Name _______________
Instructor _______________
Section/College _______________

Electrical Engineering Advancement Exam III

SPRING SEMESTER 2021

CLOSED BOOK, CLOSED NOTES
2 HOUR TIME LIMIT

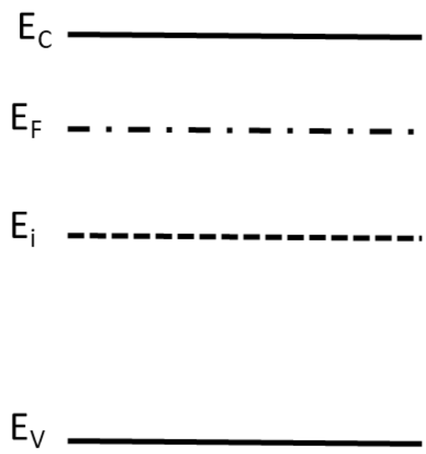
CALCULATORS ARE ALLOWED
(calculators without communication capability only)
ELECTRONIC DEVICES WITH COMMUNICATION CAPABILITY
(electronic devices such as cell phone, pagers, and iPads)
MAY NOT BE USED DURING THE EXAMINATION
(If such devices ring or are visible, a 10% penalty will be given for the first occurrence and exam failure for the second.)

There are 10 problems: please look over the exam to make sure that you have 10 different problems. **Do any eight (8) problems!** Draw a large X through the two problems that you do not want to be graded. If you do not indicate which problems you want to leave out, the first 8 problems will be graded.

Do all work for each problem only on the page supplied for that problem (you may use both sides). **DO NOT**, for instance, continue Problem #3 on the back of Problem #2. Extra blank paper will be supplied if needed. If extra paper is used, show the additional work for each problem on a separate sheet and staple the extra sheet(s) to the appropriate problems.

(1)

For parts a, b, and c, consider a GaAs semiconductor (n_i = 2.1×10^6 cm^{-3} at RT) doped with only one type of unknown dopant that results in the shown energy band diagram. Assume RT for the numerical analysis.



(a) [3 points] Is the semiconductor n-type or p-type? (Circle one)

n-type **p-type**

(b) [4 points] Identify the types of dopants that could possibly create this semiconductor. (Circle all possible cases.)

Ge **Si** **P** **N** **In**

(c) [10 points] If $E_C - E_F = 0.25$ eV, calculate the majority and minority concentration values. Go up to 7 decimal places for all answers.

$\mathbf{p_o}$ = ____________________ $\mathbf{n_o}$ = ____________________

(d) [2 points] For an **intrinsic** semiconductor, sketch the variation of $\mathbf{n_i}$ **vs. 1/T** where T is temperature.

(e) [6 points] For a doped semiconductor, sketch the variation of the majority carrier **vs. 1/T** where T is temperature. Clearly label the intrinsic and extrinsic regions.

Problem Score
/25

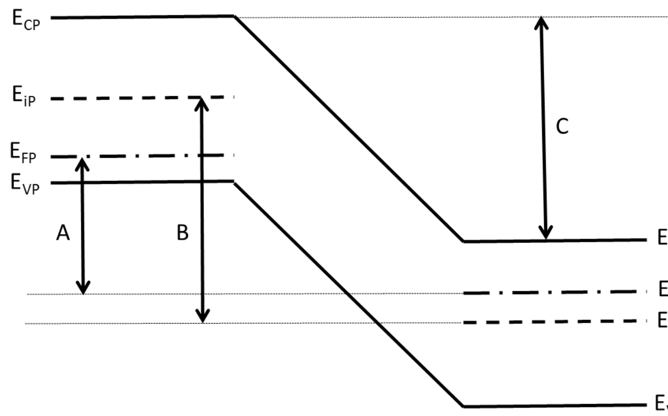
(2)

Consider the energy band diagram of a biased Si PN junction shown. An external bias voltage V_A is applied per our convention. The RT intrinsic concentration of Si is 1.50×10^{10} cm^{-3}.

$E_{iP} - E_{FP} = 0.40$ eV

$E_{FN} - E_{iN} = 0.20$ eV

Assuming room temperature.



