Experiment: Power Supply Project

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Name: Christian Frost

Red ID# : 130203785

The objective of this experiment is to develop a triple output power supply that effectively provides a smooth and robust DC output from an AC input. To do so, I will familiarize myself with the application of theoretical rectifier, filter, and regulator calculations in a practical and a hands-on manner.

STEP 1 Lecture - Power Supply Overview, Bridge Calculations

Exercise - Soldering Practice, Solder Bridge Diodes, and Measurements

For the first step of this experiment, I reviewed the background material from the text on AC to DC power supplies. The following steps include: Step 1 Transform the line level AC to a lower level AC using a transformer, Step 2 Rectify the low level AC into pulsating DC using rectifier diodes, Step 3 Filter the pulsating DC into a relatively steady state DC using capacitors, and Step 4 Regulate the steady state DC into a constant level output using regulating IC's. A full-wave bridge rectifier first receives an AC input signal 60Hz with a period of 16.7ms. The AC signal is then fed through four diodes arranged in a specific orientation (shown in figure 1.1). The AC signal is applied to two ends of the bridge and DC output is taken as the output.

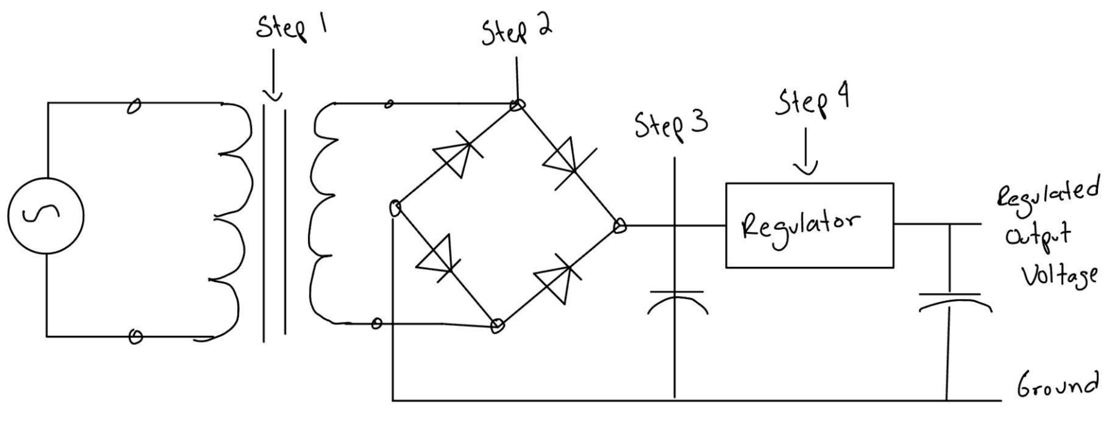


Figure 1.1 Bridge Rectifier

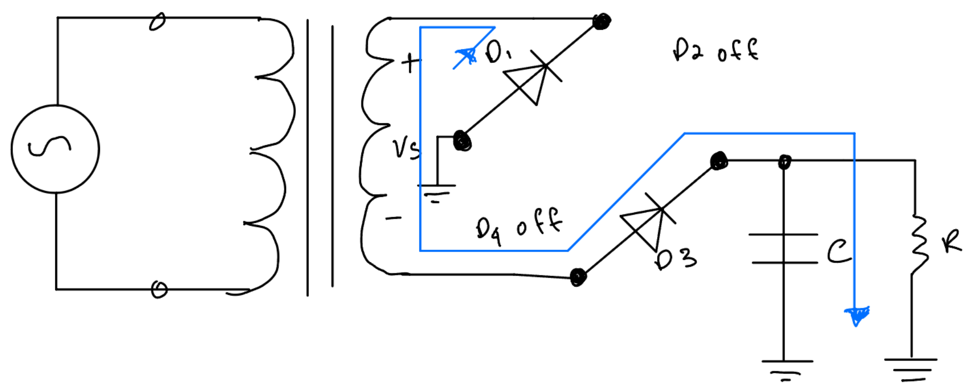


Figure 2.2 Full wave bridge rectifier circuit vs < 0

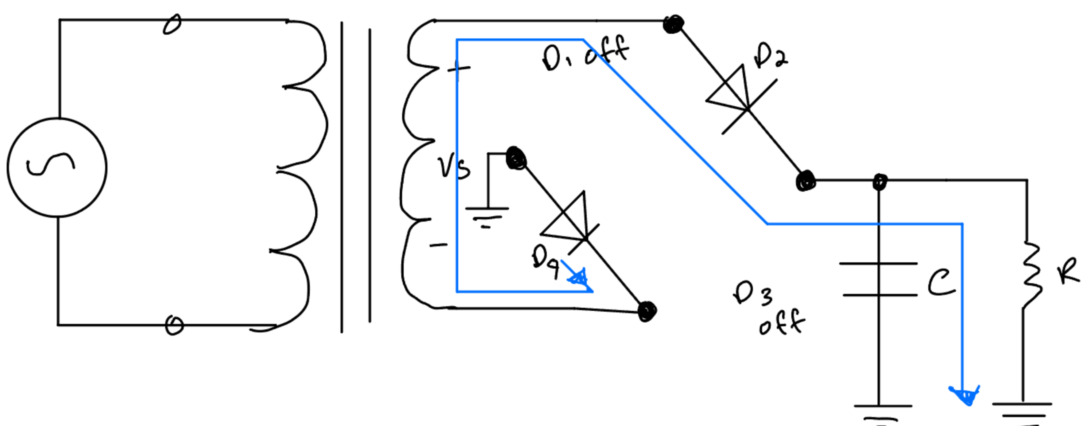


Figure 2.3 Full wave bridge rectifier circuit vs > 0

In the next step, I retrieved a Capacitor of 4.7uF and a Resistor value of 10k ohms in order to accurately measure the transformer's peak to peak secondary voltage. I then repeated the measurements with a new Capacitor value of 10uF. I performed the following preliminary calculations: calculated the transformer's peak to peak secondary voltage, peak to peak ripple filtered Vo, average voltage of the filtered output of the bridge circuit using formulas provided in the lab manual. The measurements are as follows:

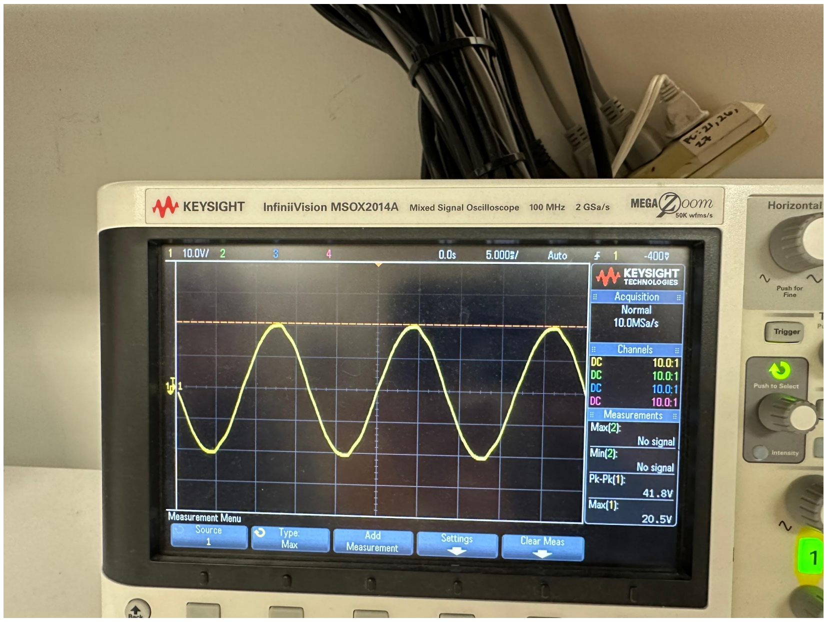


Figure 1.2 Step 1 Transformer peak to peak secondary voltage

V_{Spk-pk}	41.8V

In order to measure the actual values of the transformer I needed to install components onto my power supply PCB board. The following components installed were as follows: Rectifier diodes D5-D8, One black wire to H3, Red wires to H4 and H5, a jumper wire R1 (0 ohms), Black binding post of transformer to H3, RL and C to the protoboard, and connected H4 and H5 to the transformer box shown in Figure 1.3. I then tested the transformer using the newly installed hardware. The results are as follows:

