agcl Electrodes On FDS Muscle*

### 3.2 Preamplifier with Driven Right Leg Circuit

For first stage of signal conditioning, a preamplifier circuit with Driven Right Leg (DRL) concept is designed. Preamplifier will amplify the EMG signal and eliminate noises in the signal. To eliminate the noise signal from power line sources, a differential detecting configuration is employed. The signal is detected at two sites which are positive and negative input from the electrode, the electronic circuitry subtracts the two signals and amplifies the difference. Any signal that common for both detection sites will be removed and signals that different from the two sites will be subtracted and amplified. Several necessary steps were taken in the circuit design as described here:

1) *Instrumentation amplifier with High CMMR*

[9] mentioned higher high common mode rejection ratio (CMMR) has the capability for the instrumentation amplifier to subtract noise which appears as common mode signals to the instrumentational input. AD620 [11] is selected as instrumentation amplifier with minimum CMMR value at 100dB. The low current noise from this component is suitable for EMG monitoring. It also has low bias currents and low current noise, added low voltage noise that improves the dynamic range which makes AD620 suitable for medical application. Fig 3 show the pin configuration of AD620.

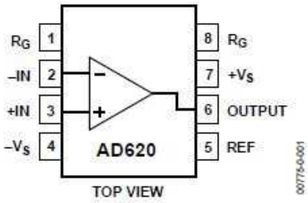


*Fig 3: AD620 Configuration[6]*

2) *Driven Right Leg (DRL) Circuit*

Pin 1 and 8 of AD620 is connected to the Driven Right Leg (DRL) circuit. This DRL circuit is referred from [12] and is used as to have better and higher CMMR where the main noise created due to the power lines removal. The common mode noise signal is fed to 'bony' human body such as elbow and serves as the reference electrode to increase the signal to noise ratio (SNR) of the preamplifier. The gain used for this circuit is 26. The circuit in Fig 4 meets the specific criteria for good preamplifier circuit with DRL concept.

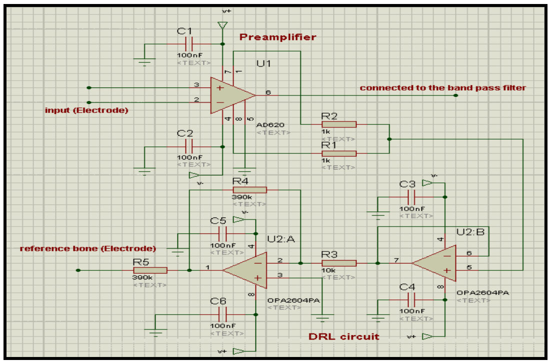


Fig 4: *Preamplifier Circuit With DRL Concept*

## 3.3 Band Pass Filter

The second stage in this circuit is band pass filter which has cut-off frequency at 20Hz to 400Hz due to the optimum EMG signal is in between that range. According to [13], the signal to noise ratio of EMG signals can increased by having filter between 20HZ to 500Hz. The design characteristic consider 400Hz as the upper bandwidth cut-off. The band pass filter is divided into two parts which are Sallen Key second order high pass filter and Sallen Key second order low pass filter. Both filters are cascaded to make a band pass filter. As mentioned in[14], Sallen Key is suitable for the application that require preservation of amplitude and linearity in the band pass region. It also removes motion artifact and high frequency noise from the signal.

Both Sallen Key high pass and low pass filter used OPA2604PA as the operational amplifier. To design Sallen Key high pass filter, capacitor range for filter design is from 100pF for high frequency and 100nF for low frequency. The value selected for C7 and C8 are 100nF. In order to calculate the resistor value of R6 and R7, the online Sallen Key high pass filter design calculator is used[15]. With capacitor C7 and C8 value at 100nF and cut-off frequency 20Hz, the resistor value obtained for R6=112539.5Ω and R7=56269.8Ω.

As for Sallen Key low pass filter, the online Sallen Key low pass filter is used[16]. The cut-off frequency value at 400Hz and capacitor value C11 and C12 are respectively 20nf with resistor value R8=R9 suitable is 20kΩ. From Fig 5, the output for band pass filter is connected to full wave precision rectifier circuit.

