ECE250 Device Modeling
Laboratory #4. More Diode Applications!

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Dept. of Electrical and Computer Engineering
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Lab Team Members: ________________________ ________________________
Date Performed: __________________________ Lab Station: ______________

As before, your lab report will consist of this lab document with all requested blanks filled in and ***all of the requested*** *attachments labeled and stapled in the proper order to the back of this document.*

*Parts Needed: Two 1N4148 small-signal diodes, one 1N4741 (Vz = 11 V) Zener diode, one 220Ω, one 330Ω , one 1kΩ, one 3.3k*Ω, one *4.7kΩ, three 10kΩ, one 100kΩ resistors; one 0.1μF capacitor.*

1) ***Diode Amplitude Modulated Waveform Detector (Review Class Notes, pp. 1.63 – 1.64)***
   a) Set up 50% AM modulated wave (with a 5 kHz carrier frequency and a 200 Hz modulating frequency) using the Agilent 33220A 20 MHz function generator.
      i) Turn on the power to this unit.
      ii) Press the "SIN" (sine wave) button to set up the sinusoidal carrier wave.
         (1) Set Frequency = 10 kHz
         (2) Set Amplitude = 10 V (p-p)
         (3) Set DC Offset = 0 Vdc
      iii) Press the "MOD" (modulation) button to set up the desired modulation
         (1) Set Type = AM
         (2) Source = Internal
         (3) AM Depth = 50%
         (4) AM Frequency = 100 Hz
         (5) Shape = Sine
      iv) Press the "OUTPUT" button to allow the modulated wave to appear at the "output" connector of the generator.
   b) Connect the output of this generator to the Agilent 54624A digital oscilloscope. Turn on the power to the oscilloscope and press the "Autoscale" button. You will find that the autoscale function zeros in on several cycles of the carrier wave, rather than several cycles of the modulation envelope as desired. Therefore, you must now turn the horizontal sweep knob (upper left knob on the scope's front panel) counter-clockwise until several modulation envelope cycles of an AM modulated carrier wave is visible, similar to that shown on p. 1.64 of the notes. Hit the "Run/Stop" button to freeze the display and plot the 50% sine wave AM modulated wave.
   c) Construct the AM diode peak detector circuit that is shown on p. 1.64 of the class notes, replacing the antenna and parallel-resonant LC circuit with the function generator. Your diode AM detector should consist of a 1N4148 small-signal diode, and a resistor R and a capacitor C. Let C = 0.1 μF, and choose R so that the time constant "RC" is considerably greater than (say, at least 10 times greater than) the period of the carrier wave, Tcarrier = 1/(10 kHz) = 0.1 ms, so that the "carrier-frequency ripple" at the output of the detector is not appreciable. If we let R = 10 kΩ, the time constant = 1 ms At the same time, we must also check to see that this time constant is considerably less than the period of the modulating sine wave so that the detected

audio signal is not also filtered out along with the carrier by the RC network, thereby "throwing the baby out with the bath water". In our case, the period of the modulating sine wave is Taudio = 1 / (100 Hz) = 10 ms, which is greater than the time constant by a factor of 10. Thus with the choice of C 0.1 μF and R = 10 kΩ, we "barely" meet these desired specifications, with:

Tcarrier = 0.1 ms < RC = 1 ms < Taudio = 10 ms

Draw your diode peak detector circuit in the space below. Record an oscilloscope plot of the AM modulated wave, vin(t). Also record a similar oscilloscope plot of the detected audio output, vo(t), including the max, min, and freq values. Be sure to display Vmax, Vmin, and frequency values on both of these plots, as you did in the previous laboratory project. Include both of these plots as ***Attachment A***.

Note the presence of a small amount of undesired carrier ripple in the output waveform. In most real situations, the carrier frequency is much larger than the modulating frequency, and so the time constant of the RC network can be made much larger than the carrier period, while the time constant also remains much less than the period of the audio wave. This results in a much cleaner looking demodulated audio wave.

