Electronic Circuits Laboratory
EE462G
Lab #3

Diodes, Transfer Characteristics, and Clipping Circuits
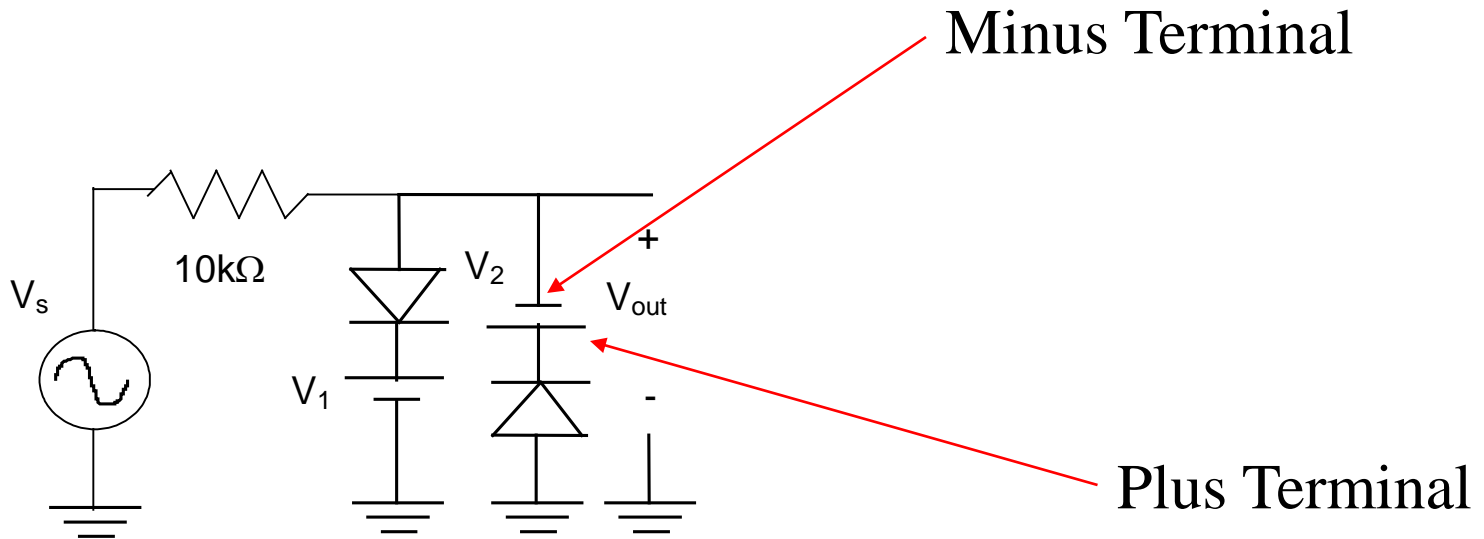
Instrumentation

This lab requires:

