Lab 3

Diodes, Power Supplies, Zeners, and SCR's

REFERENCE	Horowitz and Hill	Sections 1.25- 1.30.	rectification filtering, regulation
		Sections 6.11 - 6.14	power supply parts
		Sections 6.16	3-terminal regulator

INTRODUCTION

In this lab we examine the properties of diodes and their applications for power supplies and signals:

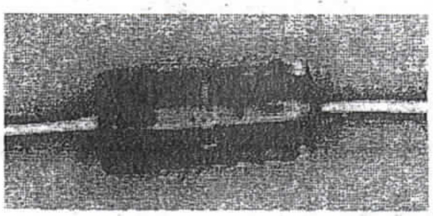
- Diode rectification in 1/2 wave and full wave bridge circuits
- Filtering in power-supply circuits
- 3-terminal voltage regulator
- Zener diode and its use as a voltage regulator
- Diode clamp circuit
- Silicon controlled rectifier (SCR)

Note: the instructor probably will choose not to do all of the above.

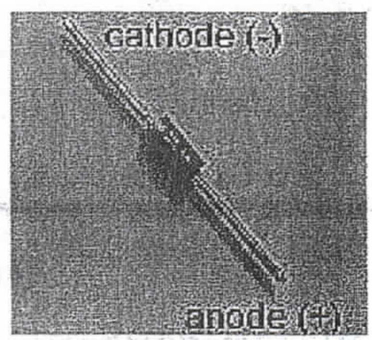
We will also build our measurement skills, learning to use a digital oscilloscope.

EQUIPMENT

Digital Oscilloscope		
Function generator		
Prototyping board		
Transformer, center tapped	~8 V	
Power diodes (4 & spares)		
Signal diodes (2)	1N914	
Zener diode (1 & spares)	5 V or 10 V	
Resistors	91 (2 W), 1 k, 2 k, 10 k	
	56 k, 110 k	[for SCR circuit]
Capacitors	0.5 μF, 10 μF, 100 μF (2),	
	1000 μF	[for SCR circuit]
	0.01 μF, 4.7 μF	[for 3-term. regulator]
Variac		[for 3-term.regulator]
Decade Box		
Potentiometer	50 k	[for SCR circuit]
SCR		[for SCR circuit]
0 - 30 V dc power supply		
6 V lamp		[for SCR circuit]
3-terminal regulator	78L05 in TO-92 package	[for 3-term. regulator]



1N914 signal diode



Power diode

TO-92 package

0. Ohmmeter Check of Diode

❝ You will need a multimeter to confirm the polarity of a diode. You don't need to report your results here in your lab report.

☞ Use your oscilloscope (or a second multimeter) to determine which of the multimeter leads has a + voltage and which is - .

☞ Look at your multimeter to see what special features it has. You can do a diode check with the resistance function, on the 200 Ω scale. Even better, try the continuity or diode-check feature, as shown by the symbol —▶|—, if your multimeter has one. The diode-check function will display the diode's voltage drop across the PN junction.

☞ Confirm the PN polarity of a signal diode (these are smaller than the power diodes). Look at the markings on the diode to see how they show the polarity.

☞ Repeat the diode tests above, using a power diode.

❝ Note that for a multimeter check to work, the multimeter must apply a voltage of at least 0.5 Volt between its two leads to bring the "diode" into conduction when it is forward biased.

CAUTION:

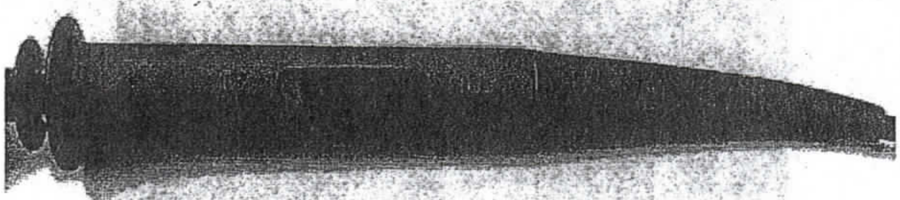
In this lab it is possible to burn up components if you are not careful to make sure everything is correct before turning on the power.