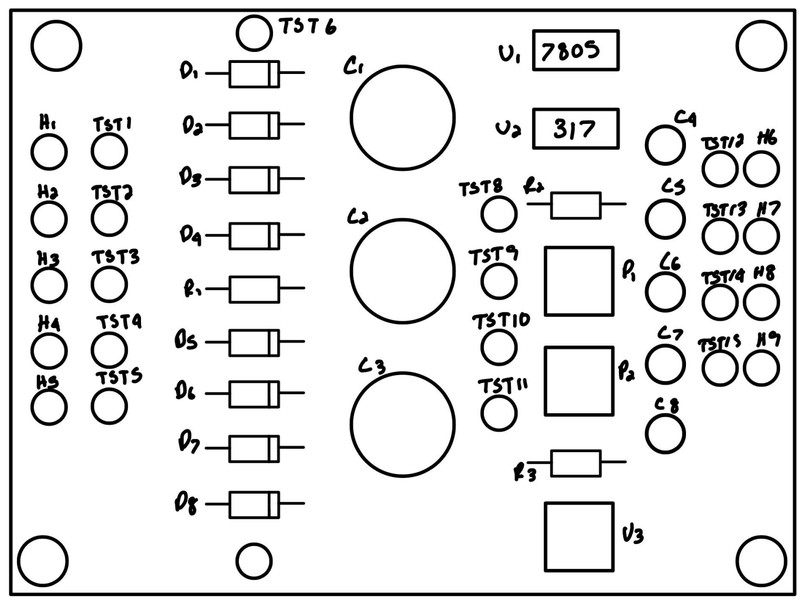


Figure 1.3 Power Supply PCB Schematic

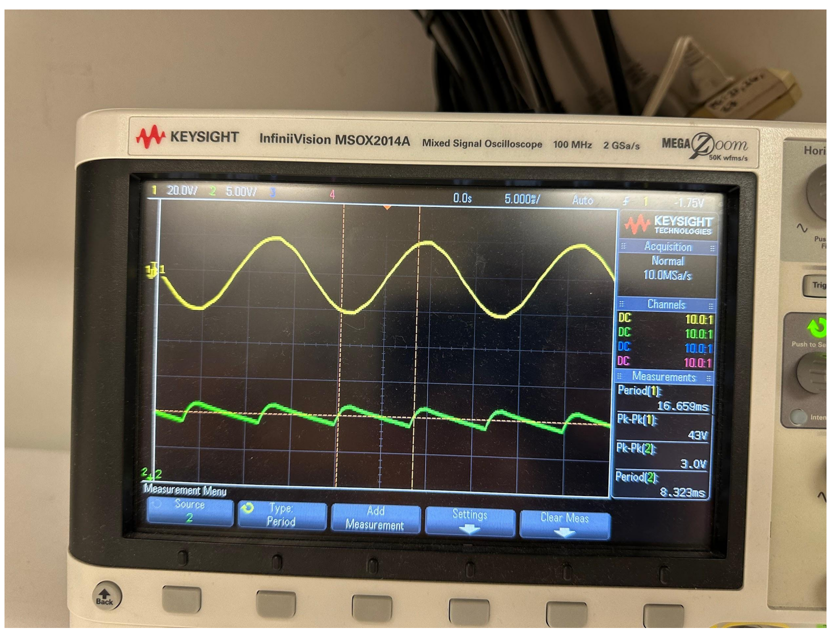


Figure 1.4 Step 3 Transformer peak to peak ripple voltage

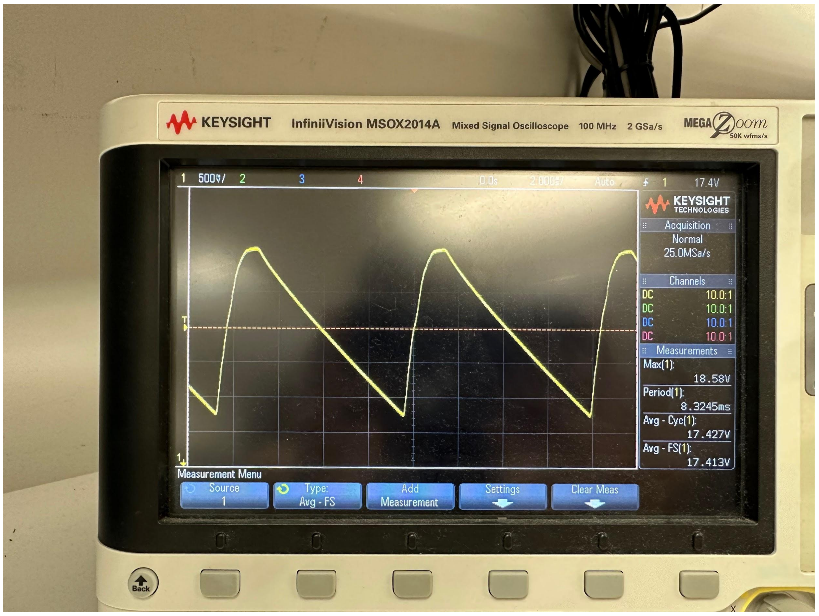


Figure 1.5 Step 3 Transformer peak to peak ripple voltage

$R_L(measured)$	$C(measured)$
9.901kΩ	5.05uF

	Calculated	Measured	% Difference
V_{Spk}	20.9V	42.5V	51%
V_{rpk-pk}	3.353V	3.0V	12%
T_{ripple}	8.335ms	8.350ms	0.18%
V_{DC}	18.52V	17.53V	6%
I_{DC}	1.87mA	1.77mA	6%

$R_L(measured)$	$C(measured)$
9.901kΩ	9.746uF

	Calculated	Measured	% Difference
V_{rpk-pk}	1.737V	5.67V	69%
V_{DC}	19.13V	18.58V	3%
I_{DC}	1.93mA	10uA	0.19%

STEP 2 Lecture - Regular calculations, Temperature calculations

Exercise - Component installations, Regulator and Temperature Measurements

In Step 2 of the power supply project, we will be focusing on regulation performance. Line regulation is the ability of a circuit to maintain a selected output under varying line voltage input conditions. Voltage regulators typically have an input of 60Hz, 110-120VAC connected to the power supply transformer. In order to stabilize the AC input signal, a ripple voltage is made using diodes and capacitors respectively. The Ripple Rejection Ratio measures how well the regulator circuit reduces the ripple voltage. The larger Rejection Ratio is ideal for a power supply. To further regulate the AC voltage, we will install DC Regulators LM7805, LM317, and LM337 to the PCB in pins U1, U2 and U3. Each regulator has specific characteristics and pin-outs according to their function. However, each regulator must follow the manufacturers guidelines such as a Quinescent Current. A Quinescent current is the unregulated current needed to operate a regulating circuit. If the current falls below the threshold, it will lead to poor performance. Although DC Regulators are essential for an AC to DC power source, it leads to an increase in heat flow throughout the circuit. In order to prevent overheating, heatsinks were applied to each regulator.

In order to calculate the output voltage and case temperature of LM317, I arranged a circuit similar to Figure 2.1. In order to test LM317, I replaced R1's potentiometer with fixed resistance values: 0, 1.2k, and 3.3k ohms and placed a 330Ω resistor in place of R2. I then proceeded to test R1's resistance values and measured the voltage across the 330Ω resistor and retrieved the following values:

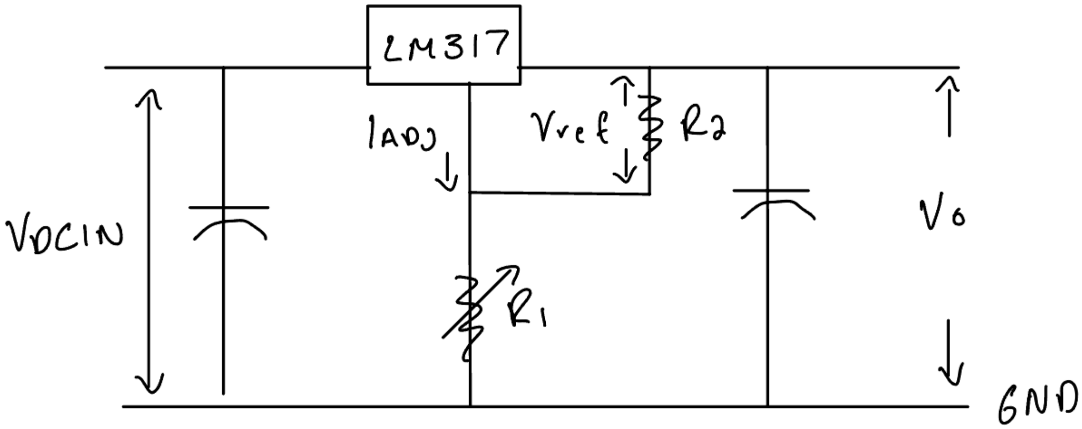


Figure 2.1 Regulator Output

$R_{1(1.2k)}$	$R_{1(3.3k)}$	$R_{2(330\Omega)}$	$R_{2(330\Omega)}$
1.175kΩ	3.256kΩ	324Ω	327Ω