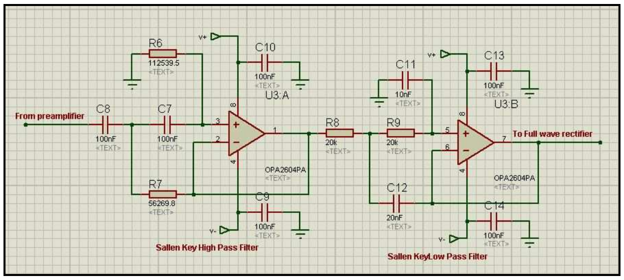


Fig 5: *Sallen Key High And Low Pass Filter*

## 3.4 Full Wave Precision Rectifier

Operational amplifier is called precision amplifier because the ability to rectify lower amplitude signal. Based on research from[17], after the signal amplification, the signal passed through a precision rectifier to get decent output in unidirectional positive phase signal.

From [14], the diode selected is 1N4148 precision diode as normal diode wont rectify the EMG signal properly and cause increased noise in the signal. OPA2604PA is selected as operational amplifier with value R10, R11, R12, R13, R14 at 150kΩ. Fig 6 show the Full Wave Precision Rectifier with output from the circuit connected to the smoothing circuit.

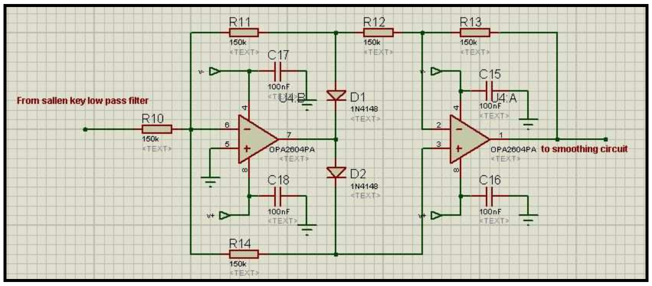


Fig 6: *Full Wave Precision Rectifier*

## 3.5 Smoothing Circuit

Low pass filter is used in smoothing circuit to passes the signals with frequency that is lower than the cut-off frequency. It attenuates the signals with higher frequency than cut-off frequency. Low pass filter exists in many forms such as anti-aliasing filters, digital filter for smoothing and etc. Low pass benefit gives a smoother form of the signal by removing short term fluctuation and leaves the long term trends.

Smoothing is done as for the EMG signal to resemble muscle force exerted by the individual. Smoothing is done by passing the output from full wave rectifier through an active low pass filter with low cut-off frequency[18]. The value for cut-off frequency for this filter is 1.95Hz with capacitor value C20 is 1µF. Noted that cut-off frequency value may vary depends on individual. Fig 7 show the low pass filter for smoothing purpose. By using online calculator of low pass filter [14], the resistor value obtained is 81.617kΩ. The resistor value of R15 and R16 is 82kΩ.

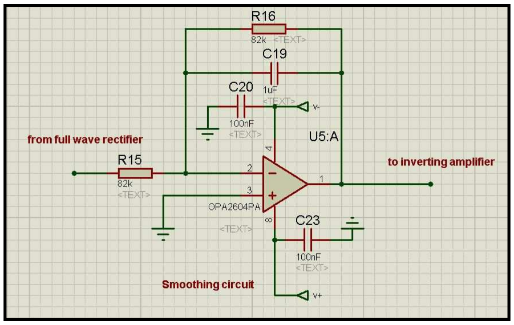


*Fig 7: Smoothing Circuit*

### 3.6 Inverting Amplifier

As stated in [18], the signal is rectified and passed through smoothing circuit with 1Hz frequency to smoothen out the peaks and obtained an enveloped of the EMG signal. This linear enveloped EMG signal can be used for further analyzing and processing. Based from early stages of circuit, the operational amplifier has gain of 26. For inverting amplifier, it has the gain of 100 where 1MΩ/10kΩ=100 to amplify the signal. Therefore the total gain of this circuit is 26 x 100 = 2600. As for to make this circuit more flexible to solve different people with different signals amplitude, R18 is replaced with 1M variable resistor. It is for the circuit have more variable value of gain as shown in Fig 8. The output from this circuit is connected to the oscilloscope to analyze the EMG signal.

