ECE 302 - Lab #1

Power supply

Abstract

The purpose of this lab was to design a dual rail DC power supply from an AC signal. This power supply needs to provide +/- 10V regulated DC ~~output~~ to a positive and negative rail respectively capable of providing each load with 25mA. The output of these rails requires a maximum ripple of 0.5%(50mV) and a voltage regulation within 5%. To achieve this the transformer was connected to a bridge rectifier to simultaneously retrieve the positive and negative half cycle input. For each of the rails, capacitors were connected in parallel to low pass filter out AC while passing DC components. A unique final regulation stage was used for each rail. For the positive rail a voltage regulator was used while for the negative rail similar results come from a Zener diode and its ballast resistance. For the positive rail we measured 9.8V output with voltage regulation of 0.31% and ripple of 19.3mV. The negative rail measured at 10.2V with a voltage regulation of 0.88% and ripple of 22.9mV. Both rail measurements abide to the specifications stated.

Objectives

The objective of this lab was to design, simulate, build and test a dual rail +/- 10V regulated DC power supply. This power supply needed to be able to supply 25mA to each of the loads while maintaining a voltage ripple below 0.5% (50mV). The reason behind this design is to create a simultaneous full wave positive and negative DC output.

Design

For the desired results of this power supply there are a few connecting parts each serving an important purpose. The circuit consisted of a transformer, bridge rectifier, low pass filters, and voltage regulators. A block diagram illustrating this layout is shown by **Figure 1.** To begin, a Hammond Type C (Model 166D25) transformer was required to step down the voltage provided from the wall outlet. This 60Hz stepped down signal then needed to be shifted down to 0Hz.

Bridge Rectifier

The first part of the design required conversion of the AC transformer bipolar output to a DC unipolar sine wave. This was done by using rectifier diodes (1N4004) arranged in an alternative forward/reverse bias fashion in order to divide the bipolar sine wave into positive and negative half cycles. This forms a bridge rectifier shown by **Figure 2**, which sends the positive half cycles to the positive rail while sending the negative half cycles through opposing diodes to the negative rail.

Part 1 – Positive Rail

The unipolar sine wave sent to the positive rail is still not purely DC and requires a low pass filter to flatten the signal. This will filter out remaining high-frequency components so that a 0Hz DC signal remains. The filter chosen was a $100\mu F$ capacitor connected in parallel, but this wasn't enough to get the voltage ripple within our specifications ($V_{pk-pk} < 1.5V$) so another $10\mu F$ was added to give us a final $110\mu F$ filter.

After the filter we added a μ78L10AC voltage regulator also in parallel to provide a constant voltage regardless of the load used by supressing any more non-zero frequencies. The resistive load value is determined by ohms law while knowing that we want a 25mA load current from the 10V positive rail input. This gives us:

$$R_L = \frac{V}{I} = \frac{10V}{25*10^{-3}A} = 400\Omega. \quad \textbf{(1)}$$

All of this put together resulted in the positive rail design labelled in **Figure 3**.

Part 2 – Negative Rail

Similar to the positive rail, the negative rail output of the rectifier is filtered with parallel $110\mu F$ capacitance. For this rail a Zener (Model 1N4740) was used in series with a ballast resistance to act as the voltage regulator by taking advantage of a low (10 V) reverse breakdown voltage. For our specifications ballast resistance is calculated by:

Peak current on resistor: $I_p = I_L + I_D = 25mA + 2.5mA = 27.5mA$

Ripple Voltage = $V_r = \frac{I_p}{fC} = \frac{27.5mA}{(120Hz)(110\mu F)} = 2.045V$ **(2)**

Ballast resistor= $R_{ballast} = \frac{V_s - V_r - 10}{I_p} = \frac{(19.75-2.045-10)V}{27.5mA} = 280.17\Omega$ **(3)**

The closest singular resistor value available was 270Ω. This regulator was also connected to a parallel load resistance found by **(1)**. This rail is also shown in **Figure 3** – the full circuit schematic.