(a) [3 points] Is the junction reverse biased or forward biased? (Circle one)

Reverse Biased

Forward Biased

(b) [16 points] Calculate the values of the effective doping on each side of the junction, of the contact potential V_O, and of the external bias voltage V_A if the observed value of depletion width is 9.0338 µm. Assume that the effective doping concentration, in each region, is equal to the majority carrier concentration in that region.

$N_{dn,eff}^{+}$ = ________________ $N_{dp,eff}^{-}$ = ________________

V_O = ________________ V_A = ________________

(c) [3 points] Express the **symbolic** values of the energies marked "A", "B" and "C" in the energy band diagram shown above in terms of the parameters V_O and V_A.

A = ____________ **eV** B = ____________ **eV** C = ____________ **eV**

(d) [3 points] Consider this pn junction **unbiased**. Will the depletion region extend more into the p-side or the n-side, i.e. which is greater x_{no} or x_{po}? (Circle one)

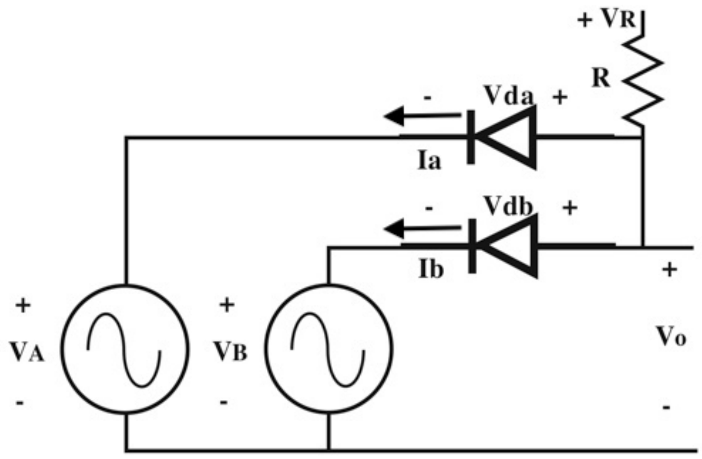
$x_{no} > x_{po}$ $x_{no} < x_{po}$

Problem Score

/25

(3)

Consider the diode circuit shown. Each diode has a turn-on voltage of 0.60 V and reverse saturation current of 0 A. The voltage $V_R = 4.0$ V and the resistor $R = 2.0$ kΩ



(a) [6 Points] If $V_A = V_B = 6.0$ V, calculate V_o, I_a, and I_b.

$\mathbf{V_o} =$ ____________ $\mathbf{I_a} =$ ____________ $\mathbf{I_b} =$ ____________

(b) [8 Points] If $V_A = 0$ V and $V_B = 6.0$ V, Calculate V_o, I_a, and I_b.

$\mathbf{V_o} =$ ____________ $\mathbf{I_a} =$ ____________ $\mathbf{I_b} =$ ____________

(c) [8 Points] If $V_A = 0$ V and $V_B = 0$ V, Calculate V_o, I_a, and I_b.

$\mathbf{V_o} =$ ____________ $\mathbf{I_a} =$ ____________ $\mathbf{I_a} =$ ____________

(d) [3 Points] What type of system does the above circuit represent? (Circle one)

OR Gate Clamper XOR Gate None of those listed

Problem Score

/25

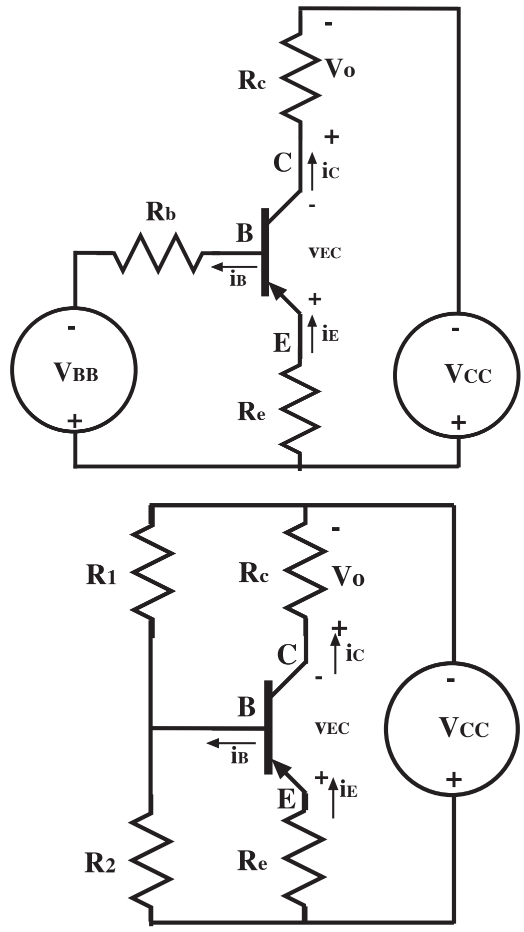
(4)