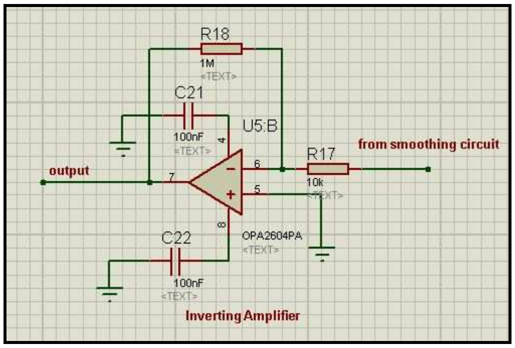


*Fig 8: Inverting Amplifier*

### 3.7 Power Supply

Each of the IC used (AD620 and OPA2604PA) is being supply with two 9V batteries for +9V and -9V. In pin 7 and pin 4 AD620, the supply is connected to this two pins. As for OPA2604PA, pin 5 and 8 are used to connect to the +9V and -9V.

### 3.8 Bypass Capacitor

Each IC has two bypass capacitors connected with 100nF value. In this bypass filter, it can defense against unwanted perturbations on the power supply. It also eliminates voltage drop on the power supply by storing electric charge to be release when voltage spike occurs[20]. Bypass capacitor should be place as near as possible to the IC power supply. Extra distance converts additional series inductance which lowers the self-resonant frequency of bypass capacitor. One capacitor is connected between +9V supply and ground while other capacitor was connected between –9V supply and ground.

### 3.9 Linear Enveloped EMG Circuit

The circuit is constructed on solderless board before transferred on Printed Circuit Board (PCB) circuit. The circuit is designed and tested using Proteus ARES software. Fig 9 show the finished PCB circuit of EMG circuit.

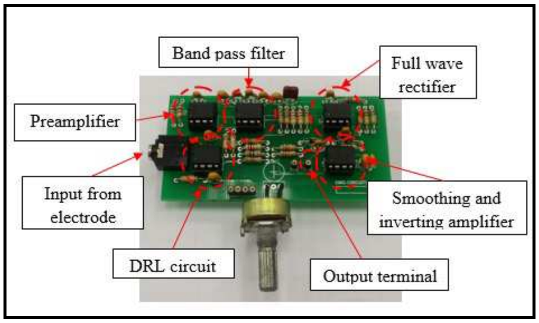


*Fig 9: Finished PCB Of EMG Circuit*

## 4. EMG SIGNAL ACQUISITION

EMG signals from subject FDS muscles were recorded using GW Instek GDS-3000 digital oscilloscope as shown in Fig 10. Measurements were taken while subject was gripping the hand dynamometer at force level 120N±0.5 with wrist angles 90°, 60° and 120° respectively. LabQuest interface as shown in Fig 10 is used as indicator for force level and printed protractor. From figure below, subject will grip the hand dynamometer at

10 seconds at each force level. The EMG waveform from oscilloscope will be saved in USB device. The signal saved from the oscilloscope is observed at different force level and wrist angles.

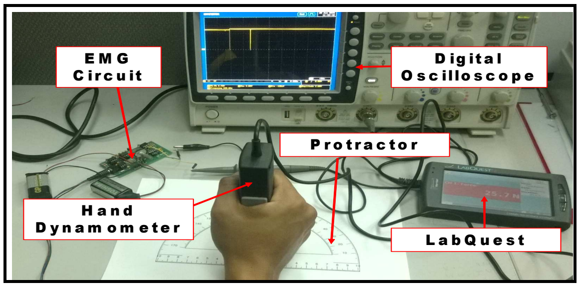


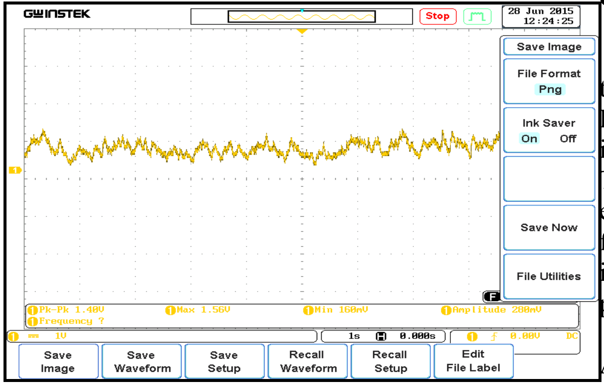
*Fig 10: Experimental Setup For EMG Acqusition*

## 5. RESULTS AND DISCUSSION

The experiments were carried out as described in the previous section and oscilloscope displayed the resulting of EMG signals at force level 120N±0.5 with wrist angle 90°, 60° and 120° respectively. The results then saved in a waveform as shown in Fig 11 for 90°, Fig 12 for 60° and Fig 13 for 120°. From the waveform, the peak to peak (Pk-Pk) is tabulated in Table 1.