Diode Peak Detector (AM Demodulator) Circuit

2) Diode Clipping Circuit (Review p. 1.67 of Class Notes)

a) Design a diode clipping circuit that clips positive peaks to 2.7 V and negative peaks to -0.7 V. Draw your designed circuit and its "vout vs. vin" voltage transfer curve in the space below. Use two 1N4148 small-signal diodes, a 4.7 kilohm resistor, and your variable dc power supply. Using the 0.7 V threshold (0-resistance) diode model, sketch the predicted output voltage waveform *vout(t)*, if the input *vin(t)* is a 5 V peak (10 V peak-to-peak), 1 kHz *triangle* wave. *As always, be sure to indicate maximum and minimum voltage values and waveform period on your sketch.*

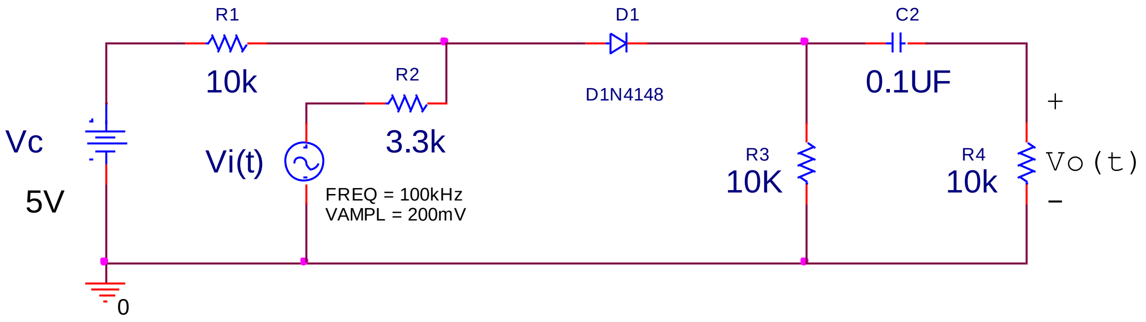
Diode Clipping Circuit **vout vs. vin VTC** **Predicted vout(t)**

b) Now build this circuit using two 1N4148 diodes. Use the function generator connected to the oscilloscope to set up the required triangle wave. Do this by selecting the "Ramp" waveform, and set the "Symmetry" to 50%. Plot the observed input waveform, vin(t), and also the output waveform, vout(t). Be sure to use the "Quick Measure" feature of the oscilloscope to display the minimum voltage, maximum voltage, and frequency displayed on your plots. Include these two plots in your report as ***Attachment B***.

3) *AC Diode Small-Signal Modeling (Review pp. 1.51 – 1.52 of Class Notes)*

Consider the analog switching circuit below:

Diagram of Analog Diode Switching Circuit



Build this circuit using a 1N4148 small-signal diode. Set your dc power supply to deliver +5 Vdc, and use this for the control voltage "Vc" in Fig. 1-18 on p. 1.51 of the Class Notes. Also, set up your function generator to deliver a 200 mV (peak-peak) sine wave at a frequency of 100 kHz. Let C = 0.1 μF. Note that the magnitude of the impedance of this value of C at the specified source frequency (100 kHz) is

$$\mathbf{X_C = 1/(2\pi fC) = 1/(2*\pi*10^5*0.1*10^{-6}) = 16\ \Omega}$$

Note that X_C is much smaller than the surrounding resistor values. Therefore, the capacitor is essentially a short circuit (compared to the much larger resistances in the surrounding circuit).

a. In the space below, draw the dc model of the circuit (with Vc = +5V), and then, working as was done in class, draw the dc model after finding the Thevenin equivalent of the source. Use the 0.7 V threshold model of the diode to calculate the approximate value of dc current through this diode, Idq.

DC Circuit Model ***DC Model After Source is Theveninized***

Idq = ____________ Amperes

b. In the space below, use the theoretical ac small-signal diode resistance (rd) equation to calculate the rd of the 1N4148 diode at the forward dc bias current level Idq that was calculated in Part A. Please assume that for the 1N4148 diode η = 2.0, and its bulk resistance is 0 Ω, which is close to the value that you measured in Laboratory Project #1.

