ECE (302) Lab #1

Dual Rail DC Power Supply

Lab section: (D41) **Bench** #xx **Date:**12/10/2022

Abstract

In this lab, we designed and prototyped a ±10 V, 25mA dual rail supply such that the voltage regulation and ripple voltage were below 5% and 0.5% respectively. The design was divided into three stages - *rectifier stage, filter stage, and regulator stage*. During lab 1A, we designed and implemented both the rectifier and filter stages one after the other. The rectifier helped chop the bipolar signal and produce positive and negative nonzero, unipolar signals, while the low pass filter helped to remove the AC component and produce a smooth signal. However, the filtered signal still had some voltage ripple which required a regulator to be completely smoothed out. This was taken care of in part B using a zener-shunt regulator. The result was a dual rail supply adhering to the objective constraints. All 3 of the stages were first simulated with the aid of LTSpice before being implemented on SK-10 breadboard with the provided 302 lab components. The prototype results were measured using the Agilent InfiniiVision 2000 X-Series oscilloscope. This report entails our design process, results, and discussion regarding the experiment.

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Our signatures certify that we are submitting our own, original work only, and do so in accordance with the University Code of Student Behaviour and APEGGA's Code of Ethics.

1.1 Objectives

The objective of the lab is to design and prototype a ±10 V, 25mA dual rail supply such that the voltage regulation and ripple voltage was below 5% and 0.5% respectively. The design is to be divided into three stages - *rectifier stage, filter stage, regulator stage*. A step down transformer should be used to reduce the input AC voltage of 120 Vrms by a factor of 4. This stepped down AC voltage would be the input for the rectifier, which serves the purpose of chopping the bipolar signal to produce both positive and negative non zero,unipolar signals. These signals are then to be passed through a low pass filter in order to remove the AC component and produce a smooth signal. The rectifier and filter stage should be designed and implemented during lab 1a before moving on to the regulator stage. The filtered signal from part-a would still have a voltage ripple to some extent which would need to be completely smoothed out. A zener shunt regulator would be ideal for this purpose in part-b.

1.2 Design

As mentioned in the objective, the design is divided and tested as three different stages which work in tandem to provide the desired output. Dividing the project into multiple stages made it easier to narrow down and identify any problems with the design. All the equations and calculations used during the design process have been included in the results section.

1.2.1 Lab 1a

This part of the lab required us to design and test the rectifier and filter stage. For the rectifier stage, we decided to use a full wave rectifier over a half wave rectifier since a full wave rectifier produces a higher average output voltage and less ripple compared to an equivalent half wave rectifier. The rectifier has two inputs and two outputs, the inputs being the transformer voltage and the output being the rectified voltage which would eventually be passed through a filter.

The first step was to design the circuit in LTSpice, including the transformer output and the rectifier. Since the other stages hadn't been designed at this point, we used loads as a replacement in order to measure the output voltage from the rectifier. Running the simulation showed that the stepped-down voltage was rectified such that the bipolar signal was chopped to produce non-zero unipolar signals(≈±20V). This gave us a good idea of the output to be expected from the prototype.

Before implementing the circuit as a prototype, the transformer output was measured and noted. The measured value was V_{max} = 20.7V and V_{min} = -20.9V. We then implemented the rectifier circuit as a prototype using diodes and resistors and used the oscilloscope to measure the rectified voltage, first the positive rail then the negative. As expected, the bipolar signal was chopped to produce non-zero unipolar signals with the appropriate amplitude. Even though the signal was rectified, there still existed an AC component which required smoothening. Hence we proceeded to the filter stage to get rid of the AC component.

A capacitor filter is capable of increasing the DC voltage while reducing the ripple voltage. Hence, to reduce the AC component, we first replaced the load with a capacitor in the LTSpice schematic to run simulations for the filter stage. The result was further smoothening of the rectified voltage. Again, having the expected results at hand, we implemented the circuit as a prototype and measured the output voltage using the oscilloscope. We obtained results that were agreeable with the simulation results and took down the measurements. These measurements were used to calculate the peak-to-peak voltage which was less than 1.5V. This marked the end of part 1a. Additionally, we performed some preliminary design work for the regulator stage.