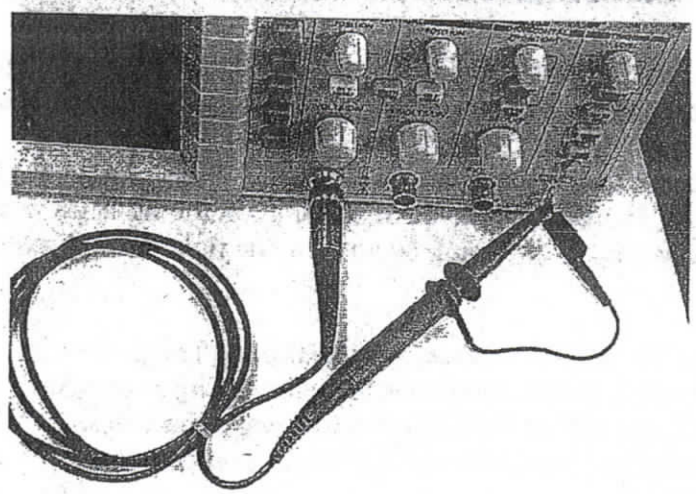
- Please note all caution statements in these instructions.
- Double-check before turning power on!
- When using the decade box, do not set the load resistance below 50 Ω.

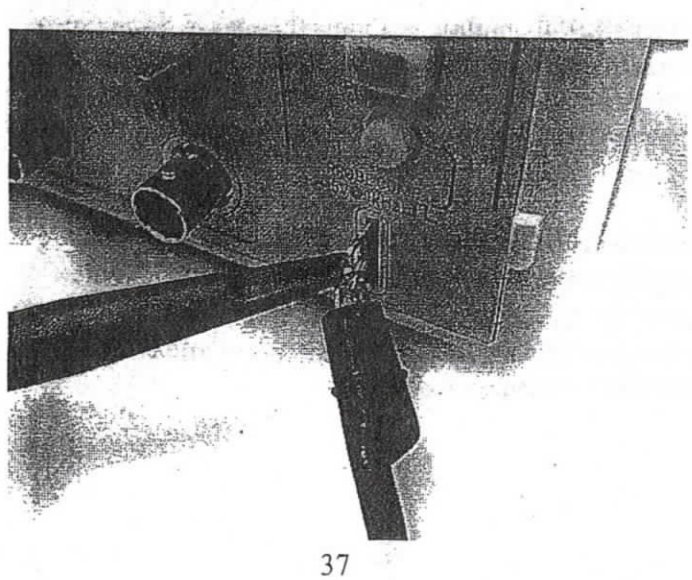
☞ Learn to use the digital oscilloscope & a scope probe – no written response required

Connect a scope probe to the digital oscilloscope as shown in the photos below.

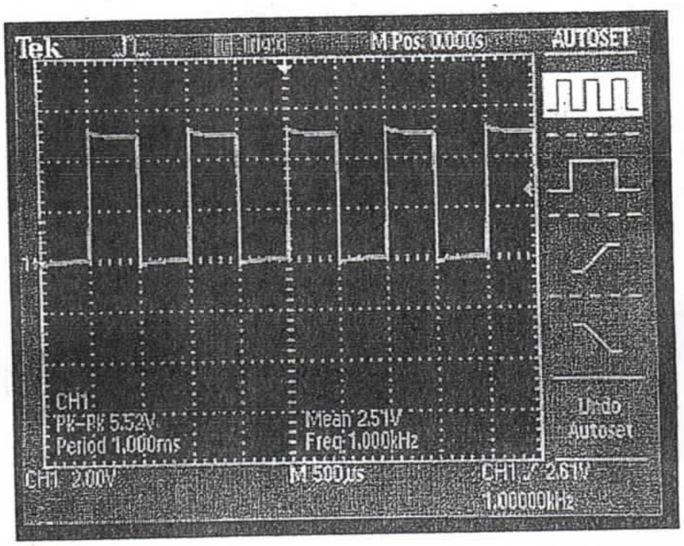
A scope probe has two settings: 1X and 10X (photo shows 10X setting). This notation might be confusing: the 10X setting has the effect of dividing, not multiplying, the signal by a factor of ten. For simplicity, always use 1X for this course, not 10X.