The two circuits shown need to have equivalent operating points. The circuit values are

$V_{CC} = 15.0$ V, $V_{BB} = 5.00$ V,

$\boldsymbol{R_b} = 50.0$ kΩ, $\boldsymbol{R_e} = 0$ Ω, and $\boldsymbol{R_C} = 500$ Ω.

Assume a gain (nominal) of $\beta = 100$ and a base-emitter turn-on voltage of $V_{to} = 0.70$ V.



(a) [10 points] Calculate the required values of R_1 and R_2 for the circuits to be equivalent.

$\boldsymbol{R_1}$ = __________________

$\boldsymbol{R_2}$ = __________________

(b) [9 points] Calculate the currents i_C, i_E, and i_B.

$\boldsymbol{i_C}$ = ____________ $\boldsymbol{i_E}$ = ____________ $\boldsymbol{i_B}$ = ____________

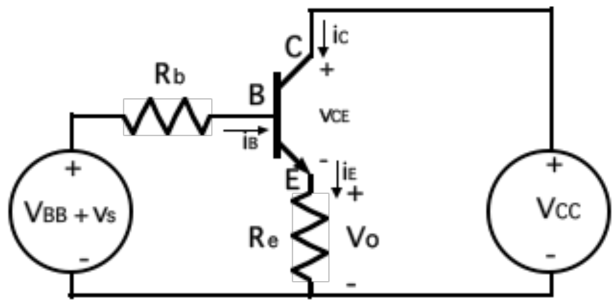
(c) [6 points] Calculate the voltages v_{EC} and V_o. Note that $\boldsymbol{R_e} = 0$ Ω.

$\boldsymbol{v_{EC}}$ = _______________________ $\boldsymbol{V_o}$ = __________________

Problem Score

/25

(5) Consider the BJT circuit shown ($v_S = 0$).
For the bipolar junction transistor,
$\beta = 200$ (nominal),
V_{to} (turn-on) = 0.7 V,
$V_{CE(SAT)} = 0.20$ V,
For the circuit let
$V_{BB} = 3.70$ V, $V_{CC} = 12.0$ V,
$\boldsymbol{R_b} = 10.00$ kΩ, $\boldsymbol{R_e} = 1.00$ kΩ.



(a) [2 points] Identify the transistor type. (Circle one)

npn **pnp**

(b) [3 points] What type of carrier is largest in the transistor current i_C? (Circle one)

holes **electrons**

(c) [15 points] Calculate the transistor currents i_B, i_E, and i_C. and the voltages V_0 and v_{CE}. Express all answer to 3 decimal places.

$i_B =$ __________ $i_E =$ __________ $i_C =$ __________

$V_0 =$ __________ $v_{CE} =$ __________

(d) [5 points] For an unbiased bipolar transistor of the type given in this problem, sketch the equilibrium energy-band diagram. Clearly label the Fermi energy levels E_F and the intrinsic levels in each region $E_{i,X}$. Label each region (collector, base, and emitter).

Problem Score
/25

(6)

(a) [5 points] For an unbiased **n-channel** JFET, sketch the equilibrium energy-band diagram. Clearly label the Fermi energy level E_F in each region and the intrinsic energy levels $E_{i,Gate}$ and $E_{i,Channel}$ in each region. Label each region (channel or gate).

(b) [5 points] Consider a **p-channel** JFET with specifications V_{po} and I_{SDS}. For the saturation case, sketch the curve i_{SD} vs. v_{SG}. Label key points of the curve.