Small-Signal (ac) Diode Resistance "r_d"Calculation

Small-Signal Diode (ac) resistance, r_d = ________ Ohms

c. In the space below, redraw the ac model of the circuit, and then show the model with the source "Theveninized". Use the result of Part b above to predict the new ac signal voltage gain, vo(t)/vi(t), working as in the class notes.

AC Small-Signal Circuit Model ***After Source is Theveninized***

Calculations for predicting vo/vi when Vc = +5 V

Small Signal Gain = vo(t) / vi(t) = ______________ (As predicted above)

d. Now build the analog switching circuit shown above. Use your oscilloscope to check to ensure that the function generator, ***vi(t),*** has been properly configured to deliver a 100 kHz, 200 mV peak-to-peak sine wave. Note that the ac signal amplitude is kept small compared to ***Vc*** = +5 V. Also note that the 50 Ω output impedance of the function generator can be neglected compared to the value of R2.

Important Note*: Set your variable dc power supply (the red and black terminals of the 0 - 6V dc supply) to deliver 5.0 V, and use it for the Vc control source in the circuit. The red and black terminals are* *<u>not</u>* *internally connected to chassis ground, therefore you can freely connect either one of these terminals to ground without shorting out the power supply. This is important, because you will need to reverse the polarity of this supply (interchange the red and black terminals) as the control voltage Vc is switched between +5.0 and –5.0 V*

Measure the peak values of the vo(t) and vi(t) ac waveforms and calculate the observed small-signal (ac) gain, vo(t)/vi(t). Also fill in the predicted voltage gain from Part C, and calculate the percent error.

Vc = 5V Measured vo/vi = ______ Predicted vo/vi = _______ % Error = ______

Now set the digital control voltage Vc = -5.0 V by reversing the black and red terminals of the 5V dc power supply. Measure the new vo/vi and compare it with the predicted value of 0.

Vc = -5V Measured vo/vi = ______ Predicted vo/vi = 0

4. Zener Diode Voltage Regulator (Review pp. 1.53 – 1.54 of Class Notes)

A. Connect a 1N4741 11.0 V (+ or - 5%), 1-watt Zener diode in series with a ***220-ohm*** resistor and a 0 - 20 V variable dc power supply, so that the Zener diode will be reverse-biased. By using your bench DVM to measure the voltage across the diode (define the diode voltage to be measured positive with respect to the cathode, not the anode, as usual) and the voltage across the resistor (from which you can calculate the diode current), make a table of diode voltage and current values (reference the current so it is positive as it enters the cathode side of the diode, not as it enters the anode side, as usual), as the dc supply voltage is varied between 0 V and 20 V. (You will want to take most of your points in the region of the Zener knee.) Carefully plot a reasonably accurate version of the Zener diode's I-V curve for diode voltages between 0 and about 11V (this upper limit depends upon the exact Zener breakdown point of your particular diode, remembering that this diode is specified to have a 11.0 V breakdown point + or - 5%.) Submit this plot as ***Attachment C*** at the end of this report. (You may make this plot by hand or use the Microsoft Excel spreadsheet, as was done in Lab 1.

What would be a reasonable value of Zener breakdown voltage to assign to your particular 1N4741 Zener diode, say the voltage at which the diode current increases to 10% of its maximum rated value (note that this diode's maximum rated current can be calculated using the fact that this diode is a 1-watt, 11 V (nominal) Zener diode, and thus its rated current must be (1 W / 11 V) = 90.9 mA.)