1.2.2 Lab 1b

Having successfully completed the rectifier and filter stage during lab 1(a), we proceeded to the regulator stage. In part (a) we managed to convert the bipolar signal to positive and negative nonzero unipolar signals using a full wave rectifier and further used a capacitor as a low pass filter to get rid of the AC components. However, there was still some ripple voltage which was to be minimized using a Zener shunt regulator. For this purpose, we utilized zener diodes, along with a ballast resistor to limit the current flowing through the diode. The first step was to determine the ballast resistance. This was achieved by first calculating the ripple voltage, which was about 2.29 V. Using this value, we evaluated two scenarios of the capacitive voltage, one where the voltage is constant, and another case when there's a ripple voltage involved. Using the two different cases we obtained two different ballast resistances, the average of which we used as our ballast resistance.

Having obtained the ballast resistance, we further modified the LTspice schematic to include a regulator for the positive rail and another for the negative rail. The simulation was run first with no load and then 400 ohm resistances placed parallel to each regulator. Running the simulation displayed complete smoothening of the filtered voltage by suppressing any variations in the voltage. In order to implement this design into a prototype, we used a 220 ohm and an 82 ohm resistor in series to achieve a ballast resistance close to our required value of 303 ohms. Similar to the simulation, we took the positive and negative rail readings for both full load and no load scenarios. Having obtained the results from the oscilloscope, we calculated the ripple voltage and voltage regulation to ensure that they met the constraints of being lower than 0.5% and 5% respectively.

1.3 Simulation Results

Note:

- For Figures 1-5 the nodes mentioned in each figure can be found in the Figure 6
- Figures 1-6 are simulations prepared by Priyanka Goradia
- Figures 14-18 are simulations prepared by Kaucek Arunkumar (found in Appendix)