Results - Simulation

Simulations run on LTSpice using the previously calculated theoretical values allowed us to test various stages before adding them to the breadboard. The values for the transformer are shown in **Figure 4** and implemented into the circuit schematics.

Rectifier

The resulting output of the rectifier terminals compared to the input terminals is shown by **Figure 5** & **Figure 6.** The bipolar sine wave has a value of +/- 22.4V while the two unipolar outputs have respective values of +/- 21.7V.

Filter – $1k\Omega$ test load

Waveforms after the capacitive low pass filter stages are shown by **Figure 7** & **Figure 8.** The voltage ripple has been reduced to an output voltage range of $V_{out} = [20.1, 21.2]V$ for the positive rail and $V_{out} = [-20.1, -21.2]V$ for the negative.

$V_{peak-to-peak} = |V_{max} - V_{min}| = 1.1$V ripple for both rails.

Regulator – 400Ω load

The voltage regulator for the positive rail was unavailable for spice simulations.

The output with the Zener regulator in place was -9.7V - **Figure 14**

Ripple voltage = (9.655054 – 9.652791) *1000mV/V = 2mV – **Figure 14.1**

Results – Lab

Rectifier

The output of the experimental rectifier measured at +/- 20.9V is shown by **Figure 9.1**.

**Filter - ** $1k\Omega$ test load

Positive rail: $V_{peak\text{-}to\text{-}peak}$ = |20.1-19.3| V = 0.8V – **Figure 10**

Negative rail: $V_{peak\text{-}to\text{-}peak}$ = |-18.437V – (-17.480V)| = 0.96V – **Figure 11**

Regulator

Positive rail: No load – **Figure 12.1,** Full load – **Figure 12.2,** Ripple – **Figure 12.3**

Voltage regulation = $\frac{V_{no\ load} - V_{full\ load}}{V_{full\ load}} = \frac{9.83-9.8}{9.8} * 100\% = 0.31\%$

Ripple voltage: $V_r = V_{peak-to-peak} = 19.3$ mV → /10V = 0.19%

Negative rail: No load - **Figure 13.1,** Full load – **Figure 13.2,** Ripple – **Figure 13.3**

Voltage regulation = $\frac{V_{no\ load} - V_{full\ load}}{V_{full\ load}} = \frac{10.29-10.2}{10.2} * 100\% = 0.88\%$

Ripple voltage: V_r =22.9 mV → /10V = 0.23%

Output voltage – 10V

$$\%\ error = \frac{x_{theory} - x_{measured}}{x_{theory}} * 100 \qquad \textbf{(1)}$$

Positive rail: 9.8V → 2% error - **Figure 12.2**

Negative rail: 10.2V→2% error – **Figure 13.2**

Discussion

The purpose of this lab was to design a dual rail power supply with a theoretical 25mA supplied to each rail for a +/- 10V output. Rectifying diodes arranged into a bridge rectifier were used to chop the bipolar sinewave into two separate positive and negative outputs. Spice simulations for this are shown by **Figure 5 & Figure 6** resulting in both a positive and negative rail input voltage of +/- 21.7V. **Figure 9** shows the real rectified voltages with value +/- 20.9V. Using **(1)** a 3.69% error is calculated which allows us to continue to simulate subsequent stages with accuracy. This error comes from a small difference in the supplied voltage in the simulation vs. what is output by the transformer.

For the positive rail a $100\mu F$ capacitor was originally used as a low pass filter to filter out high frequency components of the signal . This did not provide a small enough ripple voltage so another $10\mu F$ was added in parallel. This high capacitance value is available because the electrolytic capacitor uses a dielectric oxide layer with an ion-heavy electrolyte to serve as the cathode. Higher capacitance is directly proportional with storing more energy ($E = \frac{1}{2}CV^2$) allowing us to get a smaller voltage ripple by having a smaller discharge. Positive rail post-filter can now be measured with 1kΩ test load resistance. A Zener diode worked for our purposes but but will not be as precise or able to regulate as well over a larger current range.