	Vo (Calculated)	Vo (Measured)	% error
1.2kΩ	6.13V	5.81V	5.20%
3.3kΩ	14.69V	13.78V	6.19%

In order to test for temperature, I switched R1 to 1.2kΩ and R2 to 330Ω 2W. I then measured the ambient temperature of the room using a temperature gauge to establish a control for my calculations. I then calculated the expected case temperature of the regulator using ΘJA and ΘJCbottom from Table 7.4 of the LM317-KCS data sheet. I then allowed the circuit to thermally stabilize for 5 minutes and then measured LM317's temperature and compared it to my calculations. The results are as follows:

T_A	$T_C(calc)$	$T_C(meas)$	% error
21.8 C	27.41 C	23.36 C	8.94%

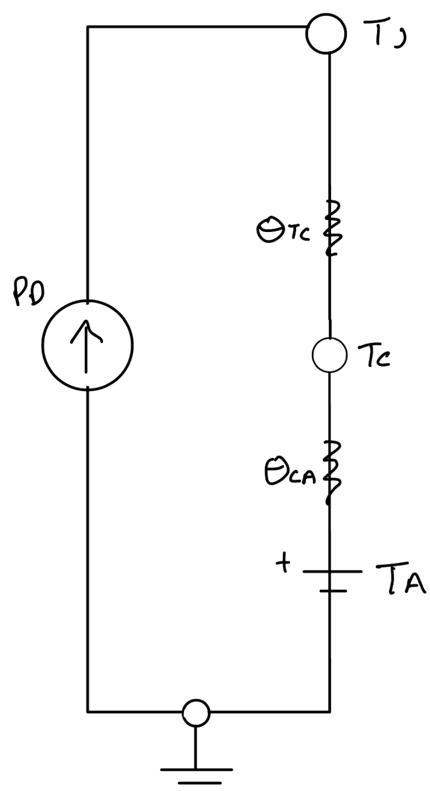


Figure 2.2 Heat Flow Modeled as a Series Circuit

P_D= The power/heat generated by the semiconductor

T_J= The temperature of the DIE junction

T_C= The temperature of the semiconductor case

T_A= Ambient temperature of the surrounding air

Θ_{JC}= Thermal resistance from the die junction to the case

Θ_{CA}= Thermal resistance from the case to the ambient air

STEP 3 Lecture - Power Supply Specifications

Exercise - Component installations, Regulator Measurements and Specifications

In Step 3, I will be measuring the output resistance of the power supply by measuring the output resistance of each of the DC Regulators LM7805, LM317, and LM337. To do so, I set Vref to 1.25V, Test to 1.5kΩ and R2 to 100Ω - 2W. With the components placed, I am able to calculate the current and power of Rl, the output voltage, and the output resistance of LM317. Using these values, I was able to calculate a thevenin equivalent of the circuit with the following values: Vth = 45.6mΩ , Rth 45.6mΩ. I then repeated the setup for each Regulator to calculate the Ripple Rejection Ratio. In order to calculate the Ripple Rejection Ratio for each regulator, I used an oscilloscope to measure each input and output and compared them accordingly. To test for load regulation, I replaced the 100Ω resistor with a 1.5kΩ resistor to calculate the current and power for RL and used the values to calculate the percentage load regulation. The load regulation of a circuit is the capability to maintain a constant voltage. To test for short circuit protection, I removed RL and shorted the output of each regulator and compared the voltage Vo with Vo measured with no resistance. In my power supply, it was evident that voltage was protected because there was no significant voltage drop after the short.

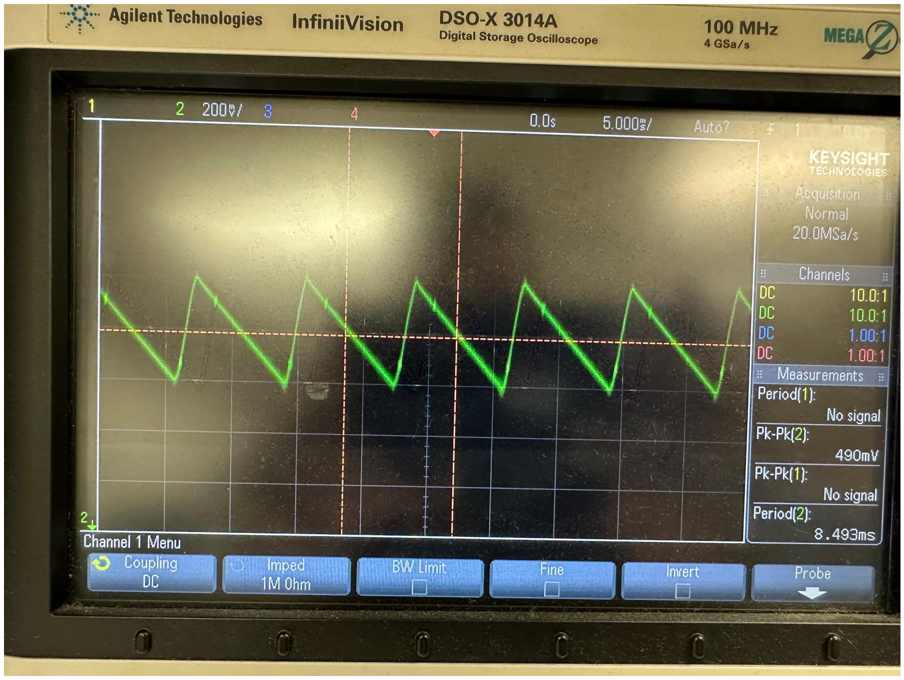


Figure 3.1 Peak to Peak Ripple at LM317's input

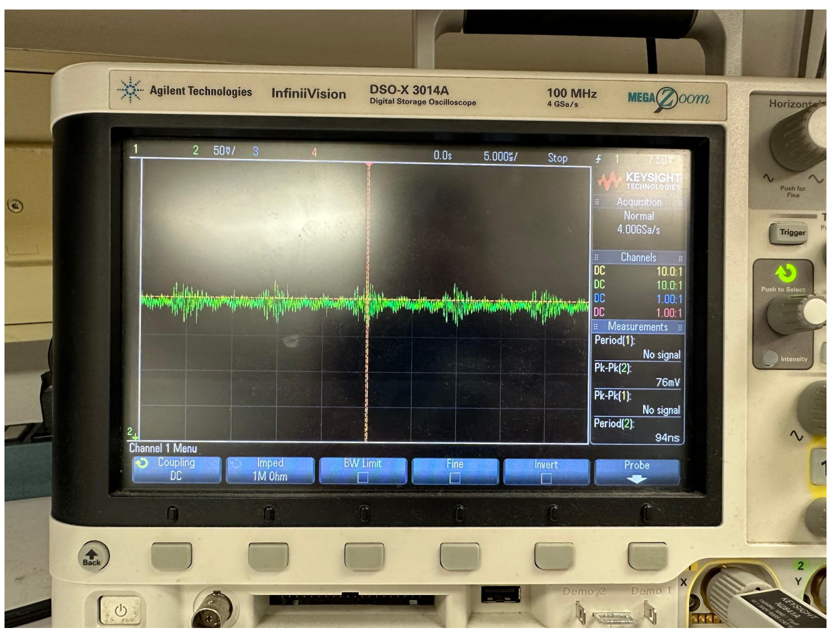


Figure 3.2 Peak to Peak Ripple at LM317's output

Figure 3.3 Peak to Peak Ripple at LM337's input

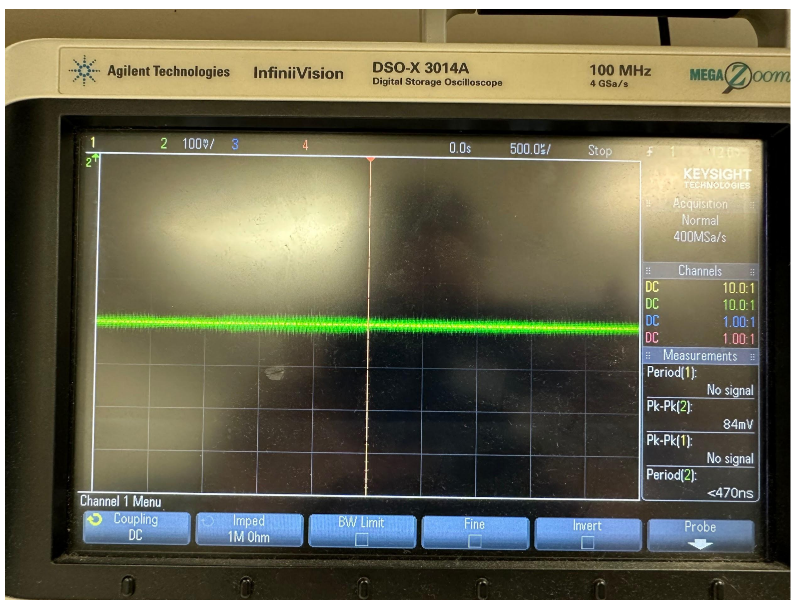


Figure 3.4 Peak to Peak Ripple at LM337's output

Observations

Filter capacitor size plays a vital role in regulating ripple current from an AC voltage source. It is able to smooth out variations in voltage caused by an AC source. Converting an AC to a pulsating DC. As shown in comparison to Figure 3.1 and Figure 3.2, once the AC current passes through the capacitor it is regulated to more fine ripple current than the input. This occurs due to the lack of voltage fluctuations with the help of the capacitors. A larger capacitor is more effective in ripple reduction as shown.