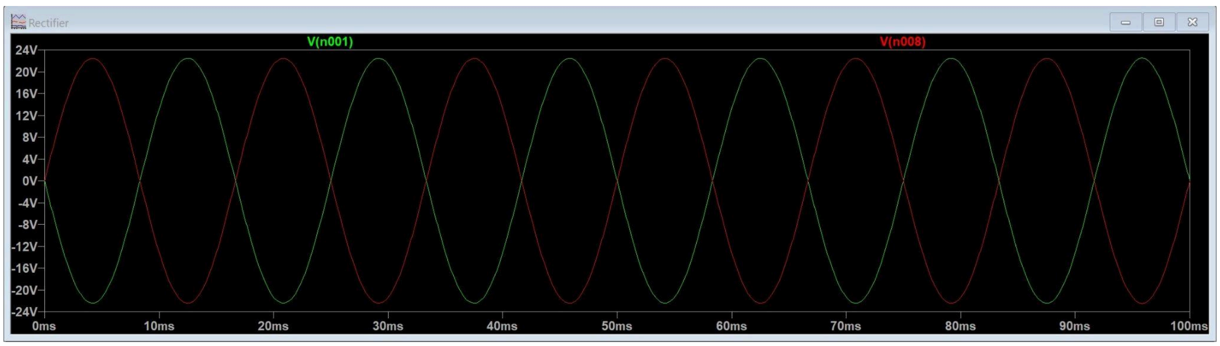

Figure 1: *Transformer Output*

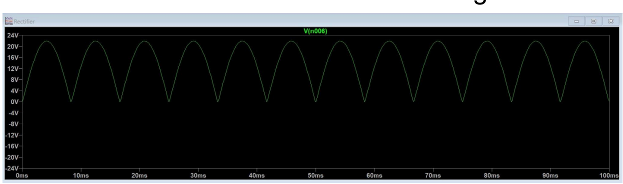

Figure 2: *Rectifier Positive Rail Output*

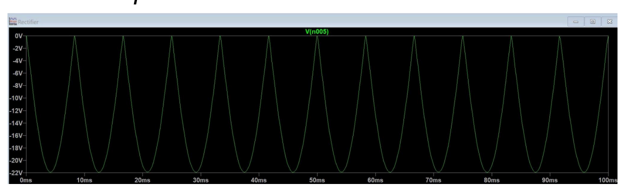

Figure 3: *Rectifier Negative Rail Output*

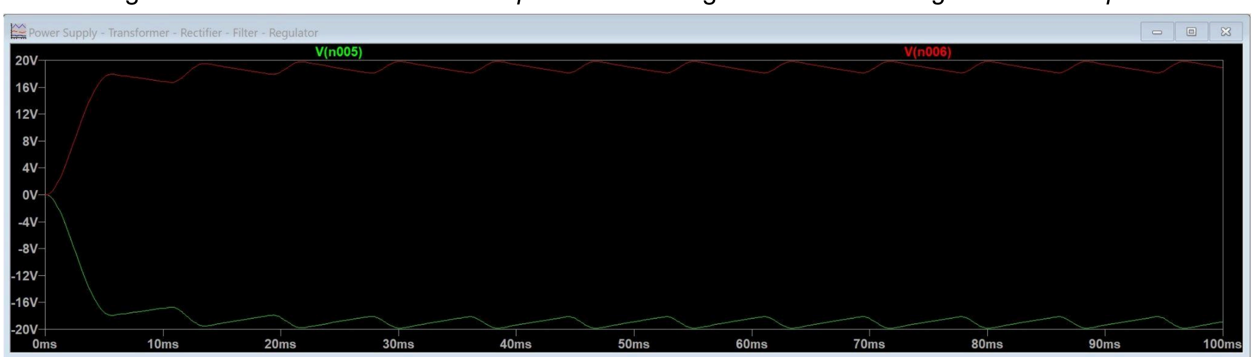

Figure 4: *Filter Outputs (Positive rail - Red, Negative Rail - Green)*

Figure 5: *Regulator Outputs (Positive Rail - Red, Negative Rail - Green)*

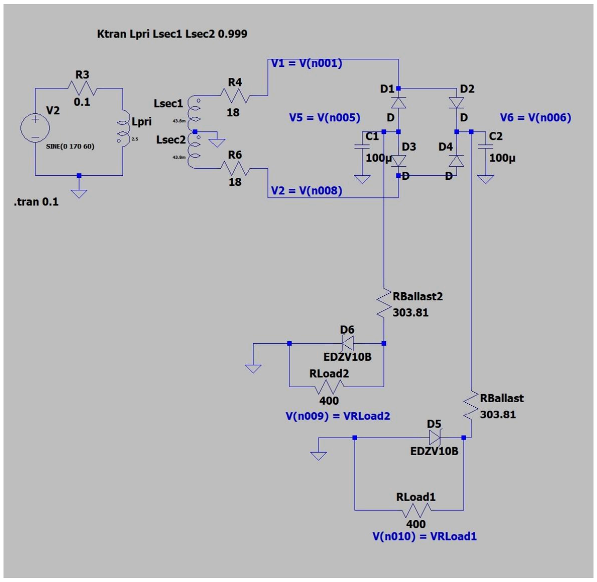

Figure 6: Dual Rail *DC Power Supply Circuit*

1.4 Discussion

The performance of the circuit was measured based on the comparison made between the results from theory, prototype and simulations. A summary of the comparison is tabulated in Table 1.

a) Theoretical results:

I_{out} : Current supply requirement for the circuit (output current) = 25mA.

V_{in} : Input Voltage = 120V rms ; (This voltage is the output voltage of the transformer)

f : Frequency = 60 Hz

C : capacitor used for the filters = 100uF

V_{out} : Output Voltage (Expected DC Voltage from the power supply) = 10 V

$V_{out,max}$ = 10V

$V_{out,min}$ = -10V

Diode : EDZV10B, Break-down Voltage= 10.21V, I_{zk} (Reverse bias current) = 0.25mA

Calculating the Load Resistor value, RLoad:

$$R_{Load} = \frac{V_{out}}{I_{out}} = \frac{10V}{25mA} = 400\ \Omega$$; *Equation 1*

Calculating $R_{Ballast}$:

For the zener diode used in reverse bias (I_{zk}: knee zener current = 0.25 mA), the effective reverse bias current will be I_z = 2.5mA ($I_z = 10*I_{zk}$). The current across R_{Load} will be maximum (i.e. I_{out}) and the current across the zener diode will be minimum (i.e. I_z). Then $I_{Ballast}$, the current through $R_{Ballast}$, is given as:

$$I_{Ballast} = I_Z + I_{out} = 2.5mA + 25mA = 27.5mA$$; *Equation 2*

We consider 2 cases for Vc (Voltage across $R_{Ballast}$) while calculating $R_{Ballast}$, which is given by,