Spice simulations for the positive rail shown in **Figure 7** indicate an unregulated +/- 0.5V voltage fluctuation about 20.6V. This is about what we would expect without the voltage regulator used in the lab.

With the 10V μ78L10AC regulator implemented in the prototype circuit, the oscilloscope is used to get no load and full load voltage measurements to determine a regulation of 0.31% with 0.19% ripple. Voltage regulation and ripple are below 5% and 0.5% respectively, meeting our expectations. For a full load specification of +10V output, an error of 2% is calculated with our measured 9.8V.

Similarly, for the negative rail spice simulations of the filtered output result in a +/-0.5V fluctuation about -20.6V displayed in **Figure 8**.

For our circuits negative rail, we used a Zener diode as the voltage regulator. With a reverse breakdown voltage of 10V, it will begin to conduct in the reverse direction once it hits our limit. A series ballast resistance was calculated to be 280.17Ω so we used a close 270Ω singular resistor to reduce error that would increase from combing two to equal our theoretical value. This adjusted value is a reason that our real measurements didn't exactly match the theoretical predictions.

Spice simulations demonstrated a regulated output voltage of -9.7V (**Figure 14)** with a ripple voltage of 2mV (**Figure 14.1)**. This is only a 3% error from our desired output.

In the prototype circuit this Zener regulator resulted in a 0.88% regulation and 0.23% ripple with an output voltage difference of 2%. Again, this falls well within our specifications.

The difference in effectiveness of the regulators is small, but noticeable. The output from the μ78L10AC voltage regulator performed slightly better in terms of a smaller regulation and ripple voltage.

Conclusion

The goal of this lab was to design a dual rail +/-10V DC power supply using power from a wall outlet. It must be able to supply a 25mA current to the load on each rail. The design included a rectifier to turn out bipolar sinewave into two separate unipolar sine waves. With this it was possible to use different stages to implement low pass filtering and voltage regulation techniques. After building each part we used test loads to simulate the loading effect of stages to come.

The positive rail used a 10V voltage regulator while the negative rail used a 10V reverse breakdown Zener diode to achieve similar but slightly less accurate results. With an aim of +/-10V regulated output, our positive rail created an experimental output of 9.8V and -10.2V on the negative rail. This gave an error of 2% for both rails. Each rail required a ripple voltage below 0.5% of the output (50mV). A measured ripple of 19.3mV and 22.9mV for positive and negative rails demonstrates an effective conversion from AC to DC output.

