THE PENNSYLVANIA STATE UNIVERSITY

EE 310 : ELECTRONIC CIRCUIT DESIGN I

Power Supply Design Project

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Introduction:

Scope

The scope of this lab was to design a power supply capable of taking an AC voltage and converting it to a regulated DC low-voltage. This was accomplished using a transformer, a bridge rectifier, and a filter capacitor circuit to create a linear regulated power supply. The power supply was connected to a Zener voltage regulator, and an IC regulator that could supply a specific voltage to a load.

Design Specifications

The power supply was designed such that it could provide a DC output voltage of +15 V ± 0.5 V to a load dissipating 1 watt, from an AC input voltage of 120 V RMS ±5% at 60 Hz. In addition, it had to provide a nominal DC voltage at the regulator input of +24 V with a ripple voltage less than 15% with the load attached.

Circuit Design:

- Transformer

The first task was to characterize the transformer being used. The purpose of the transformer was to "step down" a 120 V RMS signal to about 20 V to be connected to a rectifier.

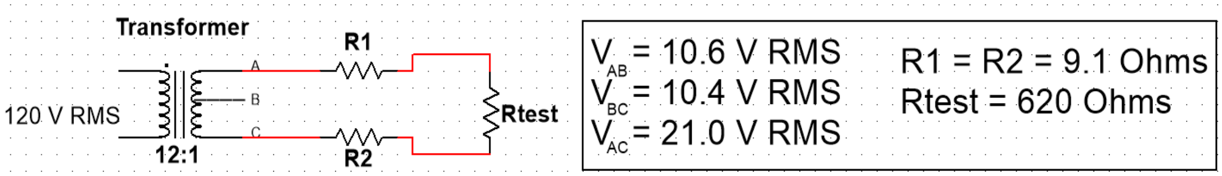


Figure 1: Model Transformer

In Figure 1, R1 and R2 represent the winding resistance associated with the transformer and Rtest was the load resistor available. The open circuit voltages are also shown. The peak open circuit voltage is $\mathbf{V_{s\text{-}pk}}$ **= <u>29.7 V</u>**.

Calculation of the winding resistance:

$$2\,R_w = V_{AC}\text{ (no load) RMS} - V_{AC}\text{ (load) RMS} / I_{Rtest}$$

Also,

$$I_{Rtest} = V_{AC}\text{ (load) RMS} / R_{test}$$
$$= 20.4\text{ V} / 620\ \Omega$$
$$= 32.9\text{ mA}$$

Therefore,

$$R_w = (21.0\text{ V RMS} - 20.4\text{ V RMS}) / [2(32.9\text{ mA})]$$

$$R_w = 9.1\ \Omega$$

Rectifier

The specifications required use of a full-wave bridge rectifier which has a few advantages compared to the full-wave center tap rectifier. First, the bridge rectifier has half as many turns for the secondary winding and second, the Peak Inverse Voltage (PIV) that the diodes must sustain is half of what the diodes would have to sustain without breakdown. One advantage that the center tapped configuration has is that it requires half as many diodes. Our specifications required a 24 V peak output.

Calculation of the Peak Inverse Voltage (PIV):

$$PIV = (V_{s\text{-}pk} - V_D)*2$$

*The factor of 2 is to build in a safety margin. V_D comes from the diode datasheets. We started by looking up the datasheet for the **1N4004 Diode**.*

$$= (29.7\text{ V} - 0.93\text{ V})*2$$

PIV in our circuit = 57.54 V

PIV from datasheet = 400 V

Therefore, we have plenty safety margin regarding the PIV experienced by the diodes.

Filter Capacitor

A filter capacitor was necessary to minimize the ripple voltage and bring the output voltage closer to a steady value.

Calculation of Filter Capacitor:

$C = V_{Max} / 2f^*R_L'^*V_r$

Where V_{Max} is the max output voltage from the rectifier (Fig. 3), f is the AC line frequency (60 Hz), RL' is the same as R_{test} (actual), and V_r is the max ripple voltage which was specified in our design requirements as no more than 15% of V_C, or ***3.6 V.***

$C = 27.8\ V / [2(60\ Hz)^*(620\ \Omega)^*(3.6\ V)]$

$C = 104\ \mu F$

In the stockroom, we got a 104 µF capacitor, keeping cost and size restraints in mind.