Press the AUTOSET button to see the display of a square wave



Push the CH2 MENU button twice, to see how this turns the display for that channel off and on. The two channels are distinguished by their color.

To see their effect, adjust these knobs: VOLTS/DIV, SEC/DIV, VERTICAL POSITION, HORIZONTAL POSITION. Look for the arrow at the top that indicates the trigger time, and the arrow at the right that indicates zero voltage.

Push the CH1 MENU button to see the display. Toggle the "Probe" setting so that it indicates the same setting as on your probe (1X, not 10X or 100X). You must always check this, before using the scope, to avoid X10 errors in your voltage measurements.

Push the TRIG MENU button and view the menu. Sometimes in this course you will be asked to use EXT TRIG, which you can accomplish with the digital oscilloscope by toggling "Source" to the "Ext" setting. At other times, you might wish to use CH1 as the "Source."

Push the MEASURE button and view the menu. Toggle the "Type" setting to measure the peak-to-peak voltage and the frequency of the waveform. Then adjust the TIME/DIV knob so that less than one full oscillation is shown, and notice how the scope is unable to measure frequency.

1. Diode Limiter

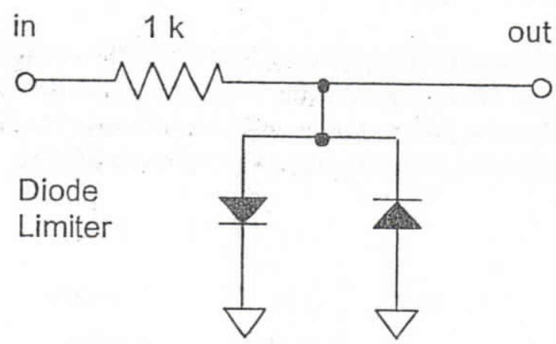
❝ Diode limiters could be used at the inputs of small-signal instruments to protect against accidental application of large input signals.

❝ This is a low-current application, so you use signal diodes, not current diodes.

☛ Using signal diodes, connect the input of the circuit shown below to the function generator, set to about 1 kHz. Check that the –20 dB attenuator switch on the function generator is not activated. Try sines, triangles, and square waves of various amplitudes.

☛ ✍ Print the output of the clamp circuit for sine wave inputs two ways -- for large and for small input amplitudes.

✍ Explain the amplitude you observe.



2. Diode Clamp

☞ Connect the clamp circuit in the figure. Use the +5V power supply built into your prototyping board.

“ This is a low-current application, so you use signal diodes, not current diodes.

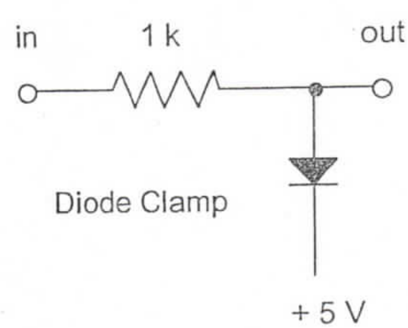
☞ Connect the input of this circuit to the function generator with a sine wave at 10 kHz. Check that the –20 dB attenuator switch on the function generator is not activated.

☞ Set up the oscilloscope to show the input and output waveforms. Use DC input coupling on the oscilloscope,

☞ Connect three grounds together: the ground of the 5 V power supply, the ground of the function generator, and the ground of the oscilloscope.

☞ Adjust the sine wave amplitude so that you can see a “clamped” output.

