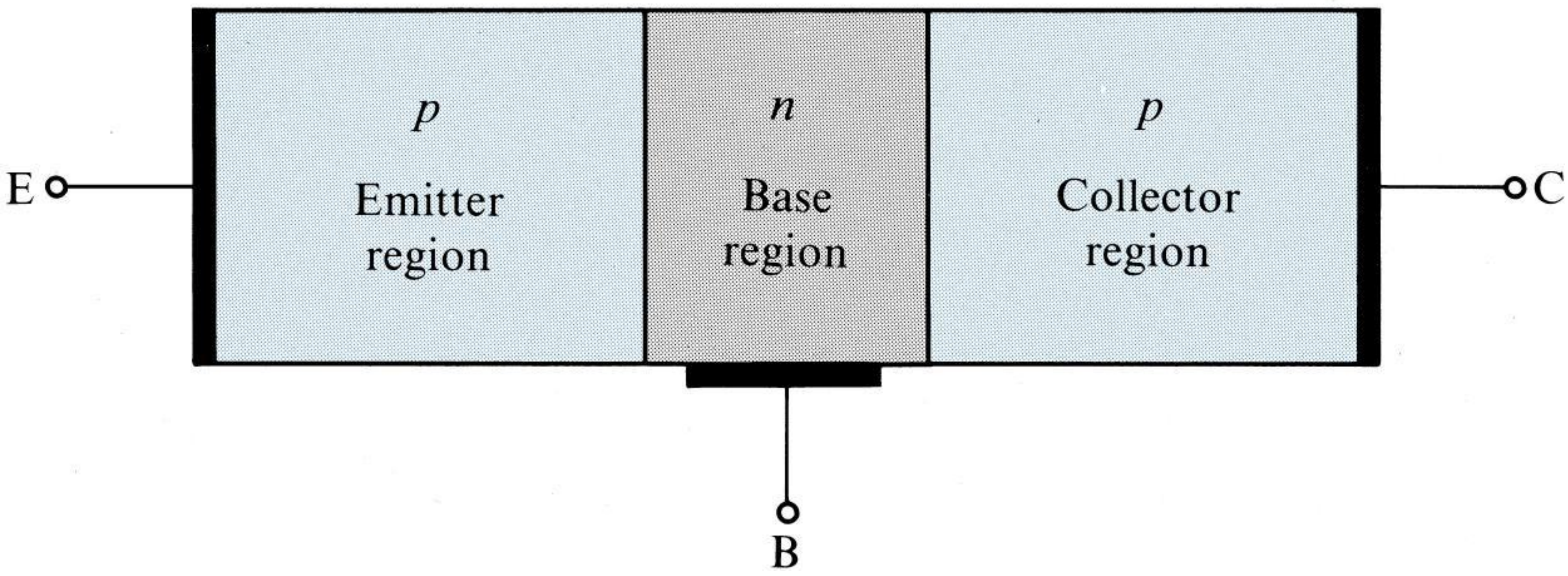
BJT

Bipolar Junction Transistor

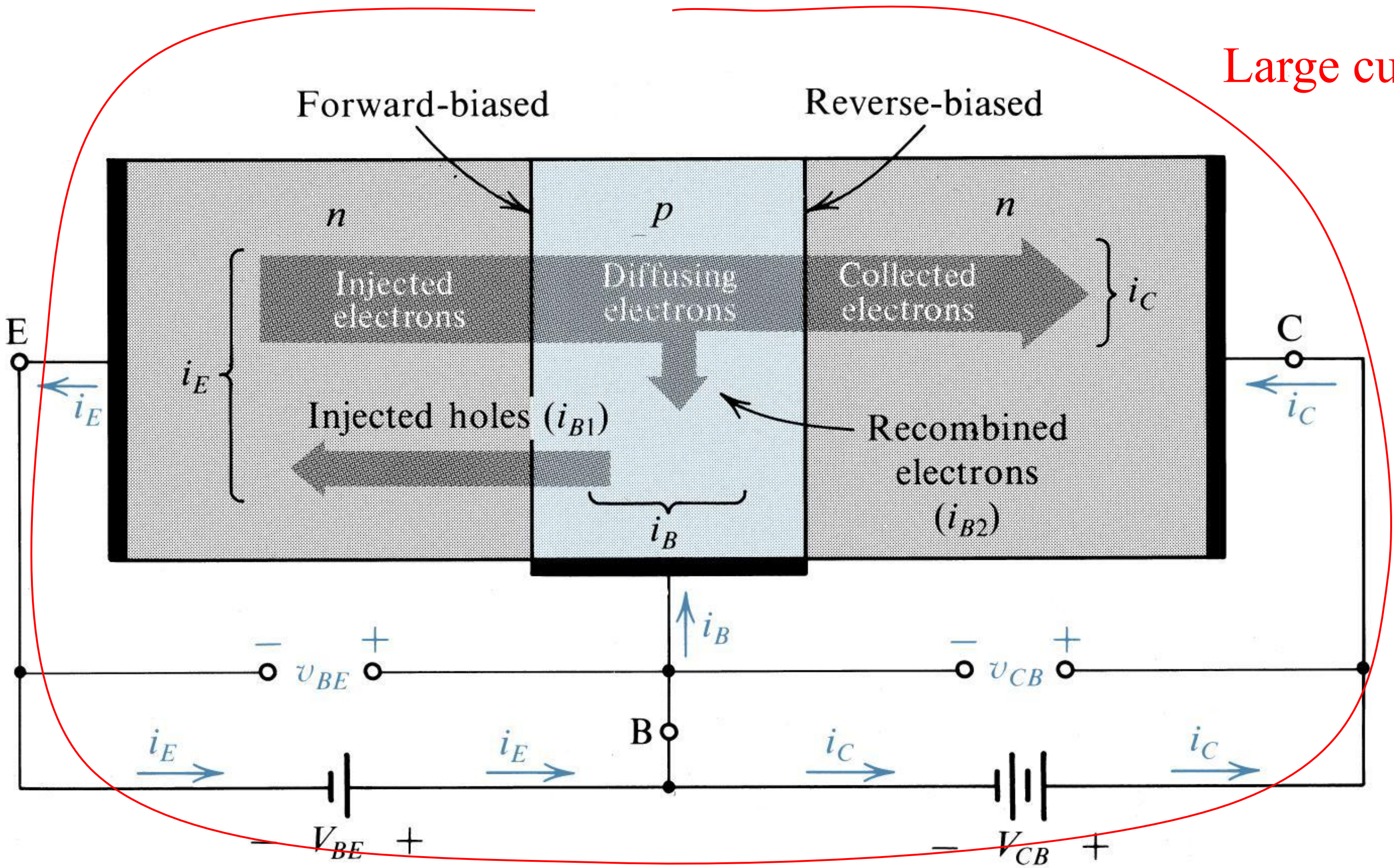
- Widely used in amplifier circuits
- Formed by junction of 3 materials
- npn or pnp structure