Prediction of max diode current:

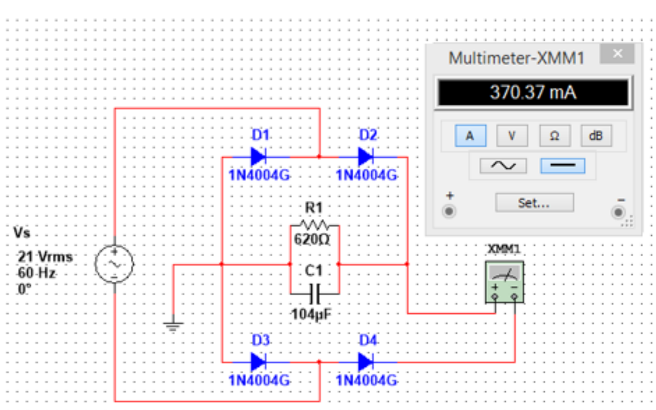
$i_D = (V_M /R)[1+2\Pi^*sqrt(V_M /2V_r)]$

Where V_M is the max output voltage from the rectifier once the capacitor was inserted, (Fig. 4), R is the resistor we used to test the transformer, and V_r is the max ripple voltage which was specified in our design requirements.

$i_D = (26.7\ V / 620\ \Omega)[1+2\Pi^*sqrt(26.7\ V / 2^*3.6\ V)]$

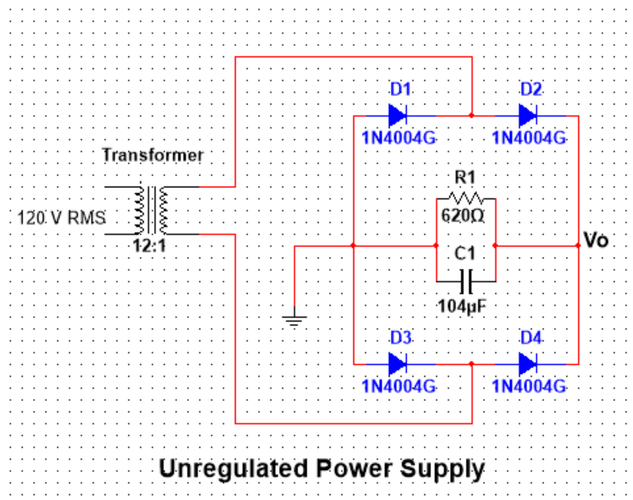
$i_D = 564\ mA$

Multisim Simulation of max diode current:



Unregulated Power Supply

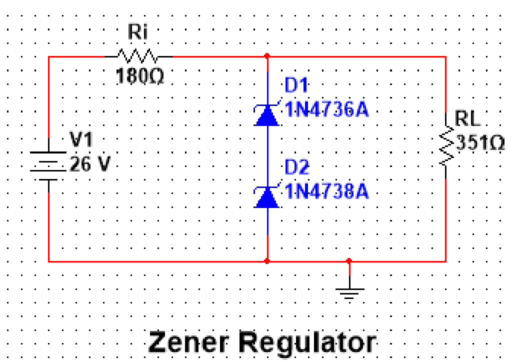
The combination of the transformer, bridge rectifier, and the filter capacitor created an unregulated power supply. The term ‘unregulated’ refers to the fact that the output voltage changes if the input voltage changes or if the load changes. The goal of this lab was to create a regulated power supply. In the following schematic, Vo is the output voltage seen at the voltage regulator input.



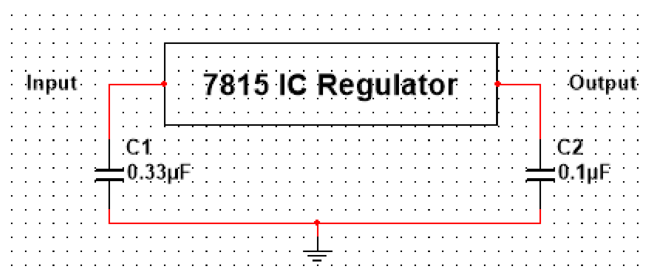
Unregulated Power Supply

Voltage Regulator

In order to create a useful power supply, it has to be regulated which can be done many ways. We implemented two voltage regulator circuits, first was using Zener diodes and second was using an IC voltage regulator.



Zener Regulator



The Zener Regulator works by adding the specific Zener voltages (6.8 V for the 4736 and 8.2 V for the 4738) to produce a total voltage of 15 V DC across the load. Any fluctuations in the input voltage get regulated by the Zeners. The IC regulator simply takes an input voltage range and provides a specific DC output voltage.

Zener Regulator:

According to our design specifications, we needed a DC output voltage of +15 V. In order to do this, we added two Zeners in series (as explained previously) so the voltage across them and hence the output voltage, was +15 V. The voltage coming into the Zeners was 26.0 V.

Parameter calculations:

Iz (max) = Pz/Vz

Where Pz=0.5W and Vz is the larger single zener voltage used and there is no load present.