Figure 3.1 Peak to Peak Ripple at LM317's input

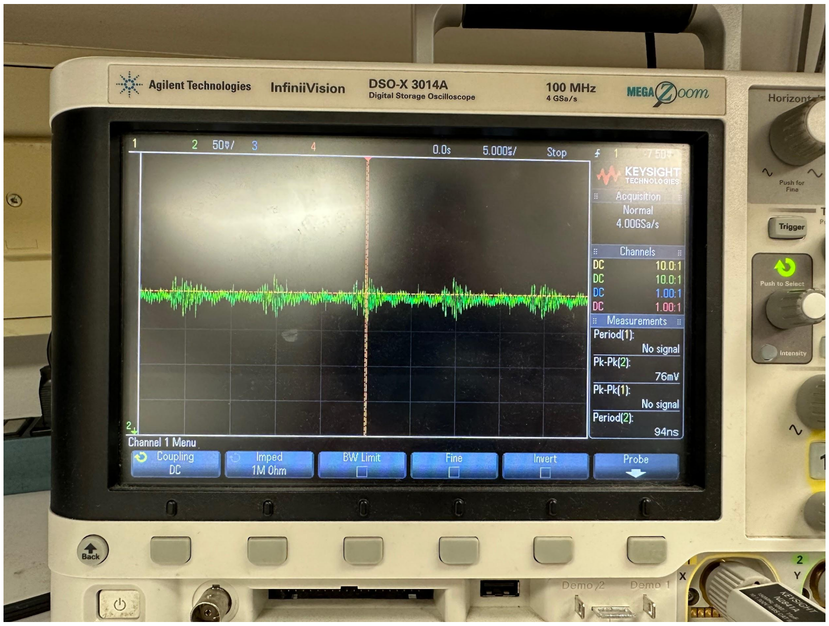


Figure 3.2 Peak to Peak Ripple at LM317's output

Regulation in a circuit is its ability to maintain a constant output voltage even with variations in voltage and current. It ensures that the power supply gives a stable output voltage. Regulators are able to reduce ripple by acting as a low pass filter. In terms of Rout, it measures how well a regulator can maintain an output voltage even with variations in voltage. A lower Rout means the output voltage is less affected by external forces. The measured output resistance for LM317 is 45.6mΩ while output resistance of the diode bridge is 238Ω. The values have a 5% percentage difference meaning that they are fairly the same. This could correlate to an optimal resistance of the Rout to supply a stable voltage current without outside interference.

MAKING <u>MANUAL</u> SCOPE MEASUREMENTS (press 'cursor' button & then adjust)

- *PEAK TO PEAK* – Adjust horizontal cursors to chosen points for ΔY.
- *PERIOD* - Adjust vertical cursors to chosen points to get T.
- *FREQUENCY* - Measure the period and then invert to get $f = 1/T$.
- *DELETING* - Press Remove Measure button – Select which measurement to remove.

Step 1 – PRELIMINARY CALCULATIONS

(For these calculations, use measured values and show the governing equations used. These calculations will be compared with their corresponding measurements in Step 3.)

WRITE NEATLY! THESE PAGES WILL BE A PART OF YOUR LAB REPORT.

- ***Each student should use his own $R_L = 10\ k\Omega$ and $C = 4.7\ \mu F$ from the parts bag. Please save these parts to use in future measurements (Parts II & III of this lab).***

(a) Measure the actual values of your R_L and C. **R**$_L$ (measured) = 9.901kΩ **C** (measured) = 5.05μF

(b) Measure transformer's ***peak to peak*** secondary voltage **V**$_{Spk\text{-}pk}$ = 41.8V
(RED to BLACK terminals). ***Record scope's waveform & put in lab report.***

(c) Calculate the ***peak*** secondary voltage (RED to BLACK) **V**$_{Spk}$ = 20.5V

(d) For your values of R_L and C, which ONE of the two equations on p. I-5 should be used ?
{Hint: Is $R_L C \geq 10T$?} Yes **Accurate** ______ **Approx.** ✓

(e) Calculate the peak-to-peak ripple filtered **V**$_o$ using the appropriate equation and the measured values for R_L and C. [Note: **V**$_{o(max)} \neq$ **V**$_{Spk}$, see p. I-4] **V**$_{rpk\text{-}pk}$ = 3.353
What is the period (T) of the ripple filtered waveform? **T**$_{ripple}$ = 8.335ms

(f) Calculate the average voltage of the filtered output of the bridge circuit **V**$_{DC}$ = 18.52

(g) Calculate the average DC current in R_L (via ohm's law) **I**$_{DC}$ = 1.87mA

- ***Use same R$_L$ and VSpk as above but with C = 10 μF. Measure the new*** **C** (measured) = 9.746μF

(h) For these new values of R_L and C, which ONE of the two equations on p. I-5 should be used ?
{Hint: Is $R_L C \geq 10T$?} $10(8.3 \times 10^{-3})s$ yes **Accurate** ______ **Approx.** ✓

(i) Calculate peak-to-peak filtered ripple using the correct equation and **R**$_L$ (measured) & **C** (measured).
{What is the frequency of the rectified waveform? Note: **V**$_{o(max)} \neq$ **V**$_{Spk}$ due to diodes} **V**$_{rpk\text{-}pk}$ = 1.737

(j) Calculate the average filtered output voltage of the bridge circuit **V**$_{DC}$ = 19.13V

(k) Calculate the average DC current in R_L (via ohm's law) **I**$_{DC}$ = 1.93mA

$$V_{ph}(sec) = 1.414 \cdot V_{rms}(sec) = V_{ph\text{-}ph}(sec)/2$$

$$V_{ph}(sec) = 20.9v$$

$$V_o(max) = V_{ph}(sec) - 0.7v$$

$$= 20.2v$$

$$V_r(ph\text{-}ph) \cong V_o(max)\left(\frac{1}{2fR_LC}\right) = V_o(max)\left(\frac{T}{R_LC}\right)$$

$$V_r = (20.2v)\ \frac{8.3ms}{(10k)(4.7\mu F)} = 3.567$$

$$V_r(ph\text{-}ph)_{Actual} = \frac{8.3ms}{(9.901k)(5.05\mu F)} \times (20.2) = 3.353$$

$$V_{DC}(ave) = V_o(max) - \frac{V_r(pp)}{2}$$

$$= 20.2 - \frac{3.353}{2} = 18.52$$

$V = IR$

$$\frac{V}{R} = I = \frac{18.52}{9901\Omega} = 1.87mA$$

$$V_r(pk-pk)\ Actual = \frac{8.3ms}{(9.901k)(9.746\times10^{-6})} \times 20.2 = 1.737$$

$$V_{DC}(ave) = 20.2 - \frac{1.737}{2} = 19.13$$

$$I = \frac{19.13}{9901\Omega} = 1.93mA$$

$$V_{DC}(Ave) = V_o(max) - \frac{V_r(pp)}{2}$$

(a) Install/solder the rectifier diodes D5 - D8 (the stripe on diode and PCB indicates polarity)

(b) Cut 2 RED and 1 BLACK hook up wires (~8" long). Strip off ½" of insulation from both ends and twist wires together. Coat the exposed ends with thin layer of solder and then solder the Black wire to H3 and the Red wires to H4 and H5.

(c) Install/solder jumper wire, R_1 (0 Ω resistor) on the PCB

(d) Connect (not solder) Diode "D5" to the breadboard as shown on previous page.

(e) Connect the black binding post of transformer to H3 and the R_L & C on the protoboard.

(f) Connect H4 and H5 to the transformer box as shown on previous page.

INSTALL NO OTHER COMPONENTS TO THE PC BOARD AT THIS TIME.
(Hint: for greater speed & efficiency, do all your measurements in parallel with your partner using the same test setup.)

