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International Journal Of Modern Engineering Research (IJMER)

The Importance of Simulation Applied to Design Thinking

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ABSTRACT: *The idea of this article is to present the importance of simulation applied to analog and microcontroller circuit. Certainly, nowadays with the advance of technology, there are available in the market many tools such as software simulation, to create from scratch, drawing animations, behavioral data with graphs, input, output tendencies as well as many other features. In the industry it is usually called platform test and it is greatly applied in the automation field, so the client may check for himself virtually in software and suggest any corrections on the design. Simulations are great tools to reduce costs, avoid accidents and to try out many disturbance model parameters, so the whole project is analyzed by the team and a decision is made to continue with the investment or a new design may need to come in handy due to some restriction that may come up. There is a point where physical assembling comes to bounder within the simulation and other parameters tend to initiate a new thinking to the design team to consider in the project. The outcome of simulation is that it is always good to stress out all the possibilities before going to the market. The result is less money spent while designing.*

KEY WARDS: *Design thinking, Microcontroller, platform tests, software simulation, reduce costs.,*

Date of Submission: 08-02-2023 Date of acceptance: 20-02-2023

I. INTRODUCTION

In 1822 English inventor Charles Babbage invented the first mechanical machine. The term "Logically" appeared right after the invention of Babbage machine (Fig.1) and by the end of war in 1945, computer Bugs and debugging began to be just a part of the entire process of software testing.

Figure 1: Babbage Machine [1]

Software testing has been around since 1951 and by that time to so on, PDCA (plan–do–check–act or plan–do–check–adjust) has become a major role in every structure that needs remodeling as well as improvements of process. The contribution of Joseph Juran who is also known as the father of software testing, implemented pareto principals in quality issues within the Japanese industries and in 1970 Japanese products began to be seen as the leaders in quality (Quality Planning, control and improvement) Fig.2.

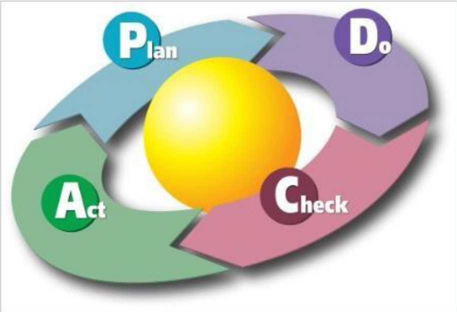


Figure 2:Babbage Machine [2]

As time flies by, programming technologies kept on escalating over the years, test standards have become the question for quality assurance not only for the industries but for the economics as it could avoid setbacks in companies and government budgets. Another favorable group that benefits from the improvements in software testing / simulation are the universities, hobbyists, and freelancers. The access to a variety of software is free nowadays and the companies want the public to know how to program and use their help document as resources, as well as forum channels for discussions within the community related to. It is especially important for the users to consider what are premises of the design and make a list of what kind of resources are available to obtain acceptable results for their project. For example, there are lot of microcontrollers with different vendors in the market with software that contains great resources and features to give their users, the time reduction for implementation and fast results with significant help and free examples to assist throughout the development.

The proposition of this article is to present a rational buildup with the use of various simulation examples that should assist technical analysis while studying electronics. The use of simulations contributes to reduce the amount of time of development as well as providing the user a visual effect of the results that were not interpreted rightly through books. The user can also change parameters as mentioned above with easy-to-use disturbances variables and check how the result may affect the outcome of project. While reading technical books, it is a common practice to have a simulation software to test each exercise so the user may see results in real time and question them if are reasonable. Again, as mentioned before, many companies are servicing their software as free to use with minor details that needs to be clarified when it comes to use their optimization, library codes or some sort of predefined intellectual work. That would speed up the process of development and of course an investment should be consider in the budget to be disbursed. The use of library codes provided as a resource to speed up coding throughout the development, in most cases, it is good practice for the user to check and compare the amount of time that was spent while scanning the code. The intellectual work of the company that provides resource for the user as mentioned above, is important to consider while developing code, specially in DSP applications where fixed and floating point are used and lots of data processing in the hardware is performed behind the scenes. The user may have the possibility to use pure mathematics or a library ready to go and few lines of code to speed up the development and those are important aspects about simulations. Another reason why library codes exist, is to make the life of the developer easier specially when it involves hardware configurations where many register should be enabled or disabled as well as timing precision that comes in play.

A set of tests will be ran using simulations which will show that results are a continuation for the user to understand that sometimes a different software will need to come into the design and keep the process on going until it reaches to its ending. In the Fig.3, it is shown a block diagram for a brainstorming of a subject such as simulation test concept. It is important for the user while trying to gather thoughts about how to initiate a design thinking, write, read, advantages and disadvantages and discuss in team each of these square blocks mentioned below as good practice. Each square block may or may not continue to be part of the project and that is why the brainstorming is important for excluding ideas that might not evolve within the project.

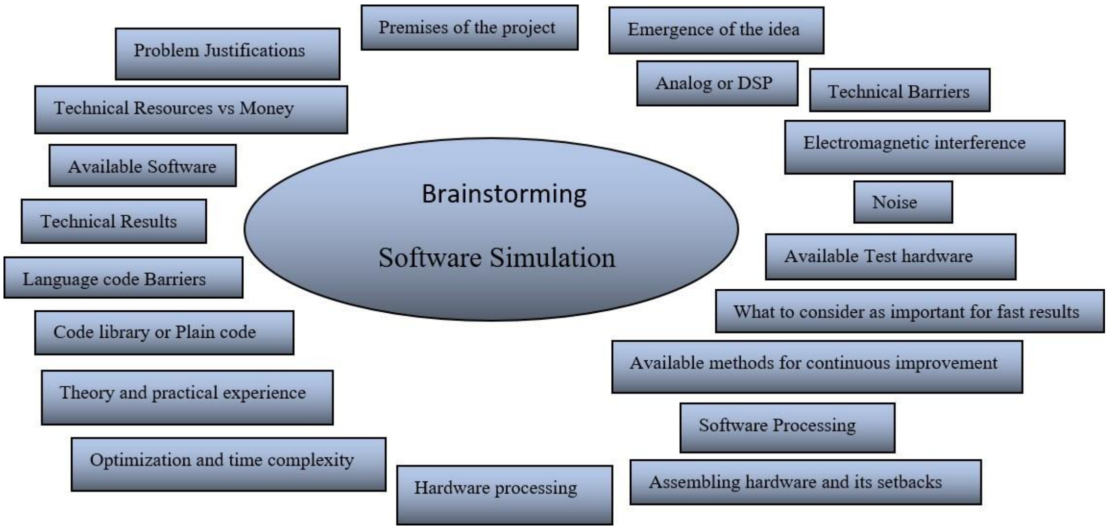


Figure 3: Brainstorming for software Simulation

In Fig.4, it is shown a work plan sheet that describes the design thinking for the buildup of the signal processing. The brainstorming was important to exclude and consider the main topics of application that should be implemented on the design. The time frame during this process was important due to the number of doubts that kept on showing up while studying and testing results. Fortunately, by organizing the thoughts even though some of them were recognized as important to be in the beginning of the studies, some important results only showed up in the end of the research. It concludes that is normal to have mistaken in the process due to the lack of experience, software resource and theory background.

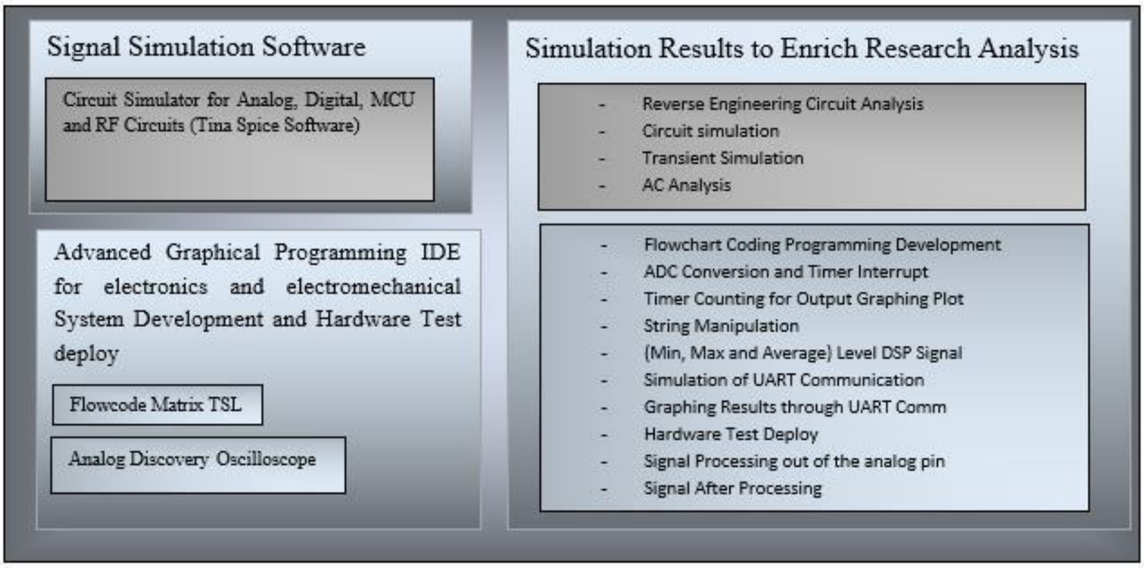


Figure 4:Work Plan Sheet

II. Computing Lab Experiments

In this section, it will be shown different analysis of analog signals with the use of Tina Design Software. The Target circuit in analyses, deals with analog circuit of an EMG application. The same implementation is also possible with the use of DSP (Digital Signal Processing - Digital Filters) as Fig. 5, however the application development of DSP is beyond the scope of this article and the focus as stated above will be only analog simulations by using Tina Design Software for the EMG analog circuit and last Flowcode by MatrixTSL for the microcontroller circuit.

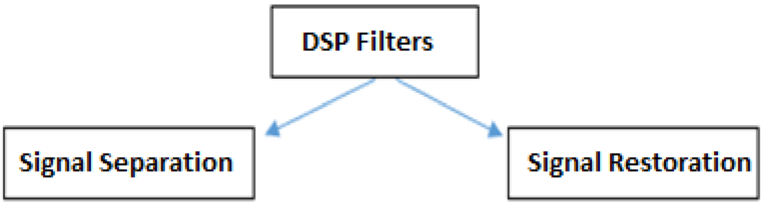


Figure 5: DSP Filter Application

Signal Separation and Signal Restoration is a field very popular and important in our lives and their use can be seen in many examples such as separating signals from signals that have been contaminated by noise or other signals. Such example is the babe in the womb having the reading of the signal of the heart and getting noise from the mothers breathing and ECG. A Filter might be used to separate these signals so they can individually be analyzed. Signal Restoration is used when a signal has been distorted, for example an audio with poor equipment may be filtered to better represent the sound, or image acquired improperly focused lens or a shaky camera. The important observation about the Signal conditioning is that these problems mentioned above, can be solved through the using of digital or analog approaches.