- **Function Generator and Oscilloscope (as in Lab 1)**
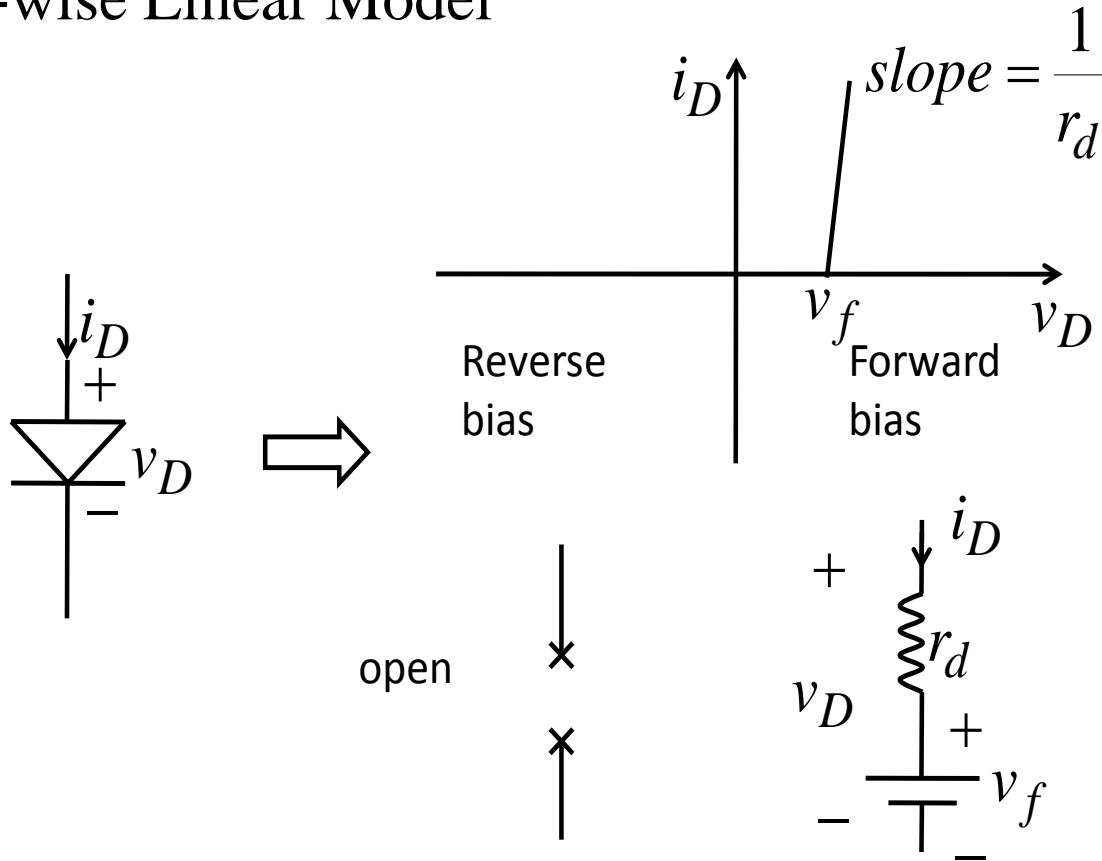- **TENMA DC Power supply 72-6905**

Instrumentation

The 2 variable outputs of the power supply will be used for batteries (DC series sources) in the experiments' circuits:

Minus Terminal

Plus Terminal

V_s

$10k\Omega$

V_2

V_{out}

V_1

+

-

PN Junction Diode Model

Piece-wise Linear Model

$$slope = \frac{1}{r_d}$$

i_D

v_f

v_D

Reverse bias

Forward bias

i_D

$+$

v_D

$-$

open

i_D

$+$

r_d

v_D

$+$

$-$

v_f

$-$

Analysis of Diode Circuit

Methods of Analysis:

➢ Load-line analysis

➢ Diode-State Analysis

➢ SPICE

Diode-State Analysis

➢ Determine the on-off state of each diode by guessing a combination of on-off states.

➢ For on-diodes assume a forward biased current direction (0 volts) and for off-diodes assume a negative anode voltage (0 amps) and then analyze circuit.

➢ If guessed state results in an inconsistent voltage or current in circuit analysis, guess another state combination until all are consistent with circuit analysis.
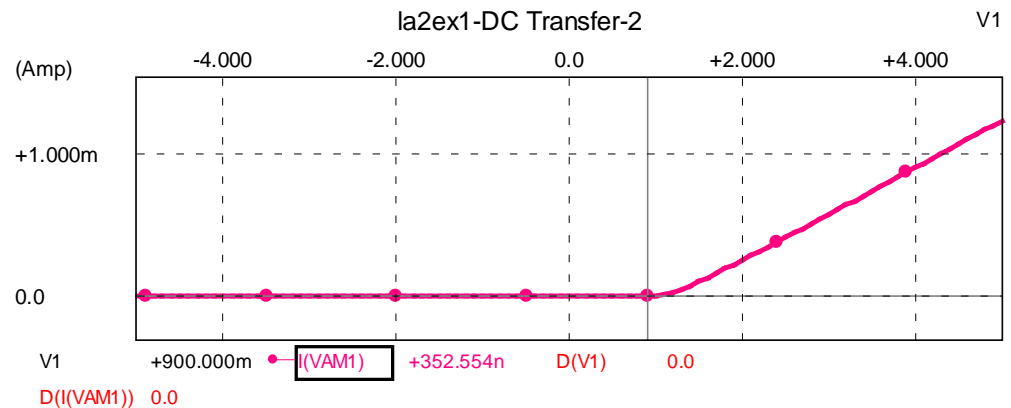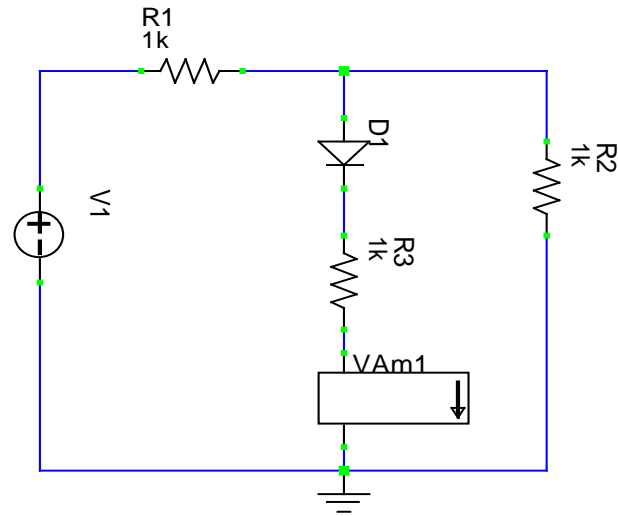
Example