$$R_{Ballast} = \frac{V_C - V_{out}}{I_{Ballast}}$$; *Equation 3*

i) $V_c = V_p$

V_p is the peak output voltage from the filter

$V_c = V_p$ = 19.5V

$R_{Ballast,1}$ = (19.5V - 10V)/27.5mA = 345.455Ω

ii) $V_c = V_p - V_r$

Vr is the Ripple Voltage

$$V_r = \frac{I_{Ballast}}{2*f*C}$$; *Equation 4*

V_r = 27.5mA / (2*60Hz*100uF) = 2.29V

V_c = 19.5 V - 2.29V = 17.21V

$R_{Ballast,2}$ = (17.21V - 10V)/27.5mA = 262.18Ω

$$R_{Ballast} = \frac{R_{Ballast,1} + R_{Ballast,2}}{2}$$; *Equation 5*

$R_{Ballast}$ = (345.55Ω + 262.18Ω)/2 = 303.81Ω

b) Prototype Results

Following were some design choices made during the prototype design:

i) $R_{Ballast}$ = 302Ω (2 resistors in series: 220Ω + 82Ω)

ii) R_{Load} = 398Ω (2 resistors in series: 330 Ω+ 68Ω)

iii) Diode used in the rectifier: General Purpose D041

iv) Measured V_{out} :

Positive Rail:

$V_{peak\text{-}to\text{-}peak}$ (AC Coupling) = 4.8mV ; Figure 7

$V_{out,\ Full\ load}$ (DC Coupling) = 10.9V ; Figure 8

$V_{out,\ No\ load}$ (DC Coupling) = 11.04V ; Figure 9

Negative Rail:

$V_{peak\text{-}to\text{-}peak}$ (AC Coupling) = 20.6mV ; Figure 10

$V_{out,\ Full\ load}$ (DC Coupling) = - 9.18V ; Figure 11

$V_{out,\ No\ load}$ (DC Coupling) = -10.09V ; Figure 12

v) Calculated $\%V_{ripple}$

Positive Rail:

$\%V_{ripple} = V_{peak\text{-}to\text{-}peak} * 100/V_{out,\ Full\ load}$ = 4.8mV*100/10.9V = 0.04%

Negative Rail:

$\%V_{ripple} = V_{peak\text{-}to\text{-}peak} * 100/V_{out,\ Full\ load}$ = 20.6mV*100/9.18V = 0.22%

vi) Calculated %VRegulation

Positive Rail:

$\%V_{Regulation} = (V_{out,\ No\ load} - V_{out,\ Full\ load})*100/\ V_{out,\ Full\ load}$

= (11.04V - 10.9V)*100/10.9V = 1.28%

Negative Rail:

$\%V_{Regulation} = (V_{out,\ No\ load} - V_{out,\ Full\ load})*100/\ V_{out,\ Full\ load}$

= ((-10.09V)-(-9.81V))*100/-9.81V = 2.85%

c) Simulation Results

V_{out}: $V_{out,max}$ = 9.95V and $V_{out,min}$ = -9.95V

$R_{Ballast}$ = 303.81Ω

R_{Load} = 400Ω

i) Measured V_{out} :

Positive Rail:

$V_{out,\ No\ load}$ (DC Coupling) = 9.97V

$V_{out,\ Full\ load}$ (DC Coupling) = 9.95V

$V_{peak\text{-}to\text{-}peak}$ (AC Coupling) = 20mV

Negative Rail:

$V_{out,\ No\ load}$ (DC Coupling) = -9.97V

$V_{out,\ Full\ load}$ (DC Coupling) = - 9.95V

$V_{peak\text{-}to\text{-}peak}$ (AC Coupling) = 20mV

ii) Calculated $\%V_{ripple}$

Positive Rail & Negative Rail

$\%V_{ripple} = V_{peak\text{-}to\text{-}peak} * 100/V_{out,\ Full\ load}$ = 20mV*100/9.95V = 0.2%

iii) Calculated $\%V_{Regulation}$

Positive Rail & Negative Rail

$\%V_{Regulation} = (V_{out,\ No\ load} - V_{out,\ Full\ load})*100/\ V_{out,\ Full\ load}$

= (9.97V - 9.95V)*100/9.95V = 0.2%

Discrepancies Observed:

On comparing the results $V_{out,max}$ and $V_{out,min}$ values in parts a), b) and c) we observed the following discrepancies:

i) V_{in} (voltage from the transformer) was lower than expected in the prototype in comparison to that measured in the simulations and theoretically, due to the internal resistance of the physical transformer device. This could also be a result of poor wiring and/or insulation resistance within the transformer. These factors tend to take a toll on the efficiency of the transformer and could potentially result in low voltage output. There is also a considerable heat-loss in the transformer, which causes the transformer voltage to fluctuate.