Characteristics of analog Filters: Cheaper and large dynamic range both in amplitude and frequency.

Fig. 6 depicts the block diagram of the target EMG circuit in fig 7. It shows primarily, a level of connectivity to understand various blocks of interaction between each step. The Diagram is composed of Electrodes (3 of them) connected to DRL (Driven Right Leg circuit); Protection circuit which is latter explained its usage as well as its pre-amplification. HPF stands for (High Pass filter), Amplifier is used to condition the signal to be adjusted for the microcontroller´s voltage range. LPF stands for (Low Pass Filter), uC which stands for (Microntroller and its generated clock) and last the acquired data by the computer though USB UART and itspower supply generated by the computer plugged in wall outlet or supplied by the notebook´s battery (Better option) due to interference noises.

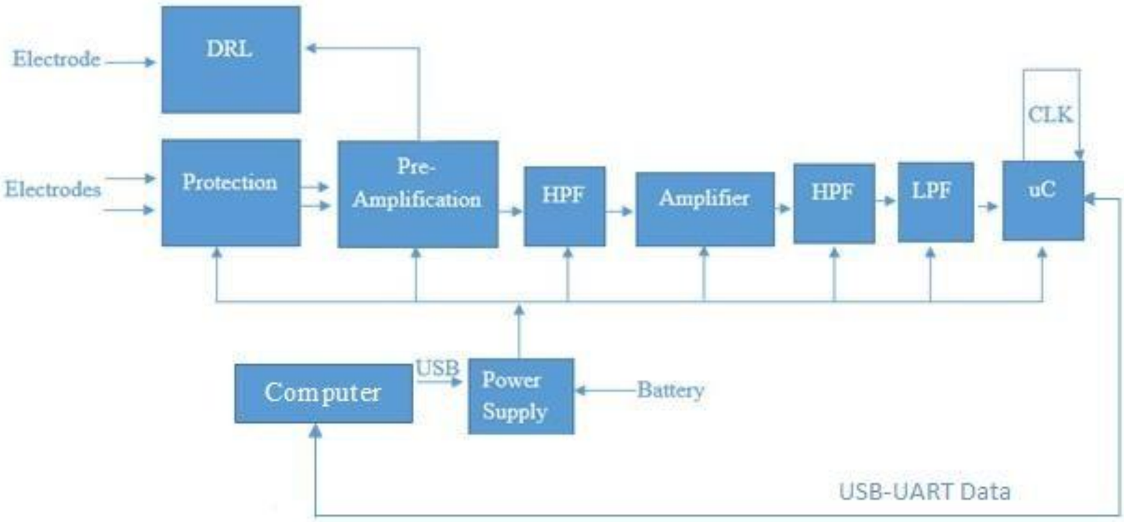


Figure 6: Block Diagram Filtering Circuit

The following technical explanation numbered from 1-7 below, is extracted from the manufacturer´swebsite, about the EMG Click Circuit functionality [3].

1. Protection - Provides ESD protection (protects EMG circuit), Overvoltage protection (protects respondents) and Overcurrent protection (protects respondents). In addition to protection, input blockhas the role of filter that prevents radio waves to “enter” the preamplifier.
2. Preamplifier – Is implemented through three operational amplifiers configured as instrumentation amplifier (IA – amplifies the voltage difference between “+” and “-“ electrode) which at its output provides single-end signal.
3. High-Pass filter – Should eliminate the DC component of the signal (f_c=1.6Hz). It is passive RC filter (first order).
4. Amplifier – Need to provide additional amplification that can be adjusted using trimmer potentiometer VR1 so the analog output could accommodate to the input voltage range of ADC. The amplifier is implemented using operational amplifier configured as non-inverting amplifier.

5. High-Pass filter – Should eliminate the DC component of the signal (f_c=0.16Hz) this time after the amplifier. It is also passive RC filter (first order).
6. Low-Pass filter – Should limit frequency range to 60Hz. It is third order active filter with gain of 15 (second-order Sallen-Key filter topology + passive RC filter first order = third order filter).
7. DRL circuit (Driven Right Leg) – is an electronic circuit that is often added to biological signal amplifiers to reduce Common-mode interference. Biological signal amplifiers such as ECG (Electrocardiogram), EEG (Electroencephalogram) or EMG circuits measure very small electrical signals emitted by the body, often as small as several microvolts (millionths of a volt). Unfortunately, the patient's body can also act as an antenna which picks up electromagnetic interference, especially 50/60 Hz noise from electrical power lines. This interference can obscure the biological signals, making them very hard to measure. Right Leg Driver circuitry is used to eliminate interference noise by actively canceling the interference. That is selective amplifier stage that shifts phase of signal for 180° (inverting) and returns it to respondents to cancel.[4]

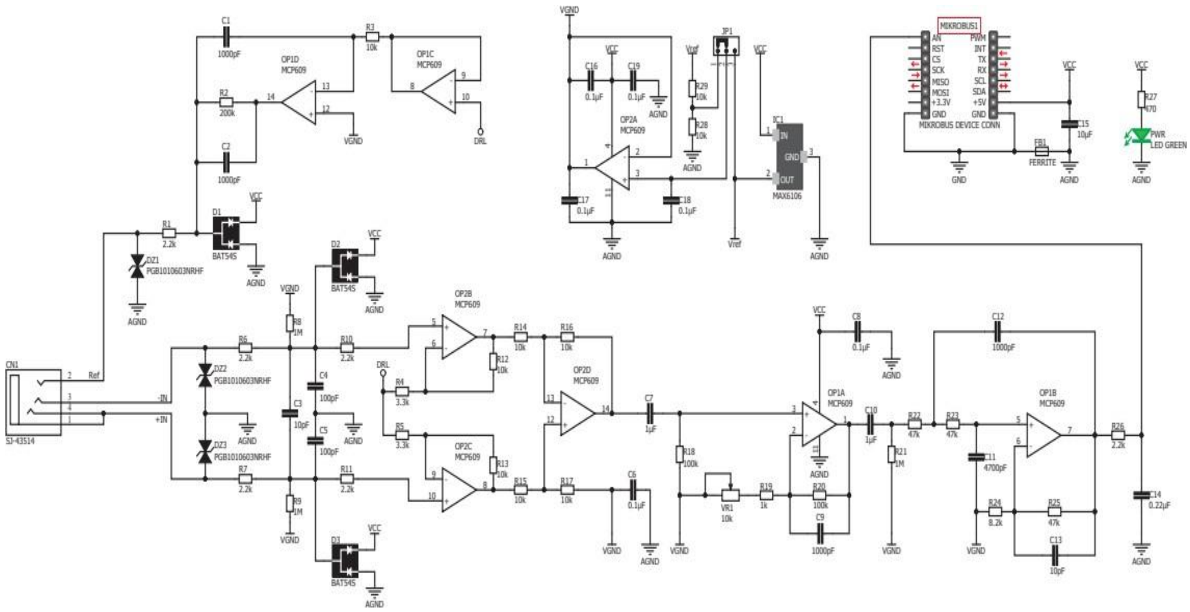


Figure 7:Schematic circuit - EMG- Click

In Fig. 8, the circuit was breakdown into various staged and each block was simulated by using TINA Design.

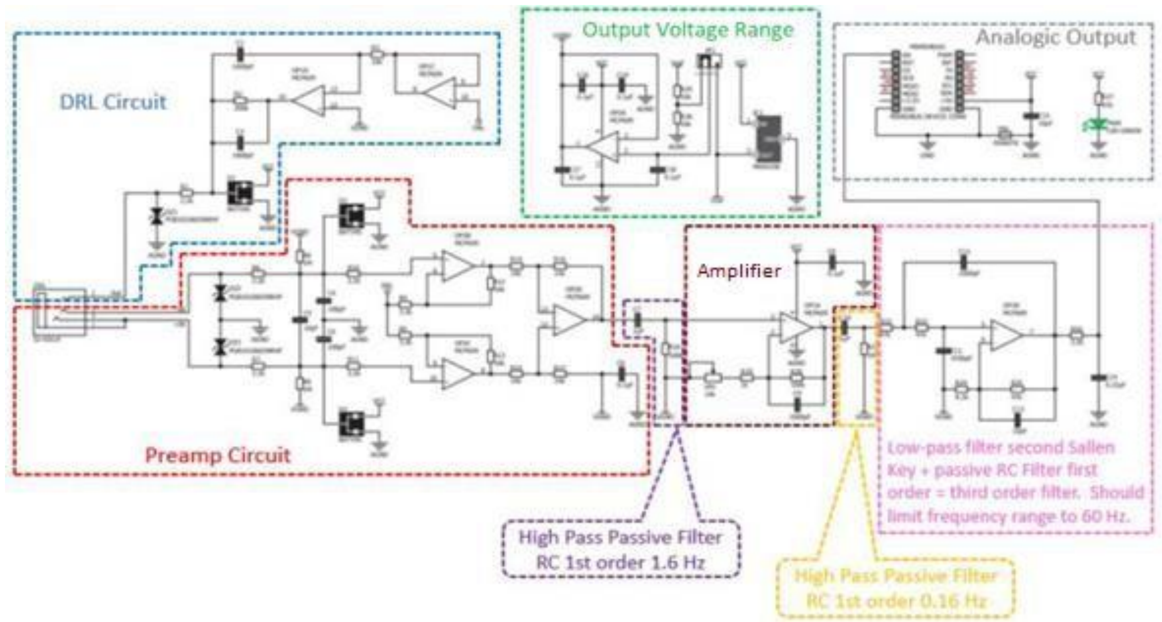


Figure 8: Different Stages of the Target Circuit

The explanation starts with the LDO (Low dropout output), voltage range circuit. It was necessary to check the voltage measurements of all the physical nodes of each component. The voltages of DRL and VGND are jumpers with different values and to improve the approximations of the values it was necessary to check the values of the voltages physically and to adjust them in the software. Another interpretation that had to be done is for simulation purposes, it was necessary to adjust the supply voltages of the entire circuit, feeding all the amplifiers with VCC (+) and GND (-). The manufacturer MICROCHIP of the opamp MCP609 did not produce the spice models for this specific component only for the MCP606. The difference between the chips is due to the number of encapsulated opamps. To adapt the circuit, it was necessary to individualize the opamps and consider power supply in all of them, which differs from the real photo of the circuit in Figure 20. The pins were analyzed with the MCP609 opamps and suitability for the MCP606. In the case of the Output Voltage Range, the difficulty was extended to the fixed voltage regulation circuit called LDO (Low Drop-out) MAX6106. The considered replacement for the MAX6106 is the REF3020 with the same electronic specifications to be used in the TINA Simulation. The MAX6106 is a low-cost, low dropout (LDO) micropower voltage reference. This three-terminal reference is available with output voltage options of 1.25V, 1.8V, 2.048V, 2.5V, 3V, 4.096V, 4.5V and 5V. the LDO output is 2.048V. [5]
The meaning of Dropout is the smallest difference between the input voltage and the output of a regulator, necessary to maintain regulation and allow the regulator to supply rated voltage and current. It is important to have a low dropout voltage for highest efficiency and minimum heat dissipation. Another feature of the MCP609mentioned in the datasheet used in the “application” section circuit is the use of “unused opamp”. Figure 9 illustrates the proposed circuit to be used to prevent the output from being inverted causing crosstalk. According to the datasheet Figure, electronically configures the opamp for the minimum noise gain. The voltage divider outputs any reference voltage within the output voltage range of the op amp. The op-amp buffers reference voltage. The result of the circuit simulation using the software demonstrates that the simulation was successful with the same reference voltage generated at the VGND output. The LDO used for the simulation is a component equivalent to the MX6106 with the same electronic characteristics maintained. The spice simulation for this circuit, ran accordingly compared to manufacture’s voltage range information listed above.