✍ Print the waveforms for the input and output of the clamp circuit. (If you can see that the clamped voltage is not quite flat, then you can see the effect of the diode’s non-zero impedance in conduction.) From your observation explain in one or two sentences what the clamp circuit is useful for.



Diode Clamp

3. Power Supply Rectifying Circuits

(a) Half Wave Rectification

☛ Set up the circuit in Figure 3-1. (For this part, ignore the center-tap (CT) terminal on the transformer, if any.) You are building a power supply, so use power diodes rated at 1 W, not the little signal diodes. Use the decade box, set at 1 kΩ, for the load resistor.

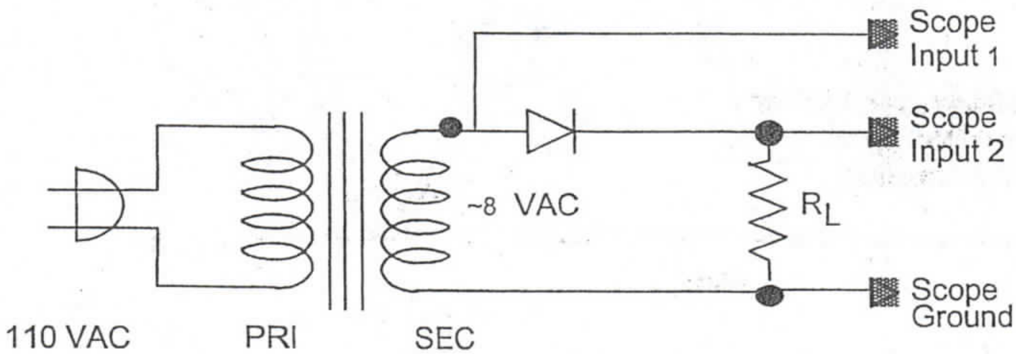
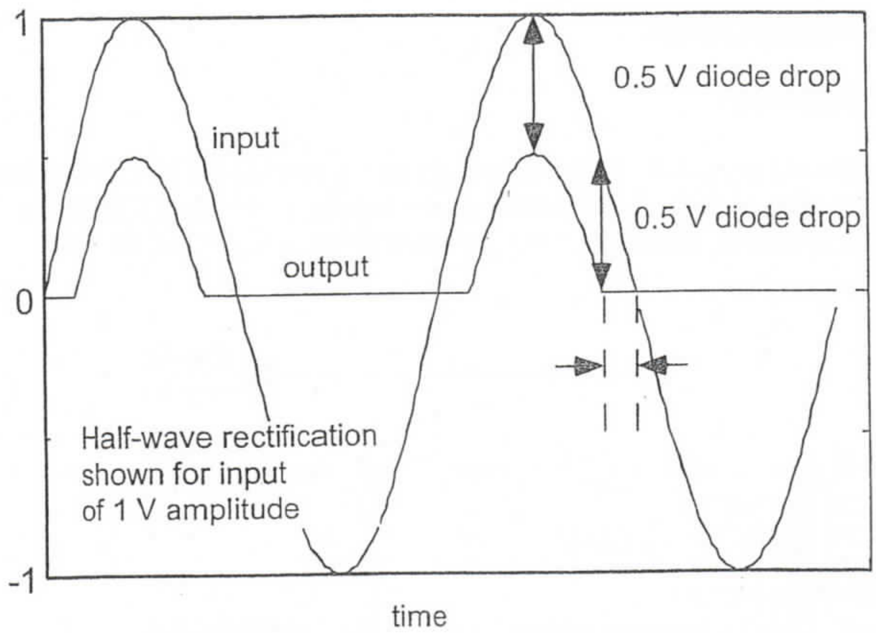


Figure 3-1

☛ Set the oscilloscope as follows:
input coupling DC (CH1 and CH2)
vertical mode BOTH and either ALT or CHOP (this is the dual trace feature)

" In the figure below, the waveforms are shown as they would look if the input voltage had a 1 V amplitude. Notice the 0.5 V diode drop. Also notice the time interval shown between the dashed lines, when the input voltage is positive but not large enough for the diode to conduct.