*Table 1.Peak To Peak From EMG Signal At 120N±0.5 With Wrist Angle 90°, 60° And 120°*

| Angle(°) | Peak to Peak (V) |
|---|---|
| 90 | 1.40 |
| 60 | 1.12 |
| 120 | 2.28 |

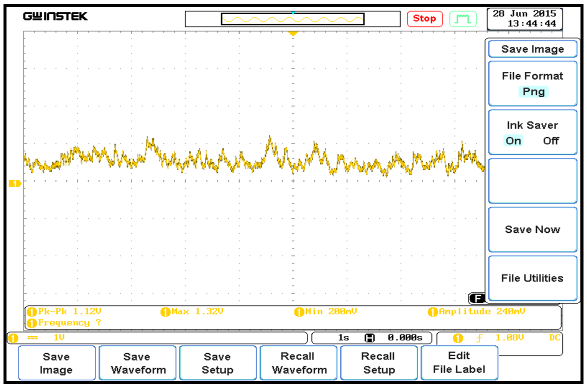


Pk-Pk 1.40V Max 1.56V Min 160mV Amplitude 280mV
Frequency ?

*Fig 11: EMG Signal For 120N±0.5 With Wrist Angle 90°*

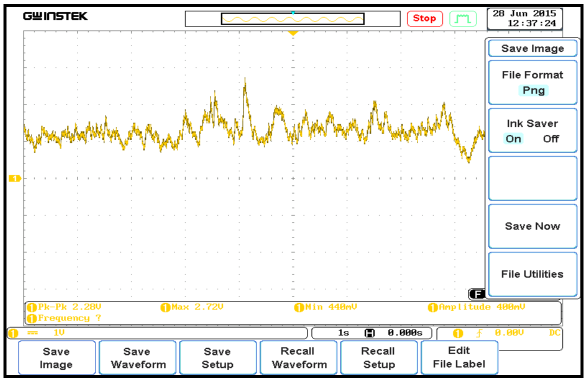
As shown in each figure, these results suggest that with different wrist angles the peak to peak value also change. Each peak to peak value from EMG signals increases with different wrist angles.

In this paper, the EMG signals obtained is in linear enveloped form. These signals doesn't need to be process by using signal processing software. The signal condition by using instrumentation technique has already gives output signal in a linear enveloped form.



Pk-Pk 1.12V Max 1.32V Min 200mV Amplitude 240mV
Frequency ?

*Fig 12: EMG Signal For 120N±0.5 With Wrist Angle 60°*



Pk-Pk 2.28V Max 2.72V Min 440mV Amplitude 400mV
Frequency ?

*Fig 13: EMG Signal For 120N±0.5 With Wrist Angle 120°*

## 6. CONCLUSION

A linear enveloped EMG circuit was developed to measure and obtain EMG signals from subject FDS muscle. Increasing angles gives resulted in increasing peak-to-peak value from EMG signal. The information will be used in future work to establish the relationship between EMG signal from forearm muscle and hand grip strength. The information also can be used as application for prostheses and exoskeleton.

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## REFERENCES:

[1] S. Parasuraman, "Bio-Mechanical Analysis of Human Hand," *2009 Int. Conf. Comput. Autom. Eng.*, pp. 93–97, Mar. 2009.

[2] M.I. Sabri, M.F. Miskon, M.R. Yaacob, ABD Samad Hasan Basri, Yewguan Soo, W.M.Bukhari (2014), MVC Based Normalization To Improve The Consistency of EMG Signal. Journal of Theoretical and Applied Information Technology ISSN: 1992-8645

[3] A.B. Y. Daud, W.M. Bukhari, Horng, C.S, R. Sudirman, "ELECTROMYOGRAPHY SIGNAL ON BICEPS MUSCLE IN TIME DOMAIN," *J. Mech. Eng. Sci.*, vol. 7, no. December, pp. 1179–1188, 2014.