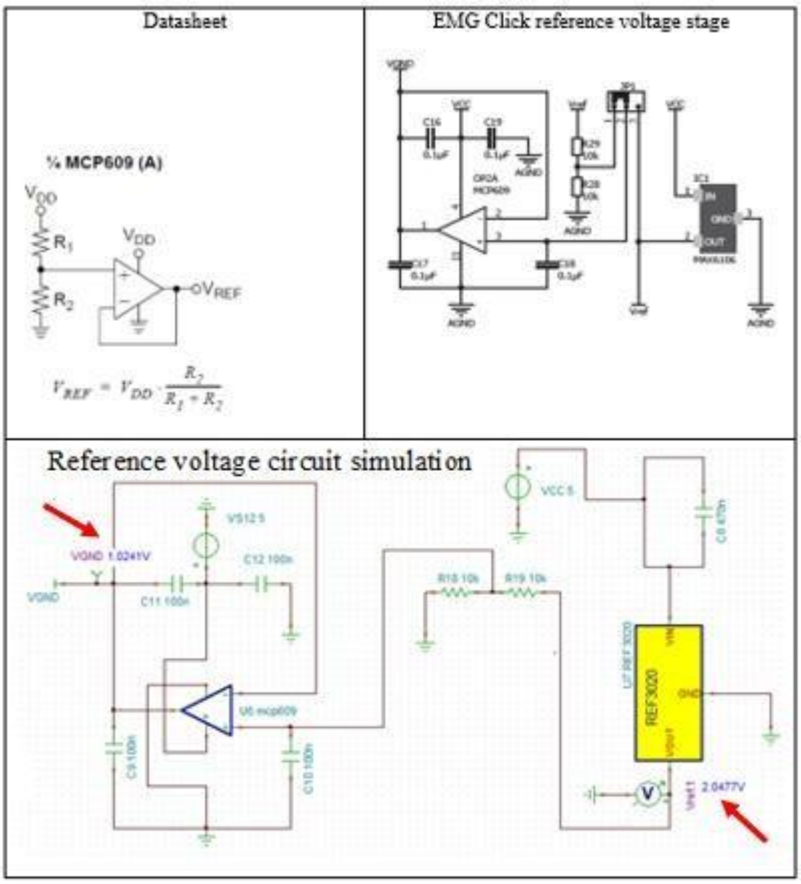


Figure 9: Spice Simulation for the LDO (Low Drop-out Output Voltage)

Instrumentation Opamp Simulation: Fig. 10 is the circuit simulation of the pre-amplification stage introduced in the block diagram in fig. 6 and fig. 7 above. An observation occurred during the simulation with the symbol for the BAT54S in fig 8. The simulation in Fig 10 had to be modified and it is important this because it can create misinterpretation about how to draw components during simulation and while assembling the circuit. That is reason why the user needs to research and study reference manuals, Software document help and community forums for any assistance that might be needed to overcome some error data (Doubt) [6].

The two electrodes provide unity common-mode and differential signal gain. The output of the opamp is a difference amplifier which converts the signal inputs from the differential to a single ended output. This rejects common mode signals at the input. The circuit gain is adjusted with the resistor and the reference voltage. Important definitions: A single-ended signal is one that is measured against a fixed potential, usually ground. In the case of the EMG click circuit, the reference is 1.0241 Volts according to figure 9 in the simulation and in the physical test it is confirmed 1.024 Volts.

The simulation of the pre-amplification circuit was elaborated using sinusoidal signals to generate signals within the characteristic power range of the EMG from 0 to 10mV and with different frequencies within the range of 40 to 1500 Hz, as shown in Fig. 11. The behavior of the pre-amplifier circuit, as expected, keeps the output waveforms in phase regardless of the input signal frequency. Soon the high pass filter will be applied, and it will be shown that when the filter is applied, the waveform changes, delaying the signal output in the circuit.

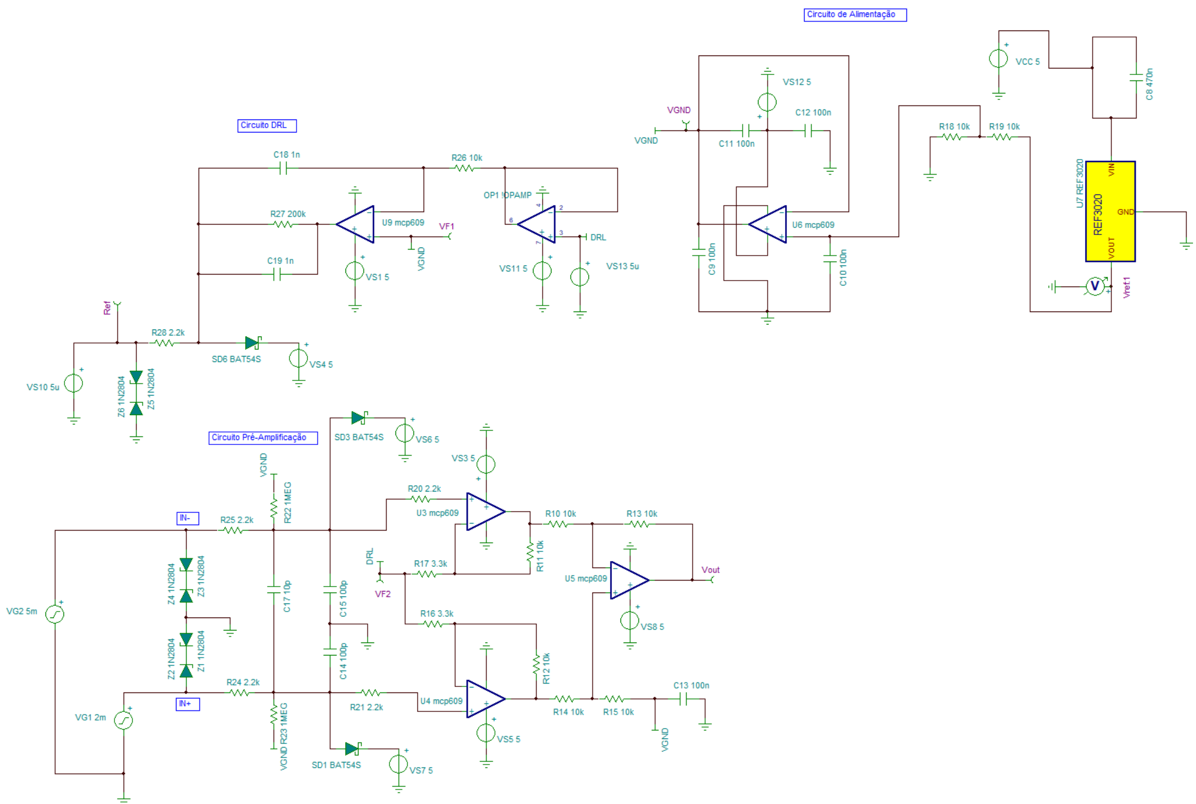


Figure 10: Spice Simulation for the Instrumentation Amplifier (Pre-Amplifier)

Transient Analysis of the Pre-Amplification Circuit is ran using 2mV and 5mV input and frequency of 40 Hz and 1.5 KHz respectively. The two signals generated is display as well as the Vout. It is the first step of the EMG circuit simulation for treating the signal and its pre amplification before conditioning with analog filters. In Fig. 11 shows the Graph result with Transient Analysis of 40Hz and 1.5KHz signal [6],[7].

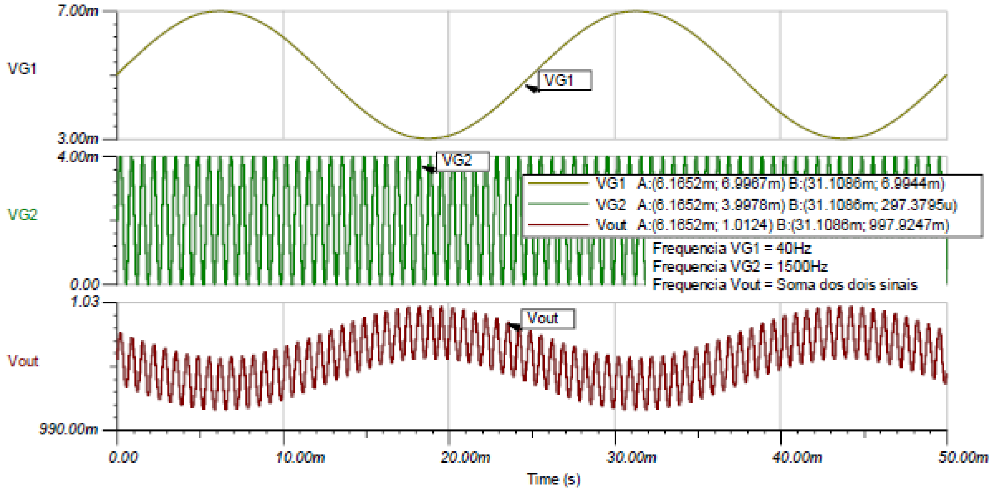


Figure 11: Graph result with Transient Analysis of 40Hz and 1.5KHz Khz signal

In Fig. 12 shows the circuit with the inclusion of High Pass Passive Filter composed of capacitor andresistor. As it was explained above, item number "3" the idea is to eliminate DC component for cutoff frequency 1.6 Hz.