Iz (max) = 0.5W / 8.2 V

Iz (max) = 60.98 mA

And,

Iz (min) = 30% Iz (max)

Iz (min) = 18.29 mA

Therefore,

I_L = 42.7 mA

And,

R_i = [Vc – Vz (max)] / Iz (max)

R_i = (26.0 V – 15.0 V) / 60.98 mA

R_i = 180Ω = 166Ω from stockroom

Finally,

R_L = Vz (total) / I_L

R_L = 15.0 V / 42.7 mA

R_L = 351Ω = 372Ω from stockroom

Percent Regulation of Zener Regulator:

% Reg. = {[V_L (no load) – V_L (load)] / V_L (no load)} x 100

% Reg. = [(15.1 V – 14.6 V) / 15.1 V] x 100

% Reg. = 3.3% (within 5% tolerance)

IC Regulator:

Based on design specifications, a 7815 IC Regulator was chosen to produce a DC output voltage of +15.0 V. Using an IC to regulate the voltage should have improved regulation and less ripple compared to the Zener Regulator.

Percent Regulation of IC Regulator:

% Reg. = {[V_L (no load) – V_L (load)] / V_L (no load)} x 100

% Reg. = [(15.1 V – 15.1 V) / 15.1 V] x 100

% Reg. = 0%

Comparing Regulators:

The Zener voltage regulator was fairly good at regulating the output voltage with a 3.3% regulation but the IC regulator had better performance as expected with a 0% regulation. The IC regulator had less ripple and had less voltage regulation which makes it clearly the better choice.

Power Considerations: Power Dissipated and Built-in Margin

For this project we had to choose components that were conservatively rated, to give us the most reliability with our circuit. We did this by including a *safety margin of 1.5 - 2* associated with power dissipation. (i.e. if a resistor will be dissipating 1W, choose a 2W resistor when you build it)

Calculating power dissipated for each component: $P=I^2R$ or $P=IV$ or $P=V^2/R$

Rtest: $P = I^2R$ = (32.9 mA)^2 x 620 Ω) = **0.671 W** (choose 1W resistor)

Filter Cap: P = IV = (372 mA)(26.0 V) = **9.7 W** (choose 18 W cap)

Rectifier Diodes: P = IV = (372 mA)[12sqrt(2) V] = **6.3 W** (choose 12 W diode)

Zener Diodes: (4736) P = IV = (60.98 mA)(6.8 V) = **0.4 W** (choose 1W)
(4738) P = IV = (60.98 mA)(8.2 V) = **0.5 W** (choose 1W)

Discussion:

Comparison of outputs to design specifications

- Our design specified:

DC output voltage = +15 V ± 0.5 V
Nominal DC voltage at the regulator input = +24 V
Ripple voltage (max) = 15% of Vc with load
R_L chosen to dissipate 1 watt
AC input voltage = 120 V RMS ± 5% @ 60 Hz

- Our results were:

DC output voltage = +15.1 V
Nominal DC voltage at the regulator input = +26 V
Ripple voltage (max) = 1.1 V (3.6 V = 15%)
R_L = 620 Ω
AC input voltage = 120 V RMS ± 5% @ 60 Hz

- Based on these results, our power supply worked as intended.

Error calculations and reasons

- Percent error is defined as:

% error = abs{[(accepted value – measured value) / accepted value]} x 100

The error in our DC output voltage is:

% error = abs{[(15 V – 15.1 V) / 15 V]} x 100

% error = 0.67%

The error in our nominal DC voltage at the regulator input is:

% error = abs{[(24 V – 26 V) / 24 V]} x 100

% error = 8.3%

The error in our AC input voltage is:

% error = abs{[(120 V RMS–120 V RMS) / 120 V RMS]} x 100

% error = 0%

- The error associated with our nominal DC voltage was probably due to the fact that components are not perfect. There is a tolerance margin associated with each component. Because of this, our voltage was probably skewed slightly. Our other percent errors show accurate creation of the power supply we were required to design.

Summary and Conclusions:

The purpose of this lab was to use a transformer, rectifier, filter capacitor, and voltage regulator to supply a specified voltage to the load. In part 1 of the lab we turned an AC input voltage to a single polarity, then confined the voltage to a small ripple. In part 2 of the lab we tested two methods for regulating this voltage; Zener diodes and an IC. Together, the two labs combined to form a regulated power supply. There were two regulators tested, a Zener Regulator, and an IC Regulator. Based upon the percent regulation, the IC regulator was the better choice.

I learned about each step of converting an AC signal to a specified DC output voltage and saw two different ways to regulate voltage. Through experimentation one method was clearly a better choice. Looking at our plots consecutively, it becomes apparent how the waveform changes at each step of the design.