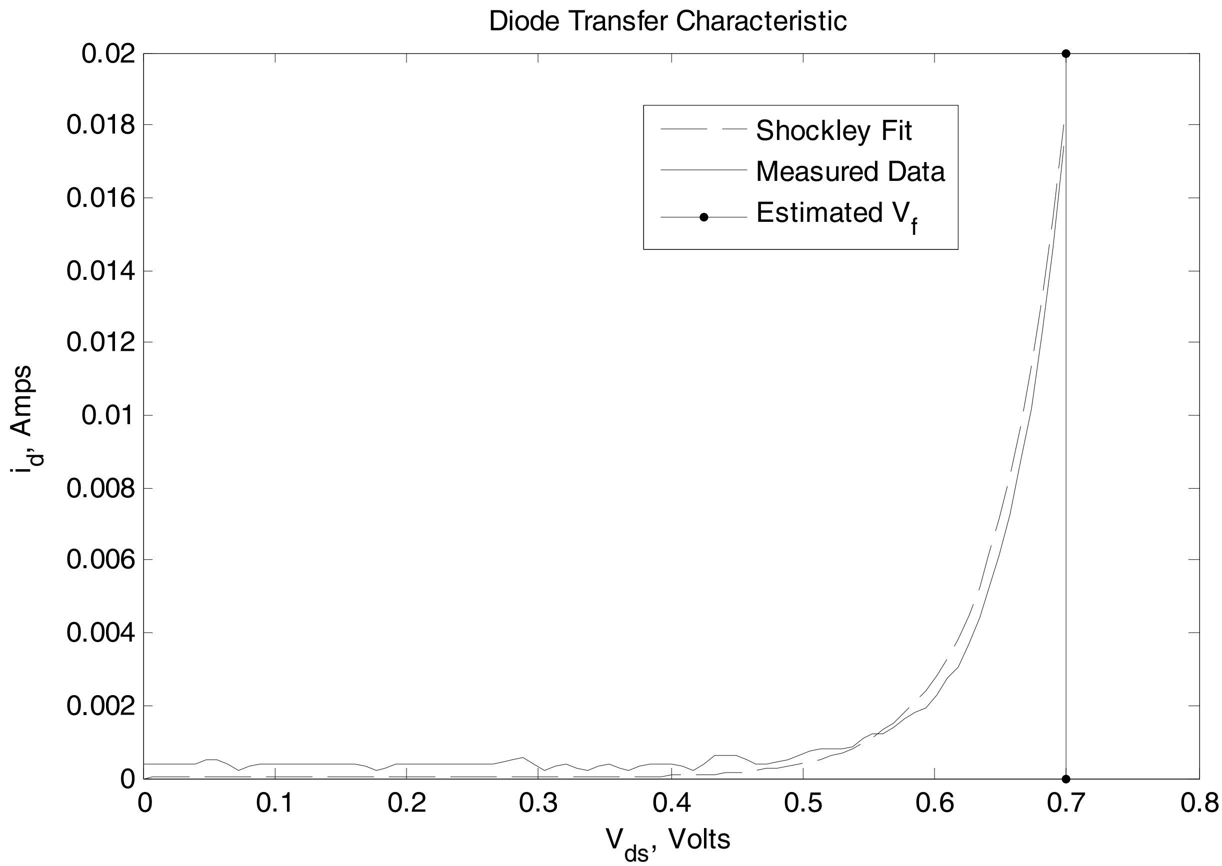
Pre-lab 3 Solution

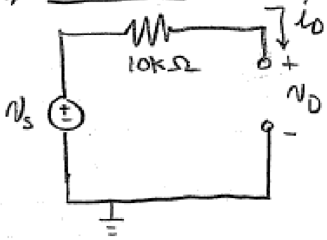
Stephen Maloney

1)