Problem:

➢ Use near-ideal model to determine the state of diode D1 when *V1*=10V. (First guess diode is off).

➢ Find range of *V1* values such that D1 is off.

➢ Assume output is current *I3* and input is *V1*, analytically find the transfer characteristics of this circuit.

➢ Solve via SPICE and plot:
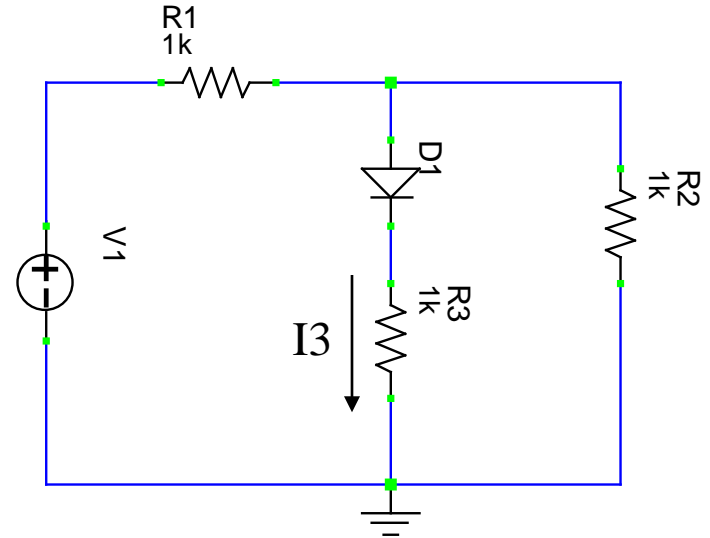
SPICE Set Up and Result

In SPICE

- build circuit and insert diode (use default characteristics)
- Place ammeter at output
- Set source to DC (value is not important)
- In "simulation set up" select (Dual) Parameter DC Sweep. Select V1 as parameter to sweep and indicate range and increment.
- Ask for graph output and run!

Ia2ex1-DC Transfer-2

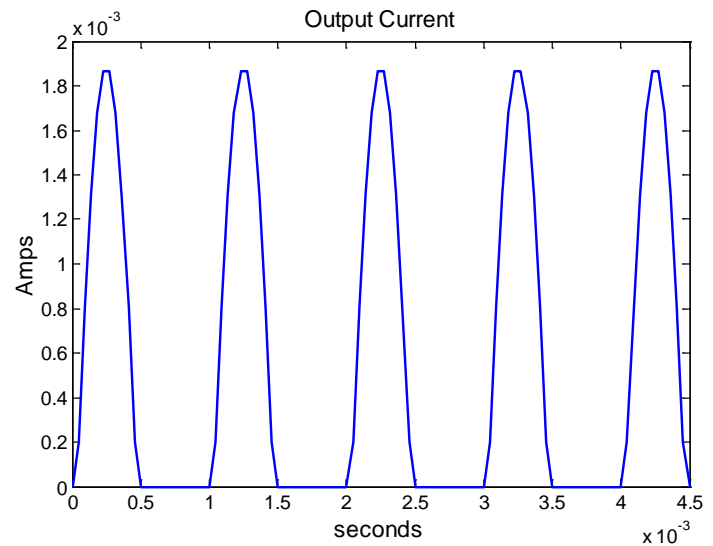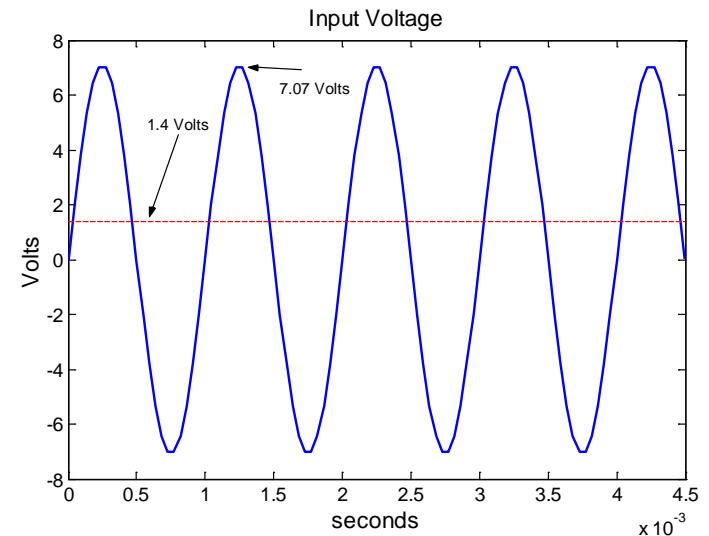| V1 | +900.000m | I(VAM1) | +352.554n | D(V1) | 0.0 |
| D(I(VAM1)) | 0.0 | | | | |