Step 3 - MANUAL SCOPE MEASUREMENTS (measure using cursors of the scope, item 7 on p. 4, and then compare these measurements with the calculations of step 1)

- **Put $R_L = 10\ k\Omega$ and $C = 4.7\ \mu F$ (measured earlier) on breadboard and connect as p. I-7.**

(a) Measure transformer's peak secondary voltage (Use DC coupled scope) Should be same as p. I-6, item (c) if using the same transformer — V_{Spk} = 42.5v

(b) Measure the period (T) and peak-to-peak ripple voltage at R_L and compare $V_{rpk\text{-}pk}$ with Step 1e of p. I-6. (Use AC coupled scope)
T_{ripple} = 8.350mS
$V_{rpk\text{-}pk}$ = 3.0V
%-difference = 12%

(c) Record the ripple waveform at R_L (by inserting USB drive into the oscilloscope) and ***put in lab report.***

(d) Measure the average DC output voltage (Use DMM) at R_L and compare with Step 1f of p. I-6.
V_{DC} = 17.53 V
%-difference = 6%

(e) Measure the average DC current through R_L (Use DMM) and compare with Step 1g of p. I-6.
I_{DC} = 1.77mA
%-difference = 6%

- **Replace the 4.7μF capacitor with a 10μF capacitor and examine its impact on the output**

330Ω
3W

(f) Measure the peak-to-peak ripple voltage at R_L and compare $V_{rpk\text{-}pk}$ with Step 1i of p. I-6.
T_{ripple} = 8.33mS
V_{rpkpk} = 5.67V
%-difference = ______

(g) Record the ripple waveform at R_L (by inserting USB drive into the oscilloscope) and ***put this waveform in your eventual lab report.***

(h) Measure average DC output voltage (use DMM) at R_L and compare with Step 1j of p. I-6.
V_{DC} = 18.58v
%-difference = ______

(i) Measure average DC current in R_L (use DMM) and compare with Step 1k
I_{DC} = 10μA
%-difference = ______

Step 4 - MEASURING OUTPUT RESISTANCE

(Okay to do the following measurements at the next lab if you run out of time today.)

The output resistance of a power supply can be calculated by measuring a change in the output voltage divided by a change in the output current as per the equation below. $R_o = 0\ \Omega$ if ideal.

$$\boxed{Output\ Resistance = \frac{|\Delta V_o|}{|\Delta I_o|}}$$

Determining the Thevenin equivalent circuit of your fullwave rectifier (with C = 10 µF):

(a) Measure the DC output voltage without a load resistor (C only) (Use DMM) — $V_{no\ load}$ = 18.75V

(b) Measure & record the actual value of a 10 kΩ load resistor (R_L). — R_L = 9.885 kΩ

(c) With R_L in parallel with C, measure the output voltage (use DMM) — V_1 = 17.97V

(d) Calculate the output current in R_L (use Ohm's law & measured value of R_L) — I_1 = 1.817mA

(e) Replace the 10kΩ resistor with a ~5.1kΩ resistor (to examine the effects of R_L on the output voltage)

R_L = 5.039kΩ

(f) With the new R_L in parallel with C, measure the new output voltage — V_2 = 17.58V

(g) Calculate the output current in the new R_L (use Ohm's law & measured value of R_L) — I_2 = 3.48mA

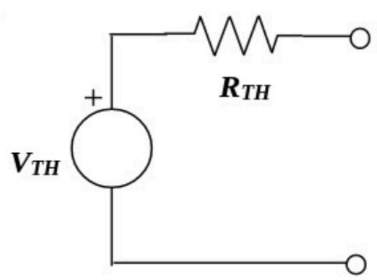
(h) Calculate the output resistance of the rectifier (Expect $R_O < 1$ kΩ) — R_O = 234.52Ω

$$\boxed{R_o = \frac{V_1 - V_2}{I_2 - I_1}}$$

(i) Model your output terminals as a Thevenin equivalent circuit:

{Hints: $V_{TH} = V_{no\ load}$ & $R_O = R_{TH}$}

Ro used 238Ω



V_{TH} = 18.75V

R_{TH} = 238Ω

Using the Thevenin equivalent circuit:

(j) Measure & record the actual value of a 6.8 kΩ load resistor (R_L). — $R_{6.8k}$ = 6.699kΩ

(k) Calculate the expected V_o if R_L = 6.8 kΩ was connected in parallel with C — $V_{o(calc)}$ = 18.12V
(Hint: Does adding R_L to the Thevenin circuit above result in a resistor divider network?)

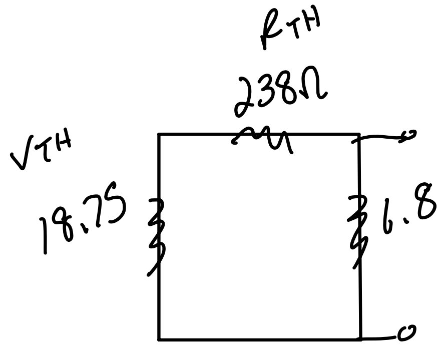
Yes

(l) Measure the actual output voltage across the 6.8 kΩ load resistor (R_L) — $V_{o(meas)}$ = 17.82V

(m) Calculate the %-difference between your measured and calculated voltage outputs. $\%\ diff = [(meas - calc) \div (calc)](100)$ — %-difference = 1.66%

$V = IR$ $\quad \frac{17.97V}{9.885k\Omega} = 1.817mA$

$$R_0 = \frac{V_1 - V_2}{I_2 - I_1} \rightarrow \frac{17.97 - 17.58}{3.48mA - 1.817mA} = 234.52\Omega$$



Voltage divider

V_o

$(18.75)(238)$

$$V_o = V_S \frac{R_2}{R_1 + R_2}$$

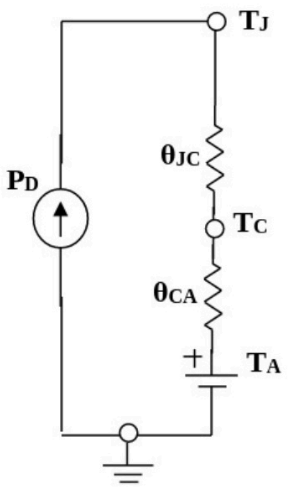
$$V_o = 18.75 \frac{6.8k\Omega}{238\Omega + 6.8k\Omega} = 18.12V$$

Using the above equation, it is straightforward to calculate the worse case junction temperature (T_{jMAX}). The thermal parameters θ_{JC} and θ_{CA} sum up to the total thermal resistance θ_{JA}. This relationship is expressed mathematically as:

$$\boxed{\theta_{JA} = \theta_{JC} + \theta_{CA}}$$

HEAT FLOW MODELED AS A SERIES CIRCUIT

Heat flow (P_D) from the semiconductor's junction to the case and then the ambient air can be modeled as a series circuit as shown below.



P_D is the power/heat generated by the semiconductor
T_J is the temperature of the DIE junction
T_C is the temperature of the semiconductor case
T_A is the ambient temperature of the surrounding air
θ_{JC} is the thermal resistance from the die junction to the case
θ_{CA} is the thermal resistance from the case to the ambient air

Heat Flow vs. Current Flow ANALOGY

P_D is analogous to electrical current
T is analogous to electrical voltage
θ is analogous to electrical resistance
Like current, heat flows from a region of higher temperature to a region of lower temperature

THERMAL EQUATIONS

Simplifying T_J using the relationship $\theta_{JA} = \theta_{JC} + \theta_{CA}$ leads to $\boxed{T_J = \theta_{JA} P_D + T_A}$ Eq. 2-1

Solving for the power dissipated by the regulator P_D leads to $\boxed{P_D = (T_J - T_A) / \theta_{JA}}$ Eq. 2-2

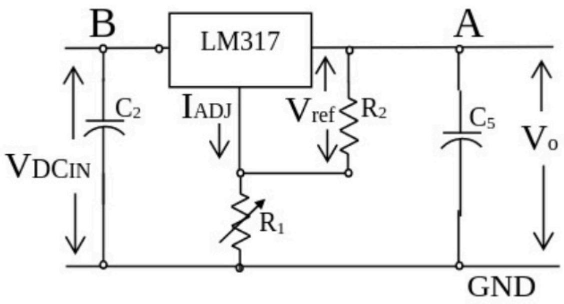
Using thermal version of Ohm's law and the heat flow circuit shown above, the case temperature T_C can be expressed in terms of the power dissipation and ambient temperature or the power dissipation and junction temperature as follows:

T_C in terms of T_A and P_D $\boxed{T_C = T_A + \theta_{CA} P_D}$ Eq. 2-3

T_C in terms of T_J and P_D $\boxed{T_C = T_J - \theta_{JC} P_D}$ Eq. 2-4

Values for θ_{CA} and θ_{JC} are usually given or can be derived from the manufacturer's data sheets.