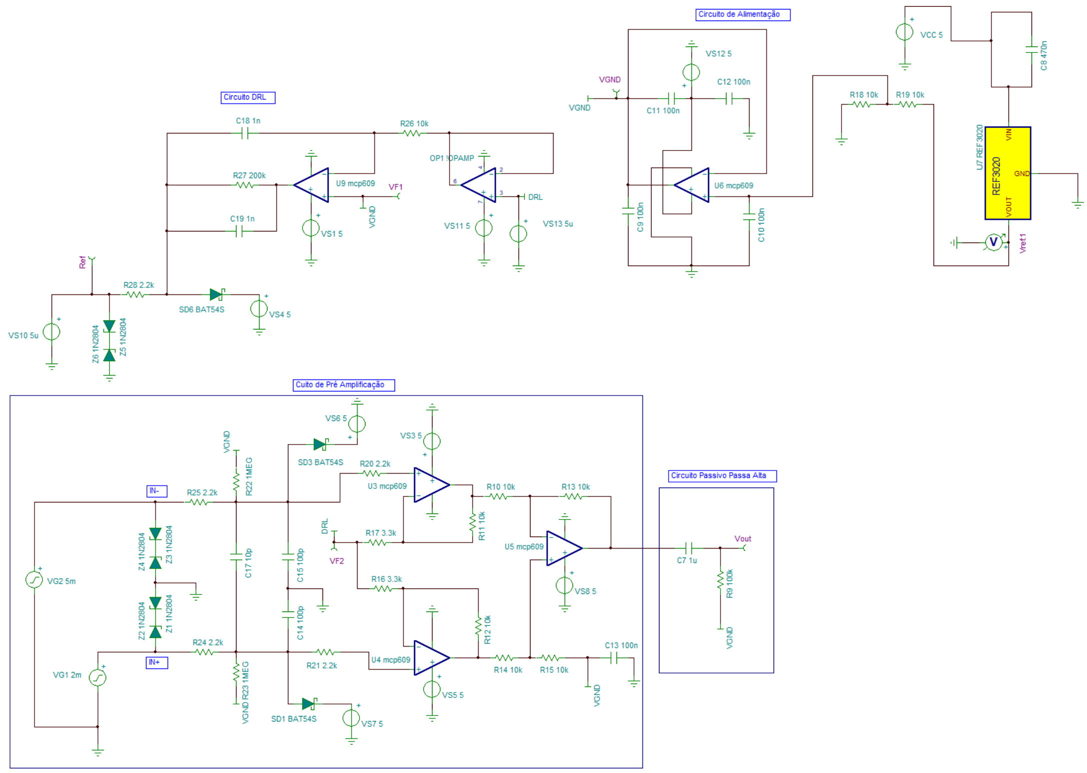


Figure 12: Inclusion of High Pass Passive Filter

In Fig 13 the graphing result of the circuit simulation that aims to eliminate the DC component of the signal at the cutoff frequency of 1.58Hz and Gain of 12.56DB. An AC analysis of the circuit is shown, showing the cutoff frequency, Gain and Phase. The AC Analysis depicts the initial of simulation starting to count from 100mHZ to 1 Meg Hz and the phase shift -134 Degrees. It confirms that the circuit blocks frequencies below 1.58 Hz.

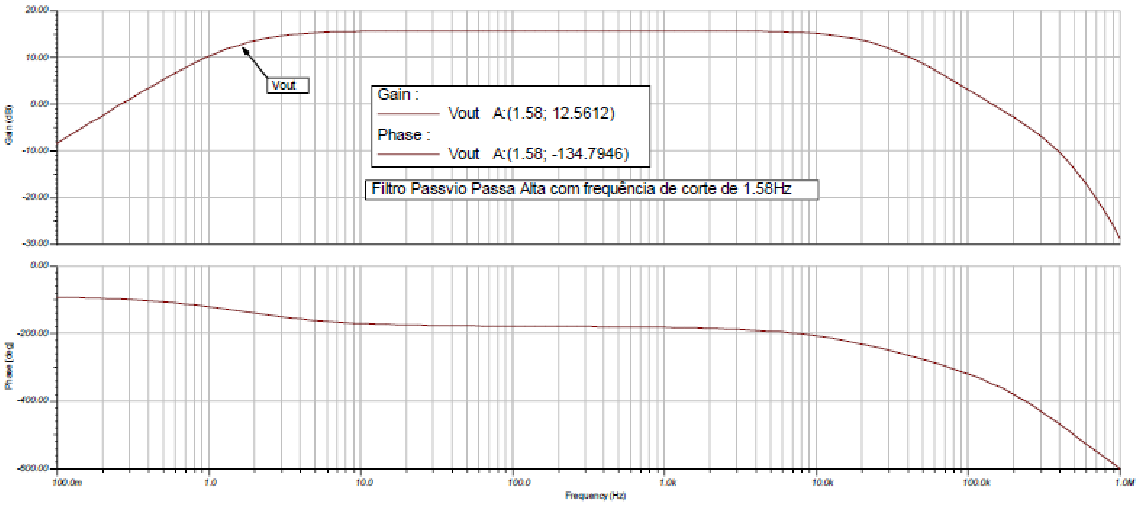


Figure 13: Graph Result Inclusion of High Pass Passive Filter AC Analysis

In Fig. 14 the transient analysis test displays the Vout waveform. The circuit blocked the signal frequencies below than 1.58 Hertz, which is the cutoff frequency. The two input signals generated to test filtering simulation were ran with 100 mHz each with sinusoidal wave (VG1 and VG2).

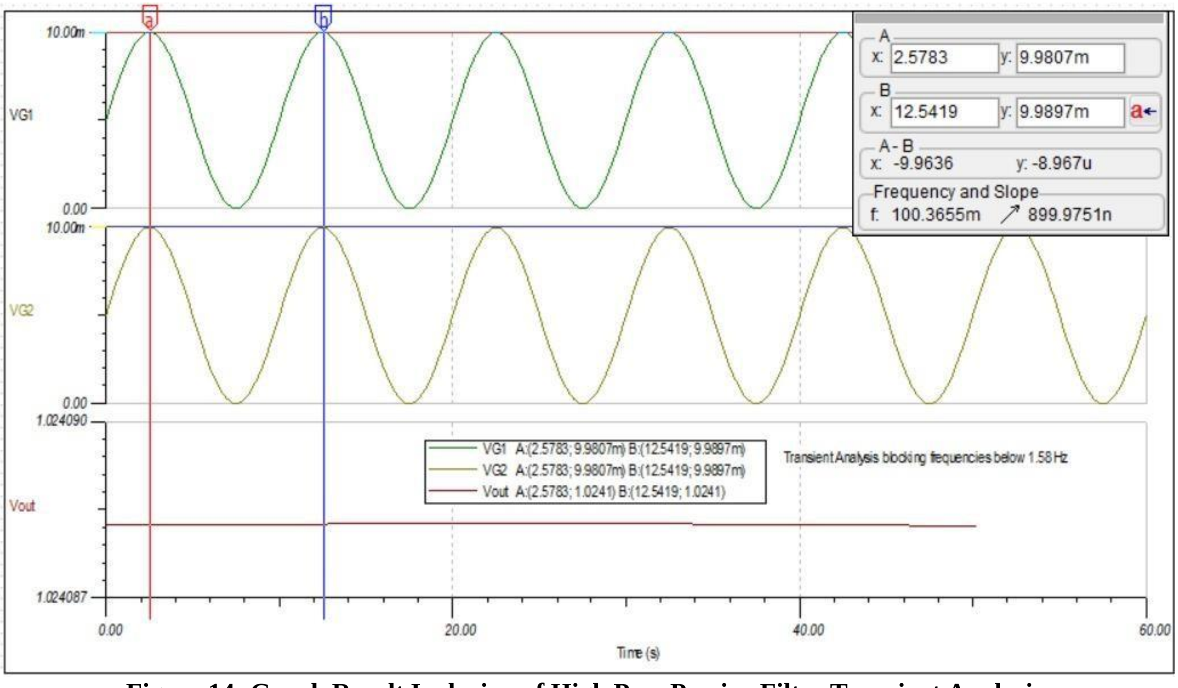


Figure 14: Graph Result Inclusion of High Pass Passive Filter Transient Analysis

In Fig. 15, the elimination of DC component. It was considered simulation of 5- and 10-Volts input signal with frequencies of 100 mHz. The circuit eliminated the DC component.

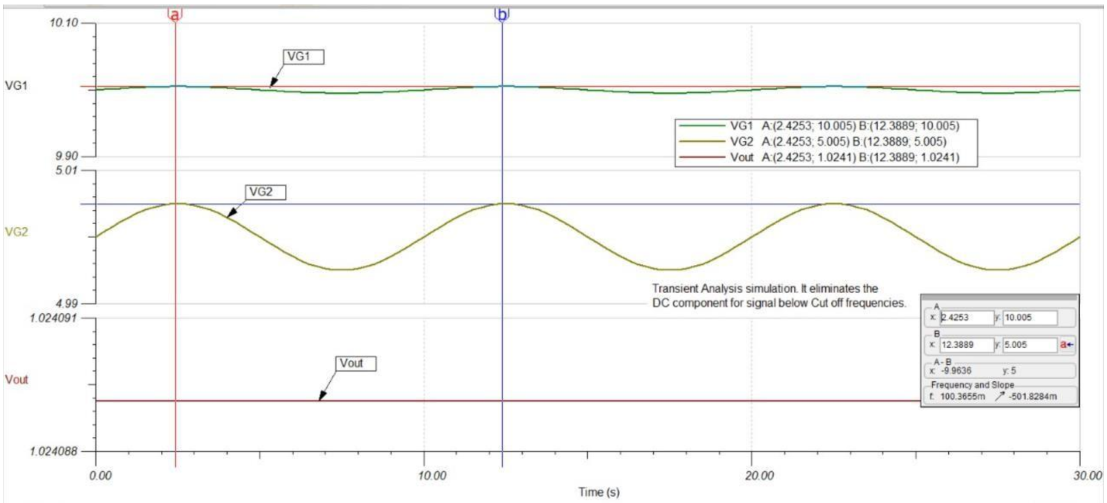


Figure 15: Graph Result Passive High Pass Filter DC component Elimination

Circuit Simulation Stage Amplification: In Fig. 16, the amplifier was implemented in the non-inverting configuration with a variable resistance of 10 Kohms. It was considered in the simulation a feature in the software Tina Design, which is possible to test the transient analysis and the AC Analysis using a sweep in the variable value of 800m to 10Kohms as shown in Fig. 17. The results are depicted in Figs. 18 and 19 with the respective transient and AC analyses.