Example

Sketch output waveform if input is a 5Vrms sinusoid of frequency 1kHz:

➢ Determine transfer characteristics from input through waveform output.

➢ Map input waveform through the transfer characteristics.

➢ Note that when diode is on:

$$I_3 = \frac{V_1 - 1.4}{3k}$$

Input Voltage

7.07 Volts

1.4 Volts

Output Current

Example with SPICE

Find output waveform if input is a 5Vrms sinusoid of frequency 1kHz:

➢ Build circuit in SPICE

➢ Set source to sinusoid, but do not check AC box. Go to transient parameters tab and select appropriate amplitude (7.0711) and frequency (1000), the rest can be zero.

➢ Set up simulation parameters, select "Parameter sweep of transient," select source with start and stop magnitudes to same value and step size to a non zero number (you don't want it to sweep, and it will not use these number since AC box was not check in source set up).

➢ The set up transient parameters to appropriate start and stop time and increment.

➢ The run simulation. If too many waveform periods appear, such that waveform details cannot be easily seen, make start and stop time shorter.

Example with SPICE

Find output waveform if input is a 5Vrms sinusoid of frequency 1kHz:


la2ex2--6

time (s)

Test Circuit A

Problem:

> Given V_s is a 2.8 Vrms 250Hz sinusoid, find V_{out} (for power analysis a 5.1kΩ load will also be considered)

Analysis:

> Use .7 V forward offset voltage and ideal diode approximation. Can derive transfer characteristics or reason out directly.

Lab Procedure:

> Describe function generator settings, oscilloscope probe placement, and oscilloscope settings. Record resulting waveforms for at least one period but not more than 5.

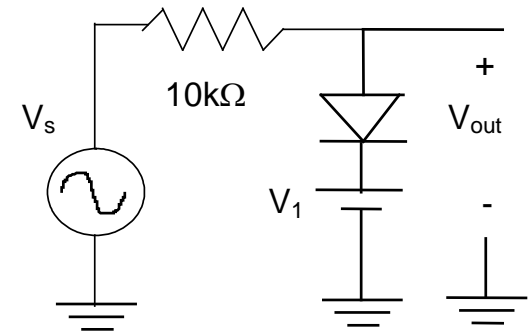10kΩ

V_s

+

V_{out}

-
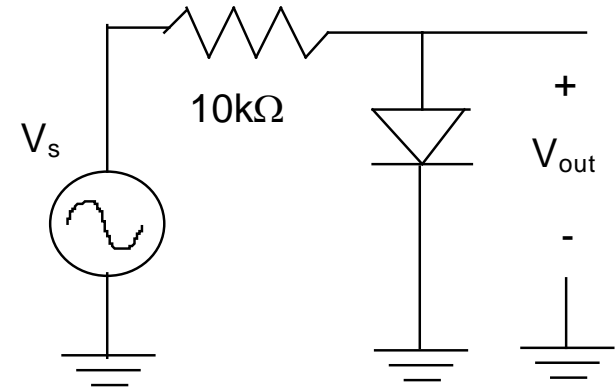
(A)

Test Circuit B

Problem:

> Given V_s is a 2.8 Vrms 250Hz sinusoid, find V_{out} without a load.

