EE 330 F12
HW 5 solution
Due 9/21/2012

10 pts 1. $R = 8K$ Poly 1 $R_{\square} = 23.5\ \Omega/sq$

Minimum Poly Width: .6µm Minimum Poly Spacing: .6µm

Choose a serpentine with 14 rows

$$R = 8K = \underbrace{17.2 \cdot 2}_{\text{Contacts}} + \underbrace{23.5 \cdot 14 \cdot x}_{\text{rows}} + \underbrace{(23.5 + .55 \cdot 23.5 \cdot 2)\,13}_{\text{Corners}}$$

where x = # of squares per row
$x = 22.26$

$$\boxed{\begin{array}{l} \text{Length} = .6 + .6 \cdot 22.26 + .6 = 14.556\ \mu m \\ \text{Height} = 14 \cdot .6 + 13 \cdot .6 = 16.2\ \mu m \end{array} > \text{within ratio}}$$

10 pts 2. $C = 2pF$ Chose Poly - Poly 2 Capacitor: $938\ aF/\mu m^2$

$$\frac{2E-12}{938E-18} = A = 2132.196\ \mu m^2$$

$\boxed{\text{Dimensions: } 46.176\ \mu m \times 46.176\ \mu m}$

15 pts 3. See attached excel for results.
Layering is:

Metal 3 Top
Metal 2 ↓
Metal 1
Poly
Substrate Bottom

636 543 46.39

3.

Material	Material Below	Width(lamda)	Height(lambda)	Area(um^2)	C/A	Capacitance(aF)
Poly	Substrate	22	16	31.68	84	2661.12
Metal 1	Poly	6	16	8.64	56	483.84
	Substrate	6	9	4.86	27	131.22
Metal 2	Metal 1	6	8	4.32	31	133.92
	Poly	16	8	11.52	15	172.8
	Substrate	10	8	7.2	12	86.4
Metal 3	Metal 2	4	8	2.88	35	100.8
	Metal 1	6	4	2.16	13	28.08
	Poly	4	15	5.4	9	48.6
	Substrate	4	7	2.52	7	17.64

4 -10 $I = J_s \cdot A \left(e^{\frac{V_d}{V_t}} - 1\right)$

10 points

$V_{d_1} = 0.55v$ | $V_{d_2} = 0.65v$

$A = 50\mu m^2$ | $A = 50\mu m^2$

$J_s = 10^{-15} \frac{A}{\mu m^2}$ | $J_s = 10^{-15} \frac{A}{\mu m^2}$

$V_t = \frac{KT}{q}$ assume room temp, 20°C

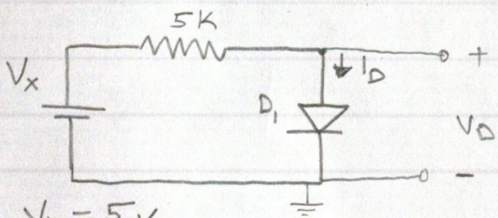
$$V_t = \frac{1.38065 \times 10^{-23} [J/K] \cdot (273.15 + 20)[K]}{1.60217 \times 10^{-19} [C]} = 0.02526 [V]$$

$$I_1 = (10^{-15})(50)\left(e^{\left(\frac{0.55}{0.02526}\right)} - 1\right) \qquad I_2 = (10^{-15})(50)\left(e^{\left(\frac{0.65}{0.02526}\right)} - 1\right)$$

$$\boxed{\begin{aligned} I_1 &= 1.42714 \times 10^{-4} \ [A] \\ I_2 &= 7.4756 \times 10^{-3} \ [A] \end{aligned}}$$

5

10 points



$V_{X_1} = 5V$

Guess D_1 is $\boxed{ON}$

$$I_{D_1} = \frac{V_X - V_D}{5K} = J_s \cdot A \cdot \left(e^{(V_D/V_t)} - 1\right)$$

assume $J_s = 10^{-15} \frac{A}{\mu m^2}$, $A = 50\mu m^2$, $V_t = 0.02526$ } from previous problem #4

$$\frac{5 - V_D}{5K} = (10^{-15})(50)\left(e^{\left(\frac{V_D}{0.02526}\right)} - 1\right)$$

$$\boxed{V_{D_1} = 0.5959 \ [v]}$$

then

$$I_{D_1} = (10^{-15})(50)\left(e^{\frac{0.5959}{0.02526}} - 1\right)$$

$$\boxed{I_{D_1} = 8.808 \times 10^{-4} \ [A]}$$

$V_{X_2} = 450mV$

$$I_{D_2} = \frac{0.450 - V_D}{5K} = (10^{-15})(50)\left(e^{\left(\frac{V_D}{0.02526}\right)} - 1\right)$$

$$V_{D_2} = 0.440607 \ [V]$$

then

$$I_{D_2} = (10^{-15})(50)\left(e^{\left(\frac{0.440607}{0.02526}\right)} - 1\right) \qquad \boxed{I_{D_2} = 1.8785 \times 10^{-6} \ [A]}$$