(For these calculations, use measured resistance values where possible.)



$$V_o = V_{ref}\,(1 + R_1/R_2) + I_{ADJ}\,(R_1)$$

NOTE: The equation above shows that the output voltage is set by R_1 and R_2. For the LM317 regulator (U2), the R_2 in the equation above is labeled as R_2 (= 330Ω) on the PCB. R_1 in the above equation eventually will be replaced by the potentiometer labeled as P_1 on the PCB. For the LM337 regulator (U3), R_2 in the equation above is labeled as R_3 (= 330Ω) on the PCB while R_1 in the equation above eventually will be replaced by the potentiometer labeled as P_2 on the PCB.

(a) Find typical $\boldsymbol{V_{ref}}$ in the specifications sheet for LM317 (see p. II-6) **Vref** = 1.2 – 1.3 v

(b) Find the typical value for $\boldsymbol{I_{ADJ}}$ for the LM317 regulator (see p. II-6) **IADJ** = 100 µA

(c) Measure & record the actual values of two 330Ω, ¼ W resistors
(Get from parts bins if needed and save for later use)
R2 **R330Ω** = 324Ω
R3 **R330Ω** = 327Ω

(d) Use the DMM to measure actual value of the ~1.2kΩ, ¼ W resistor **R1.2kΩ** = 1.175kΩ
(Get from parts bins and save for later use)

(e) Use the DMM to measure actual value of the 3.3kΩ, ¼ W resistor **R3.3kΩ** = 3.256kΩ
(Get from parts bins and save for later)

(f) Calculate $\boldsymbol{V_o}$ if $R_2 = 330\Omega$ and $R_1 = 0\Omega$ **Vo** = 1.3v
(use actual resistor values in the design equation for *Vo* at top)

(g) Calculate $\boldsymbol{V_o}$ if $R_2 = 330\Omega$ and $R_1 \approx 1.2k\Omega$ **Vo** = 6.13v
(use actual resistor values in the design equation for *Vo* at top)

(h) Calculate $\boldsymbol{V_o}$ if $R_2 \approx 330\Omega$ and $R_1 \approx 3.3k\Omega$ **Vo** = 14.69v
(use actual resistor values in the design equation for *Vo* at top)

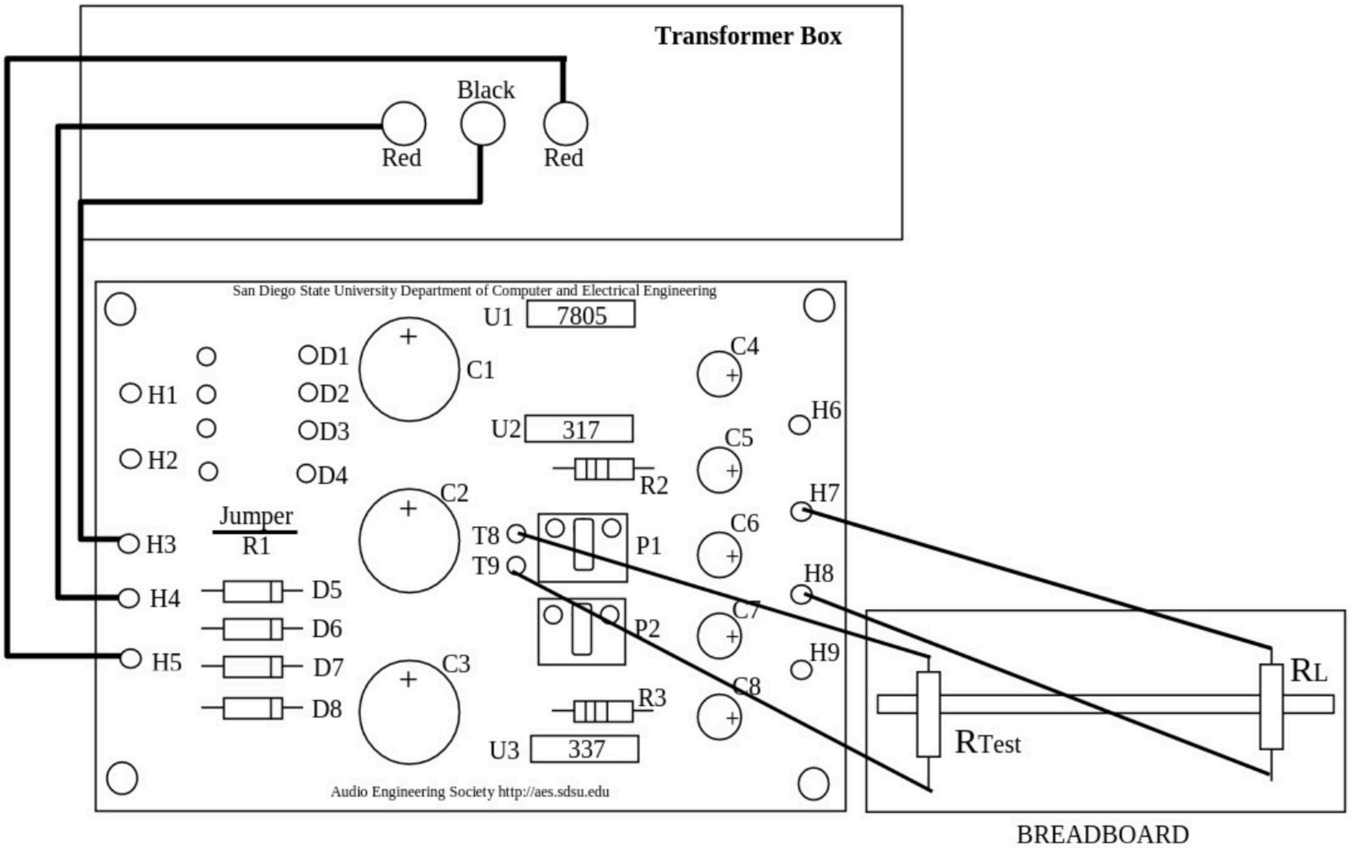
f) $V_o = V_{ref}\left(1 + \frac{R_1}{R_2}\right) + I_{adj}(R_1)$

$V_o = 1.3\left(1 + \frac{0\,\Omega}{324\,\Omega}\right) + 100\mu A(0) \approx 1.3\,v$

g) $V_o = 1.3\left(1 + \frac{1.175k\Omega}{324\Omega}\right) + 100\mu A(1.175k\Omega) = 6.13\,v$

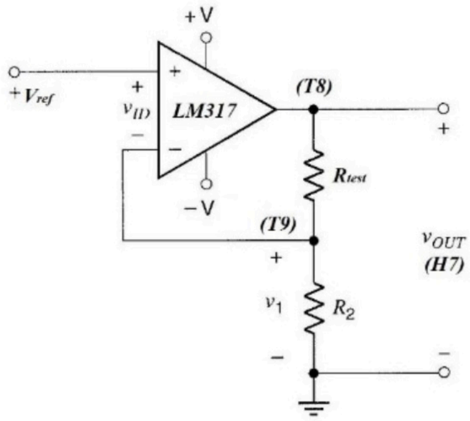
h) $V_o = 1.3\left(1 + \frac{3.256k\Omega}{327\Omega}\right) + 100\mu A(3.256k\Omega) = 14.69\,v$

Solder Hook up and Output wires



CONNECTING THE TRANSFORMER BOX, BREADBOARD, AND PCB

- Connect the H3 wire to the black binding post on the transformer box as shown
- Connect the H4 and H5 wires to a red binding post as shown
- Depending on your PCB, test points T8 (the output of LM317) and T9 also can be named TST8 and TST9



For Step 3 (next page), you will be using fixed resistors (***R****test* = 0, 1.2k, 3.3k) in place of the trim pot (*P1*) to set LM317 regulator's output as per the following equation:

$$\boldsymbol{V_o = V_{ref}\,(1 + R_{test}/R_2)}.$$

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TEMPERATURE OF LM317

IMPORTANT NOTE: For the following steps, you will be using fixed resistors (R_{Test} = 0, 1.2k, 3.3k) in place of the trim pot (P1) to set LM317 regulator's output, as per $V_o = V_{ref}(1 + R_{test}/R_2)$. *Get ¼ W resistors from the parts bin on the wall and the 2W resistor from the instructor.*

** **OUTPUT VOLTAGE (at H7)** ***<u>with no load connected ($R_L = \infty$)</u>***

(a) With a short between T8 and T9 (making $R_{Test} = 0\ \Omega$), measure the DC output voltage of the LM317 (H7) with respect to ground (H8). **V_o** = 23.54mV