Stephen Maloney | Lab 3 Prelab

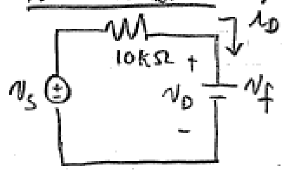
2. a) Reverse Bias



$\rightarrow \left[v_D = v_S \,, \text{ where } v_s < v_f \right]$

$\underline{v_D = v_{out}}$

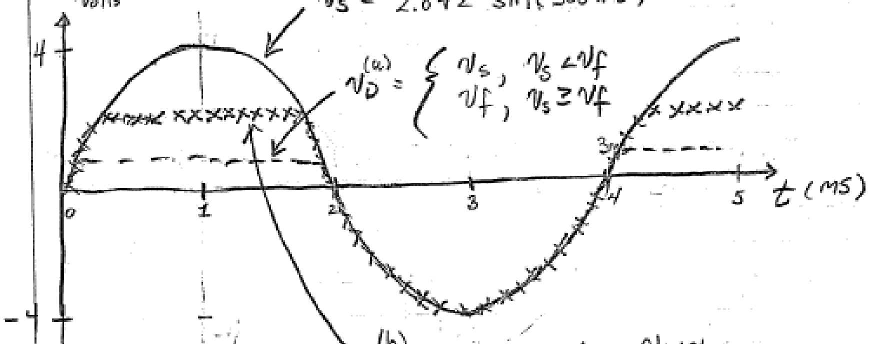
Forward Bias



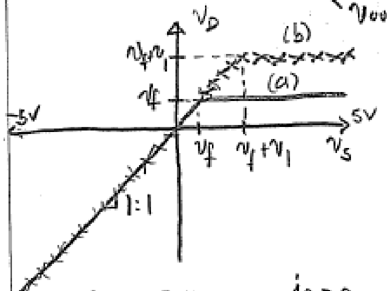
$\rightarrow \left[v_D = v_f \,, \text{ where } v_s \geq v_f \right]$

$v_s = 2.8\sqrt{2}\,\sin(500\pi t)$

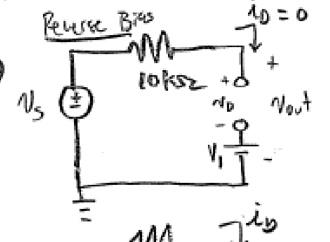
$v_D^{(a)} = \begin{cases} v_s, & v_s < v_f \\ v_f, & v_s \geq v_f \end{cases}$



(b) $v_{out} = \begin{cases} v_s, & v_s < v_f + v_1 \\ v_f + v_1, & v_s \geq v_f + v_1 \end{cases}$



b) Reverse Bias

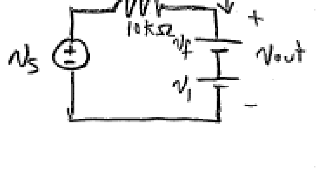


$-v_s + \cancel{i_D}^{\,0}(10k\Omega) + v_D + v_1 = 0$

$v_D = v_s - v_1$

$\therefore \quad v_s - v_1 < v_f$

$v_{out} = \begin{cases} v_s, & v_s - v_1 < v_f \\ v_f + v_1, & v_s - v_1 \geq v_f \end{cases}$

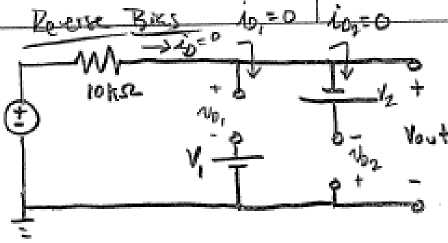


$-v_s + i_D(10k\Omega) + v_f + v_1 = 0$

$\rightarrow v_{out} = v_f + v_1$

(see diagrams above)

2. c)



Diode1

$-v_s + \cancel{i_D}^{\,0}(10k) + v_{D_1} + v_1 = 0$

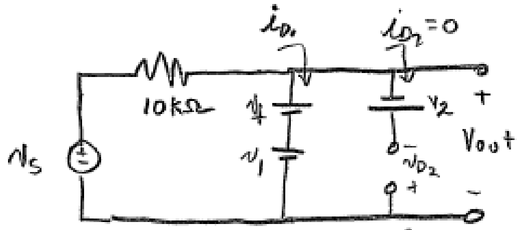
$v_{D_1} = v_s - v_1 \rightarrow v_f > v_s - v_1, \quad v_f + v_1 > v_s$

Diode 2

$-v_s + \cancel{i_D}^{\,0}(10k) - v_2 - v_{D_2} = 0$

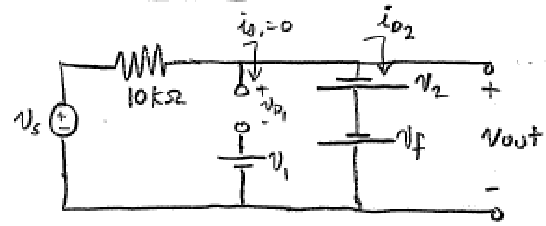
$v_{D_2} = -v_s - v_2 \rightarrow v_f > -v_s - v_2, \quad v_s > -v_f - v_2$

$\therefore \left[v_{out} = v_s, \ \underset{(D_1)}{(v_s < v_f + v_1)} \ \& \ \underset{(D_2)}{(v_s > -v_f - v_2)} \right]$