ii) $V_{out,max}$ and $V_{out,min}$ values in the results from the prototype and the simulations vary slightly in comparison to the expected theoretical value of +10V and -10V. This is because theoretically, it is assumed that the resistance of the zener diode used is minimal, however when implemented physically, the prototype and the simulations take it into account and thus the voltage across the diode and the diode resistance drops below 10V. Moreover, our ballast resistance was calculated to be around 303.81 ohms, however we could only use a couple of resistances in series to produce 302 ohms. The discrepancy in the output voltage could be a result of this slight variation in $R_{Ballast}$.

iii) V_{out} is different for the prototype and the simulation because in the case of simulations it is assumed that the rectifier diodes (general diodes) used are ideal, i.e. there is no voltage drop across them when they are on. However in the prototype, resistance values associated with the diodes affect V_{out}, causing V_{out} to be lesser when measured from the prototype compared to the simulation. A marginal difference in V_{out} also results from the fact that wires have internal resistance in the prototype and the wires used in the simulations do not have resistance.

Sensitive Components

Electrolytic capacitors are used in the prototype which means the voltage on the positive terminal must always be greater that the voltage on the negative terminal, otherwise the dielectric strength will break down resulting in the insulating aluminum oxide layer to melt. This causes the outer insulation layer to heat up and eventually the enclosure bursts. During the experiments for this project, one of the capacitors burst due to the above reason.

Possible Improvements in the Design:

To get more accurate results following design modifications can be implemented:

i) Minimizing the number of wires used can reduce the voltage drop due to the internal resistance of the wires. One way to achieve this is to design the whole circuit on a PCB.

ii) The readings for the positive and negative rails were taken using different transformers, causing some discrepancies in V_{in} (output voltage of the transformer).

Performance Evaluation of the Prototype Circuit
Based on the results of the prototype circuit,
i) V_{Ripple} % < 0.5 % (for both positive and negative rails)
ii) And $V_{Regulation}$ % < 5% (for both with and without load conditions in the positive rail and negative rail)

1.5 Conclusions

The purpose of this project was to design a DC power supply with a current supply of 25mA and the output DC voltage of +10V (max) and -10V (min) (Figure 6). This was achieved using a transformer, bridge rectifier, capacitive filters and zener shunt regulators. From the discussion, we can see that the $\%V_{Ripple}$ and $\%V_{Regulation}$ are within the expected ranges. Thus, the performance of the power supply design is satisfactory. Improvements in the results can be expected if the difference between the $R_{Ballast}$ used in the circuit and the theoretical value is further minimized. $\%V_{Ripple}$ is comparable for prototype and simulation results with a difference of 0.02% for the negative rail and 0.18% difference for the positive rail, simulation % being higher and lower respectively (Table 1). There's a noticeable difference in the %VRegulation with a difference of 1.26% and 2.83% in the positive and negative rails respectively, with simulation % being lower (Table 1). Overall, the results are within the expected ranges as per the performance evaluation.