Analysis:

> Use estimated forward offset voltage and ideal diode approximation. Can derive transfer characteristics or reason out directly.

Lab Procedure:

> Describe function generator settings, power supply attachment with grounding issues, oscilloscope probe placement, and oscilloscope settings. Record resulting waveforms for at least one period but not more than 5. For the power analysis when circuit has a load, the DMM can be put in series with each branch to measure RMS current.
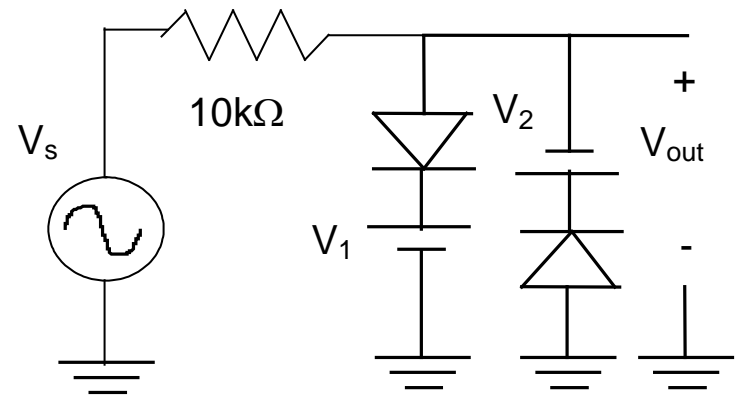
Test Circuit C

Problem:

> ➢ Given V_s is a 2.8 Vrms 250Hz sinusoid, find V_{out} without a load

Analysis:

> ➢ Use estimated forward offset voltage and ideal diode approximation. Can derive transfer characteristics or reason out directly. ($V_{peak} \sim 4V$, T~4 ms)

Lab Procedure:

> ➢ Describe function generator settings, power supply attachment and grounding issues, oscilloscope probe placement, and oscilloscope settings. Record resulting waveforms for at least one period but not more than 5.

10kΩ

V_s

V_1

V_2

+

V_{out}

-

Test Circuit D

Problem:

- ➤ Similar to Circuit B: Does order of diode and DC source change output?

Analysis:

- ➤ Does this affect the KVL or KCL equation?

Lab Procedure:

- ➤ Power supply is isolated from earth ground; however stray capacitance from chassis ground to earth ground exists that practically affects the output. How will a capacitive path to ground at the 2 different points in Circuits B and D affect the output? Will this effect be observed at some frequencies better than others?
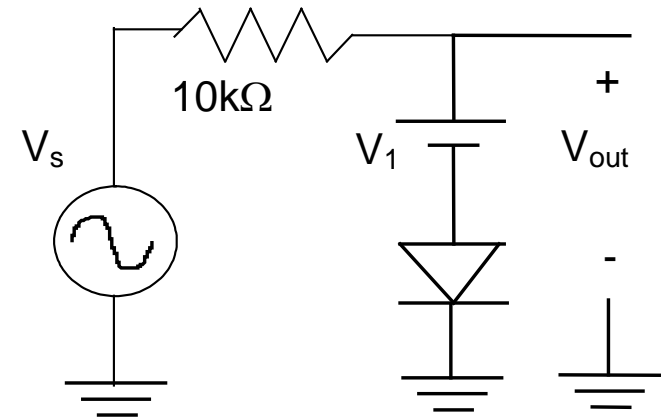
Other Notes

Power:

> Recall instantaneous power is a product of the voltage and current waveforms. So for source power find V_s and I_s waveforms for one period and multiply point per point:

$$p(t) = v_s(t)i_s(t)$$

> Recall average power is the integral of the instantaneous power divided by the period:

$$P_{av} = \frac{1}{T}\int_T v_s(t)i_s(t)dt$$

> For sinusoid waveforms the integral reduces to:

$$P_{av} = V_{rms}I_{rms}\cos(\theta_v - \theta_i) = \frac{1}{2}VI\cos(\theta_v - \theta_i)$$

> Is power absorbed by an ideal diode?

Analysis:

> A Thévenin equivalent circuit around the nonlinear component in the circuit may be helpful in explaining changes due to load resistances.