Appendix

Figure 1 – Power supply diagram

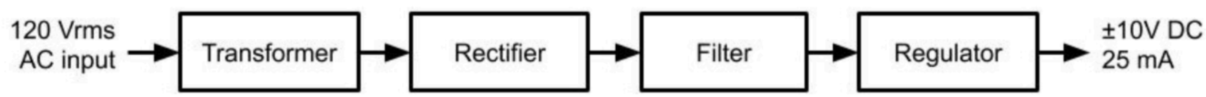


Figure 2 – Bridge Rectifier design

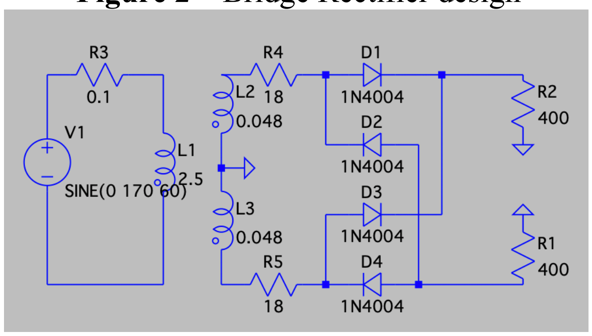


Figure 3 – Full circuit design

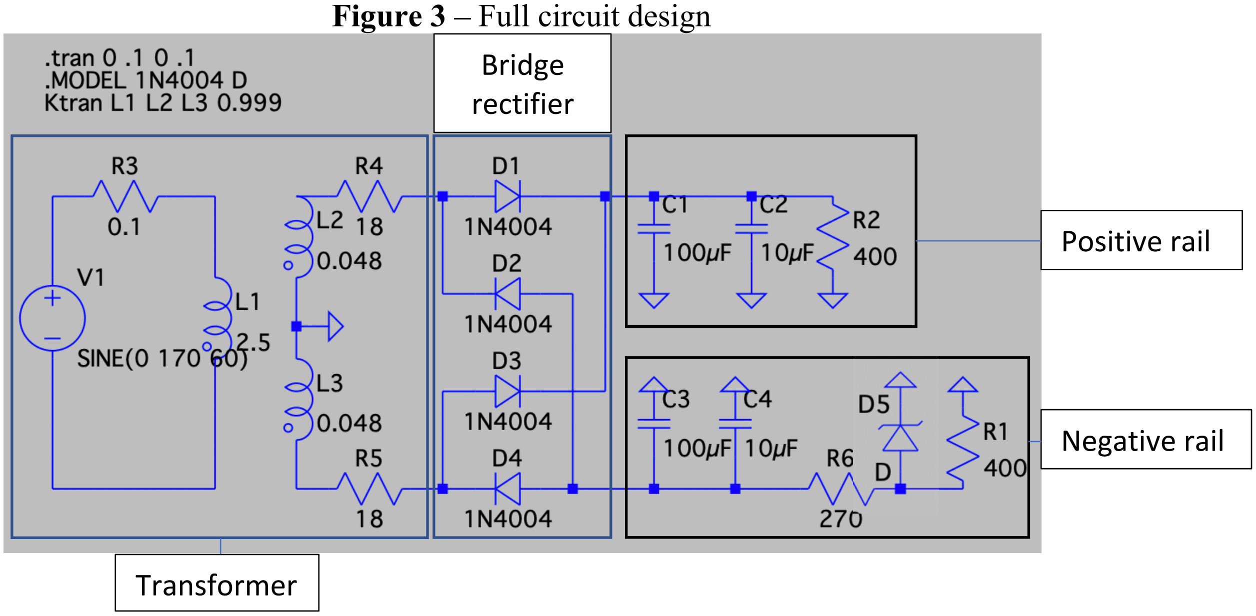


Figure 4 - LTSpice transformer layout

Ktran Lpri Lsec1 Lsec2 0.999

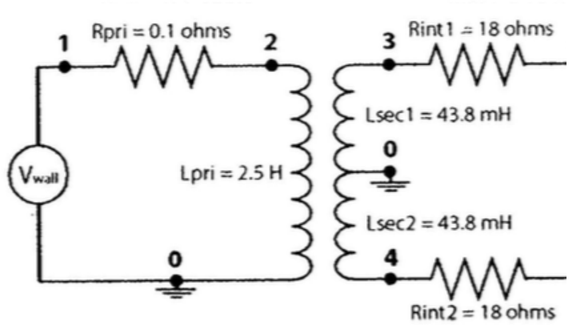


Figure 5 - Input to rectifier