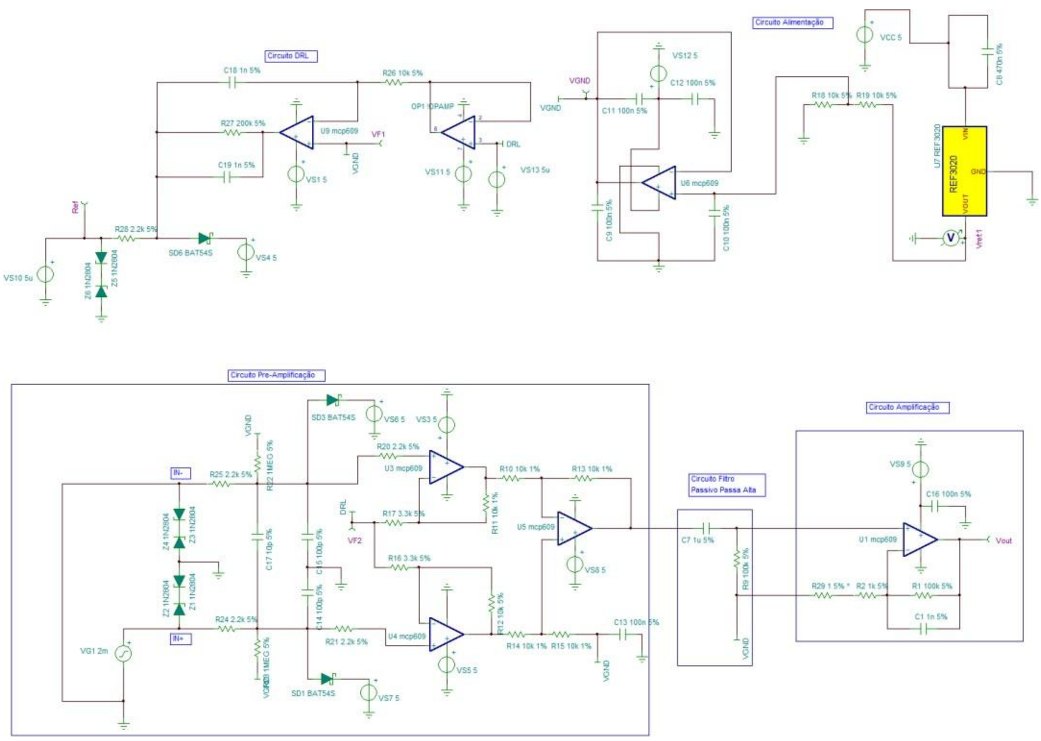


Figure 16: Amplifier Circuit Stage

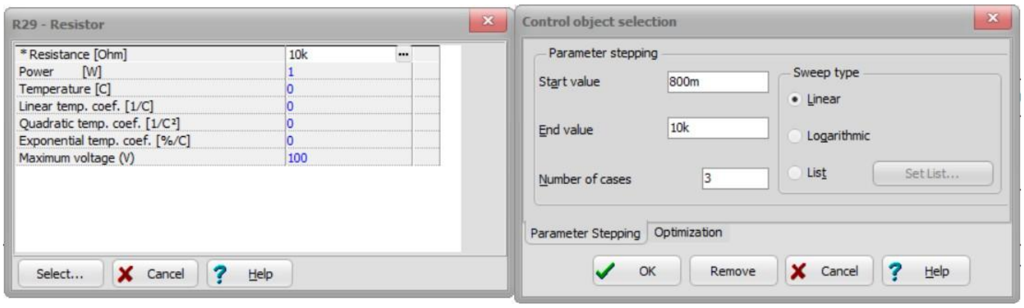


Figure 17: Variable Resistor Control Object

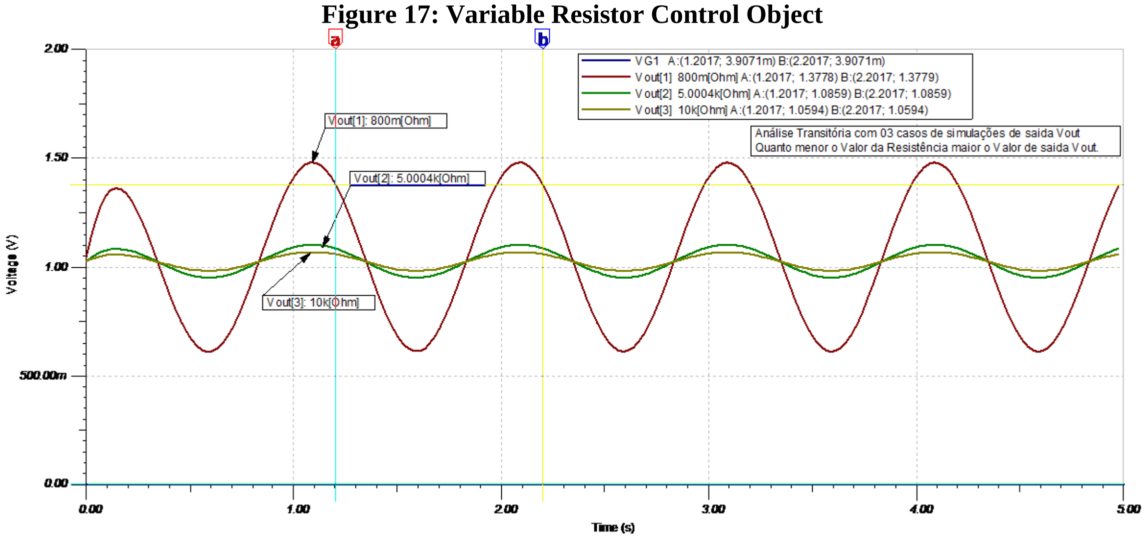


Figure 18: Transient Analysis to verify Amplification

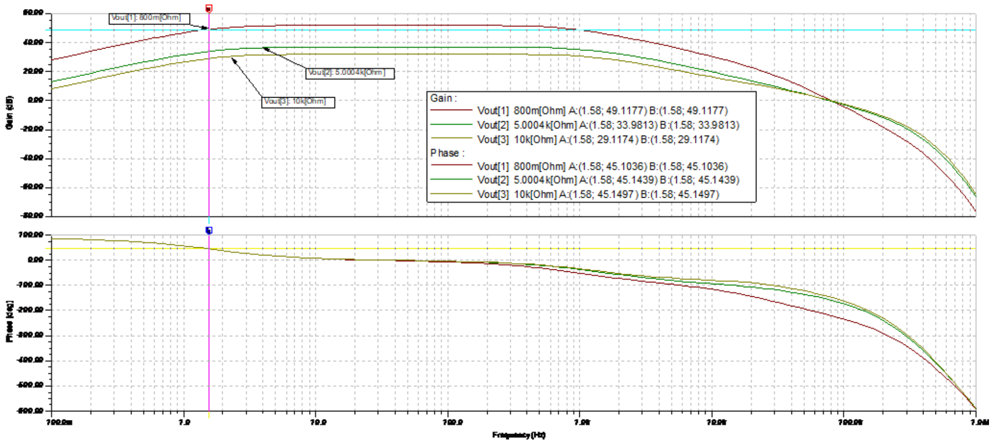


Figure 19: AC Analysis Graphing Results

In Fig. 20 the transient analysis graphing results varying the resistor is illustrated.

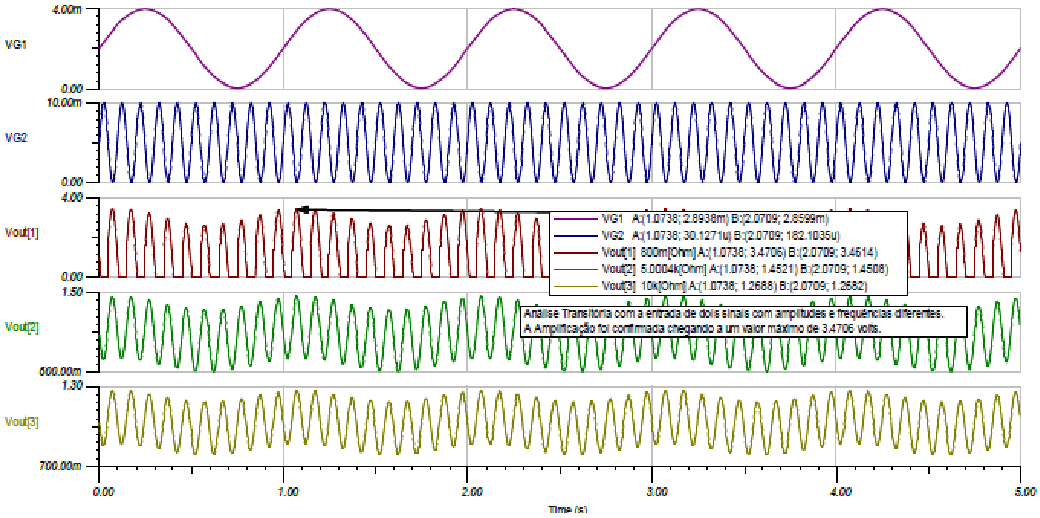


Figure 20: Transient Analysis Graphing Results Varying the Resistor

In Fig. 21 transient analysis was performed for two input signals in the amplification circuit and as aresult there is variation in the waveform of the circuit amplifying at a voltage of 3.4614 Volts [6],[7].

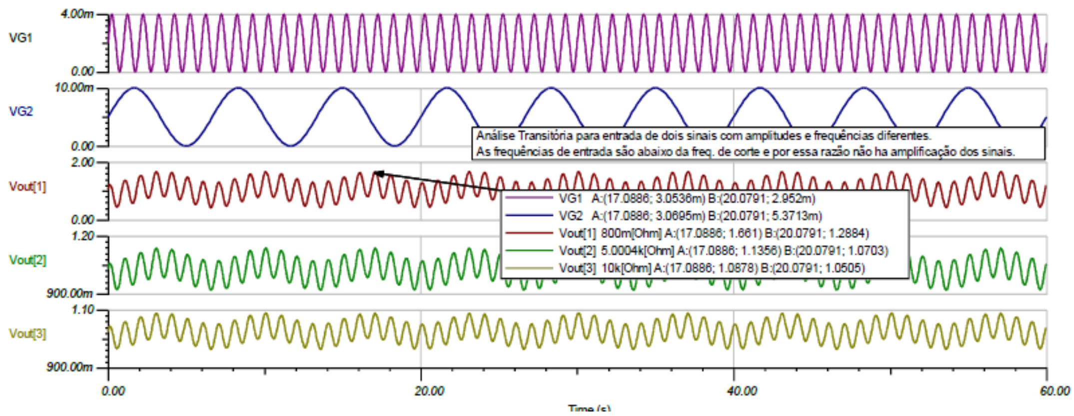
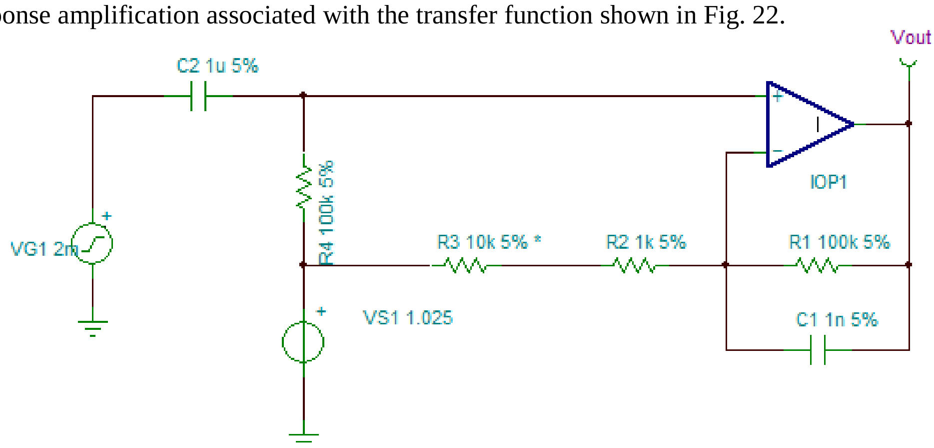


Figure 21: Transient Analysis for Maximum impendence in the Pot

Fig. 22 shows the isolated circuit test with its mathematical model in terms of the transfer function. Maximum impedance by varying the resistor to 10K results in a 1.661 Volts. It is important to consider the right

balance and find the result the suits the performance and values to be input in the microcontroller. Fig. 23 shows the step response amplification associated with the transfer function shown in Fig. 22.