[4] Wan Mohd Bukhari Wan Daud, Rubita Sudirman, Abu Bakar Yahya, Kamaruzaman Jusoff (2013) *Surface Electromyography of Eyes Potential Behaviour using Wavelet Transform Analysis.* Australian Journal of Basic and Applied Sciences, 7 (3). pp. 64-71. ISSN 1991-8178

[5] W. Daud, W. M. Bukhari and Sudirman, Rubita (2011) *Wavelet Frequency Estimation Parameter Of Energy Distribution For Electrooculograph Signal Analysis.* Jurnal Teknologi , 54 Special Edition (Sci. & Eng.) . pp. 299-309. ISSN 2180-3722

[6] W. Daud, W. M. Bukhari and Sudirman, Rubita and Omar, Camallil (2011) *Identification of Electrooculography Signals Frequency Energy Distribution Using Wavelet Algorithm.* Journal of Computer Science, Volume 7 (Issue 11). pp. 1619-1625. ISSN 1549-3636

[7] A. Salman, J. Iqbal, U. Izhar, U. S. Khan, and N. Rashid, "Optimized circuit for EMG signal processing," *2012 Int. Conf. Robot. Artif. Intell. ICRAI 2012*, pp. 208–213, 2012.

[8] P. Konrad, *The ABC of EMG*, no. March. 2006.

[9] a. J. H. Mohideen and S. N. Sidek, "Development of EMG circuit to study the relationship between flexor digitorum superficialis muscle activity and hand grip strength," *2011 4th Int. Conf. Mechatronics*, no. May, pp. 1–7, May 2011.

[10] A. Finneran and L. O'Sullivan, "Effects of grip type and wrist posture on forearm EMG activity, endurance time and movement accuracy," *Int. J. Ind. Ergon.*, vol. 43, no. 1, pp. 91–99, 2013.

[11] A. Devices, "AD620 Low Cost, Low Power Instrumentation Amplifier," *Online] www. datasheetcatalog. com.[Online]*, pp. 1–20, 1999.

[12] C. Liu and X. Wang, "Development of the system to detect and process Electromyogram signals.," *Conf. Proc. IEEE Eng. Med. Biol. Soc.*, vol. 6, pp. 6627–6630, 2005.

[13] C. J. De Luca, "S Urface E Lectromyography : D Etection and R Ecording," *DelSys Inc.*, vol. 10, no. 2, pp. 1–10, 2002.

[14] M. H. Khan, A. Wajdan, M. Khan, H. Ali, J. Iqbal, U. Shahbaz, and N. Rashid, "Design of low cost and portable EMG circuitry for use in active prosthesis applications," *2012 Int. Conf. Robot. Artif. Intell. ICRAI 2012*, pp. 204–207, 2012.

[15] "Online Calculator .:. Sallen Key Highpass Filter." [Online]. Available: http://www.changpuak.ch/electronics/calc_09.php. [Accessed: 26-Jun-2015].

[16] "Online Calculator .:. Sallen Key Lowpass Filter." [Online]. Available: http://www.changpuak.ch/electronics/calc_08.php. [Accessed: 26-Jun-2015].

[17] S. Das Gupta, S. Al Yusuf, J. Karim Ammar, and K. Hasan, "An analysis to generate EMG signal and its perspective: A panoramic approach," *2012 Int. Conf. Adv. Power Convers. Energy Technol. APCET 2012*, 2012.

[18] Ahmad Jazlan* and Shahrul Naim Sidek, "Development of a myoelectric interface for indirect hand grip force and wrist angle measurement/analysis," *Int. J. Biomechatronics Biomed. Robot. Vol. 3, No. 1, 2014 Dev.*, vol. 3, no. 1, pp. 42–53, 2014.

[19] "Online RC Lowpass filter Calculator - Ekswai." [Online]. Available: http://www.ekswai.com/en_lowpass.htm. [Accessed: 26-Jun-2015].

[20] M. Wong, "Choosing and Using Bypass Capacitors," pp. 1–10, 2011.