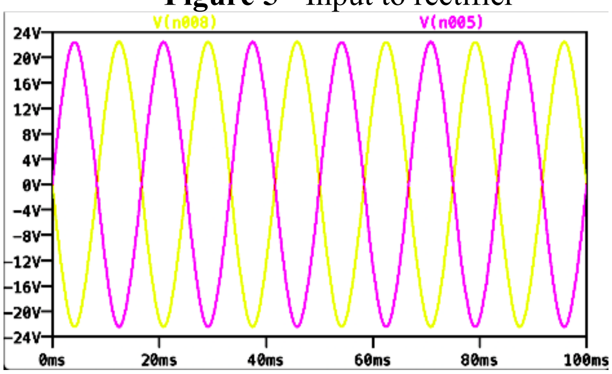


Figure 6 - Output of rectifier

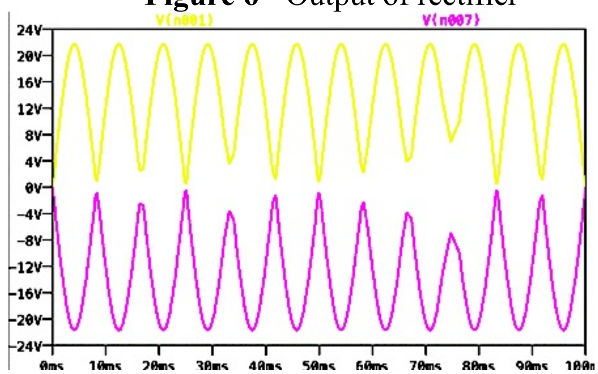


Figure 7 – Positive rail filtered

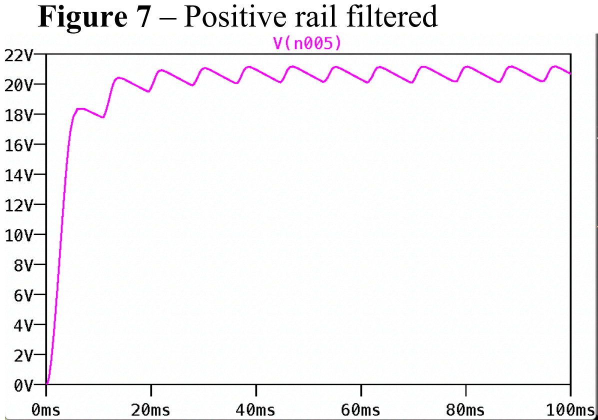


Figure 8 – Negative rail filtered

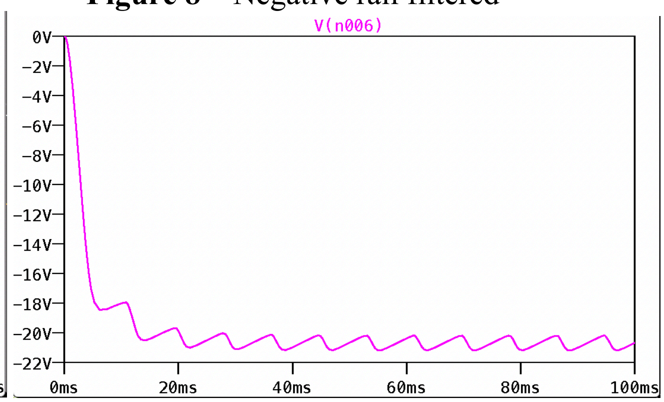


Figure 9 – Input to rectifier

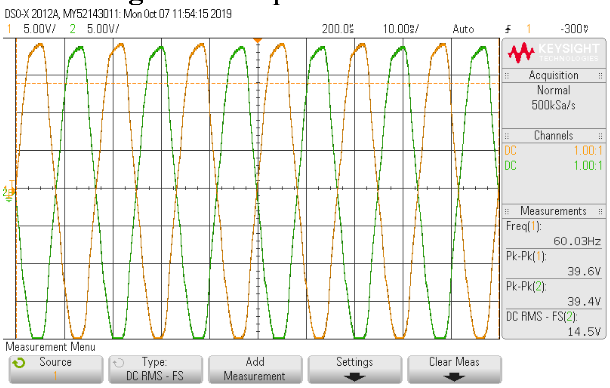


Figure 9.1 – Output of rectifier