Stray Capacitance Models

In reverse bias mode, a practical diode can be considered as a stray capacitance in parallel with open circuit.
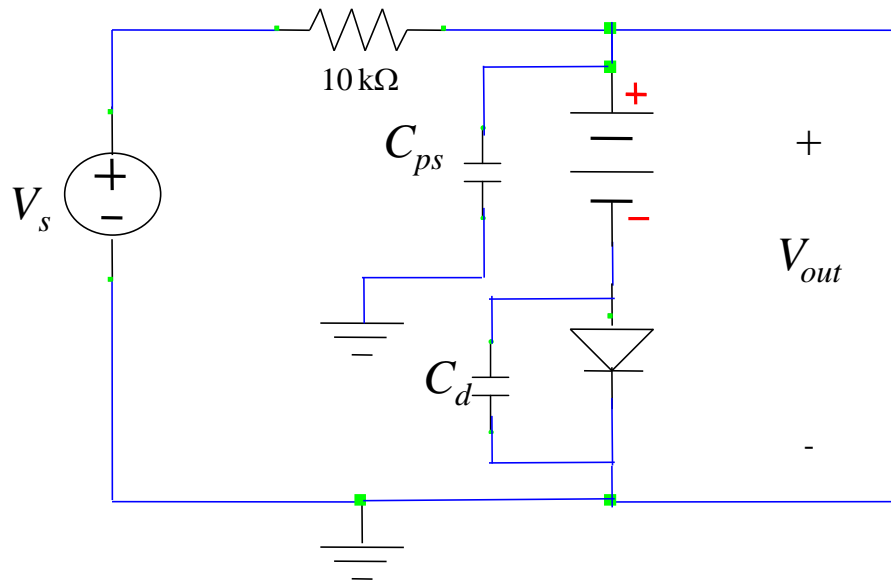The power supply can be considered as a DC source with parallel capacitance to ground.
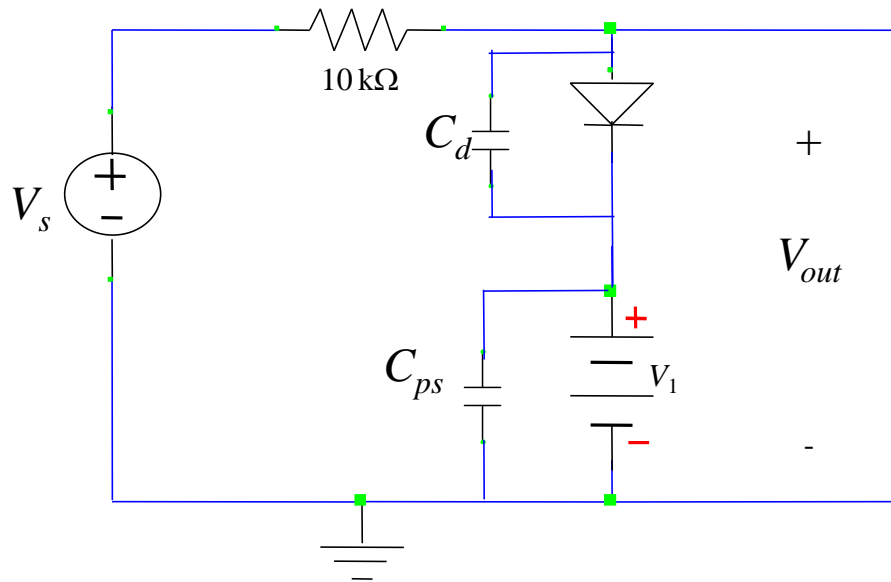
Compute effective capacitance over V_{out}

Stray Capacitance Models

Reverse order of power supply and diode in previous circuit and consider effects of stray capacitance.
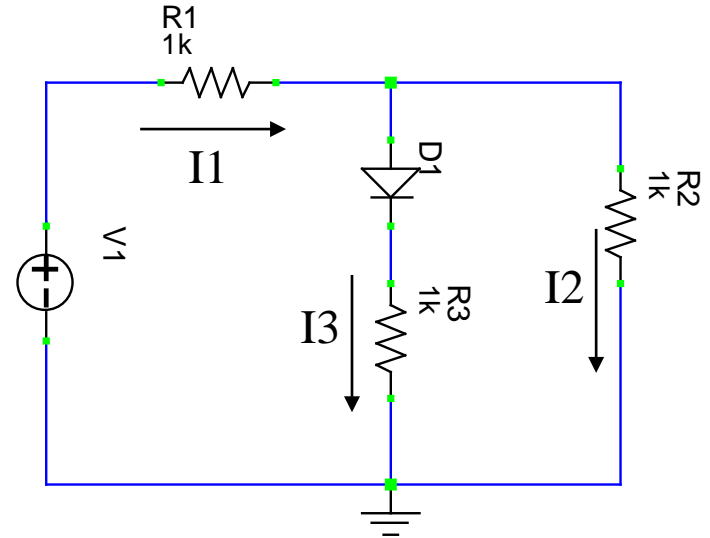