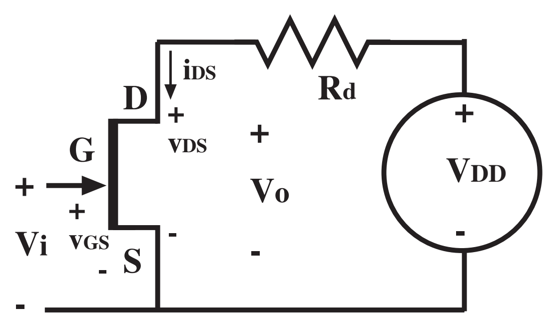
(c) [6 points] Consider an **n-channel** JFET with specifications V_{po} and I_{DSS}. On a single graph, sketch the current-voltage curves i_{DS} vs. v_{DS} for the following three input voltage cases. Clearly label which curve corresponds to each input voltage case.

A) $v_{GS} = 0$ V
B) $-V_{po} < v_{GS} < 0$ V
C) $v_{GS} < -V_{po}$

(c) Consider the circuit shown in which the **n-channel** JFET has the following specification:

$V_{po} = 4.0$ V and $I_{DSS} = 2.0$ mA.

The supply voltage is $V_{DD} = 10.0$ V. The operating current is $i_{DS} = 1.0$ mA.



i) [3 points] Assuming saturation conditions exist, calculate the needed value of $V_i = v_{GS}$.

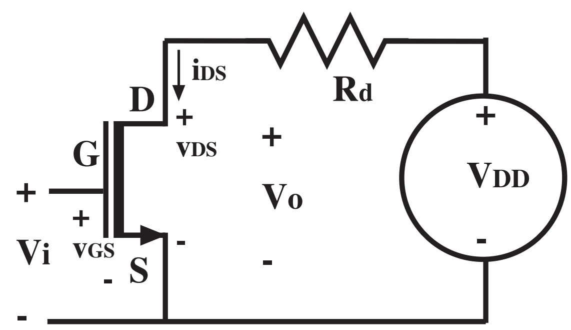
$V_i = v_{GS} =$ ______________

ii) [6 points] Calculate the resistor value R_d needed to have the JFET operating voltage $v_{DS} = 6.0$ V

$R_d =$ ______________

Problem Score
/25

(7) Consider a depletion-mode MOSFET circuit with V_{PO} = 4.00 V, I_{DSS} = 2.00 mA, i_G = 0 A, and V_{DD} = 15.0 V.



(a) [3 points] Identify the MOSFET type (circle one).

n-channel Depletion-mode MOSFET
p-channel Depletion-mode MOSFET

(b) [6 points] Determine the intercepts in **symbolic** terms on a (i_{DS} vs. v_{DS}) graph for the load-line KVL, i.e. voltage-axis intercept when current is zero and current-axis intercept when the voltage is zero.

Voltage-axis intercept = (______, 0 A) **Current-axis intercept = (0 V, ______)**

(c) [4 points] Calculate the maximum value of V_i for which the current $i_{DS} = 0$.

V_i = __________________

(d) [8 points] If the current i_{DS} = 2.00 mA, calculate the value of R_d for which the MOSFET operates at the threshold of saturation.

R_d = __________________

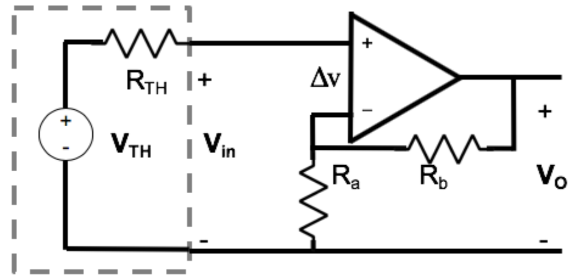
(e) [4 points] Let $v_{GS} = v_{GS,C}$ be the input voltage that produced i_{DS} = 2.00 mA in part c (using the value of R_d calculated in part c). If the input voltage increases, i.e. $v_{GS} > v_{GS,C}$, what is the condition of the MOSFET. (Circle one.)

Saturated Operation **Unsaturated Operation**

Problem Score
/25

(8)

Consider the OpAmp circuit shown. Assume **ideal** OpAmp parameters.



(a) [3 points] For this ideal case, what is the input resistance of the OpAmp? (Circle one.)