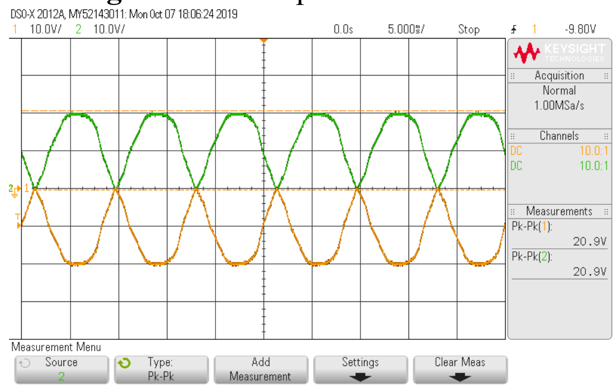


Figure 10 – Positive rail filter

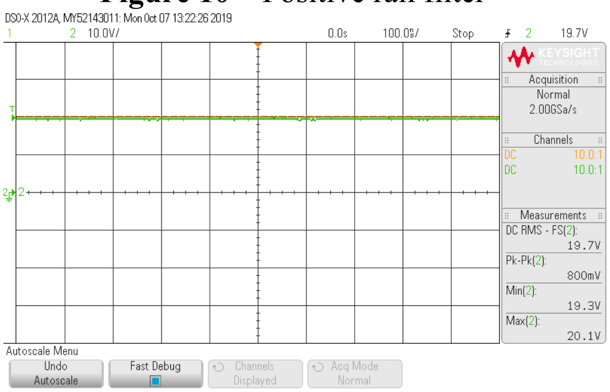
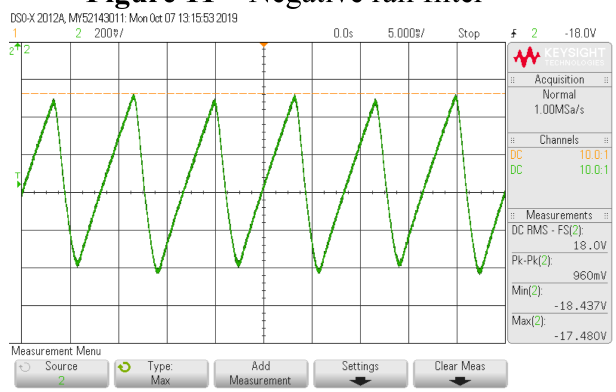


Figure 11 – Negative rail filter



12 - Positive Rail regulator

Figure 12.1 - No load

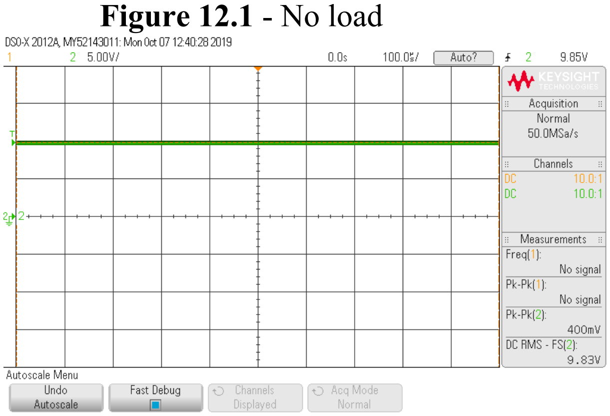


Figure 12.2 - Full load

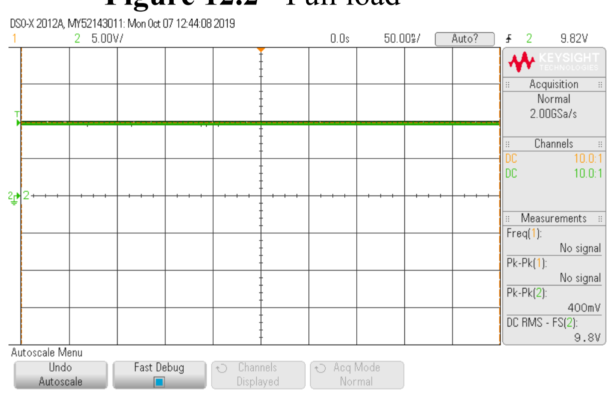
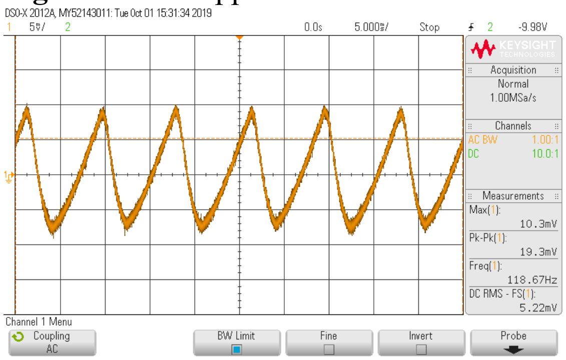