Compute effective capacitance over V_{out}

Power Analysis Example

Problem:

➢ Use range of *V1* values for cases in which D1 is (*i*) off and then (*ii*) on. Find analytical expressions for all branch currents (over a full cycle of the excitation waveform).

➢ Determine the power absorbed/supplied by each element.

Branch Currents

Waveforms for currents if input is a 1KHz 5Vrms sinusoid:

➢ Branch currents:

For $V_1 > 1.4$

$$I_1 = \frac{2V_1 - 0.7}{3k}$$

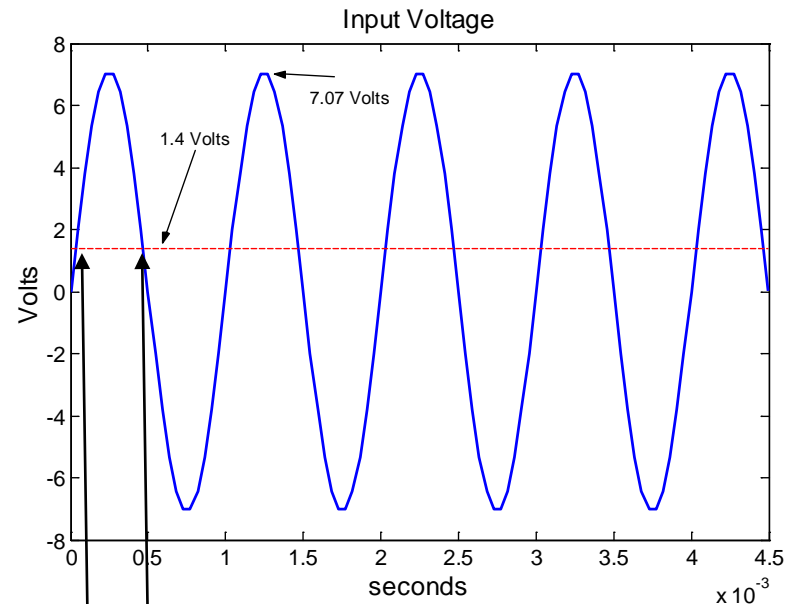$$I_2 = \frac{V_1 + 0.7}{3k}$$

$$I_3 = \frac{V_1 - 1.4}{3k}$$

For $V_1 \leq 1.4$

$$I_1 = \frac{V_1}{2k}$$

$$I_2 = \frac{V_1}{2k}$$

$$I_3 = 0$$

Input Voltage

7.07 Volts

1.4 Volts

Volts

seconds

x 10^{-3}

t_1 t_2

Time interval for $V1 > 1.4$

Power Formulae

Power:

> ➢ Recall instantaneous power is a product of the voltage and current waveforms. So for source power find V_s and I_s waveforms for one period and multiply point per point:

$$p(t) = v_s(t)i_s(t)$$

> ➢ Recall average power is the integral of the instantaneous power divided by the period:

$$P_{av} = \frac{1}{T}\int_T v_s(t)i_s(t)dt \qquad P_{av} = \frac{1}{T}\int_T \frac{v_S^2(t)}{R}dt \qquad P_{av} = \frac{1}{T}\int_T i_S^2(t)Rdt$$

$$P_{av} = V_{srms}I_{srms} \qquad P_{av} = \frac{V_{srms}^2}{R} \qquad P_{av} = I_{srms}^2 R$$