$$W(s)=1.01\cdot\frac{s+9.91\cdot10^{-6}\cdot s^{2}}{1+1\cdot10^{-1}\cdot s+1\cdot10^{-5}\cdot s^{2}}$$

Figure 22: Isolated Circuit Test

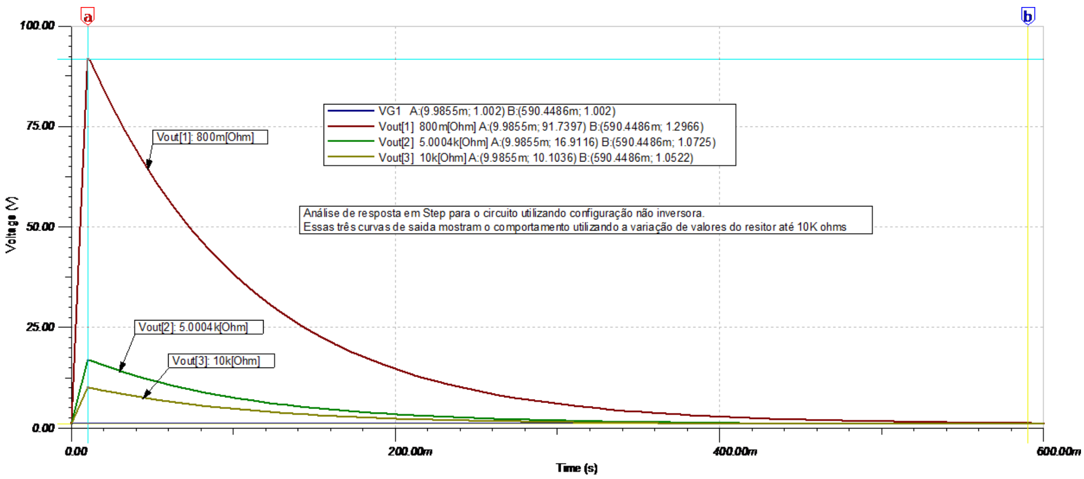


Figure 23: Step Response Amplification

Fig. 24 is the assemble of passive High-Pass Circuit Simulation Right after the Amplification stage:The purpose of considering the passive high-pass filter is to eliminate the DC component at the cutoff frequency.

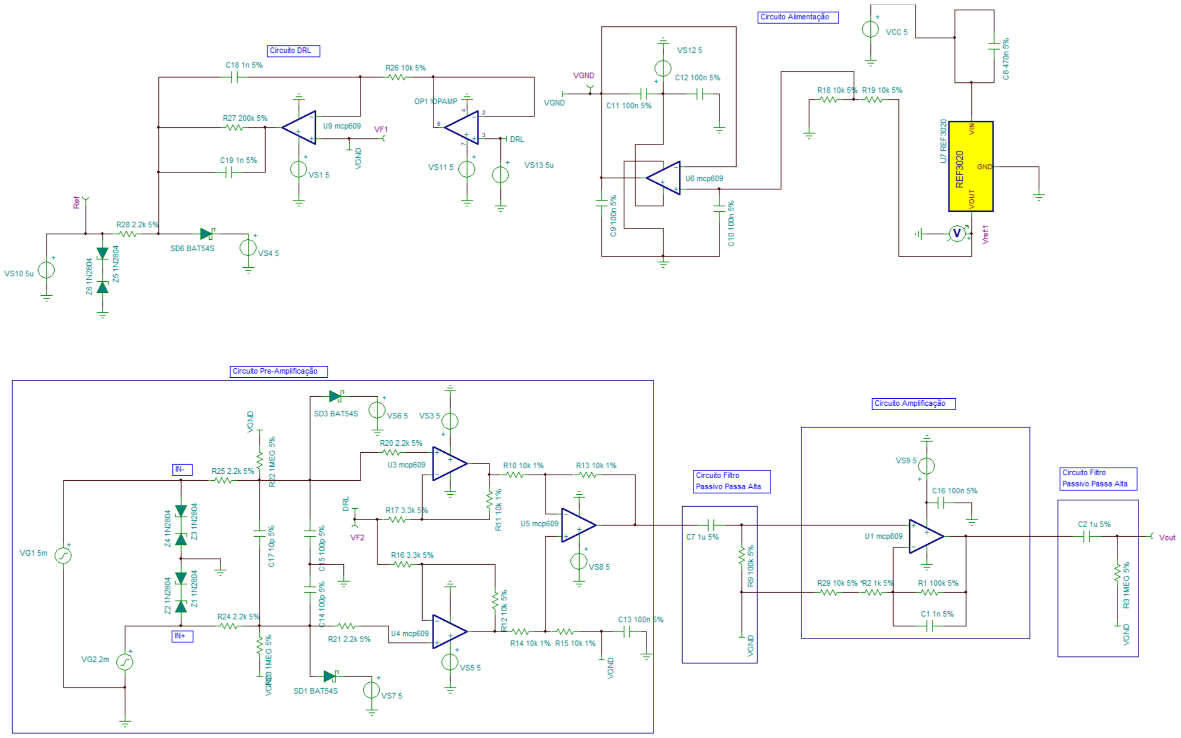


Figure 24: High Pass Filter After Amplification

Fig. 25 shows the simulation in a time window of 120 seconds since the frequencies are low at the input of the circuit to attest the lack of amplification in the circuit and the elimination of the DC component.

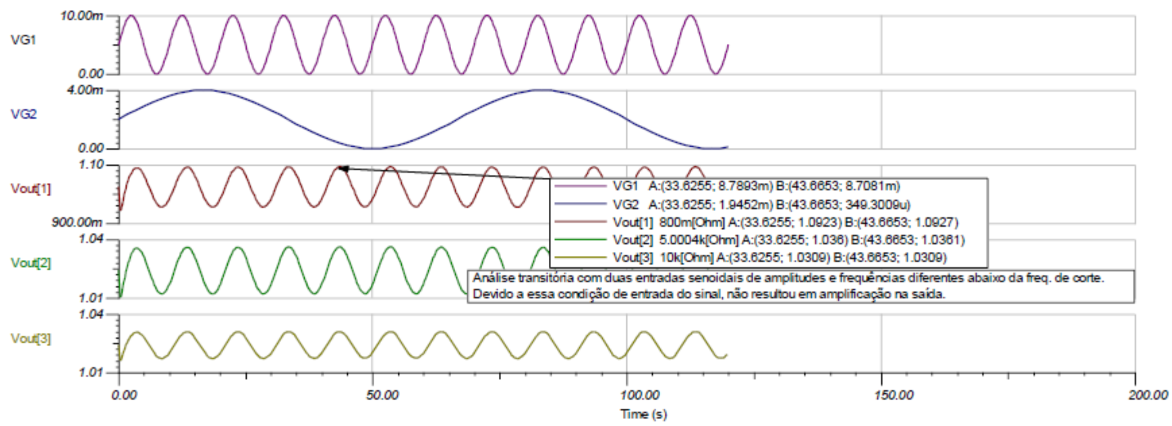


Figure 25: Transient Analysis with Frequencies Lower than the Cut-Off Frequency

In Fig. 26 shows the elimination of the Dc component in the Cir. PA filter. Frequencies below 0.16Hzare blocked and the signal decreased as well.

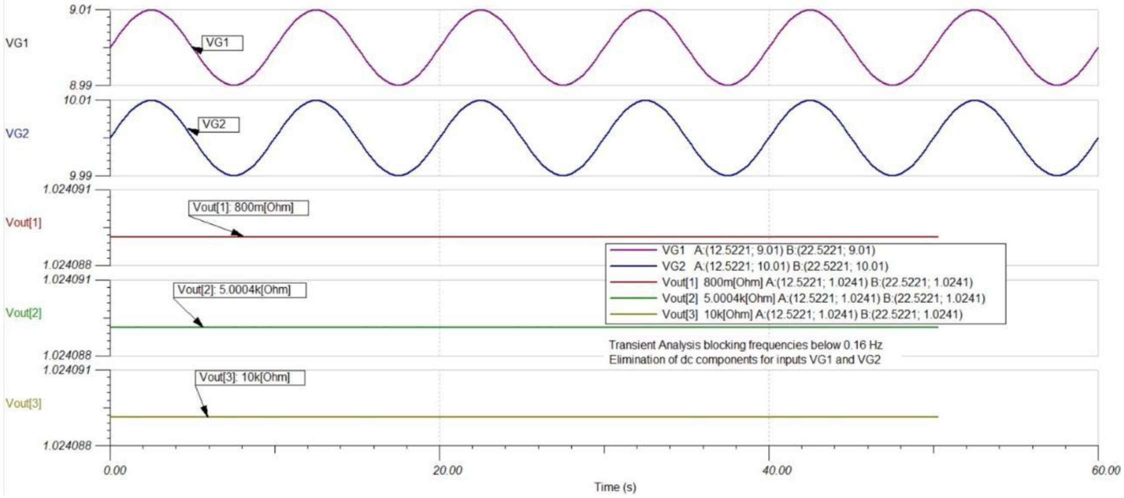


Figure 26: Elimination of the Dc component in the Cir. PA filter

Circ. Simulation. 3rd Order Low Pass (2nd Sallen Key and 1st Passive Filter): In Fig. 27 shows the circuitbuilt in TINA. This is the completion of the circuit in its last stage of virtual assembly to certify the operation of frequencies limited to 60 Hz.

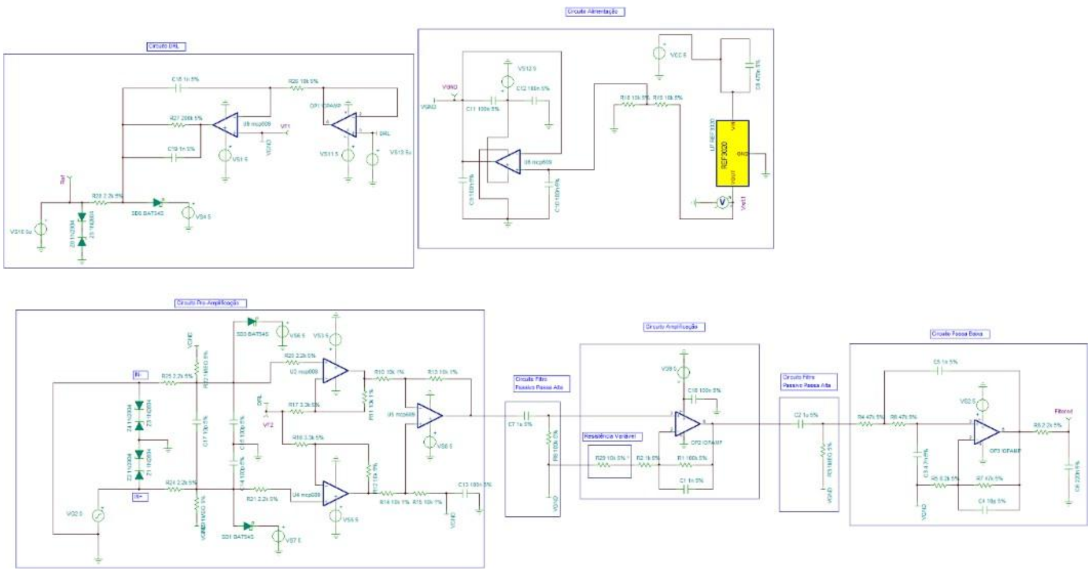


Figure 27: Inclusion of 3rd Order (Active Low Pass Filter Sallen Key + Low Pass Passive Filter RC)

Fig. 28 depicts the transient analysis with signals in 40Hz and by sweeping the potentiometer within therange of conversion for the microcontroller.

