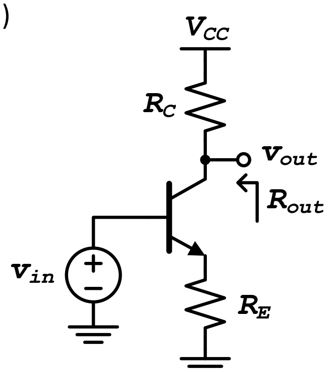
University of Michigan
EECS 522: Analog Integrated Circuits
Winter 2009

Problem Set 1

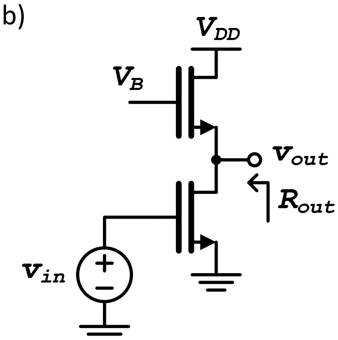
Issued 1/21/2008 – Due 1/28/2008

Problem 1.1: For each of the following circuits, find simplified expressions for gain ($A_v = v_{out} / v_{in}$) and R_{out}. Solving by inspection is preferred. It is ok to keep parallel combinations of resistors in the form ($R_1||R_2$). For simplicity, assume that g_m, r_o, and r_π are identical for all devices, ignore body effect, and ignore r_o when appropriate ($1/g_m$, R_C and $R_E \ll r_o$).

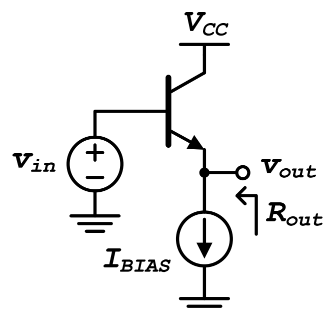
a)



b)



c)

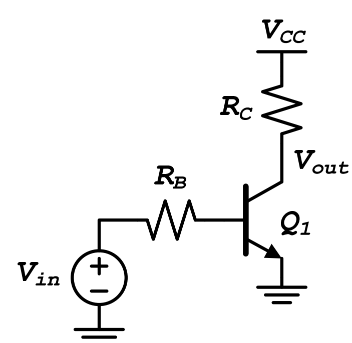


Problem 1.2: Use the circuit on the right for this problem. Include base width modulation in your calculations. Assume $\beta_F = 120$, $V_A = 35V$, $V_{CE(sat)} = 0.3V$, and $V_{BE} = 0.7V$ when Q_1 is in the forward active region.

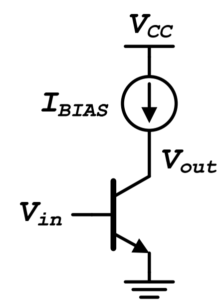
a) Find the DC values of I_B, I_C, and V_{out} at the quiescent point. Assume $V_{IN} = 2.7V$, $R_B=100k\Omega$, $V_{CC} = 5V$, and $R_C = 1k\Omega$. What region is Q_1 operating in?

b) Find the values of g_m, R_π, and r_o at the quiescent point found in part a) and room temperature.

c) Derive a small signal expression for v_{out}/v_{in}, you do not need to solve for the numerical value.



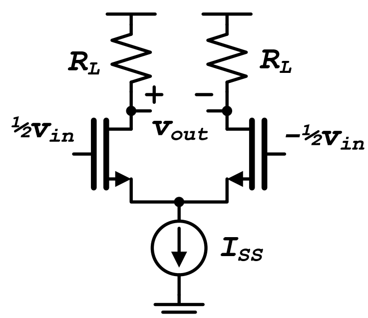
Problem 1.3: Use the circuit on the right for this problem. Assuming the transistor is biased in the forward active region, calculate the numerical value for small signal gain given V_A = 35V. Assume room temperature. This is what is referred to as the "intrinsic gain" of the device.