☞ ✍ Measure the P-P amplitude in two places: the input voltage V_i from the transformer, and the rectified sine wave output voltage V_o across the 1 kΩ "load resistor" R_L.

✍ Print the input and output waveforms and compare the peak output voltage with half of the PP input voltage. Explain the difference.

(b) Full Wave Rectification

☞ CAUTION: In this part, carefully *check the polarity of your diodes* before turning on the 110 VAC power-- otherwise you may burn up the diodes.

☞ ✍ Measure the output waveform of the full-wave *bridge circuit* in Figure 3-3. Do not attempt to measure the input waveform. Use a 1 kΩ load resistor.
✍ Print the output waveform. Compare to the half-wave rectifier.

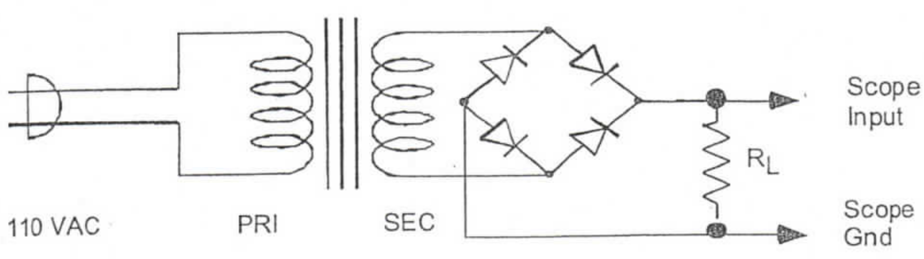


Figure 3.3. Full-wave rectifier bridge circuit. The input is 110 VAC line voltage.

4. Power Supply Filtering

☞ CAUTION: In this part, carefully *check the polarity of your capacitor* before turning on the 110 VAC power.

☞ Starting with the full wave rectifier circuits in Figure 3-3, add a capacitor C = 100 μF across the load resistor as shown in Figure 3-4. Note that capacitors of such a large value are polarized: one of the capacitor's two leads is marked – or +.

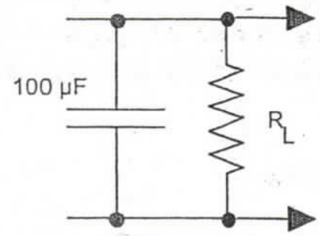


Figure 3-4 Filter Capacitor

☞ Measure the DC output voltage.

☞ ✍Measure the PP AC ripple using the oscilloscope.

[Try this two ways:
- first with DC input coupling
- repeat with AC input coupling.

You should find that AC coupling allows you to use a smaller scale in Volts/div and thereby make a more accurate measurement.]

✍ Print the output waveform. Discuss in one sentence how the filter capacitor improves the performance of a power supply.

☞ Repeat with a capacitance of 1000 μF.

☞ Using the capacitance of 100 μF, try a smaller load resistance (CAUTION: do not set the load resistance below 50 Ω).

✍ List your results. Compare with the calculated values of the DC output and ripple voltages. (See **text** p. 46.)

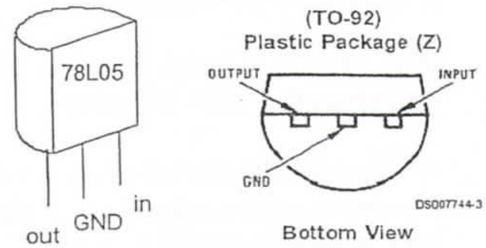
✍ Dsicuss (in two of three sentences) two factors that cause ripple to become worse.

“ Note that in a power supply, a bigger capacitance gives better filtering, but with the tradeoff that the component is costlier, larger and heavier.

“ Note that the smaller the load resistance, i.e. the larger the current that the power supply must deliver, the worse the ripple.