> where RMS (root mean square) value of a waveform with period T is given by:

$$X_{rms} = \sqrt{\frac{1}{T}\int_T x^2(t)dt}$$

RMS Circuit Values

For $v_1(t) = 5\sqrt{2}\sin(2000\pi t)$V, the RMS values for source and branch currents are

$$V_{1rms} = 5$$

$$I_{1rms} = \sqrt{\frac{1}{T}\left[\int_{t_1}^{t_2}\left(\frac{2v_1(t)-0.7}{3000}\right)^2 dt + \int_{t_2}^{T+t_1}\left(\frac{v_1(t)}{2000}\right)^2 dt\right]} \approx 2.83mA$$

$$I_{2rms} = \sqrt{\frac{1}{T}\left[\int_{t_1}^{t_2}\left(\frac{v_1(t)+0.7}{3000}\right)^2 dt + \int_{t_2}^{T+t_1}\left(\frac{v_1(t)}{2000}\right)^2 dt\right]} \approx 2.21mA$$

$$I_{3rms} = \sqrt{\frac{1}{T}\left[\int_{t_1}^{t_2}\left(\frac{v_1(t)-1.4}{3000}\right)^2 dt\right]} \approx 0.89mA$$

Power Analysis

For each element in the circuit the power is:

Power Supplied

$$P_{avv1} = V_{1rms}I_{1rms} \approx 14.2mW$$

Power Absorbed

$$P_{avR1} = I_{1rms}^2(1k\Omega) \approx 8.0mW$$

$$P_{avR2} = I_{2rms}^2(1k\Omega) \approx 4.9mW$$

$$P_{avR3} = I_{3rms}^2(1k\Omega) \approx 0.8mW$$

$$P_{avD1} = I_{3rms}(0.7V) \approx 0.6mW$$

Note that power delivered is equal to power absorbed
(Matlab script for evaluating integrals and power values is on next slide)

Matlab Symbolic Computations

```matlab
%define symbol for equation analysis
syms t
% Compute intersection of sine with the 1.4 voltage amplitude
t1 = solve('5*sqrt(2)*sin(2*pi*1e3*t) = 1.4', t)
%  Define expression for source voltage as function of t
v1 = 5*sqrt(2)*sin(2*pi*1e3*t)
%  define period of signal
tp = 1e-3
% Compute other intersection point of sine with the 1.4 volt level
t2 = tp/2 - t1
%  Integrate for rms currents
i1rms = sqrt(int(((2*v1-0.7)/3e3)^2,t,t1,t2)/tp + int((v1/2e3)^2,t,t2,tp+t1)/tp)
i2rms = sqrt(int(((v1+0.7)/3e3)^2,t,t1,t2)/tp + int((v1/2e3)^2,t,t2,tp+t1)/tp)
i3rms = sqrt(int(((v1-1.4)/3e3)^2,t,t1,t2)/tp)
%  RMS source voltage
v1rms = 5
%  Power delivered by source
%pavsource = int(v1*(2*v1-.7)/3e3,t,t1,t2)/tp +int(v1*v1/2e3,t,t2,tp+t1)/tp
pavsource = v1rms*i1rms
% Compute powers in all components (all resistors were 1e3 ohms)
pavr1 = i1rms^2*1e3    %  Resistor 1 power
pavdiode = i3rms*.7     %  Diode power
pavr3 = i3rms^2*1e3    %  Resistor 2 power
pavr2 = i2rms^2*1e3    %  Resistor 3 power
%  by conservation of power all absorbing components should add up to power delivered
pavabsorbed = pavr1+pavr2+pavr3+pavdiode
disp(['Compare power absorbed: ' num2str(double(pavabsorbed)) 'W to power supplied: ' num2str(double(pavsource)) 'W'])
```

Final Notes

Data Sheet

- ➤ Make up a Data Sheet before coming to class and fill in measurement in an orderly fashion.
- ➤ All general comments from previous labs apply.

Procedure Description

- ➤ Address all questions asked in the lab assignment sheet and lecture that pertain to the procedure of making a measurement and getting the requested quantity.
- ➤ Grounding issues are discussed in this section if they complicate probes placement.
- ➤ Discuss how the forward offset voltage is determined from the measurements made of the V-I diode transfer characteristics.
- ➤ All general comments from previous labs apply.

Final Notes

Discussion of Results

> Respond to all bold face comments and questions in the lab assignment in this section.

> Explain why the waveforms appear as they do from diode theory and measurement issues. Make comparisons between measured values when appropriate (i.e. if something changes in the circuit, how does this affect the output!)

Conclusion

> Briefly sum up results and indicate what was learned through doing this experiment. Respond directly to the lab objectives.

General

> Number all figures, tables, and equations sequentially (learn how to use equation editors), and avoid first person voice.

> Describe all figures and table in text. What are the important features the reader should see?