$\boldsymbol{R_{in}}$ **= Zero Ohms** $\boldsymbol{R_{in}}$ **= 100 Ohms**

$\boldsymbol{R_{in}}$ **= 100,000 Ohms** $\boldsymbol{R_{in}}$ **= Infinite Ohms**

(b) [3 points] What type of OpAmp circuit is shown? (Circle one.)

Inverting (V_O / V_{TH} neg.) **Non-Inverting (V_O / V_{TH} pos.)**

(c) [12 points] Derive the symbolic expression for the circuit gain V_O / V_{TH} in terms of the resistances.

$V_O / V_{TH}.$ = _______________

(d) [7 points] The circuit values are

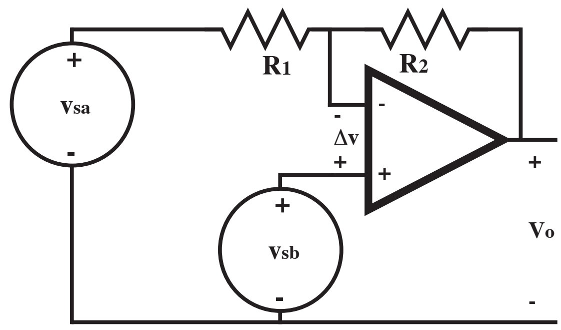
$R_{TH} = 5.00\ \text{k}\Omega$, $R_a = (1 - x)\ 4.00\ \text{k}\Omega$, and $R_b = x\ 4.00\ \text{k}\Omega$.

Let the voltage across R_A be V_A. If $|V_O/V_A| = 6$, calculate the needed value of the fraction x.

x = _________

Problem Score
/25

(9) Consider the OpAmp circuit shown.



(a) [5 points] Sketch the equivalent circuit in which the OpAmp is replaced with appropriate circuit elements. Assume **ideal** values for the OpAmp resistances.

(b) [10 points] Use superposition to derive the influence of just the input v_{Sb} with $v_{Sa} = 0$, i.e. $V_{0,b}$ as a function of the resistances R_1 and R_2 and voltage v_{Sb}. Assume an **ideal** OpAmp.

$\mathbf{V_{0,b}}$ = ______________________________

(c) [10 points] The resistance values are **R_1** = 2.00 kΩ and **R_2** = 10.00 kΩ.
If the input voltage v_{sb} = 6 V, calculate the input voltage v_{sa} which gives zero for the (total) output voltage, i.e. $V_0 = 0$. Assume an **ideal** OpAmp.

$\mathbf{v_{sa}}$ = ______________________________

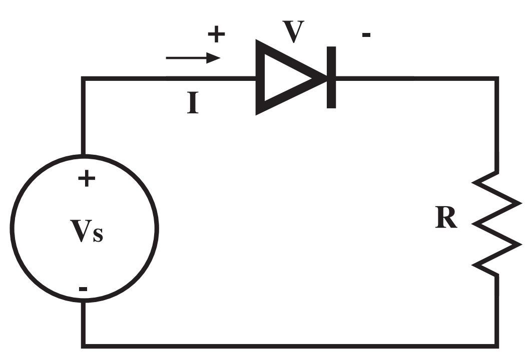
Problem Score
/25

(10)

(a) [12 points] Consider crystalline Si which has a bandgap energy of $E_G = 1.12$ eV. Complete the table with the correct calculation and selection, i.e. calculate the photon energies of these wavelengths and note whether Si is absorbing or transparent.

Wavelength	Photon Energy in eV	Si is (circle one)
900 nm		**Absorbing** **Transparent**
1500 nm		**Absorbing** **Transparent**

Consider the Si pin photodiode circuit shown with source voltage V_S = - 12.0 V and with load resistance $\boldsymbol{R}$ = 5000 Ohms. The reverse saturation current (for "dark" conditions) is 0.20 mA. Assume the photodiode voltage $|V| >> kT/q$ and room temperature.



(b) [6 points] Calculate the photodiode operating point for dark conditions (no incident light).