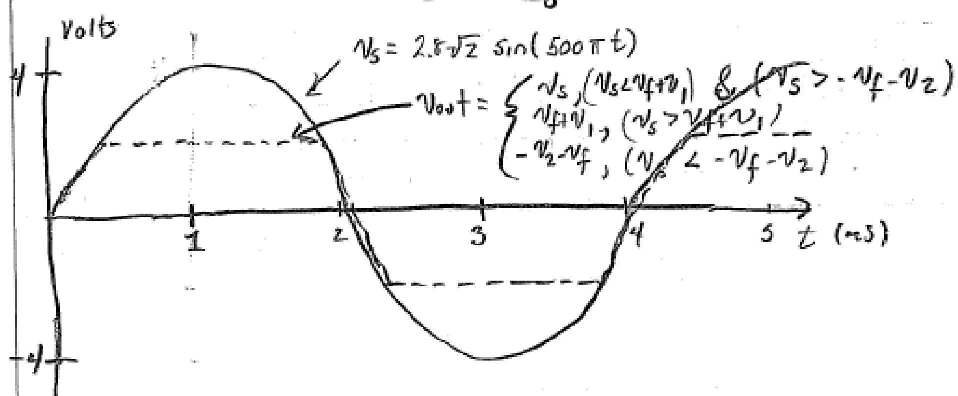
If $v_s > v_f + v_1$

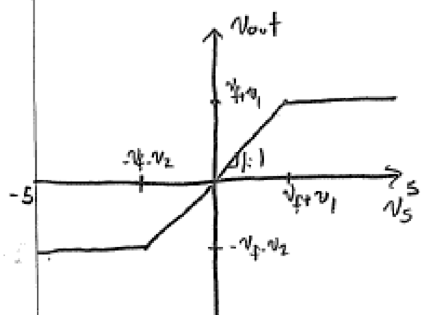
$v_{out} = v_f + v_1$



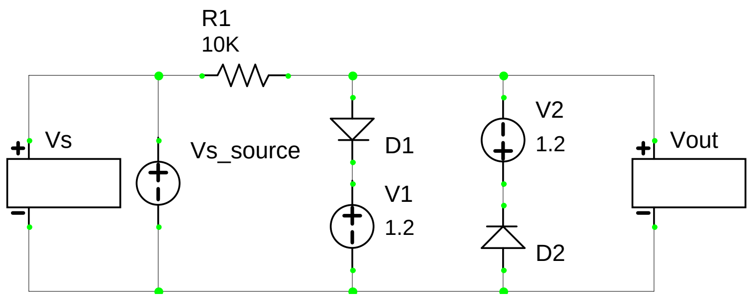
If $v_s < -v_f - v_2$

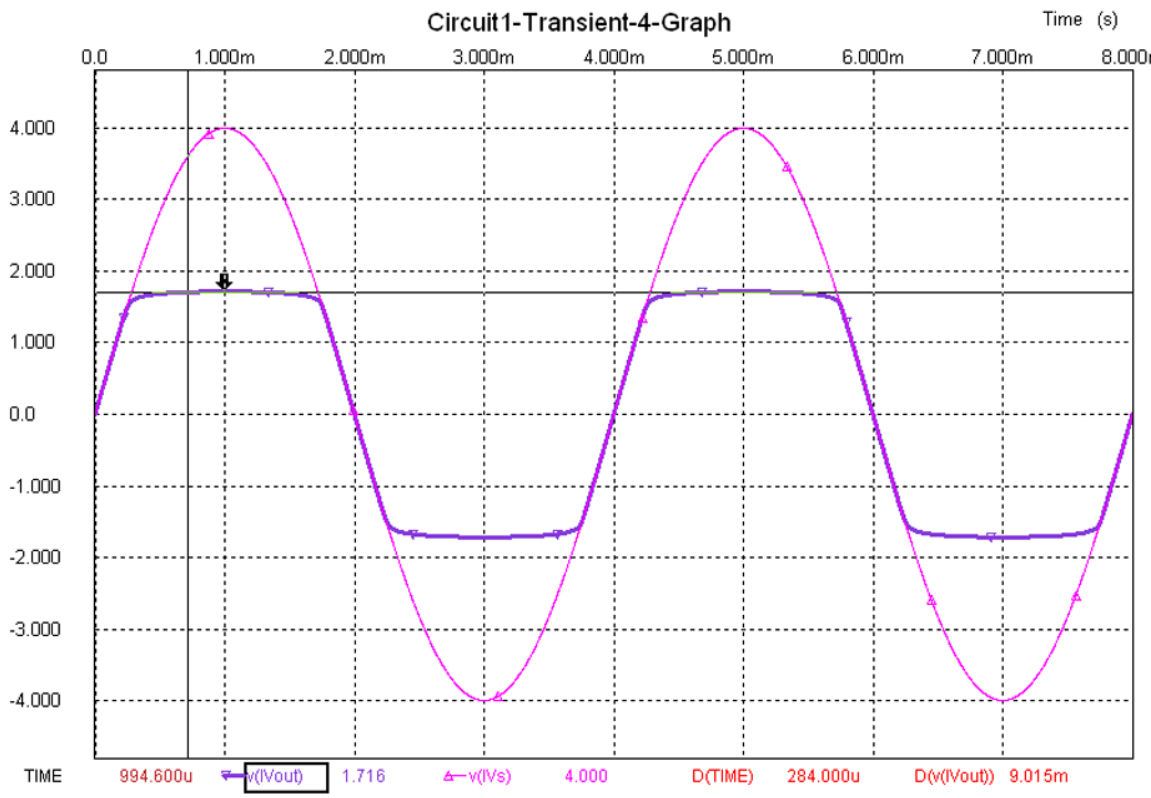
$v_{out} = -v_2 - v_f$

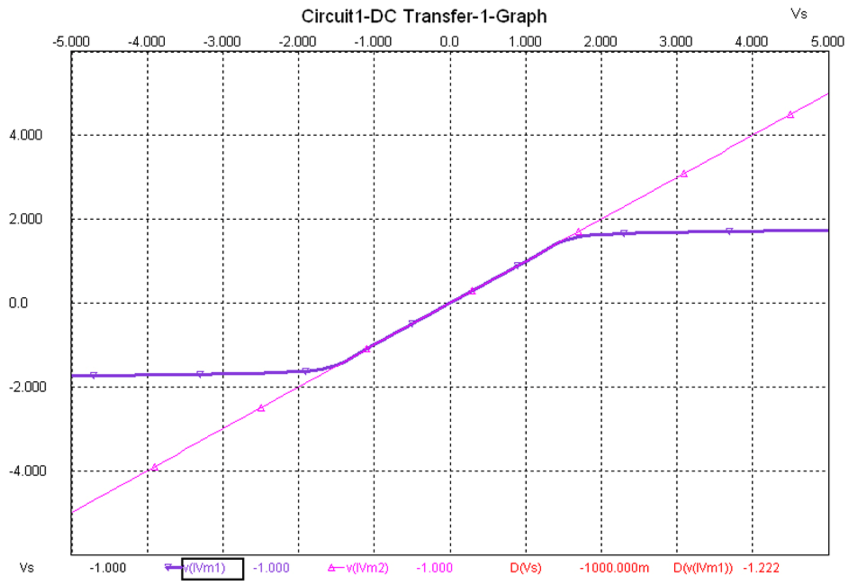




3)


R1
10K
Vs
Vs_source
D1
V1
1.2
V2
1.2
D2
Vout


Circuit1-Transient-4-Graph
Time (s)
0.0
1.000m
2.000m
3.000m
4.000m
5.000m
6.000m
7.000m
4.000
3.000
2.000
1.000
0.0
-1.000
-2.000
-3.000
-4.000
TIME
994.600u
v(lVout)
1.716
v(lVs)
4.000
D(TIME)
284.000u
D(v(lVout))
9.015m



4)

When we are analyzing the diode, one of the assumptions we have made is that the diode can be modeled when in forward bias by a simple battery or voltage source. In the real world, the diode has some internal resistance and capacitance.

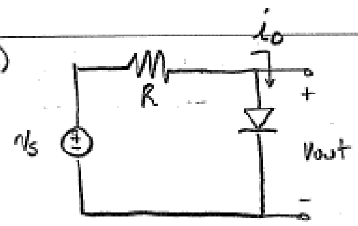
In figure b, if stray capacitances for the diode and power supply are incorporated, they appear to the circuit to be in series. Capacitance in series adds inversely and will appear to the circuit as a much smaller capacitance in this model.

When the power supply is switched to being above the diode, the capacitance of the power supply and diode will appear to be in parallel. Capacitance in parallel simply adds, and will appear much larger to the circuit in this configuration.

The larger the capacitance, the more frequency dependant effects will be observed, and in this case, the output voltage will become smaller at high frequencies.

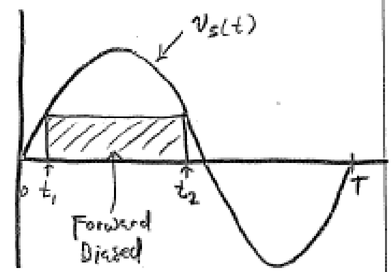
Separately from this, from a connection standpoint, it is possible that one could inadvertently short out the diode for (d) if the negative terminal of V_1 is grounded rather than left floating, whereas in (b) this potential error cannot occur because the negative terminal of V_1 is connected to ground. The purpose of the chassis grounding in the lab power supplies is exemplified here.

