In this lab we will complete the regulated DC power supply shown in Figure 1.

![Figure 1](image1.png)

In lab 1 we built the unregulated DC supply shown in figure 2:

![Figure 2](image2.png)

Two problems with this supply are that the output voltage under load has a large amount of ripple and that when no load is applied to the supply, the output voltage (V_Unreg) becomes very large. To fix these problems we will build a linear voltage regulator. (We could also use an LM7815 like we did in ECE 351 or build a switching DC-DC converter like we will do later in the class.) We will design the circuit shown in Figure 3:
Note that 1% resistors are available for R3 and R4. We will use an LM324 OPAMP because it can be used with a single supply. There is a problem however with using the LM324. The maximum supply voltage it can tolerate is 32 volts. V_{Unreg} will normally reach voltages as high as 60 volts. Thus, we need to provide a separate regulator to supply power for the LM324. We will do this with a Zener linear regulator as shown in Figure 4:

You will need to design the Zener regulator to provide 30 volts to the LM324 at about 10 mA. The complete schematic is shown in Figure 5:
**Figure 5**

**Design Specifications:**
1. Design $R_3$ so that the current through the LM385 is within the minimum and maximum specifications for this device for all possible values of $V_{Unreg}$.
2. Design a Zener regulator to supply approximately 30 V at 10 mA to the LM324. The input voltage to this regulator will be between 35 and 60 volts. You must calculate the power dissipated by each component dissipated in the Zener regulator. Note that the worst case power dissipation occurs when the input voltage is constant at 60 volts.
3. Design a OP-AMP based linear regulator that will supply an output voltage of 25 volts at a maximum output current of 2 amps. The input voltage to this regulator will be between 35 and 60 volts.

**Some Available Parts:**
Tip 102, 1000 µF 25 V Capacitor, 1N4741 Zener, 1N4740 Zener, 1N4738 Zener, Some 2 W resistors, 1% resistors from 1 KΩ to 100 KΩ (for R3 and R4 only).

**Wiring**
Use the following wiring colors for connections:
- Bus bar wire – All high current connections (or use colored 18 gauge wire)
- Black – low current ground connections
- Red - Vcc_Unreg
- Blue – Miscellaneous connections

**Testing Procedure**
1. **No Load Testing**
   - I must be around when you initially test your DC supply.
   - Use a VARIAC to power your DC supply. Do not plug your supply directly into an outlet. A VARIAC will allow you to slowly increase the power to your supply and determine if something is wrong.
   - You will be working with 162 volts peak. This is a higher voltage than any other voltage you have previously worked with in an electronics lab and is potentially lethal. When making measurements or testing your circuit, work slowly and work with one hand in your pocket to reduce the possibility of creating a current path through your heart.
   - With the VARIAC set to zero, measure $V_{CC}$ with a DC Multimeter and measure the voltage $V_{Unreg}$ with the scope. Slowly increase the VARIAC from zero to 120. Once $V_{CC}$ reaches
the point where it should start regulating (somewhere around 30 volts) the voltage should remain constant even though the voltage $V_{\text{Unreg}}$ will increase. Verify that the voltage $V_{\text{CC}}$ never goes above 32 V as $V_{\text{Unreg}}$ varies from 35 V up to 60 V. (Note that the OPAMP can actually tolerate more than 32 volts, but it is not guaranteed by the manufacturer.)

- With the VARIAC set to zero, measure $V_{\text{OUT}}$ with a DC Multimeter and measure the voltage $V_{\text{Unreg}}$ with the scope. Slowly increase the VARIAC from zero to 120. Once $V_{\text{OUT}}$ reaches the point where it should start regulating (somewhere around 25 volts) the voltage should remain constant even though the voltage $V_{\text{Unreg}}$ will increase. Verify that the output voltage remains constant at 25 V as $V_{\text{Unreg}}$ varies from 35 V up to 60 V. The output should be extremely constant and only vary by a few millivolts at most as the input changes.

2. **Full Load Testing**

- While still using the VARIAC, connect the output of your supply to a 50 $\Omega$ rheostat in series with two 25 $\Omega$ power resistors in parallel. We will use this load to draw current from your supply and see how it behaves. We will measure the average current through the load using the Multimeter and measure the voltage of your supply using the oscilloscope.
- Measure the voltage $V_{\text{Unreg}}$ with channel A and measure $V_{\text{OUT}}$ with Channel B. Verify at full load that there is a large amount of ripple at the input and almost no ripple at the output.
- At full load, set the oscilloscope coupling for channel B to AC and see if you can measure any ripple on the output of your supply.
- Using the DC meters find out how much the DC output of your supply varies between no load and full load.
- Measure/estimate the efficiency of your linear regulator at full load.