(b) With a short between T8 and T9 (making $R_{Test} = 0\ \Omega$), measure the DC voltage across the 330Ω resistor (R_2) on PCB **V_{ref}** = 45.4mV

(c) Connect R_{Test} = 1.2kΩ between T8 and T9 and measure Vo (H7). Calculate %-diff from your calculation in Step 1g earlier. **V_o** = 5.811V **%-diff** = 5.20%

(d) Connect R_{Test} = 3.3kΩ between T8 and T9 and measure Vo (H7). Calculate %-diff from your calculation in Step 1h earlier. **V_o** = 13.78V **%-diff** = 6.19%

** **TEMPERATURE (in °C)** ***<u>with R_{Test} = 1.2 kΩ and R_L = 330 Ω (2W size or larger)</u>***

(e) Measure the actual value of the 330Ω - ***2W*** load resistor (R_L) (Need to use a 2W or larger resistor because $P = IV = V^2/R$.) **$R_{330\Omega}$** = 328Ω

(f) Connect R_L between H7 and H8 (on the protoboard) and measure voltage across it (i.e., the output voltage of LM317) **$V_{O\_330\Omega}$** = 5.81V **$I_{O\_330\Omega}$** = 17.55mA

(g) Calculate the current & power in R_L (use actual resistor value) **$P_{L\_330\Omega}$** = .103W

(h) Measure the DC voltage at the input (TST6) of LM317 regulator **V_{DCin}** = 19.41V

(i) Calculate In/Out voltage drop (V_{DCin} - V_o) through the regulator **$V_{I/O}$** = 13.6V

(j) Calculate the power dissipated in the regulator **($P_D = V_{I/O} \times I_O$)** **P_D** = 0.24W

(k) Measure the ambient temperature (°C) in the room **T_A** = 21.8°C

(l) Calculate (via Eq. 2-3) expected case temperature (°C) of regulator (Get θ_{JA} and θ_{JC_bottom} from Table 7.4 of the LM317-KCS data sheet) **$T_{C(calc)}$** = 27.41°C θ_{JA} = 25.3°C/W θ_{JC} = 1.94°C/W

(m) Estimate (via Eq. 2-4) the junction temperature inside the regulator (Note: $\theta_{CA} = \theta_{JA} - \theta_{JC\_bottom}$) **$T_J$** = 23.36°C

$T_{C(meas)}$ = 30.1°C

(n) Measure regulator case's temperature & compare with $T_{C(calc)}$. Allow circuit to thermally stabilize for 5 min BEFORE measuring its temp from about 1 cm away. Explain possible sources of discrepancy (heat sinks?) between your measured and calculated temps. **%-diff** = 8.94%

330Ω 3W

$$P = \frac{V^2}{R} = \frac{5.81^2}{328} = 0.103\,W$$

i) VDCin - Vo

19.41v - 5.81V =

68.1 F°

j) $P_D = V_{I/O} \times I_O$

$P_D = 13.6 \times$

$P_D = 13.6 \times 17.55mA$

$P_D = 0.24\,W$

THERMAL EQUATIONS

Simplifying T_J using the relationship $\theta_{JA} = \theta_{JC} + \theta_{CA}$ leads to $\boxed{T_J = \theta_{JA} P_D + T_A}$ Eq. 2-1

Solving for the power dissipated by the regulator P_D leads to $\boxed{P_D = (T_J - T_A) / \theta_{JA}}$ Eq. 2-2

Using thermal version of Ohm's law and the heat flow circuit shown above, the case temperature T_C can be expressed in terms of the power dissipation and ambient temperature or the power dissipation and junction temperature as follows:

T_C in terms of T_A and P_D $\boxed{T_C = T_A + \theta_{CA} P_D}$ Eq. 2-3

T_C in terms of T_J and P_D $\boxed{T_C = T_J - \theta_{JC} P_D}$ Eq. 2-4

Values for θ_{CA} and θ_{JC} are usually given or can be derived from the manufacturer's data sheets.

m) $\theta_{CA} = \theta_{JA} - \theta_{JC}$ - Bottom

$\theta_{CA} = 23.36 = 25.3 - 1.94$

l) $T_C = T_A + \theta_{CA} P_D$

$T_C = 21.8°C + \theta_{CA}(0.24W)$

$T_C = 21.8°C + 23.36(0.24W)$

$T_C = 27.41°C$

Step 1 - MEASURING LM317 OUTPUT RESISTANCE

The output resistance of a power supply can be calculated by measuring a change in the output voltage divided by a change in the output current as per the equation below. $R_o = 0\ \Omega$ if ideal.

$$\boxed{Output\ Resistance = \frac{|\Delta V_o|}{|\Delta I_o|}}$$

With R_{Test} = 2.2 kΩ - ¼W & R_2 = 330Ω, expect V_{out} = $V_{ref}(1+R_{test}/R_2)$ where V_{ref} = 1.25V

(a) Measure actual resistance (DMM) of the 2.2kΩ test resistor (from parts bin) & connect to T8 & T9 as shown on next page — **R_{Test}** = 2.133kΩ

(b) Measure LM317's output voltage (at H7) with no resistor connected — **$V_{no\ load}$** = 9.516 V

(c) Measure the actual resistance of the 1.5kΩ - ¼ W load resistor — **$R_{1.5k\Omega}$** = 1.474kΩ

(d) With R_L = 1.5kΩ connected between H7 & H8, measure LM317's DCV (H7) (use the DMM) — **$V_{O\_1.5k\Omega}$** = 9.519 V

(e) Calculate the current and power in R_L (use measured values) — **$I_{O\_1.5k\Omega}$** = 6.46mA; **$P_{L\_1.5k\Omega}$** = 61.4mW

(f) Measure the actual resistance of a 100Ω - 2W load resistor (get from instructor) — **$R_{100\Omega}$** = 99.22Ω

(g) Replace the 1.5kΩ load resistor with a 100Ω - 2W load resistor

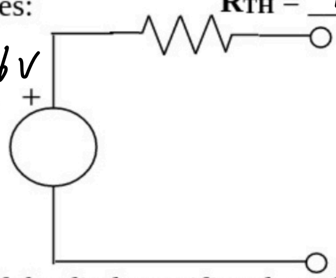
(h) Measure the output voltage with R_L connected between H7 & H8 — **$V_{O\_100\Omega}$** = 9.323V

(i) Calculate the current and power in R_L (use measured values) — **$I_{O\_100\Omega}$** = 94.17mA; **$P_{L\_100\Omega}$** = 895.5mW

(j) Calculate the output resistance of the LM317 (use equation at top) — **R_O** = 45.6mΩ

(k) Construct a Thevenin equivalent circuit with your values: (Hint: see p. I-9) — **R_{TH}** = 45.6mΩ

V_{TH} = 9.516V



$$\%\ \boldsymbol{change} = [(\boldsymbol{new} - \boldsymbol{old}) \div \boldsymbol{old}](100)$$

(l) Compare R_o of LM317 (Step j above) with the R_{TH} of the diode rectifier alone (Step 4i on p. I-9) by calculating the percentage change. **%-change** = 0%

(m) What is the advantage of using a regulator? High efficiency, better thermal performance

(n) Which circuit (diode rectifier or regulated rectifier) is a more ideal voltage source? Diode

d) $P_L = IV = (9.51)(6.46\,mA)$

$P_L = 0.0614 = 61.4\,mW$

i) $P_L = IV = (9.51)(94.17\,mA)$

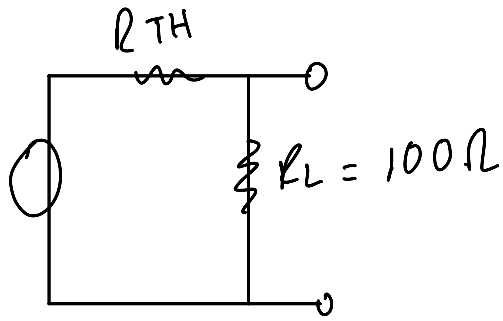
$P_L = 0.8955 = 895.5\,mW$

j) $\text{Output Res} = \dfrac{\Delta V_o}{\Delta I_o} = \dfrac{9.523 - 9.519}{94.17\,mA - 6.46\,mA} = 0.0456$

$= 45.6\,m\Omega$

k =

VTH=



$V_{TH} = V_{no\ load} = 9.516\,V$

$R_{TH} = R_o = 45.6\,m\Omega$

$V_o = 9.516 \dfrac{100\Omega}{45.6\,m\Omega \times 100\Omega}$

SPECIFICATION MEASUREMENTS

Measure the actual value of the 100Ω-2W resistor (get from instructor) $R_{100\Omega}$ = 99.24Ω
(okay to use the resistor substitution box if 2 Watt resistors are unavailable)