5 pts 6. $R = 1.0345\,K\Omega$ @ $T = 250\,K$ > $TCR = 100ppm/°C$
$R = ?$ @ $T = 400\,K$

$$R(T_2) = R(T_1)\left[1 + (T_2 - T_1)\,TCR/10^6\right]$$

$$R(400K) = 1.0345K\left[1 + (400-250)\cdot(100/10^6)\right] = \boxed{1050.02\,\Omega}$$

20pts 7.

a) $$I_S = J_{Sx} A\left[T^m e^{-V_{GO}/V_t}\right] = .45\cdot 100\cdot T^{2.3}\cdot e^{1.17/(kT/q)}$$

see attached Matlab graph

b) $I_S(27°C) = 5.08\,E{-13}$
$I_S(30°C) = 8.132\,E{-13}$

Percent Change = 60.08 % Change

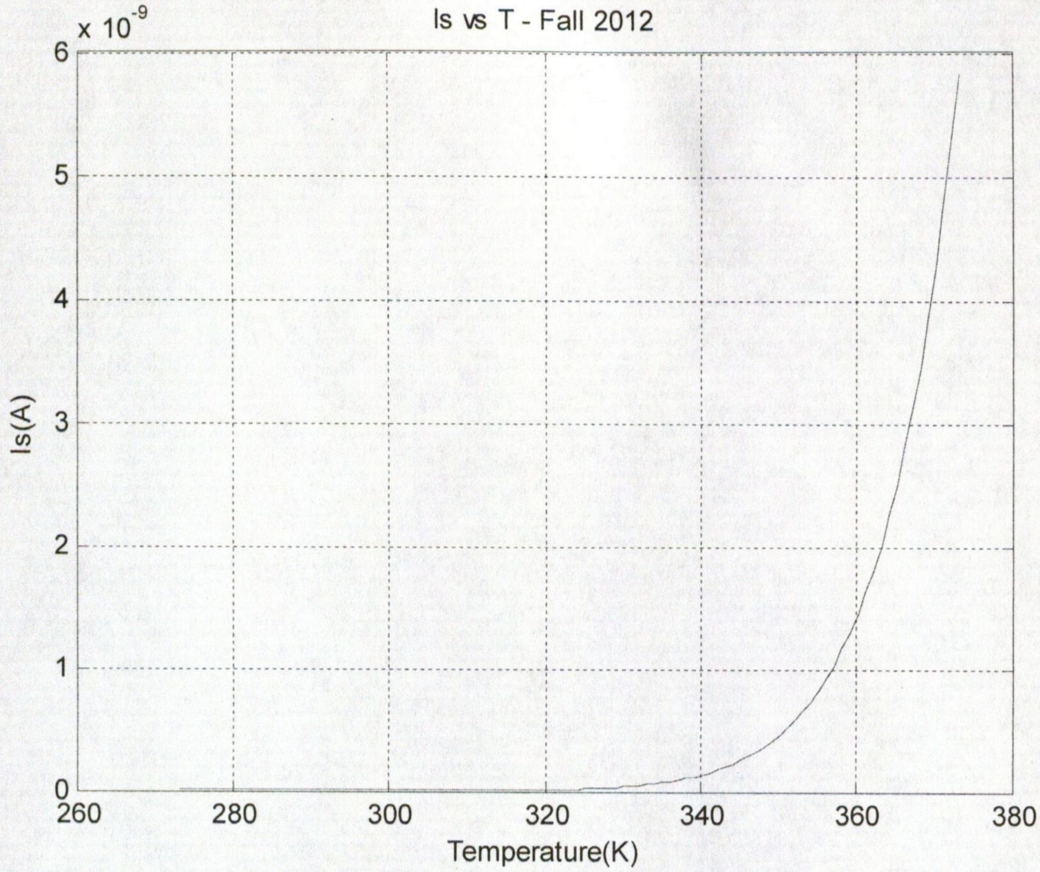
see attached matlab Code

c) Max errors of 24.24% if it is 2° higher
31.56 % if it is 2° less

see attached matlab Code

7.

```
clear;
clc;

%a)
Jsx = 0.45;
A = 100;
T = (0:1:100) + 273.15;
m = 2.3;
Vg0 = 1.17;
k = 1.38065E-23;
q = 1.60217E-19;
Vt = k * T / q;

Is = Jsx * A * T .^ m .* exp(-Vg0 ./ Vt);

plot(T, Is);
title('Is vs T');
xlabel('Temperature(K)');
ylabel('Is(A)');

%b)
T1 = 27 + 273.15;
T2 = 30 + 273.15;
Is1 = Jsx * A * T1 ^ m * exp(-Vg0 / (k*T1/q));
Is2 = Jsx * A * T2 ^ m * exp(-Vg0 / (k*T2/q));

PercentChange = (Is2 - Is1) / Is1;

%c)
for i = 50:99