1.6 Tables and Figures

Oscilloscope screenshots

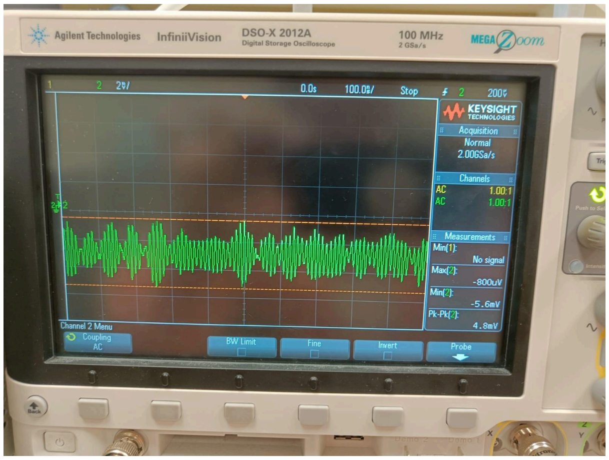

Figure 7: *Positive Rail AC Coupling with Load*

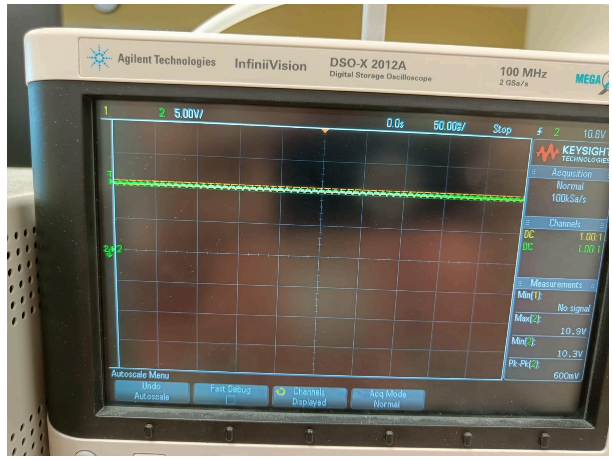

Figure 8: *Positive Rail DC Coupling with Load*

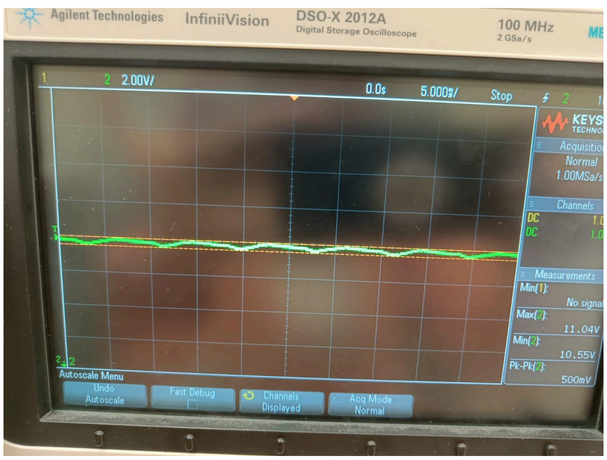

Figure 9: *Positive Rail DC Coupling without Load*

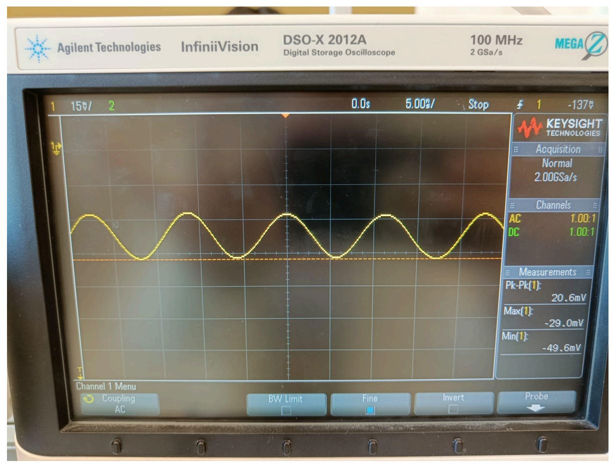

Figure 10: *Negative Rail AC Coupling with Load*

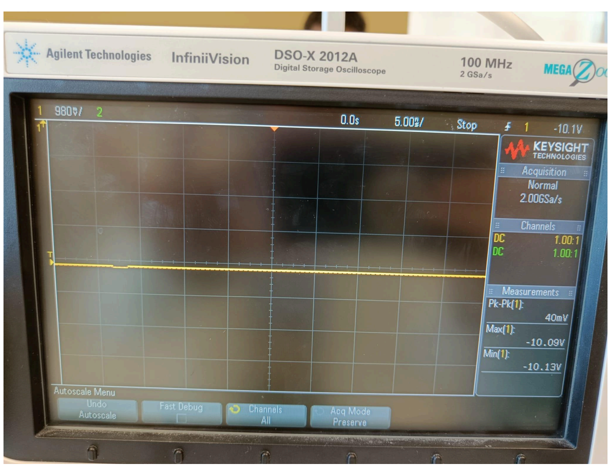

Figure 11: *Negative Rail DC Coupling with Load*

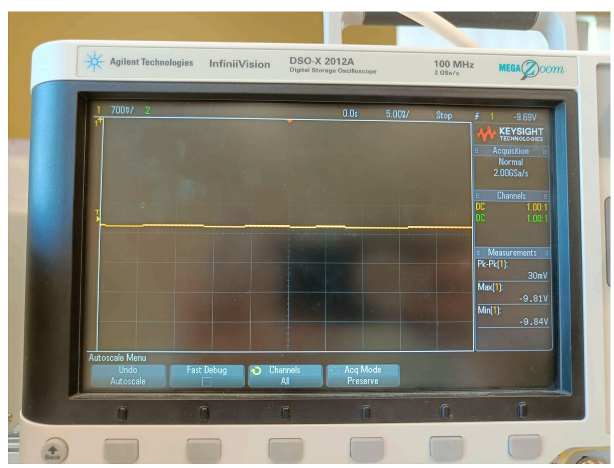

Figure 12: *Negative Rail DC Coupling without Load*

Parameter	Theoretical Results (Reference Values)	Prototype Results	Simulation Results
%VRegulation (Positive Rail)	0	1.28	0.2
%VRegulation (Negative Rail)	0	2.85	0.2
%VRipple (Positive Rail)	0	0.04	0.2
%VRipple (Negative Rail)	0	0.22	0.2