Measure the actual value of the 1.5 kΩ-¼W resistor (get from parts bin) $R_{1.5k\Omega}$ = 1.478 kΩ

Step 3 - CHARACTERIZING THE LM7805 (fixed V_{out})

• **OPEN CIRCUIT OUTPUT VOLTAGE OF THE LM7805 ($R_L = \infty$)**

(a) Measure the DC output voltage at H6 with no load **V_O** = 4.996V

• **RIPPLE REJECTION RATIO (use AC coupling to magnify the 120Hz ripple and then measure it manually as per item 7 on p. 4)**

$\frac{V_r In}{V_r out} = RRR$

(b) Connect a 100Ω-2W load resistor between H6 and ground (H8). **V_{rIN}** = 290 mV
Manually measure the ripple's ***peak-to-peak*** voltage & period ***entering*** the LM7805 (at TST 6).
T_r = 8.5m/s

(c) Measure the ***peak-to-peak*** ripple at LM7805's output (H6) **V_{rOUT}** = 76mV
(expect $V_{rOUT} << V_{rIN}$ so zoom in on V_{rOUT} before manually measuring its ripple)

(d) Calculate LM7805's Ripple Rejection Ratio (see p. II-2) **RRR** = 3.82

• **% LOAD REGULATION OF LM317 (ideally want V_O to be independent of R_L)**

(e) With $R_L = 100\Omega$, measure LM7805's output voltage (H6) **$V_{O\_100\,\Omega}$** = 4.991V

$V = IR$

(f) Calculate the current flowing in R_L (based on measured values) **$I_{O\_100\,\Omega}$** = 50.3mA

$\frac{V}{R} = I$

(g) With $R_L = 1.5k\Omega$, measure LM7805's output voltage (H6) **$V_{O\_1.5k\,\Omega}$** = 4.996V

(h) Calculate the new load current (use Ohm's law and R_L's measured value) **$I_{O\_1.5k\,\Omega}$** = 3.38mA

$\frac{4.991}{99.24} = 49.91$ mA

(i) Using data from Steps 3e-3h, calculate percentage load regulation **% Reg** = 0.1%

$$\boxed{\%\,Reg = \frac{|V_{o2} - V_{o1}|}{V_{o1}}\,X\,100\%}$$

$\frac{4.996V}{1.478k} =$

(j) Calculate the power delivered to the two resistors **$P_{L\_100\Omega}$** = 251.04mW
(Note: $P_L = IV = I^2R_L = V^2/R_L$ so smaller resistors must dissipate more power)
$P_{L\_1.5k\Omega}$ = 16.89mW

• **SHORT CIRCUIT ($R_L = 0$) PROTECTION (with power transformer ON)**

$P_{L\,100} = (4.991)(50.3mA)$

$P_{L\,1.5} = (4.996)(3.38mA)$

(k) Remove R_L and short LM7805's output (H6) to ground for two seconds.

(l) Remove the short, measure V_O, & then compare it with Step 3a **V_{O_after}** = 4.986V

(m) Is the output protected? How did you know? Yes, the Capacitors and Voltage remained the same

Step 4 - CHARACTERIZING THE LM317 (adjustable POS V_o)

[$V_{out} = V_{ref} (1+P_1/R_2)$ where $V_{ref} = 1.25V$]

• **OPEN CIRCUIT OUTPUT (at H7) OF THE LM317 ($R_L = \infty$)**

(a) With no load connected to H7, slowly adjust trim pot P1 to determine LM317's minimum and maximum output voltage (expect $1.25v < V_o < 20v$) **Vo range** = 1.246V < Vo < 18.22V

(b) Adjust P1 for +10V output & record its actual output **Vo** = 10.06 V

• **RIPPLE REJECTION RATIO (use AC coupling to magnify the 120Hz ripple and then measure it manually as per item 7 on p. 4)**

(c) With the 100Ω-2W load resistor between H7 and ground (H8), measure LM317's output voltage (H7). **Vo_100Ω** = 10.06 V

(d) Calculate the load current (use Ohm's law and R_L's measured value) **Io_100Ω** = 101.37mA $\frac{10.06v}{99.24}$ =

(e) Use scope's cursors to measure the peak-to-peak ripple *entering* LM317 (TST6). ***Record V_{rIN} (on Ch 1) and put in your eventual report.*** **VrIN** = 470mV ÷

(f) Use scope's cursors to measure the peak-to-peak ripple at LM317's output (H7). ***Enlarge ripple before measuring V_{rOUT}. Record waveform & put in report.*** **VrOUT** = 72mV

(g) Calculate LM317's Ripple Rejection Ratio (see p. II-2) **RRR** = 6.53

• **% LOAD REGULATION OF LM317 (ideally want V_O to be independent of R_L)**

(h) Replace the 100Ω load resistor between H7 & H8 with a 1.5 kΩ - ¼W load resistor

(i) Measure LM317's output voltage (at H7) with this new load **Vo_1.5kΩ** = 10.06V $\frac{10.06}{1.478k}$

(j) Calculate the new load current (use Ohm's law and R_L's measured value) **Io_1.5kΩ** = 68.1mA

(k) Calculate Percentage Load Regulation (for R_L = 100Ω & 1.5kΩ) **% Reg** = 0%

$$\boxed{\% Reg = \frac{|V_{o2} - V_{o1}|}{V_{o1}} X\ 100\%}$$

• **SHORT CIRCUIT (R_L = 0) PROTECTION (with power transformer ON)**

(l) Remove R_L and short LM317's output (H7) to ground (H8) for two seconds.

(m) Remove the short, measure V_O, & then compare it with Step 4b. **Vo_after** = 10.087 V

(n) Is the output protected? How did you know? Yes, Voltage remained the same

Step 5 - CHARACTERIZING THE LM337 (adjustable NEG V_o)

[V_{out} = V_{ref} (1+P_2/R_3) where V_{ref} = -1.25V]

• **OPEN CIRCUIT OUTPUT (at H9) OF THE LM 337 ($R_L = \infty$ & PCB's $R_3 = 330\Omega$)**

(a) With no load connected to H9, slowly adjust trim pot P_2 to determine LM337's minimum and maximum output voltage **$V_{o\ range}$** = -1.26V > Vo > -18.02V (expect -1.25v > V_o > -20v)

(b) Adjust P_2 for -10V output & record its actual output **Vo** = -10.08V

• **RIPPLE REJECTION RATIO (use AC coupling to magnify the 120Hz ripple and then measure it manually as per item 7 on p. 4)**

(c) With the 100Ω-2W load resistor between H9 and ground (H8), measure LM337's output voltage (H9) **$Vo_{\_100\Omega}$** = -10.076 V ÷ 99.24

(d) Calculate the current and power in R_L (use the measured values)` **$Io_{\_100\Omega}$** = - 101.5mA **$P_{L\_100\Omega}$** = 1.02W

P = 1V

(e) Use scope's cursors to measure the peak-to-peak ripple at LM337's input (TST7). ***Record V_{rIN} (on Ch 1) and put in your eventual report.*** **V_{rIN}** = 880mV

(f) Use scope's cursors to measure the peak-to-peak ripple at LM337's output (H9). ***Enlarge ripple before measuring V_{rOUT}. Record & put in report.*** **V_{rOUT}** = 84mV

(g) Calculate LM337's Ripple Rejection Ratio (see p. II-2) **RRR** = 10.48

• **% LOAD REGULATION OF LM337 (ideally want V_O to be independent of R_L)**

(h) Replace the 100Ω resistor with a 1.5 kΩ - ¼W load resistor between H9 and ground (H8).

(i) Measure LM337's output voltage (H9) with this new load. **$Vo_{\_1.5k\Omega}$** = -10.097V

(j) Calculate the current and power in R_L (use the measured values)` **$Io_{\_1.5k\Omega}$** = -6.83mA **$P_{L\_1.5k\Omega}$** = 68.97mW

(k) Calculate Percentage Load Regulation (for R_L = 100Ω & 1.5kΩ) **% Reg** = 0.21%

$$\boxed{\% Reg = \frac{|V_{o2} - V_{o1}|}{V_{o1}} X\ 100\%}$$

• **SHORT CIRCUIT (R_L = 0) PROTECTION (with power transformer ON)**

(l) Remove R_L and short LM337's output (H9) to ground (H8) for two seconds.

(m) Remove the short, measure V_O, & then compare it with Step 5b. **$Vo_{\_after}$** = -10.13V

(n) Is the output protected? How did you know? Yes

(o) Remove wires (no longer needed) that may be connected to diode D5, TST6 and TST7 and show off your finished power supply.