pnp transistor



Operation of npn transistor

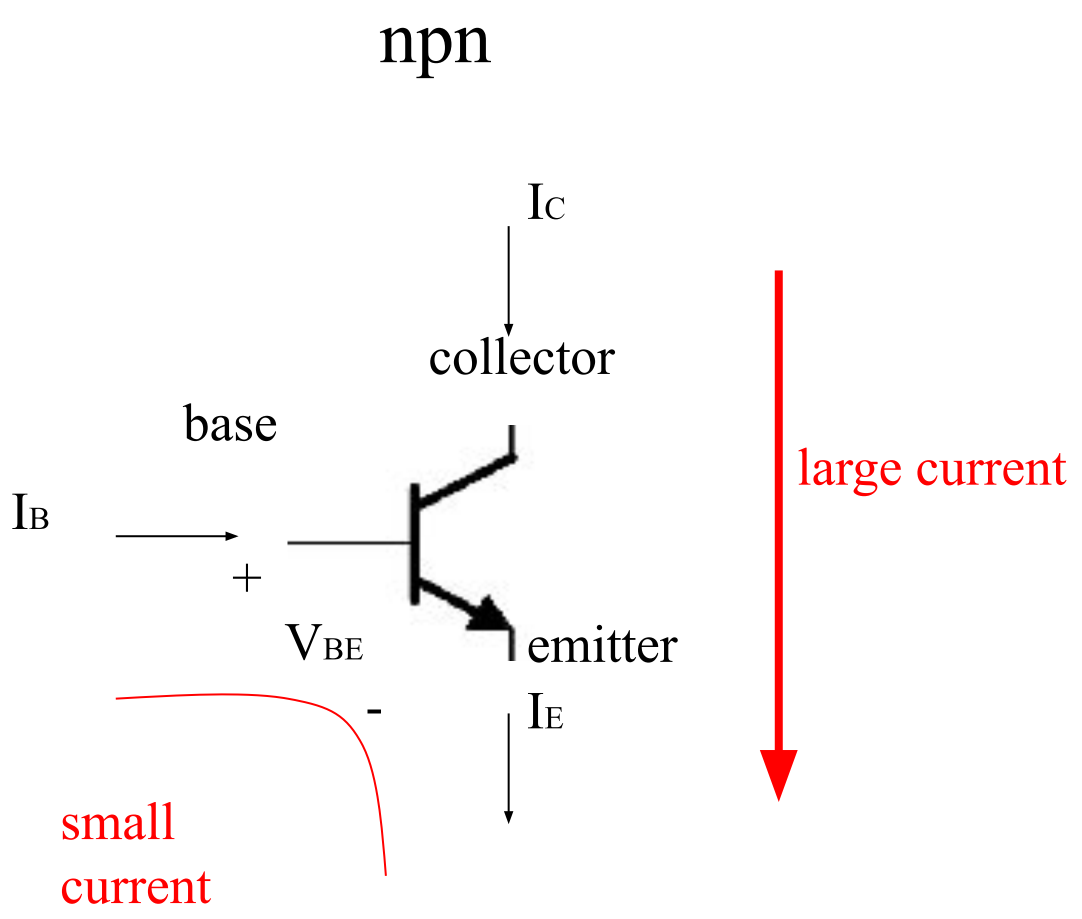
Large current



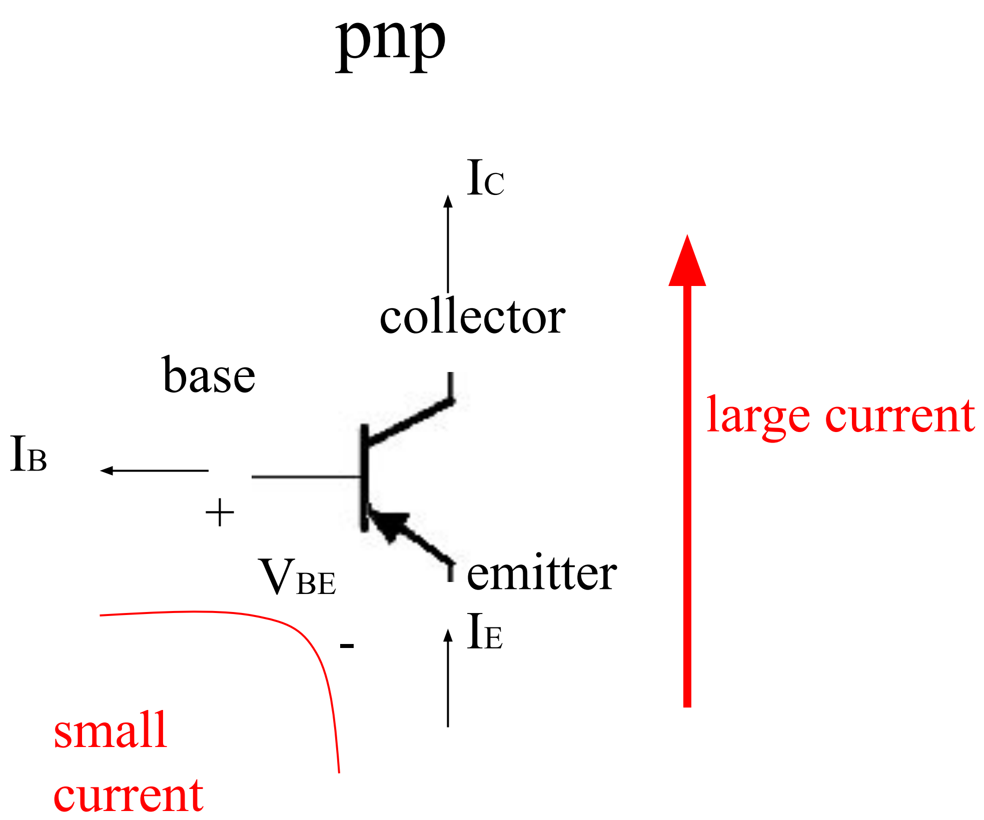
Modes of operation of a BJT transistor

Mode	**BE junction**	**BC junction**
cutoff	reverse biased	reverse biased
linear(active)	**forward biased**	**reverse biased**
saturation	forward biased	forward biased