V= ________________ **I =** ________________

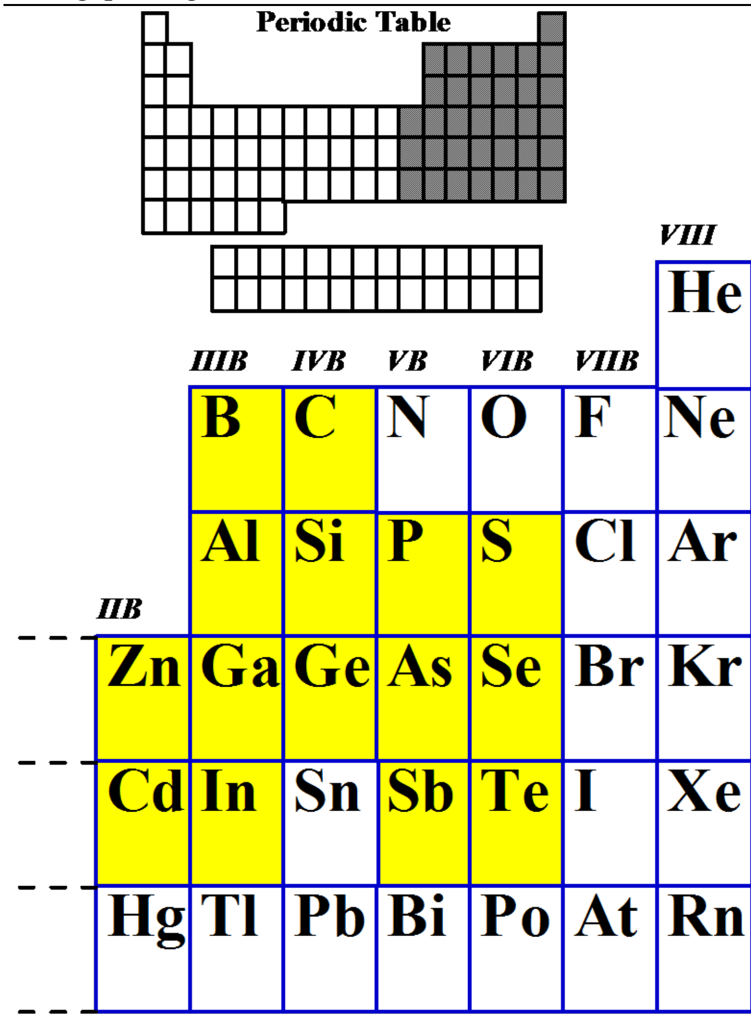
(c) [7 points] Calculate the photodiode operating point for conditions in which the photo-induced current I_{light} = 1.00 mA. (The incident light is at an absorbing wavelength).

V= ________________ **I =** ________________

Problem Score
/25

EE 2200 Equation Sheet

Boltzmann's constant:	$k = 1.381 \times 10^{-23}$ J/K $= 8.618 \times 10^{-5}$ eV/K		
Planck's constant	$h = 4.136 \times 10^{-15}$ eV-sec $= 6.626 \times 10^{-34}$ J-sec		
Electronic charge:	$q = 1.602 \times 10^{-19}$ C		
kT at 300 K	$kT = 0.0259$ eV		
eV-J conversion	1 eV $= 1.602 \times 10^{-19}$ J		
Free-space permittivity	$\varepsilon_0 = 8.854 \times 10^{-14}$ F/cm		
Speed of Light	$c = 2.998 \times 10^{10}$ cm/s		
Relative permittivity	Si: 11.9	Ge: 16.0	GaAs: 13.1
Bandgap energies	Si: 1.12 eV	Ge: 0.67 eV	GaAs: 1.42 eV



$$\rho(T) = \rho_{20}[1 + \alpha_{20}(T - 20)]$$

$$(E_F - E_i) = kT \ln\left(\frac{n_0}{n_i}\right)$$

$$n_0 + N_a^- = p_0 + N_d^+$$

$$(E_F - E_i) = -kT \ln\left(\frac{p_0}{n_i}\right)$$

$$n_0 p_0 = n_i^2$$

$$n_0 = n_i e^{\frac{(E_F - E_i)}{kT}}$$

$$J = qD_n \frac{dn}{dx} - qD_p \frac{dp}{dx}$$

$$J = q(n_o\mu_n + p_0\mu_p)E = \sigma E$$

$$\frac{D_n}{\mu_n} = \frac{kT}{q}$$

$$\frac{D_p}{\mu_p} = \frac{kT}{q}$$

$$W_0 = \left\{\frac{2\varepsilon_0\varepsilon_r V_0}{q}\left[\frac{(N_{ap}^-)_{Eff} + (N_{dn}^+)_{Eff}}{(N_{ap}^-)_{Eff}(N_{dn}^+)_{Eff}}\right]\right\}^{1/2}$$