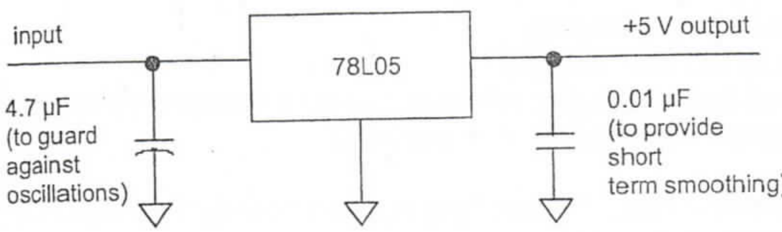
5. Voltage regulation with 3-terminal regulator

❝ 3-terminal voltage regulators are easy to use. From the outside it looks like a transistor, but on the inside there is a good regulator that makes use of negative feedback. It features thermal protection so that it is hard to burn up.



(a) Simple test

☞ Connect the 78L05 regulator on your prototyping board, as shown below. For an input, use the +12 Volt power supply that is built into your prototyping board, or an external power supply set to about +10 V.

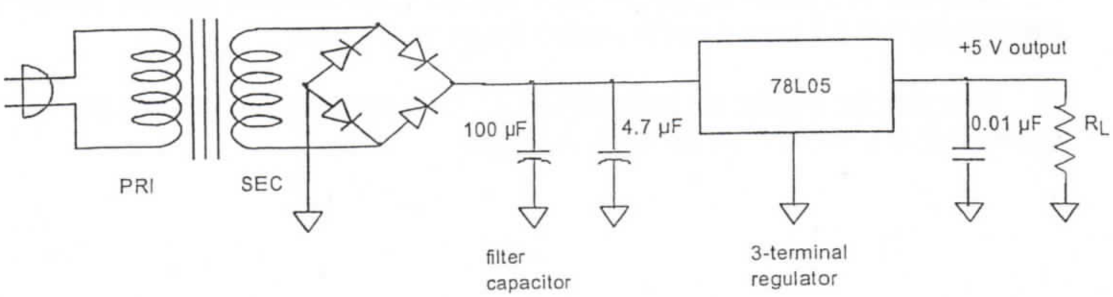


☞ ✍ Confirm that the output is +5 Volts.

❝ An ideal voltage regulator supplies the same output voltage,
- regardless of the input voltage, as in test (b), below
- regardless of the output load, as in test(c), below

(b) Use as a power supply regulator

☞ Now connect the input of the 78L05 regulator, as shown below, to the output of the power supply you built in step 2. Include a 1 kΩ load resistor.

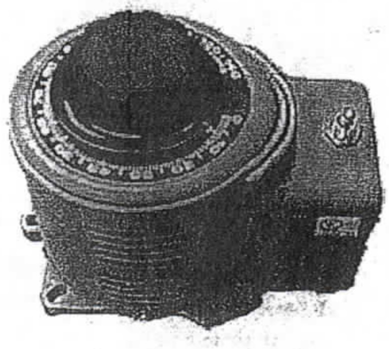


☞ Turn on the power supply, and observe the output voltage.

☞ ✍ Compare to the filtered output without regulation, as measured in step 2.

(c) Regulation as the input voltage is varied

☞ Now plug the transformer of your power supply into a variac instead of into 110 VAC. Connect a multimeter to measure the Volts ac from the variac



Variac

☞ Set R_L to 1 kΩ.

☞ Adjust the variac output voltage, beginning at110 VAC and going downward, using the printed scale on the top of the variac. (Caution: Do not operate the variac at voltages above 110 V)

☞ ✍ Confirm that the regulator maintains the same +5 Volt output over a wide range of AC voltage (typically from 80 to 110 VAC).

(d) Regulation as the load is varied

☞ Disconnect the variac. Connect your multimeter to measure current through the load.