Table 1 : Comparing Results based on %VRegulation and %VRipple values

1.7 Appendix

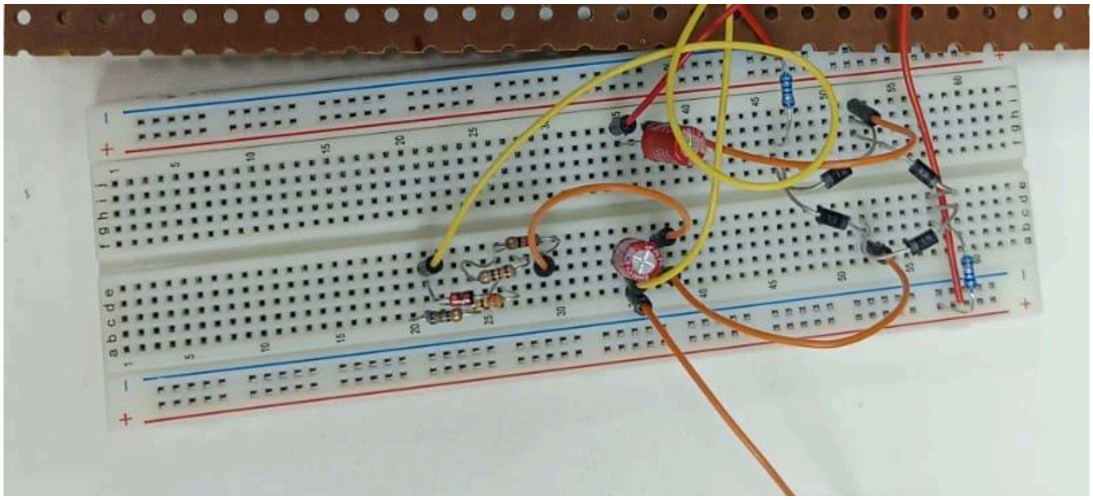

Figure 13: Prototype Circuit

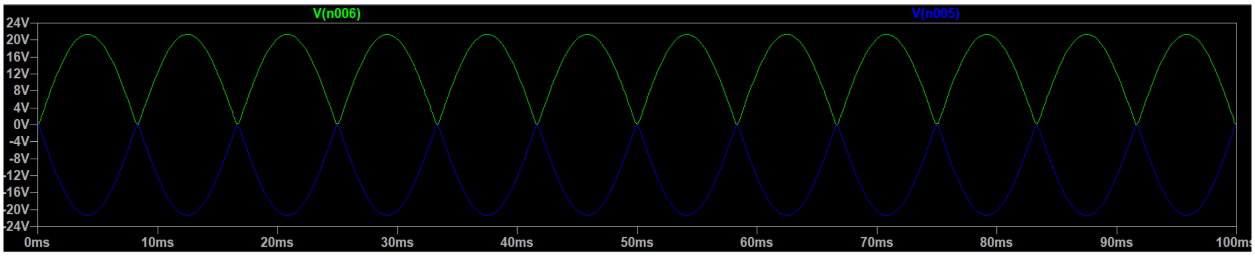

Figure 14: Transformer Output

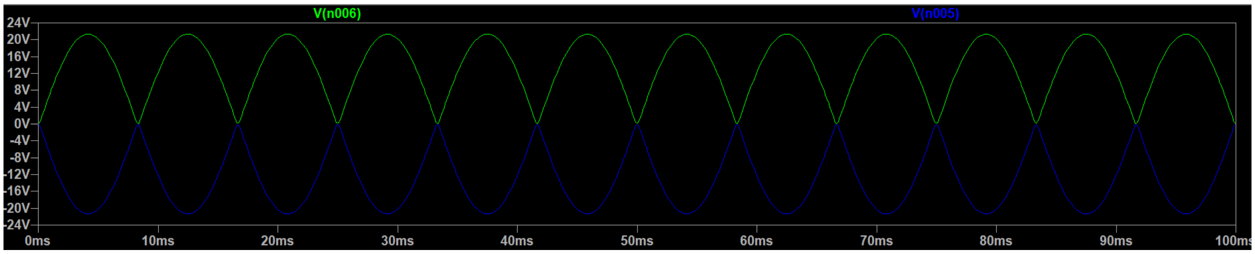

Figure 15: Rectifier Outputs (Green - Positive, Blue - Positive)