Figure 12.3 - Ripple



13 - Negative rail regulator

Figure 13.1 - No load

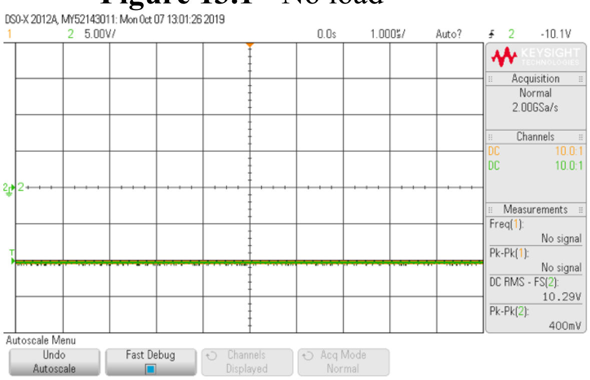


Figure 13.2 - Full load

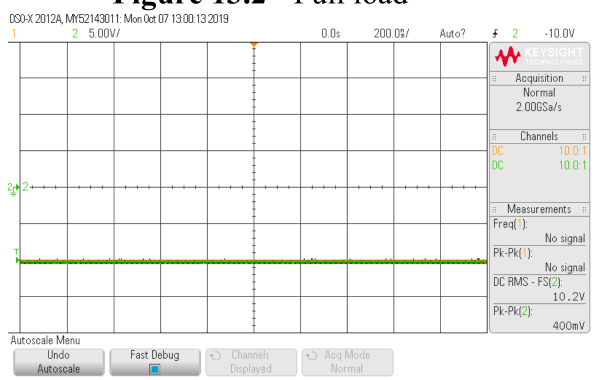


Figure 13.3 - Ripple

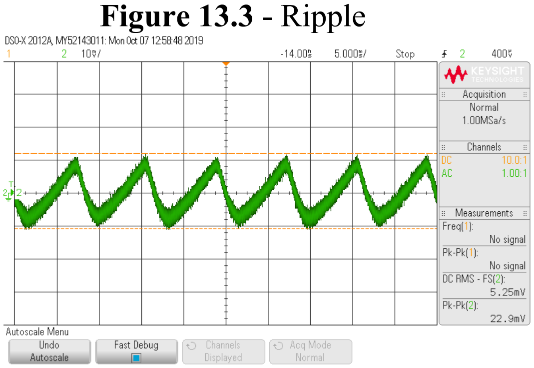


Figure 14 – Negative rail ripple

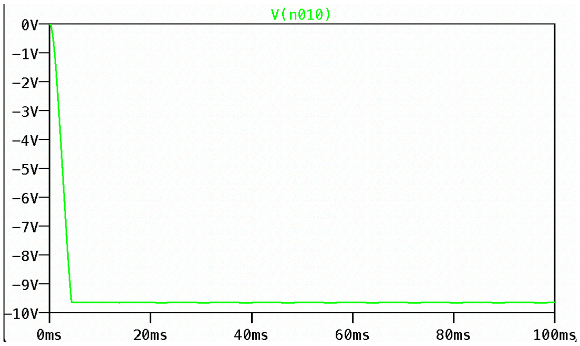


Figure 14.1 – Negative rail ripple

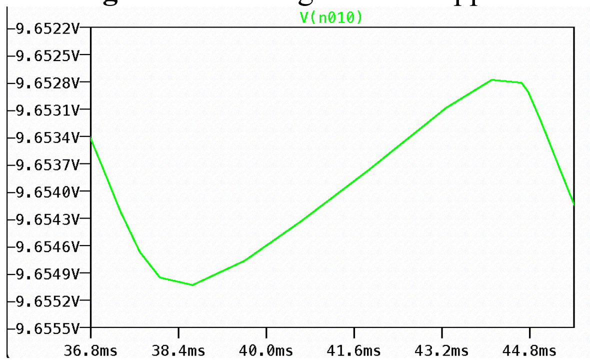


Figure 15 - Agilent DSO-X 2012A oscilloscope/waveform generator for measuring lab results