Summary of *npn* transistor behavior



Summary of pnp transistor behavior



Summary of equations for a BJT

$I_E \approx I_C$

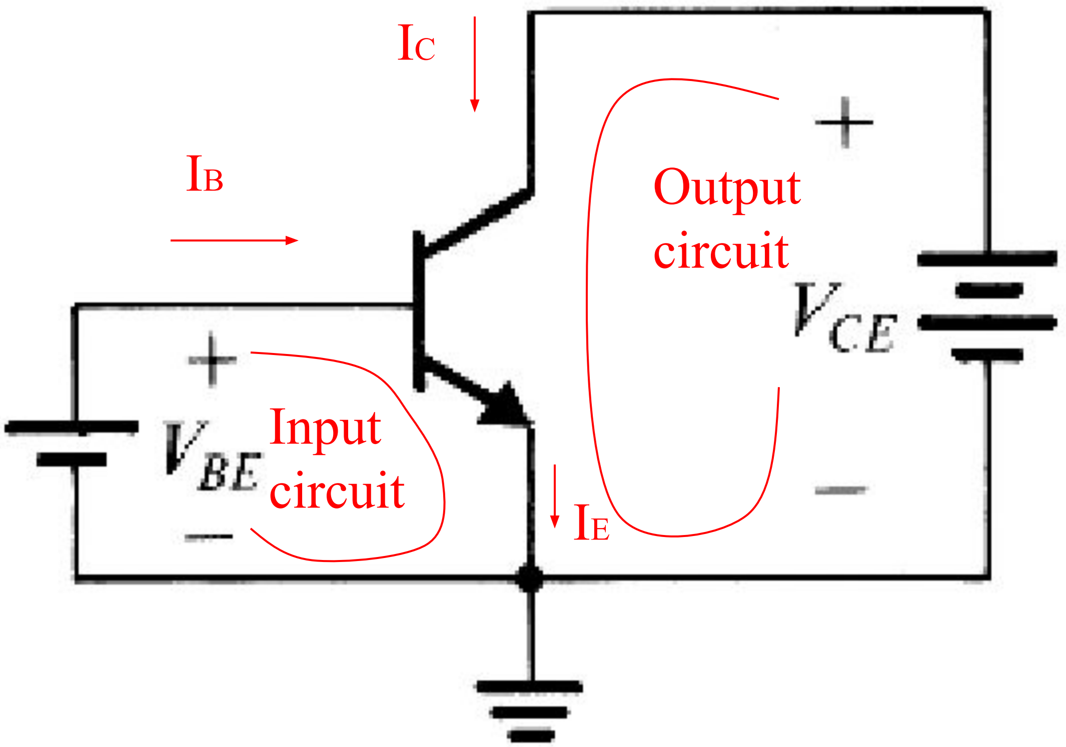
$I_C = \beta I_B$