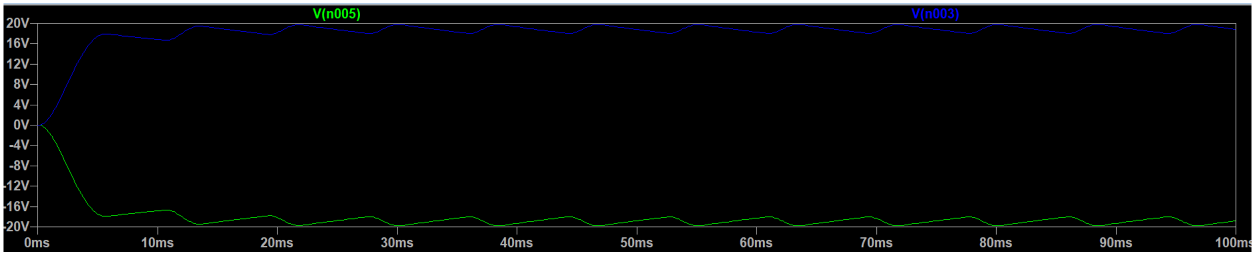

Figure 16: Filter Outputs (Blue - Positive, Green - Negative)

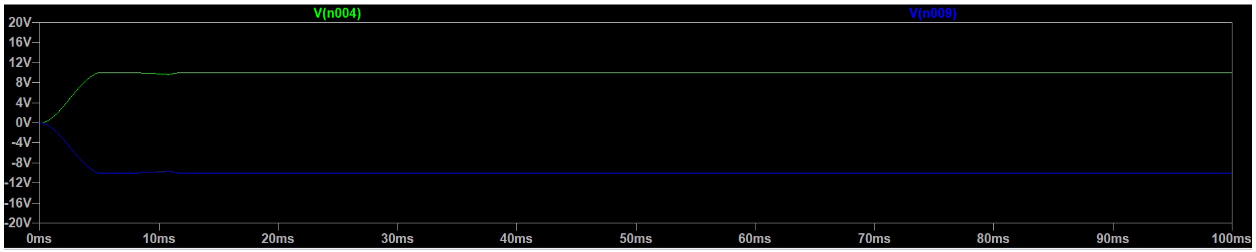

Figure 17:Regulator Outputs (Blue - Positive, Green - Negative)

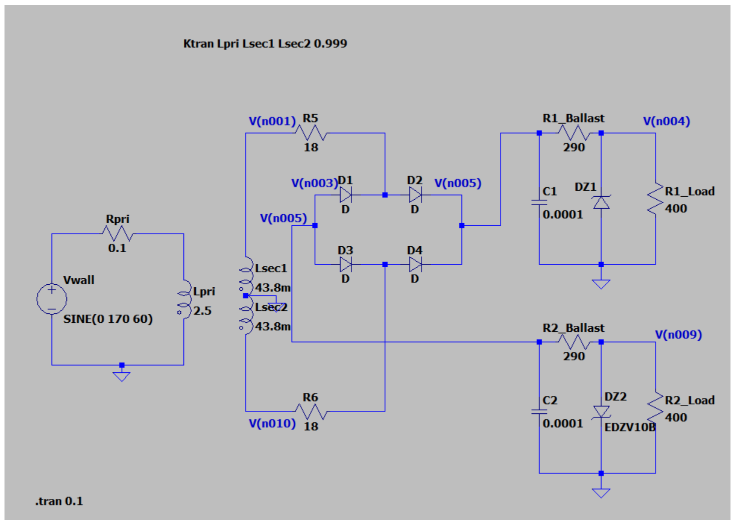

Figure 18: Dual Rail *DC Power Supply Circuit*