  changePositive(i) = (Is(i) - Is(i+2)) / Is(i);
end

for p = 101:-1:50
  changeNegative(p) = (Is(p) - Is(p-2)) / Is(p);
end

maxPositive = min(changePositive);
maxNegative = max(changeNegative);
```

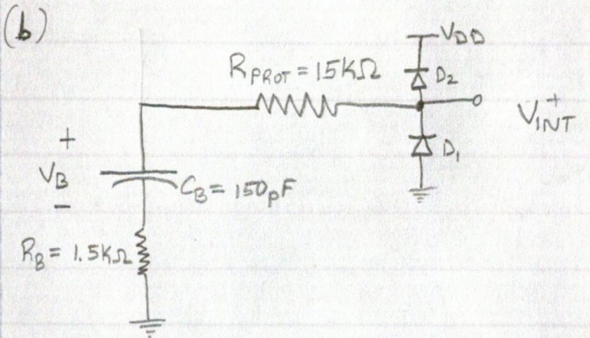

Is vs T - Fall 2012
x 10^-9
6
5
4
3
2
1
0
Is(A)
260
280
300
320
340
360
380
Temperature(K)

8 (a) $HBM_1 \rightarrow \boxed{V_{INT_1-MAX} = 250\,[V]}$

20 points

$HBM_2 \rightarrow \boxed{V_{INT_2-MAX} = 2000\,[V]}$

(b)



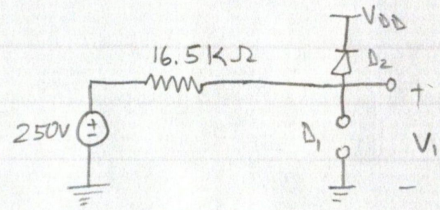
$V_{DD} = 5\,[V]$

$J_s = 10^{-20}\left[\frac{A}{\mu m^2}\right]$

$A = 1000\,[\mu m^2]$

$V_t = 0.0252617\,[V]$ at 20°C (room temp)

HBM1



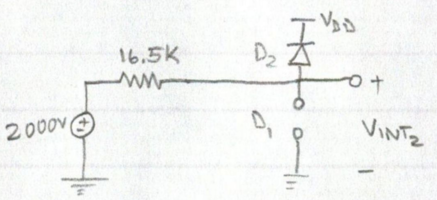
Guess D_1 OFF

D_2 ON

$$I_{D_2} = (10^{-20})(1000)\left(e^{\frac{(V_{INT_1}-5)}{V_t}} - 1\right) = \frac{250v - V_{INT_1}}{16.5K}$$

$$\boxed{V_{INT_1} = 5.8824\,[V]}$$

HBM2



$$I_{D_2} = (10^{-20})(1000)\left(e^{\frac{(V_{INT_2}-5)}{V_t}} - 1\right) = \frac{2000v - V_{INT_2}}{16.5K}$$

$$\boxed{V_{INT_2} = 5.9355\,[V]}$$

(c) HBM1 $I_{D_{2MAX}} = (10^{-20})(1000)\left(e^{\frac{(V_{INT_1}-5)}{V_t}} - 1\right)$