V_{Zener} = _____________ (at Id = 9.09 mA)

B. The circuit constructed above can be viewed as an elementary (approximate) 11 V voltage regulator, if output terminals are defined across the Zener diode. Now place a load resistor RL across these output terminals (across the diode) and measure the voltage developed across RL with your bench DVM. Let us start with RL = 1 kilohm. To evaluate the "percent regulation" of this circuit for this value of load resistance as the dc source is allowed to vary between Vin = 15 V and 20 V, measure the output voltage across RL when Vin = 15 V ($Vout_{LOW}$), and then measure the output voltage when Vin = 20 V ($Vout_{HIGH}$). Then calculate the "% regulation" assuming that it is defined by:

$$\%Reg = 100\%*(\Delta Vout / \Delta Vin)$$

Thus, in our case,

$$\%Reg = 100\%*(Vout_{HIGH} - Vout_{LOW}) / (20 - 15)$$

Then change the load resistor to 330 ohms, 4.7 kilohms, 10 kilohms, 100 kilohms, and fill in the table below:

	$Vout_{LOW}$ (@Vin=15V)	$Vout_{HIGH}$ (@Vin=20V)	% Regulation (over 15 -20V input range)
RL = 330 ohms	_________	_________	______%
RL = 1 kilohm	_________	_________	______%
RL = 4.7 kilohms	_________	_________	______%
RL = 10 kilohms	_________	_________	______%
RL = 100 kilohms	_________	_________	______%

C. For RL = 1 kilohm, calculate (predict) the value of Vin = $(Vin)_{drop\text{-}out}$ at which your voltage regulator circuit drops out of regulation. In your prediction, use your diode's measured Zener breakdown voltage, Vzener, which you measured in Part A. Find the value of Vin that will result in biasing the diode at its "edge of the Zener knee." This is the highest value of Vin for which the Zener diode current is still essentially zero. *Hint: Perform the drop-out voltage prediction calculation by assuming that the voltage has been lowered to a point where the Zener diode has just turned OFF (is an open circuit). At this point, the voltage across the diode is still approximately at (just below) the Zener knee voltage (Vzener) that you observed above, so you may use the voltage divider formula to find the value of Vin at this point. At the point of dropout Vo = Vzener = Vin*(RL/(220 + RL)), so we can solve for the value of Vin that produces this dropout condition.*

Next measure the actual "drop-out" input voltage $(Vin)_{drop\text{-}out}$ in the actual circuit by decreasing Vin down to the point where the output voltage begins to decrease rather "appreciably" (say by about 10%) from its nominal regulated value. The drop out voltage $(Vin)_{drop\text{-}out}$ is the value of Vin at which the voltage regulator appears to suddenly "drop out of regulation". Calculate the % error between your predicted and observed values of drop-out voltage. Repeat for RL = 330 ohms.

Input Drop-Out Voltage* $(Vin)_{drop\text{-}out}$ *Calculations for RL = 1 kilohm and RL = 330 ohms

For RL = 1 kOhm

Vindropout = _________ (Calculated)
Vindropout = _________ (Measured) % error = _______

For RL = 330 ohms

Vindropout = _________ (Calculated)
Vindropout = _________ (Measured) % error = _______

D. Finally, for a fixed load resistance of 1 kilohm, ***carefully*** plot a load line corresponding to Vin = 15 V *directly over* the nonlinear Zener diode I-V curve shown in ***Attachment C*** (use the method discussed on page 1.53 – 1.54 of the course notes), and predict the output voltage, $Vout_{LOW}$. Then draw a second load line corresponding to Vin = 20V, and determine the new output voltage, $Vout_{HIGH}$. Compare these predicted values (using the graphical load line technique) with those calculated in Part B above.

For RL = 1 kilohm:

Predicted $Vout_{LOW}$ = _____ Measured $Vout_{LOW}$ (from Part B) = ____ % error = ______

Predicted $Vout_{HIGH}$ = _____ Measured $Vout_{HIGH}$ (from Part B) = ____ % error = ______

Finally, plot two more load lines for RL = 330 ohms, first with Vin = 15 V, and then with Vin = 20 V.

For RL = 330 ohms

Predicted $Vout_{LOW}$ = _____ Measured $Vout_{LOW}$ (from Part B) = ____ % error = ______

Predicted $Vout_{HIGH}$ = _____ Measured $Vout_{HIGH}$ (from Part B) = ____ % error = ______

Note that upon completion of this lab, you should have FOUR load lines drawn over the Zener diode I-V curve in ***Attachment C****.*