β is the current gain of the transistor ≈ 100

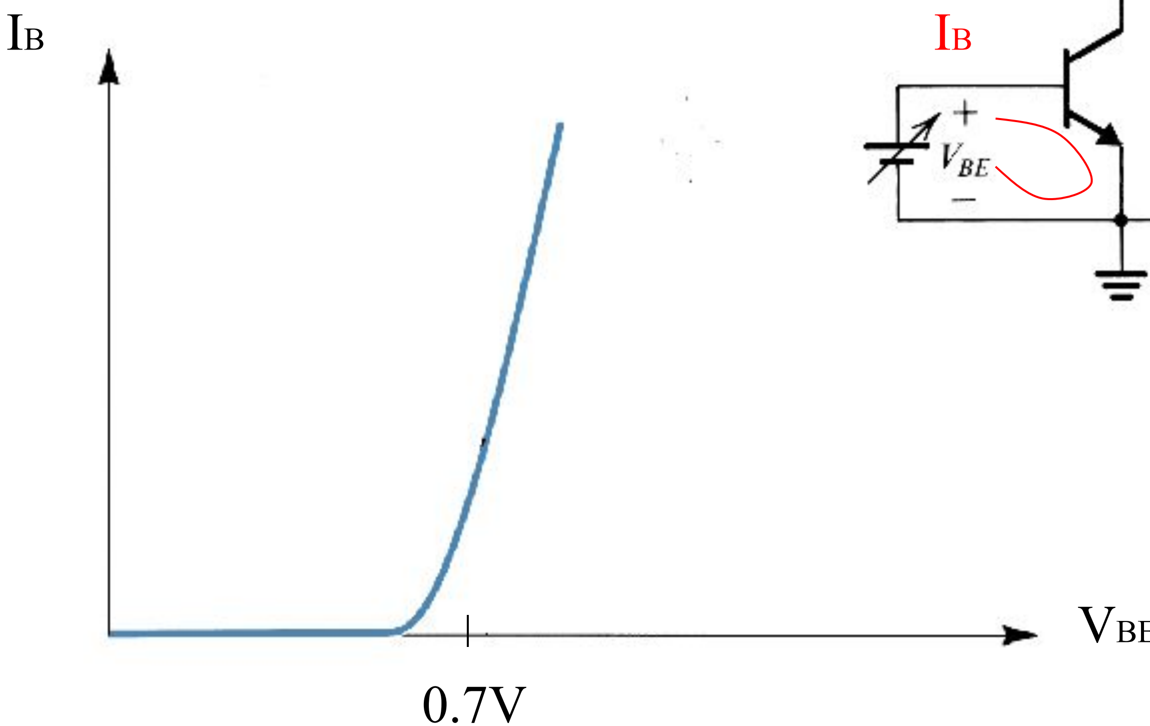
$V_{BE} = 0.7V$(npn)

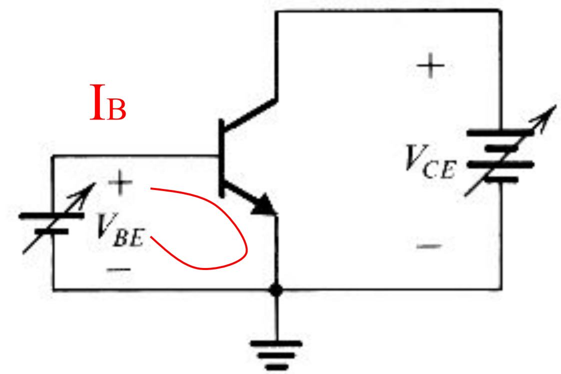
$V_{BE} = -0.7V$(pnp)