$$\boxed{I_{D_2max} = 14.795\,[mA]}$$

HBM2 $I_{D_2MAX} = (10^{-20})(1000)\left(e^{\frac{V_{INT_2}-5}{V_t}} - 1\right)$

$$\boxed{I_{D_2MAX} = 120.85\,[mA]}$$

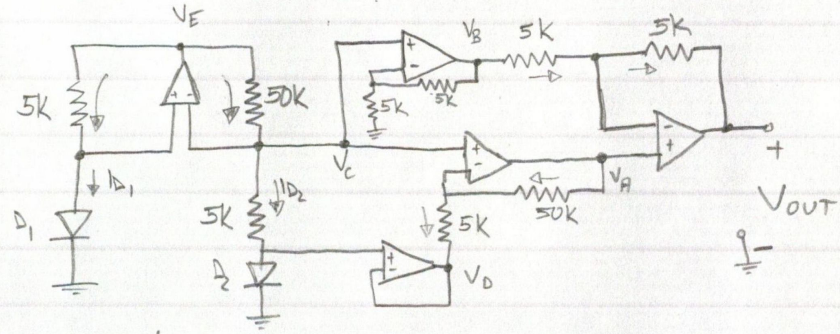
(d) R_{PROT} provides the input current something to dissipate through. Without it R_{IN} would significantly decrease, and the resultant current flow through the diodes would increase a lot, potentially damaging the protection circuit.

The Disadvantage is the added area on the die the resistor adds.

Extra Credit

Problem 9

+10 points



D_1 + D_2 matched

$$\frac{V_B - V_A}{5k} = \frac{V_A - V_{OUT}}{5K}$$

$$V_B = V_c\left(1 + \frac{5K}{5K}\right)$$

$$\frac{V_C - V_D}{5K} = \frac{V_A - V_C}{50K} \qquad \text{where } V_D = V_{D_1}$$

$$I_{D_2} = (I_s)\left(e^{\left(\frac{V_{D_2}}{V_t}\right)} - 1\right) = \frac{V_c - V_{D_2}}{5K} \qquad V_C = V_{D_1} \quad V_{D_2} = V_D$$

(no current through op-amp inputs)

$$\frac{V_{D_1} - V_{D_2}}{5K} = \frac{V_A - V_{D_1}}{50K} \qquad V_A = \frac{V_B + V_{OUT}}{2} \qquad V_B = V_{D_1}(2)$$

$$\frac{V_{D_1} - V_{D_2}}{5K} = \frac{V_{D_1} + \frac{1}{2}V_{OUT} - V_{D_1}}{50K} \qquad V_A = \frac{2V_{D_1} + V_{OUT}}{2} = V_{D_1} + V_{OUT}\left(\frac{1}{2}\right)$$

$$10(V_{D_1}) - 10(V_{D_2}) = \left(\frac{1}{2}\right)V_{OUT} \qquad V_{OUT} = 20\,(V_{D_1} - V_{D_2})$$

$$I_{D_1} = I_s\left(e^{\frac{V_{D_1}}{V_t}} - 1\right) \approx I_s e^{V_{D_1}/V_t}$$

$$I_{D_2} = I_s\left(e^{\frac{V_{D_2}}{V_t}} - 1\right) \approx I_s e^{V_{D_2}/V_t}$$

$$\frac{I_{D_1}}{I_{D_2}} = e^{\left(\frac{V_{D_1}}{V_t} - \frac{V_{D_2}}{V_t}\right)} \qquad V_{D_1} - V_{D_2} = V_t \cdot \ln\left(\frac{I_{D_1}}{I_{D_2}}\right)$$

$$V_t = \frac{KT}{q}$$

$$\frac{I_{D_1}}{I_{D_2}} = \frac{\left(\frac{V_E - V_{D_1}}{5K}\right)}{\left(\frac{V_E - V_{D_1}}{50K}\right)} = 10 \qquad V_{D_1} - V_{D_2} = \frac{KT}{q}\ln(10)$$

$$\boxed{V_{OUT} = 20 \cdot \frac{KT}{q}\ln(10)}$$

10. $R_2 = R_2(0)[1+(VCR \times V_{cross})]/10^6$

$V_{out} = -\left(\frac{R_2}{R_1}\right) \cdot V_{in}$ $V_{cross} = |V_{out}|$

$R_1 = 1K$ $R_2(0) = 10K$ $VCR = 400ppm$

a) $V_{in} = .1\sin(2000t)$

Ideal $= -1V$ non-ideal $= -1.0004V$

$\boxed{V_{diff} = 4E-4 \ V}$

b) $V_{in} = 1\sin(2000t)$

Ideal $= -10V$ non-ideal $= -10.04V$

$\boxed{V_{diff} = 0.04V}$