Problem 1.4: Use the circuit on the right for this problem. Assume the circuit is symmetric.

a) Draw the small signal half-circuit of the diff pair. Include channel length modulation and body effect in your model.

b) Find an expression for gain v_{out}/v_{in}.

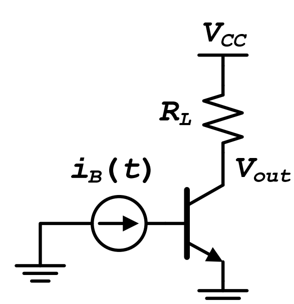


Problem 1.5: For this problem, use the parameter values given in the table below. Use the charge control model to solve the following parts.

Parameter	NPN	Units
β_F	100	A/A
β_R	10	A/A
τ_F	10	ps
τ_R	5	ns
$V_{CE(sat)}$	0	V

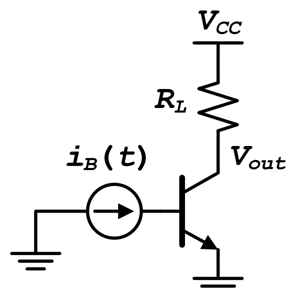
a) For the circuit on the right, assume i_B is initially 0, and steps from 0 to 10μA at time 0s and remains at 10μA. V_{CC} = 5V and R_L = 2kΩ. What region will the transistor be in at t = ∞? Calculate the final values of q_F (in Coulombs), i_C, and v_{OUT}.

b) Sketch the transient current i_C from part a) as a function of time. What is the time constant of the response?



Problem 1.6: For this problem, use the parameter values given in the table below. Use the charge control model to solve the following parts.

Parameter	NPN	Units
β_F	100	A/A
β_R	10	A/A
τ_F	10	ps
τ_R	5	ns
$V_{CE(sat)}$	0	V



a) Now assume i_B is initially 0, and steps from 0 to 100μA at time 0s and remains at 100μA. V_{CC} = 5V and R_L = 2kΩ. Verify that the BJT will be in saturation at t = ∞. Using the charge control models in the saturation region, calculate the final values of $q_{TOTAL} = q_F + q_R$, i_C, and v_{OUT}.
Hint: I_C is determined by the circuit, and at time t = ∞ (steady state), all *dq*/*dt* terms equal 0.

b) At time t = 0 the base charge is 0 and the device is in the forward active region. Let's assume for now that the device will remain in forward active and not saturate. Calculate the final value of i_C and V_{out} using the *forward active* charge control models (V_{out} will be negative). Sketch V_{out} as a function of time, and indicate what the time constant of the response is. Calculate the time at which V_{out} reaches the saturation voltage 0V.

c) The base charge just prior to the onset of saturation is defined as q_{B0}. In part b), you calculated the time at which the BJT transitions from forward active to saturation. Calculate q_{B0} using the forward active region charge control model. Calculate i_{B0}, which is the value of base current that biases the BJT right at the edge of saturation.
Hint: I_C is determined by the circuit, and $q_{B0} = q_F$ when $V_{CE} = V_{CE(sat)}$.

d) You now have enough information to calculate the value of q_S, the excess charge stored in the base at time t = ∞, assuming now that the BJT goes into saturation.

e) Now assume the base current is switched back to 0 after q_S has been stored in the base. With i_B = 0, the differential equation for q_S becomes: $-i_{B0} = q_S/\tau_S + q_S/dt$. The final value of q_S from this equation is $-i_{B0}\tau_S$. In reality, a negative q_S is not allowed, and instead the device will enter the forward active region when q_S = 0. However, we use this final value to find the time when q_S = 0. Sketch the solution to the above differential equation with an initial value of q_S found in d), and the final value of $-i_{B0}\tau_S$. Calculate the value of τ_S. Now calculate the time at which q_S = 0. This is the time required to bring the BJT out of saturation, *after* which it will enter the forward active region and v_{out} begins to rise.