$$W = \left\{\frac{2\varepsilon_0\varepsilon_r (V_0 - V_A)}{q}\left[\frac{(N_{ap}^-)_{Eff} + (N_{dn}^+)_{Eff}}{(N_{ap}^-)_{Eff}(N_{dn}^+)_{Eff}}\right]\right\}^{1/2}$$

$$p_0 = n_i e^{\frac{-(E_F - E_i)}{kT}}$$

$$V_0 = \frac{kT}{q}\ln\left[\frac{(N_{ap}^- - N_{dp}^+)(N_{dn}^+ - N_{an}^-)}{n_i^2}\right]$$

$$qV_0 = (E_F - E_{in}) - (E_F - E_{ip})$$

$$(N_{ap}^-)_{Eff}\, x_{p0} = (N_{dn}^+)_{Eff}\, x_{n0}$$

$$I = I_0\left[e^{\left(\frac{qV}{kT}\right)} - 1\right]$$

BJT Relationships

$$i_B = \frac{1}{\beta} i_C \qquad i_E = i_B + i_C \qquad \alpha_0 = \frac{\beta}{\beta + 1}$$

$$\alpha_F = \frac{i_{Cn}}{i_{En}} \quad \text{or} \quad \alpha_F = \frac{i_{Cp}}{i_{Ep}} \qquad \gamma = \frac{i_{En}}{i_{En} + i_{Ep}} \quad \text{or} \quad \gamma = \frac{i_{Ep}}{i_{En} + i_{Ep}}$$

Saturation Conditions

$$v_{DG} = v_{DS} - v_{GS} \geq V_{po} \qquad v_{GD} = v_{SD} - v_{SG} \geq V_{po}$$

$$v_{DS} - v_{GS} \geq -V_{on} \qquad v_{SD} - v_{SG} \geq -V_{on}$$

FET Relationships

$$i_{DS} = I_{DSS}\left[2\left(1 + \frac{v_{GS}}{V_{po}}\right)\left(\frac{v_{DS}}{V_{po}}\right) - \left(\frac{v_{DS}}{V_{po}}\right)^2\right] \qquad i_{DS} = I_{DSS}\left(1 + \frac{v_{GS}}{V_{po}}\right)^2$$

$$i_{SD} = I_{SDS}\left[2\left(1 + \frac{v_{SG}}{V_{po}}\right)\left(\frac{v_{SD}}{V_{po}}\right) - \left(\frac{v_{SD}}{V_{po}}\right)^2\right] \qquad i_{SD} = I_{SDS}\left(1 + \frac{v_{SG}}{V_{po}}\right)^2$$

$$i_{DS} = K{V_{on}}^2\left[2\left(\frac{v_{GS}}{V_{on}} - 1\right)\left(\frac{v_{DS}}{V_{on}}\right) - \left(\frac{v_{DS}}{V_{on}}\right)^2\right] \qquad i_{DS} = K{V_{on}}^2\left(\frac{v_{GS}}{V_{on}} - 1\right)^2$$

$$i_{SD} = K{V_{on}}^2\left[2\left(\frac{v_{SG}}{V_{on}} - 1\right)\left(\frac{v_{SD}}{V_{on}}\right) - \left(\frac{v_{SD}}{V_{on}}\right)^2\right] \qquad i_{SD} = K{V_{on}}^2\left(\frac{v_{SG}}{V_{on}} - 1\right)^2$$

$$f = \frac{c}{\lambda}$$

$$I = I_0 e^{-\alpha_L x}$$

$$I = I_0\left[e^{\frac{qV_d}{kT}} - 1\right] - I_{light}$$

$$E_p = hf = \frac{hc}{\lambda}$$

$$v_p = \frac{c}{n}$$

$$I_{light} = \frac{\eta q P \lambda}{hc}$$