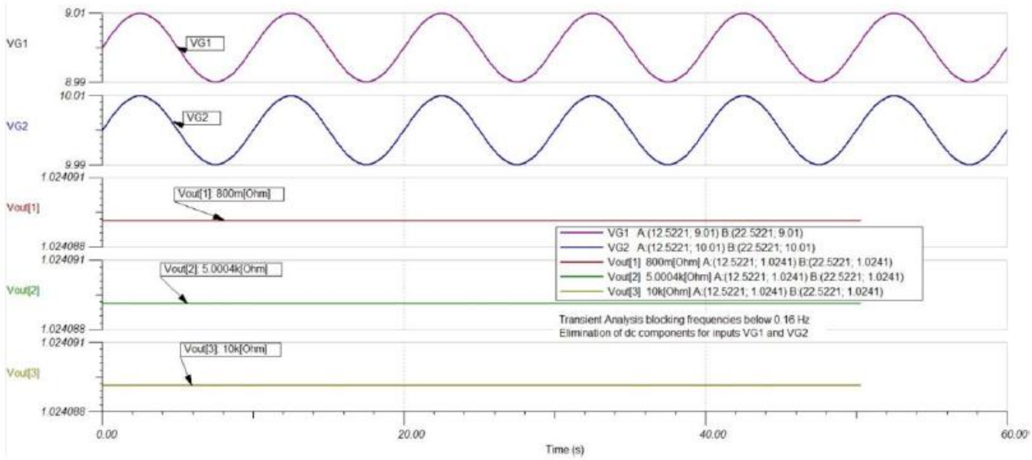


Figure 28: Transient Analysis of the Complete Circuit 40Hz by Sweeping the Potentiometer

Fig. 29 shows the graph results for the transient analysis performed by the same circuit with frequenciesof 500Hz and 1000Hz. The idea is to show the waveform by testing the circuit and check how the values are plotted with frequencies generated by the sources (VG1 and VG2) into the circuit.

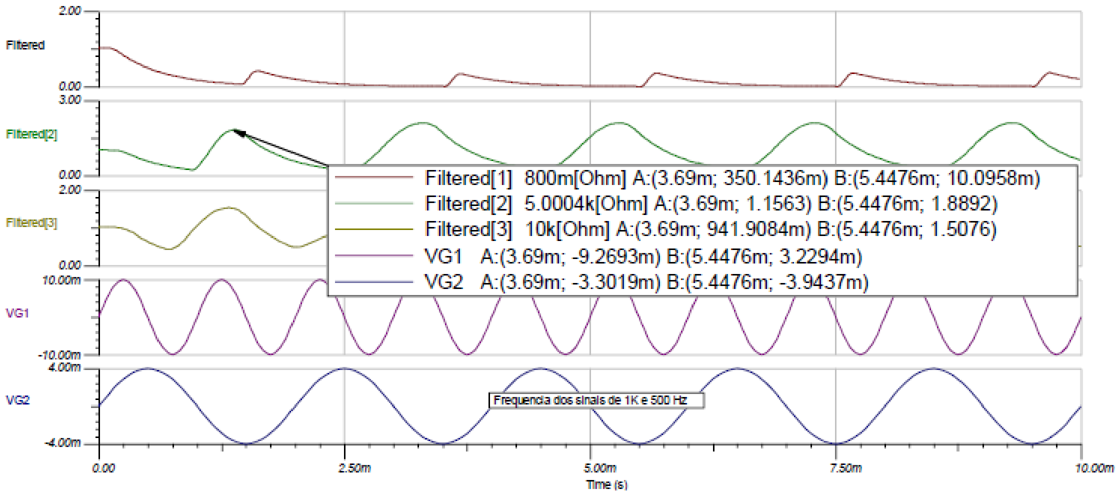


Figure 29: Transient Analysis of the Complete Circuit 500Hz and 1KHz by Sweeping the Potentiometer

Fig. 30 shows the result of the transient analysis of the simulation of the EMG circuit with data acquired from the Analog Discovery Oscilloscope, which has a resource that allows recording the acquired data in .csv and once in possession of these data, Tina can transfer these data in the Piecewise Linear signal generator as input in the signal conditioning circuit and analyze the behavior of the waveform and due conversions of the signal in terms of amplitude to have as a next step the discretization in the Microcontroller. The result of the waveform shown comes from the Biceps EMG and the colors green, yellow, and brown are the different amplitudes generated in the acquisition of the signal with the resistance variation of 10Kohms described in the Circuit as Variable Resistance.

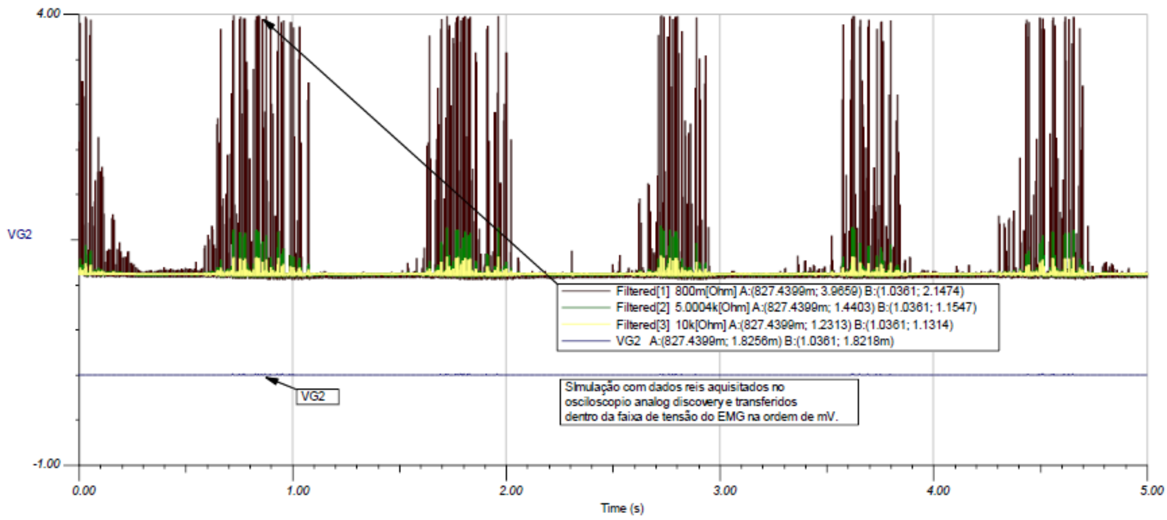


Figure 30: Transient Analysis of the Complete Circuit with Piece Wise Linear Input Signal

1.2 Microcontroller Graphical simulation

After analysis of reversing Engineering of each application of the circuit with its different filters and behaviors along the circuit simulation, the next step is the simulation for the following topics: Flowchart Coding, Programming Development, ADC Conversion and Timer Interrupt, Timer Counting for Output Graphing Plot, String Manipulation, (Min, Max and Average) Level DSP Signal, Simulation of UART Communication, Graphing Results through UART Comm. Graphics Simulation Software for Microcontrollers: The other software to consider for simulation and “Deploy” in hardware is Flowcode from MatrixTSL version 8. It is an advanced graphical programming IDE for electronic and electromechanical system development and hardware test deployment. Fig. 30 shows the main screen environment to illustrate the IDE's coding environment.

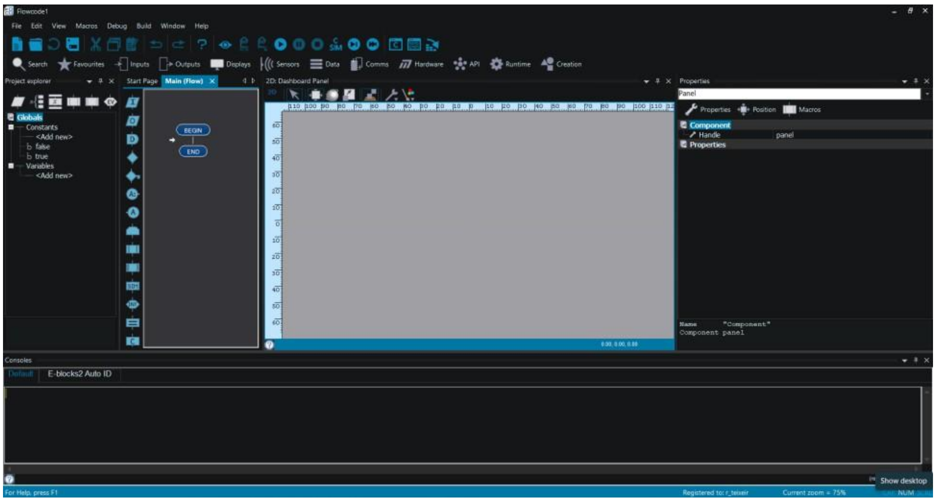


Figure 31: Advanced Graphical Programming IDE for Electronics System Development

In Figs. 32, 33 and 34 illustrated below, show a step by step of the coding using Flowcode by Matrix-TSL. The code starts with the main program by calling the macros that are responsible for each interaction within the components (UART, ADC, DSP). Each component needs to be configured in the properties window with peculiar characteristics for each functionality. For example, the UART Comm, the user needs to configure the COM Port, Baud Rate. For the ADC component the channel must be defined by the user because it is a physical pin. The DSP components must be configured by dragging the input signal into the DSP level, each with its own name and for last the DSP System is the one who manages buffer count, bit depth and if the signal is signed or unsigned. [8], [9],[10],[11],[12].