5 a)



$$v_{out} = \begin{cases} v_s, & v_s < v_f \\ v_f, & v_s \geq v_f \end{cases}$$

$$i_D = \begin{cases} 0, & v_s < v_f \\ \frac{v_s - v_f}{R}, & v_s \geq v_f \end{cases}$$



$t_1 \rightarrow$ where $v_s = v_f$

$t_2 = \frac{T}{2} - t_1$

$$P_{avg} = \frac{1}{T}\int_T v_s(t)\, i_D(t)\, dt$$

$$v_s(t) = 2.8\sqrt{2}\,\sin(250(2\pi)t)\;; \quad T = \frac{1}{f}$$

$$\left[P_{AVG,DIODE} = \frac{1}{T}\int_{t_1}^{t_2} (v_f)\left(\frac{v_s(t) - v_f}{R}\right) dt\right]$$

$$= \frac{1}{T}\int_{t_1}^{t_2} \frac{v_f\, v_s(t) - v_f^2}{R}\, dt$$

$$= \frac{v_f}{TR}\int_{t_1}^{t_2} v_s(t)\,dt - \frac{v_f^2}{RT}\left[t_2 - t_1\right]$$

$$\left[P_{AVG,Resistor} = \frac{1}{T}\int_{t_1}^{t_2} R\, i_D^2(t)\,dt = \frac{1}{T}\int_{t_1}^{t_2} \left(\frac{v_s - v_f}{R}\right)^2 R\, dt\right]$$

$$= \frac{1}{RT}\int_{t_1}^{t_2} v_s^2 - 2 v_s v_f + v_f^2\, dt$$

$$= \frac{1}{RT}\int_{t_1}^{t_2} v_s^2\,dt - \frac{2v_f}{RT}\int_{t_1}^{t_2} v_s\, dt + \frac{v_f^2}{RT}\left[t_2 - t_1\right]$$

$$\left[P_{AVG,Circuit} = \frac{1}{T}\int_{t_1}^{t_2} v_s(t)\, i_D(t)\,dt = \frac{1}{T}\int_{t_1}^{t_2} v_s(t)\left(\frac{v_s - v_f}{R}\right) dt\right]$$

$$= \frac{1}{RT}\int_{t_1}^{t_2} v_s^2 - v_s v_f$$

Done with trapezoidal quadrature:

```
Average diode power (mW)
PavgD =

    0.0650

Average resistor power (mW)
PavgR =

    0.2389

Average circuit power (mW)
Pavg =
```

```
    0.3039
% Prelab 3 - Problem 5a
% Stephen Maloney

clear all; clc

% Set up variables needed for the calculation
f = 250;
T = 1/f;
Vf = .7;
R = 10e3;
t = linspace(0, T, 1000);

Vs = 2.8*sqrt(2)*sin(2*pi*f*t);

plot(t, Vs, 'k');
title('V_s vs. Time');
xlabel('Time, (s)'); ylabel('Voltage, (V)');
hold on;

% Find the points where the diode is in forward bias -> vs >=.7
fBias = find(Vs >= .7);
t1 = t(fBias(1));
t2 = t(fBias(length(fBias)));
clear fBias

plot(t1, .7, 'ro', t2, .7, 'ro');

% The only part we are interested in is in this area; regenerate Vs just
% over this region
% n = the granularity of the function generation. This controls accuracy,
% as more points = more accuracy, but slower computation.
n = 1000;
tInterest = linspace(t1, t2, n);
Vs = 2.8*sqrt(2)*sin(2*pi*f*tInterest);

plot(tInterest, Vs, 'g', 'Linewidth', 2);

% Perform trapezoidal quadrature to find diode power
% See - http://en.wikipedia.org/wiki/Trapezoidal_rule
% integral(func, t1, t2)= (b-a)/(2*n)*(f(x0) + 2f(x1) + 2f(x2) + ... f(xn))
% P = 1/T * integral(Vf*(Vs-Vf)/R, t1, t2)
func = Vf*(Vs-Vf)/(T*R);
area = (t2 - t1)/(2*n)*(2*sum(func) - func(1) - func(length(func)));

disp('Average diode power (mW)');
PavgD = area * 10^3

% Perform trapezoidal quadrature to find resistor power
% P = 1/T * integral(((Vs-Vf)/R)^2*R, t1, t2)
func = ((Vs-Vf)/R).^2*R/T;
area = (t2 - t1)/(2*n)*(2*sum(func) - func(1) - func(length(func)));
disp('Average resistor power (mW)');
```

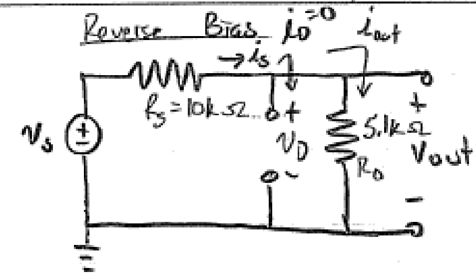
```
PavgR = area * 10^3

% Perform trapezoidal quadrature to find circuit power
% P = 1/T * integral(Vs*(Vs-Vf)/R), t1, t2)
func = Vs.*(Vs-Vf)/(R*T);
area = (t2 - t1)/(2*n)*(2*sum(func) - func(1) - func(length(func)));
disp('Average circuit power (mW)');
Pavg = area*10^3
```