Graphical representation of transistor characteristics



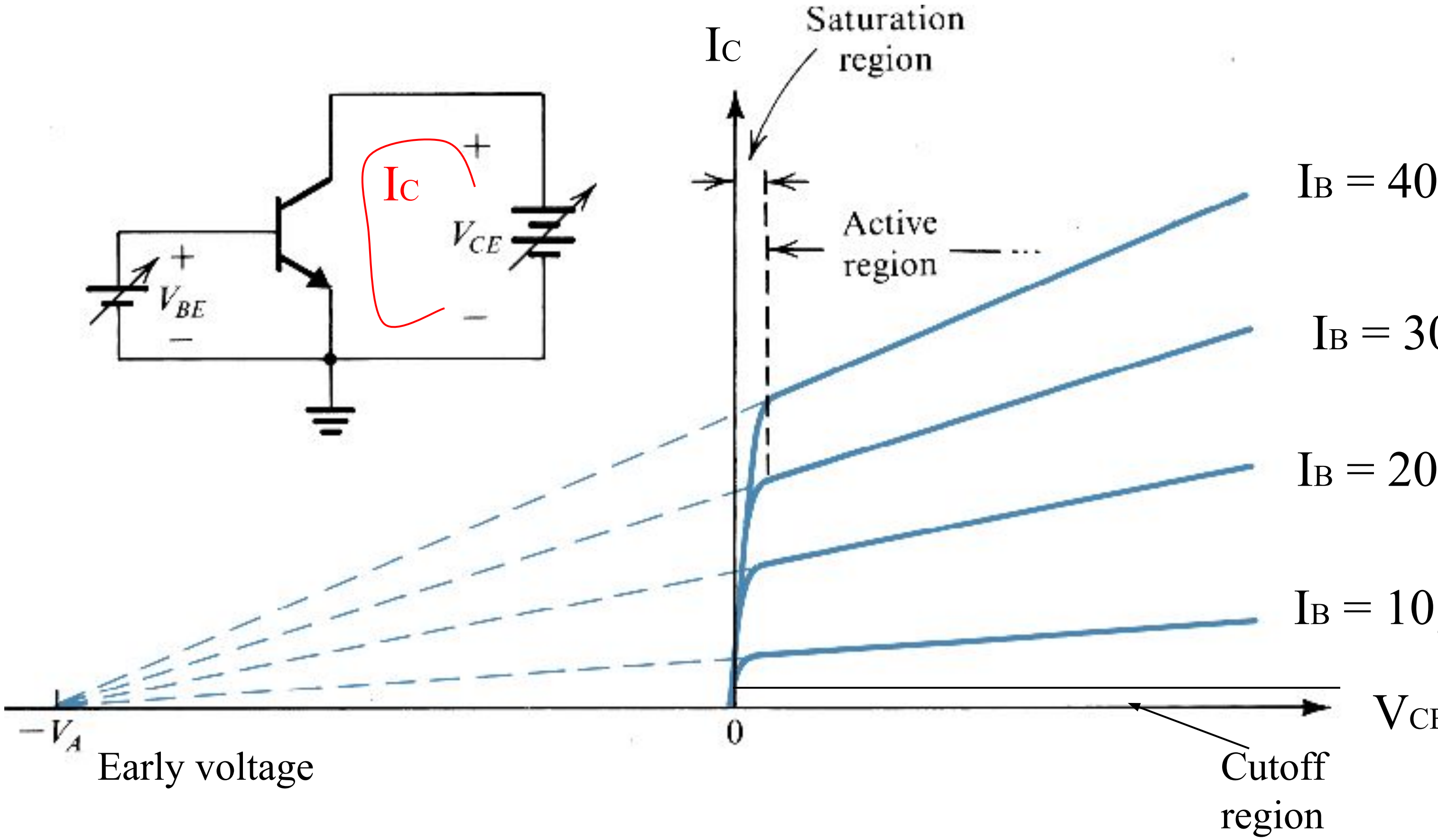
Input characteristics





- Acts as a diode
- $V_{BE} \approx 0.7V$

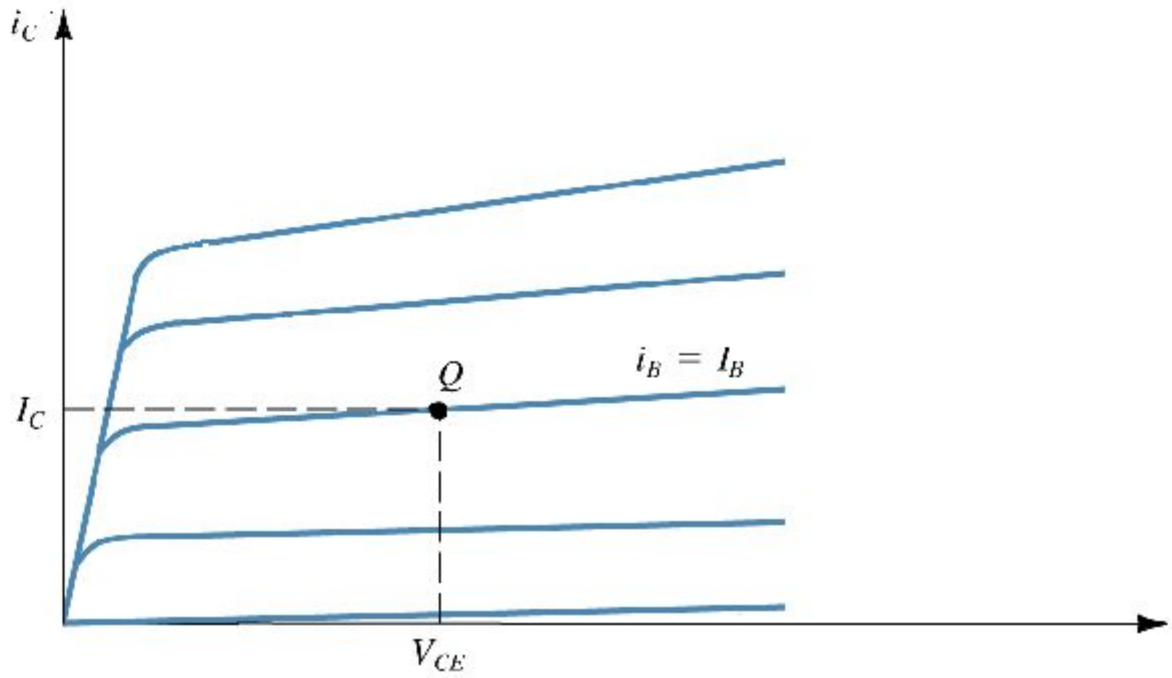
Output characteristics



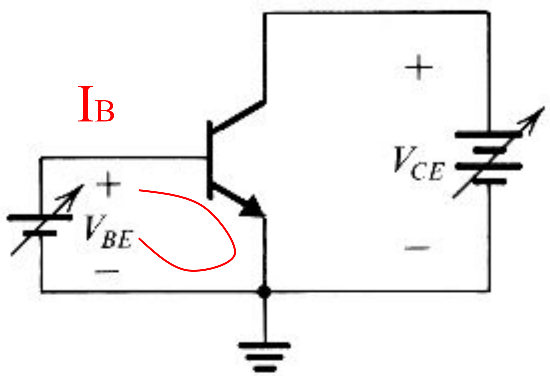
- At a fixed I_B, I_C is not dependent on V_{CE}
- Slope of output characteristics in linear region is near 0 (scale exaggerated)