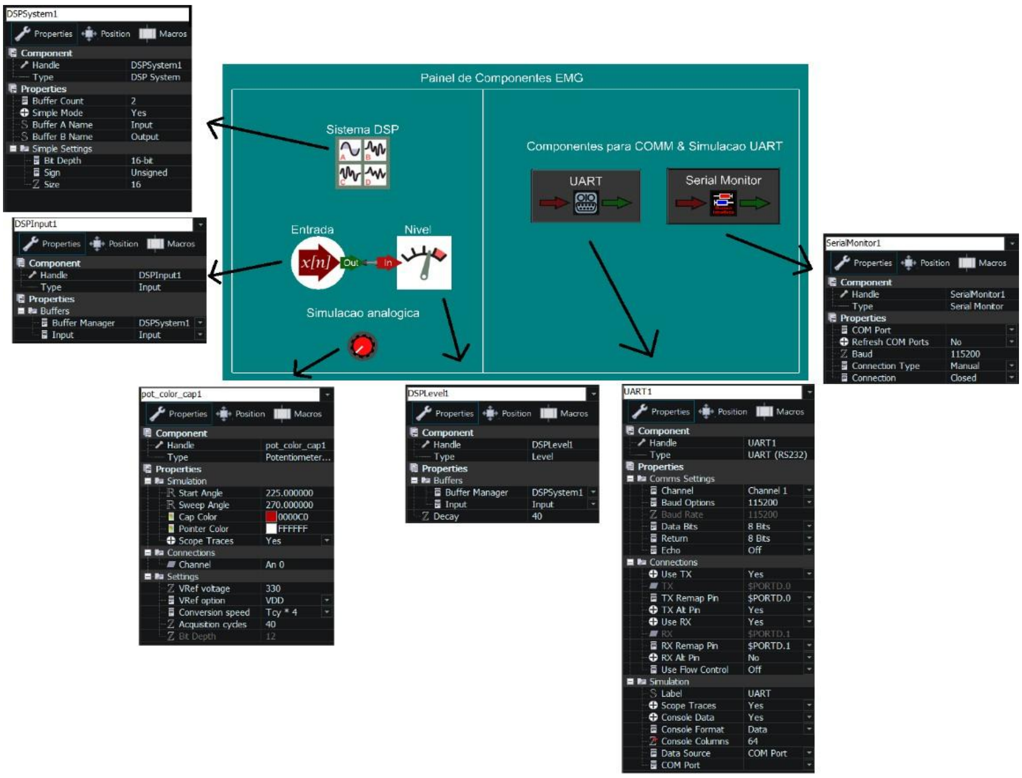


Figure 32: Component Properties

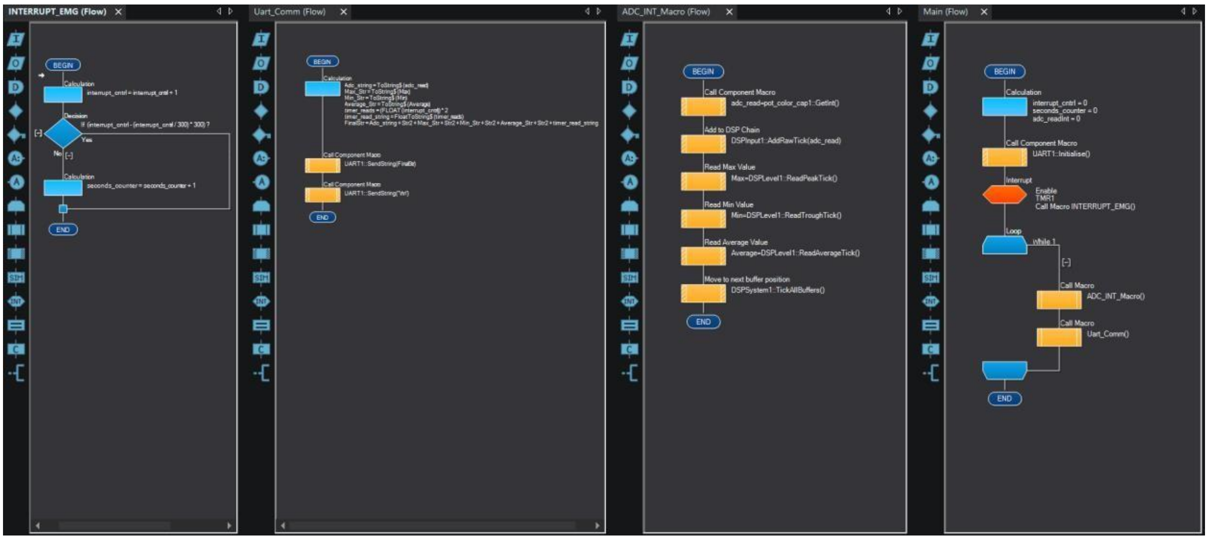


Figure 33: Developed Coding Macros

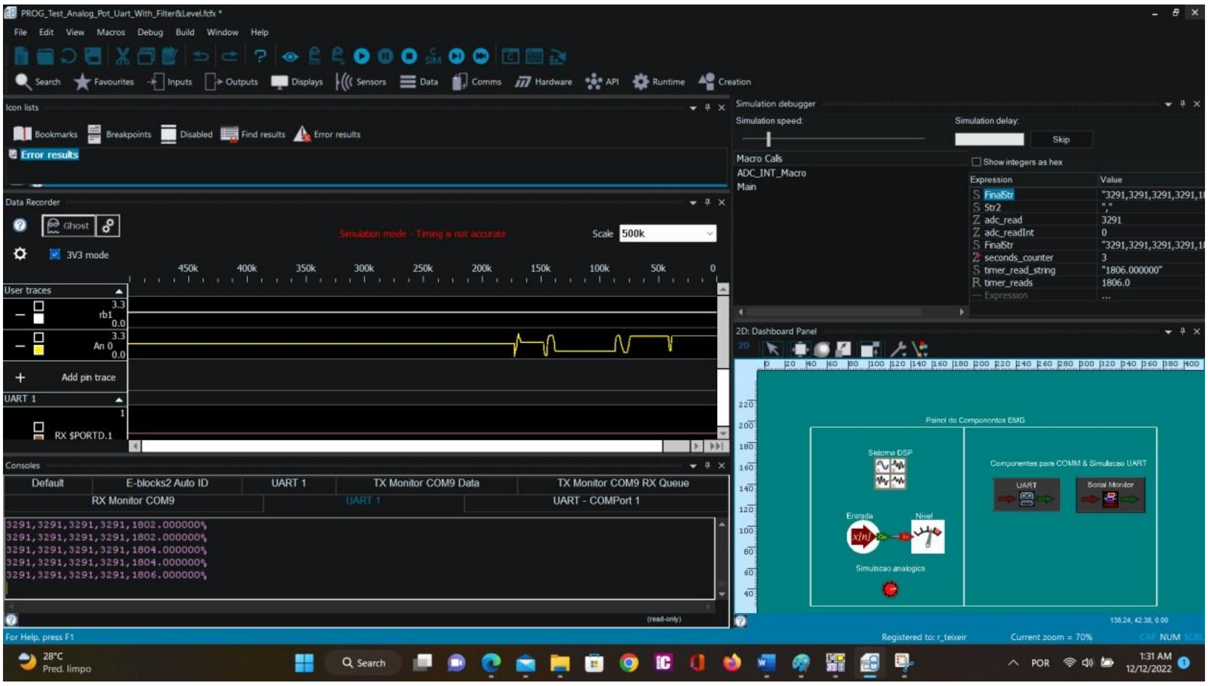


Figure 34: Simulation Data Program

1.3 Hardware Bench Test

Fig. 35 depicts the hardware used for the real data acquired from EMG lick. In Fig. 36 shows the graphic outputted from the USB-UART comm. The signal is discretized from analog to digital converter´s MCU pin. The discretized signal has 200 Hz, time based, interrupt considered, and a time frame for starting the counting timer is also considered for starting of the graphing output the USB-UART. It means that every 3ms staring from 0 seconds, a new measurement in read in the coding and transmitted into Uart. In the analog ADC macro is included the conditioning of the signal with average, maximum and minimum values evaluated in real time by the algorithm as it can be seen of the graphic output.

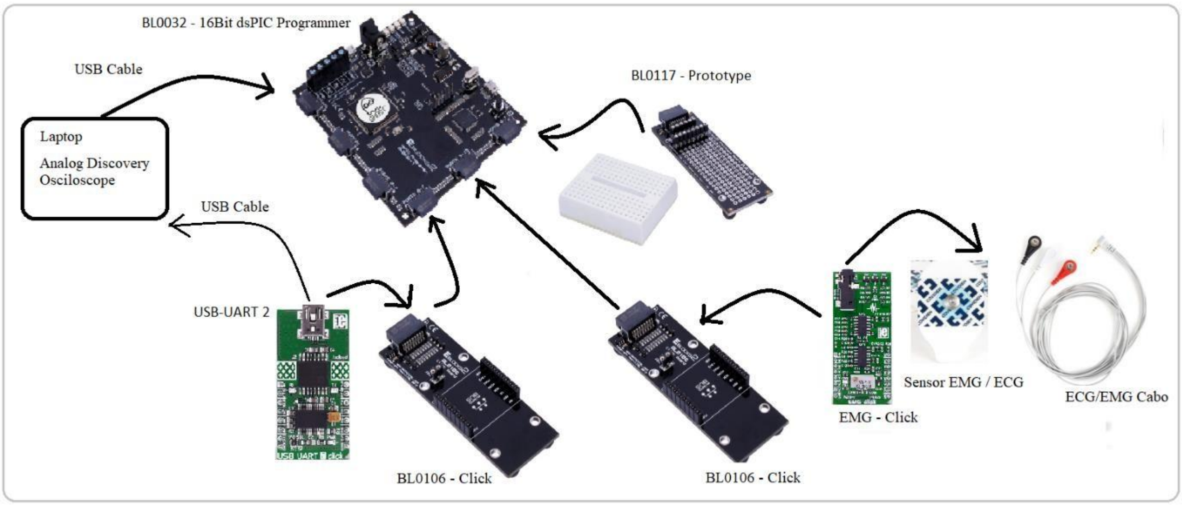


Figure 35: Hardware kits

Figure 36: USB-UART Output data live streaming from EMG Click – MCU [12]

III. CONCLUSIONS AND RECOMMENDATIONS

Based on the results of my studies clearly the use of simulation software speeds up the understanding and analysisof circuits. Each running function standard and very usual on every spice analysis software, brings to the user many features that are important for designs and reduction of budgets before going to assembling on bench tests with real components. One of the features that can add great results for assembling in bench tests and should be on future projects is the thermal results, smoking and noise analysis. It improves the mount pcb traces and increaseeven more the gain when silicon ratio match of resistors is considered during the placement of them on pcb that can affect the value and degrade the matching. For last, the development and testing thru simulation and bench test using DSPic from MatrixTSL were valid experience for checking end results while comparing with oscilloscope waveform reading. The clean signal with great number of features makes the oscilloscope in comparison to the processed embedded system a better option for fast and testing results for the analog and digitalfeatures. The user needs to know that an embedded system needs to be dedicated and the price for and volume as well as other issues cannot be a setback for the customer while running a product. The embedded system has to be totally dedicated for a purpose and easy to manage by the client as a final product.

Acknowledgments
We thank UEMA and PECS for the theoretical and practical classes for the development of this work. Wealso thank UFCG for the partnership in research and scientific guidance. We would like to thank FAPEMA for

encouraging high-level research in the State of Maranhão, Brazil. We thank CAPES and CNPq for promoting and supporting the advanced studies that contributed to this work. Finally, we would like to thank the company Vale S.A. for making its experts available for practical guidance in carrying out the experiments.

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