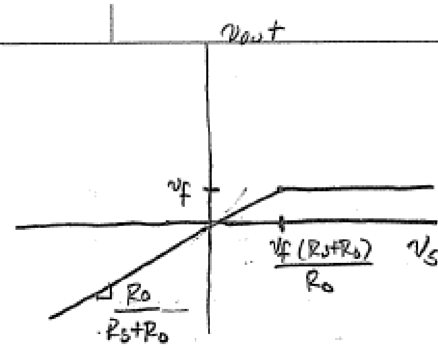
Done with symbolics:

```
Avg. Power for the Circuit : 0.30423 mW
Avg. Power for the Diode    : 0.065113 mW
Avg. Power for the Resistor : 0.23912 mW

% Power Calculation, Prelab 3 Problem 5
% Stephen Maloney

clear all; close all; clc;

f0 = 250;   %Sine wave frequency
T0 = 1/f0;  %Period of the signal
R = 10E3;   %Resistor value

syms t
Vs = 2.8*sqrt(2)*sin(2*pi*t*f0);    %Source voltage

t1 = solve('2.8*sqrt(2)*sin(2*pi*t*250) = .7'); %Find transition above .7
t2 = T0/2 - t1;                                 %Find transition below .7

% Use PAvg = 1/T0 * int(v(t)*i(t), t, 0, T0)
Pavg_Ckt = eval(int((Vs*((Vs-.7)/R)), t, t1, t2)/T0);

% Power absorbed by the resistor
Pavg_Resistor = eval(int(((Vs-.7)*((Vs-.7)/R)), t, t1, t2)/T0);

% Power absorbed by the diode
Pavg_Diode = eval(int((.7*((Vs-.7)/R)), t, t1, t2)/T0);

disp(['Avg. Power for the Circuit : ' num2str(Pavg_Ckt*1E3) ' mW']);
disp(['Avg. Power for the Diode    : ' num2str(Pavg_Diode*1E3) ' mW']);
disp(['Avg. Power for the Resistor : ' num2str(Pavg_Resistor*1E3) ' mW']);
```

5 b)

Reverse Bias



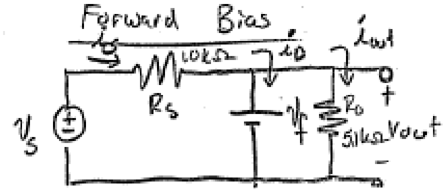


$\frac{v_s R_o}{R_s+R_o} = v_{out}$; $v_{out} < v_f$ for Reverse Bias

$\frac{v_s R_o}{R_s+R_o} < v_f \rightarrow$

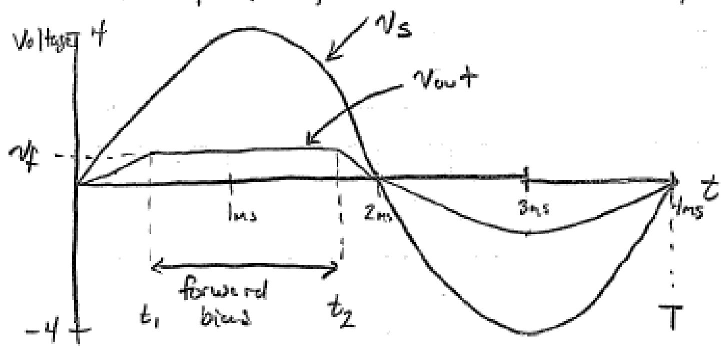
$$v_{out} = \begin{cases} \frac{v_s R_o}{R_s+R_o}, & v_s < \frac{(R_s+R_o)v_f}{R_o} \\ v_f, & v_s \geq \frac{(R_s+R_o)v_f}{R_o} \end{cases}$$

Forward Bias



$$i_{out} = \begin{cases} \frac{v_s}{R_s+R_o}, & v_s < \left(\frac{R_s+R_o}{R_o}\right)v_f \\ \frac{v_f}{R_o}, & v_s \geq \left(\frac{R_s+R_o}{R_o}\right)v_f \end{cases}$$