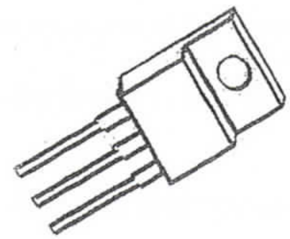
CAUTION: In this step, to protect the decade box, always keep 50 or 100 Ω switched in while you adjust the other scales. This precaution will keep you from accidentally setting the decade box to zero resistance.

CAUTION: As always, measure current beginning with the meter set to the highest scale.

☞ Set R_L to about 10 kΩ, and vary it downward.

☞ ✍ Note the load resistance at which ripple begins to appear. What current value does this correspond to? (This is the maximum regulated current.)

TO-92 package



TO-220 package

(e) Thermal protection

☞ ✍ Continue to decrease the load resistance. Does the output of the regulator shut down when the current exceeds a certain threshold? This is the current limit of your regulator.

[To work, this shut-down test requires using a regulator in the TO-92 package; don't use a larger package like TO-220 (LM78M05CT) for this lab -- it won't shut down under these conditions.]

❝ One of the advantages of these three-terminal regulators is the shutdown feature. Another alternative for voltage regulation is the zener diode in the next experiment, but zeners do not have thermal protection, so you must be careful to select the right one and use it within its design parameters.

<u>6. Voltage Regulation with Zener Diodes</u>

[TA note: usually there is enough time to do all of this lab except that some instructors omit the SCR circuit to save time. If it is necessary to reduce the time further, this section is the next choice for omission.]

❝ Zener diodes can be used as a simple voltage regulator to establish a reference voltage source for non-critical applications.

CAUTION:
Zener diodes are <u>very</u> easy to burn up if you make a goof in wiring them up.

☞ Remove the 3-terminal regulator and its accompanying two capacitors.

☞ Select an appropriate Zener, depending on your transformer (5V for a 6.3 V transformer or 12 V for a 12.6 V transformer). Assume the Zener has a power rating of 0.4 W in either case.

☞ Add a Zener diode across the output of the PI filtered power supply you built in part 2, as shown in Figure 3-6.

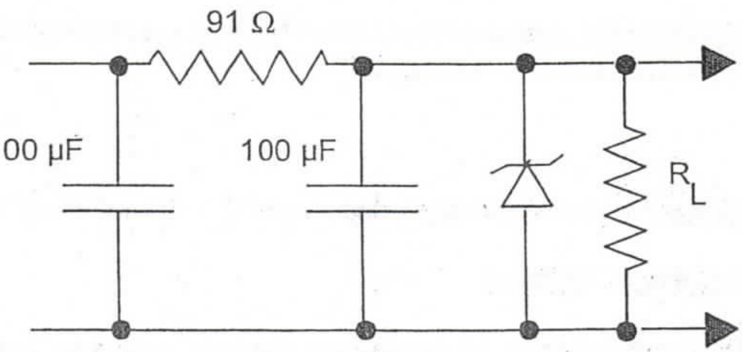


Figure 3-6 Pi filter with Zener diode voltage regulator

(a) Calculations

☞ ✍ Before you power up your circuit, do the following:

(i) Determine the maximum Zener current $I_{Z\,max}$ from the power rating.
(ii) Determine the total current through the 91 Ω resistor:

$$I_{tot} = (V_{in} - V_Z) / 91.0\ \Omega$$

This current is the sum of the Zener current I_Z and the load current I_L. Check whether it exceeds $I_{Z\,max}$ because there must then be a minimum load current to prevent overloading the Zener. This will imply a maximum load resistance.

(b) Measurements

(i) Output voltage

☞ Power up your circuit.

☞ ✍ Measure the voltage across the load resistance.

CAUTION: in the next step, to protect the decade box, always keep 100 Ω switched in while you adjust the other scales. This precaution will keep you from accidentally setting the decade box to zero resistance.

(ii) Regulation

☞ Vary R_L beginning at 10.1 kΩ and stepping downward to 500 Ω.

