Bipolar Transistors: current components and conductances, capacitances, and small-signal model

Problem - 1

An n-p-n BJT has the following parameters:

W_E=1 μm, N_{DE}=10^{19} /cm^3, D_{pE}= 2 cm^2/s, τ_{pE}=0.01 μs; W_B=0.7 μm, N_{AB}=10^{17} /cm^3, D_{nB}= 20 cm^2/s, τ_{nB}=0.1 μs; W_C=2.5 μm, N_{DC}=5x10^{15} /cm^3, D_{pC}= 10 cm^2/s, τ_{pC}=1 μs. Here W_E, N_{DE}, D_{pE} and τ_{pE} are respectively the width, donor doping concentration, minority carrier (hole) diffusion constant and minority carrier life time for emitter region. Similarly other parameters are defined for base and collector regions.

Calculate the emitter injection efficiency (γ), base transport factor (α_T), common base current gain (α) and common emitter current gain (β) for this transistor.

Problem - 2

The EB junction of an n-p-n transistor is forward biased by V_{BE}=0.8 V, while the collector terminal is left floating. The reverse common base current gain α_R is given as 0.4.

(a) What is the open circuit voltage developed across the CB junction?

(b) What is the value of V_{CE} at this point?

(c) What is the mode of operation of this BJT?

Problem - 3

An n-p-n BJT has the following parameters:

W_E=1.4 μm, N_{DE}=10^{20} /cm^3, D_{pE}= 2.5 cm^2/s, τ_{pE}=0.01 μs; W_B=0.7 μm, N_{AB}=10^{18} /cm^3, D_{nB}= 20 cm^2/s, τ_{nB}=0.1 μs; W_C=3 μm, N_{DC}=5x10^{16} /cm^3, D_{pC}= 10 cm^2/s, τ_{pC}=1 μs.

Calculate (a) BC voltage and (b) CE voltage when the collector terminal of the transistor is kept floating and V_{BE}=0.7 V.

Problem - 4

For an n-p-n BJT with γ=1 and Early effect factor $\delta W_B/\delta V_{CB}$=0.01 μm/Volt, derive an expression for the common base and common emitter output conductances (g_{cb} and g_{ce}) at sufficiently large collector-base voltage in terms of collector current (I_C), base width (W_B) and minority carrier diffusion length (L_n) within base. If g_{cb} is given as 0.001 and calculate g_{ce} for base transport factor α_T=0.99.

Problem - 5

Two transistors T1 and T2 are identical in all respects except in their base widths. The emitter efficiencies are unity in both cases. The base width of T1 is 1 μm and that of T2 is 2 μm. The transistors are biased in the active region of operation. The base current of T1 is 10 μA when the collector current is 1 mA. Determine the base current of T2 when the collector current is 1 mA.

Problem - 6

In an n^+pn^+ transistor with uniform base doping, the neutral base width is 1.2 μm when V_{CB}=5 V. The depletion layer width at the CB junction for this case is 0.3 μm. Find out the value of CB voltage at which the entire base gets depleted (called base punch through effect). Neglect the built-in potential as well as the depletion layer width at the EB junction.

Problem - 7

Derive the complete small-signal equivalent circuit for a BJT at I_C=1mA, V_{BE}=0.6V, V_{CB}=3V and V_{CS}=5V. Given C_{be0}=10 fF, V_{bie}=0.9V, $C_{\mu 0}$=10fF, V_{bic}=0.5V, C_{cs0}=20fF, V_{bis}=0.65V, β_{ac}=100, τ_f=10ps, V_A=20V, r_b=200W, r_c=50W, r_e=5W,r_μ=10$\beta_{ac}r_0$. Assume all junctions are abrupt. V_{bie}, V_{bic}, and V_{bis} are the built-in potentials for BE, BC and CS junctions. C_{be0}, $C_{\mu 0}$ and C_{cs0} are the zero bias junction capacitances of the respective junctions. V_A is the Early voltage.