$v_{out} \geq v_f$ for forward bias $\rightarrow v_{out} = v_f$



$$i_s = \begin{cases} i_{out}, & v_s < \left(\frac{R_s+R_o}{R_o}\right)v_f \\ \frac{v_s - v_f}{R_s}, & v_s \geq \left(\frac{R_s+R_o}{R_o}\right)v_f \end{cases}$$

$$i_D = \begin{cases} 0, & v_s < \left(\frac{R_s+R_o}{R_o}\right)v_f \\ i_s - i_{out}, & v_s \geq \left(\frac{R_s+R_o}{R_o}\right)v_f \end{cases}$$

$$P_{diode,AVG} = \frac{1}{T}\int_{t_1}^{t_2} (v_f)(i_D)\,dt$$

$$P_{R_o,AVG} = \frac{1}{T}\int_0^T (v_{out})(i_{out})\,dt$$

$$P_{s,AVG} = \frac{1}{T}\int_0^T (v_s)(i_s)\,dt$$

$$P_{R_s,AVG} = \frac{1}{T}\int_0^T (v_s - v_{out})(i_s)\,dt$$

Done with trapezoidal quadrature:

```
Average Rout Power : (mW)
PavgRo =
    0.1246
Average Source Power : (mW)
PavgS =
    0.5670
Average R_s Power : (mW)
PavgRs =
    0.4144
Average Diode Power: (mW)
PavgD =
    0.0280
```

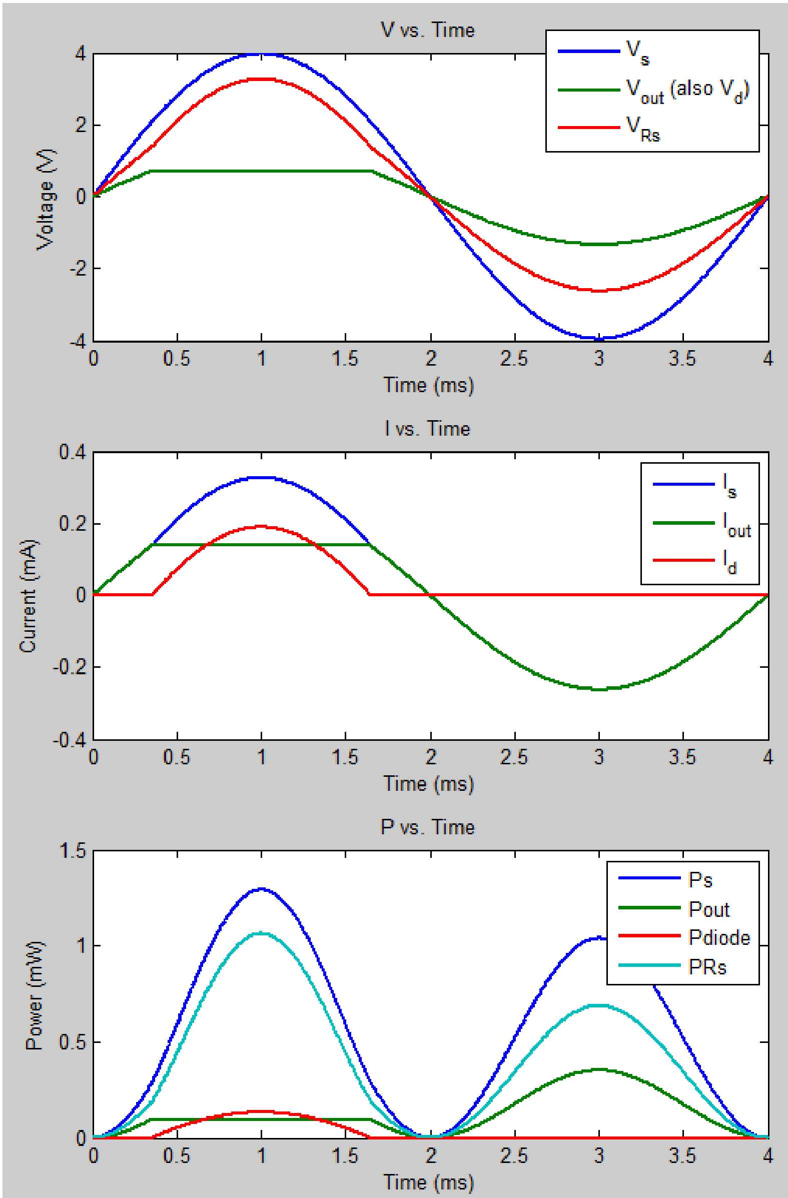
```
% Prelab 3 - Problem 5b
% Stephen Maloney

clear all; clc;

% Set up all the needed variables
n = 1000;
Rs = 10e3;
Ro = 5.1e3;
f = 250;
A = 2.8*sqrt(2);
T = 1/f;
Vf = .7;

t = linspace(0, T, n);
Vs = A * sin(2*pi*f*t);

%Set up V(t) and I(t) by finding the forward bias and reverse bias regions
%See the handwritten part for derivations of these equations
fBias = find(Vs >= (Rs+Ro)/(Ro)*Vf);
t1 = t(fBias(1));
t2 = t(fBias(length(fBias)));

Vout = Vs*Ro/(Rs+Ro);
Vout(fBias) = Vf;

VRs = Vs - Vout;

Iout = Vs/(Rs+Ro);
Iout(fBias) = Vf/Ro;

Is = Iout;
Is(fBias) = (Vs(fBias)-Vf)/Rs;

Id = zeros(1, length(Is));
Id(fBias) = Is(fBias) - Iout(fBias);

%Display plots
subplot(3, 1, 1);
plot(t*10^3, Vs, t*10^3, Vout, t*10^3, VRs, 'LineWidth', 2); title('V vs.
Time');
xlabel('Time (ms)'); ylabel('Voltage (V)');
```

```
legend('V_s', 'V_o_u_t (also V_d)', 'V_R_s');

subplot(3, 1, 2);
plot(t*10^3, Is*10^3, t*10^3, Iout*10^3, t*10^3, Id*10^3, 'LineWidth', 2);
title('I vs. Time'); xlabel('Time (ms)'); ylabel('Current (mA)');
legend('I_s', 'I_o_u_t', 'I_d');

subplot(3, 1, 3);
plot(t*10^3, Vs.*Is*10^3, t*10^3, Vout.*Iout*10^3, t*10^3, Vout.*Id*10^3, ...
    t*10^3, (Vs-Vout).*Is*10^3, 'LineWidth', 2);
title('P vs. Time'); xlabel('Time (ms)'); ylabel('Power (mW)');
legend('Ps', 'Pout', 'Pdiode', 'PRs');

%Calculate Power
func = Vout.*Iout/T;
area = (T - 0)/(2*n)*(2*sum(func) - func(1) - func(length(func)));
disp('Average Rout Power : (mW)');
PavgRo = area * 10^3

func = Vs.*Is/T;
area = (T - 0)/(2*n)*(2*sum(func) - func(1) - func(length(func)));
disp('Average Source Power : (mW)');
PavgS = area * 10^3

func = (Vs-Vout).*Is/T;
area = (T - 0)/(2*n)*(2*sum(func) - func(1) - func(length(func)));
disp('Average R_s Power : (mW)');
PavgRs = area * 10^3

%Diode Power calculation
%We are only interested in the portion of time where the diode is forward
%biased, and thus has current
tInterest = linspace(t1, t2, n);
Vs = A*sin(2*pi*f*tInterest);
func = Vf*((Vs-Vf)/Rs - Vf/Ro)/T;
area = (t2 - t1)/(2*n)*(2*sum(func) - func(1) - func(length(func)));

disp('Average Diode Power: (mW)');
PavgD = area * 10^3
```