☞ ✍ Note the load resistance above which the voltage stays approximately constant. To what current does this correspond?

7. SCR Circuits *[optional depending on whether TA finds there is enough time]*

(a) DC Control – *RC* Timer

" The circuit in Figure 3-8 switches on a voltage across the load after a delay. The SCR switches on when the gate voltage (G) exceeds the cathode voltage (C). The gate voltage is developed across the capacitor C_1 by the *R-C* combination.

☞ Short C_1 to remove all charge.

(i) Switching time

☞ ✍ Turn on the supply and determine the time for the voltage to be switched across the load.

(ii) Gate voltage

☞ Short C_1 again and repeat with each of the resistors in the time constant portion of the circuit.

☞ ✍ Determine the gate voltage necessary for firing.

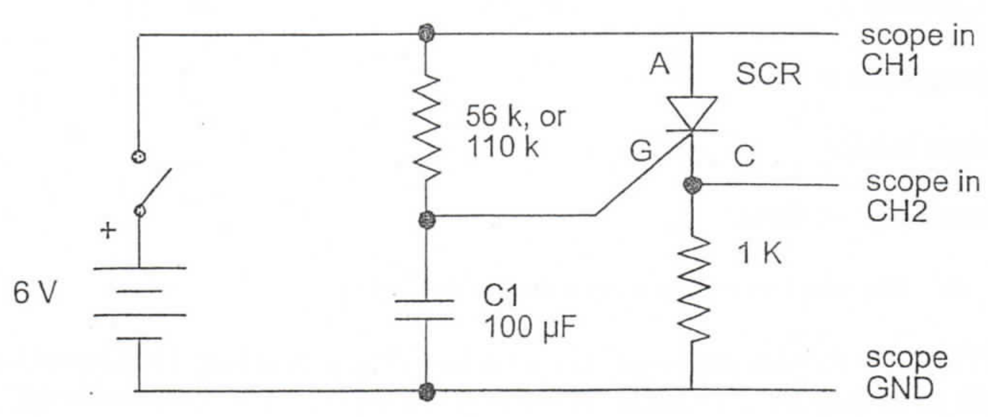


Figure 3-8 RC Timer

(b) AC Control -- Lamp Dimmer

❝ In the circuit in Figure 3-9, the *R*-*C* combination acts as a phase shifter for the 60 Hz AC voltage. As *R* is increased, the phase is shifted from 0° to -90 °. With this circuit it is possible to control the output half wave from completely on to completely off.

☛ Use the input from the transformer secondary as a reference signal for the oscilloscope.

☛ ✍ Observe the phase shifted wave across *C* and the output wave across R_L. Explain why the lamp dims.

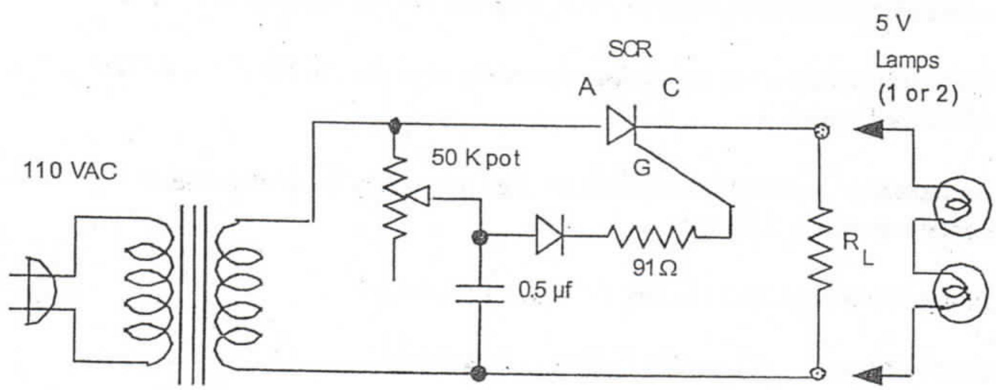


Figure 3-9