Done with symbolics:

```
Average Power for the Circuit : 0.56758 mW
Average Power for the Diode   : 0.02808 mW
Average Power for the Load    : 0.12472 mW
Average Power for the InputR  : 0.41478 mW

% Power Calculation, Prelab 3 Problem 5
% Stephen Maloney

clear all; close all; clc;

f0 = 250;   %Sine wave frequency
T0 = 1/f0;  %Period of the signal
```

```
R = 10E3;   %Resistor value

syms t
Vs = 2.8*sqrt(2)*sin(2*pi*t*f0);    %Source voltage

% This area is the only place where the diode is forward biased
t1 = solve('2.8*sqrt(2)*sin(2*pi*t*250) = 2.07255'); %Find transition
t2 = T0/2 - t1;

% Complicated integrals due to the changing ouput during t1 to t2
Pckt = eval(1/T0*(int(Vs^2/(10E3+5.1E3), 0, t1) + int(Vs*(Vs-.7)/10E3, t1,
t2) ...
    + int(Vs^2/(10E3+5.1E3), t, t2, T0)));

Pdiode = eval(1/T0*int(.7*((Vs-.7)/10E3-137.25E-6), t, t1, t2));

PRLoad = eval(1/T0*(int(Vs*6.6225E-5*.337748*Vs, t, 0, t1) + ...
    int(.7*137.25E-6, t, t1, t2) ...
    + int(Vs*6.6225E-5*.337748*Vs, t, t2, T0)));

PR1 = eval(1/T0*(int((1-.337748)*Vs*6.6225E-5*Vs, t, 0, t1) + ...
    int((Vs-.7)*(Vs-.7)/10E3, t, t1, t2) + ...
    int((1-.337748)*Vs*6.6225E-5*Vs, t, t2, T0)));

display(['Average Power for the Circuit : ' num2str(Pckt*1E3) ' mW']);
display(['Average Power for the Diode   : ' num2str(Pdiode*1E3) ' mW']);
display(['Average Power for the Load    : ' num2str(PRLoad*1E3) ' mW']);
display(['Average Power for the InputR  : ' num2str(PR1*1E3) ' mW']);
```


V vs. Time
Voltage (V)
Time (ms)
V_s
V_out (also V_d)
V_Rs
I vs. Time
Current (mA)
Time (ms)
I_s
I_out
I_d
P vs. Time
Power (mW)
Time (ms)
Ps
Pout
Pdiode
PRs