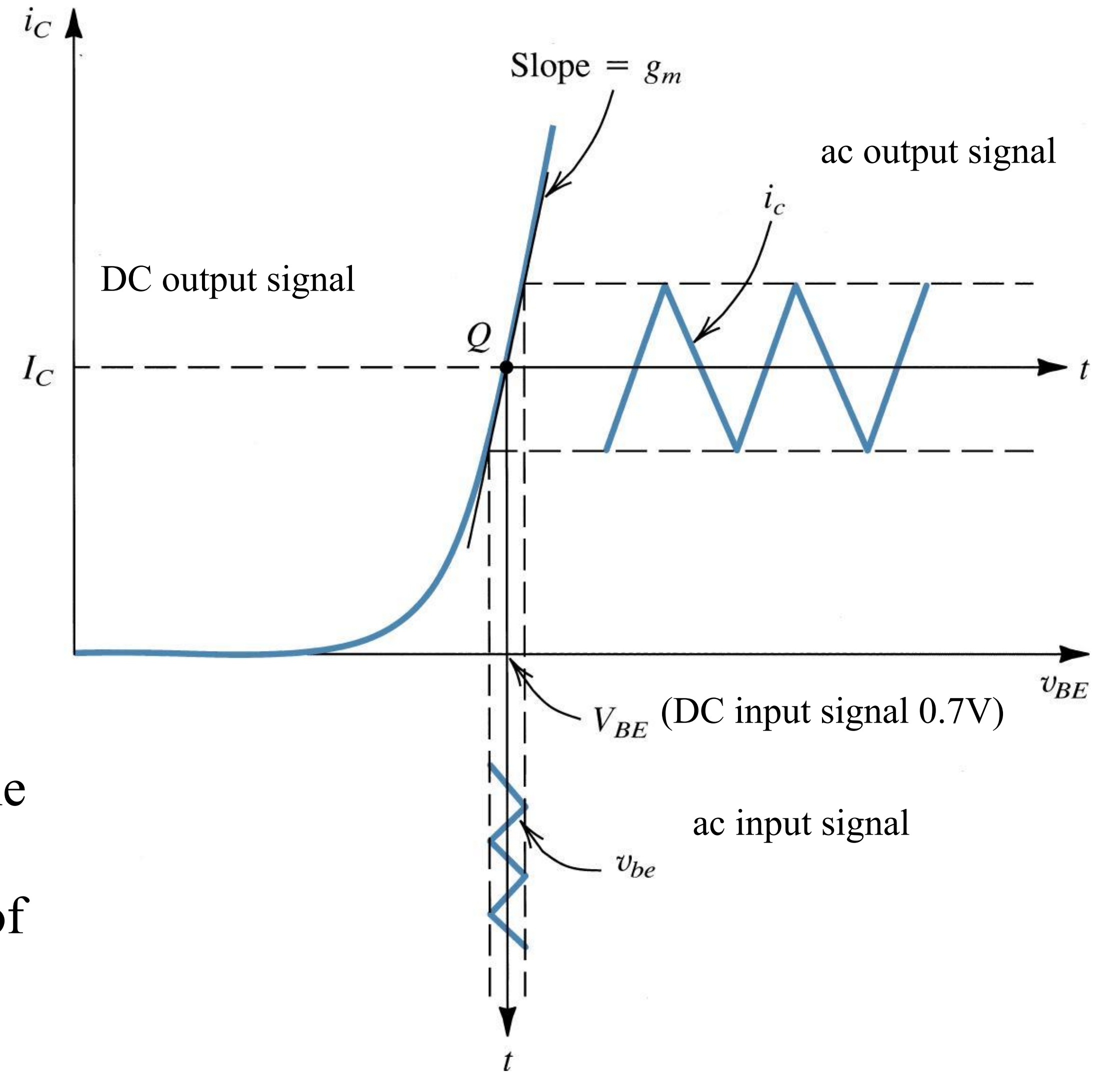
Biasing a transistor

- We must operate the transistor in the linear region.
- A transistor's operating point (Q-point) is defined by I_C, V_{CE}, and I_B.



Transconductance



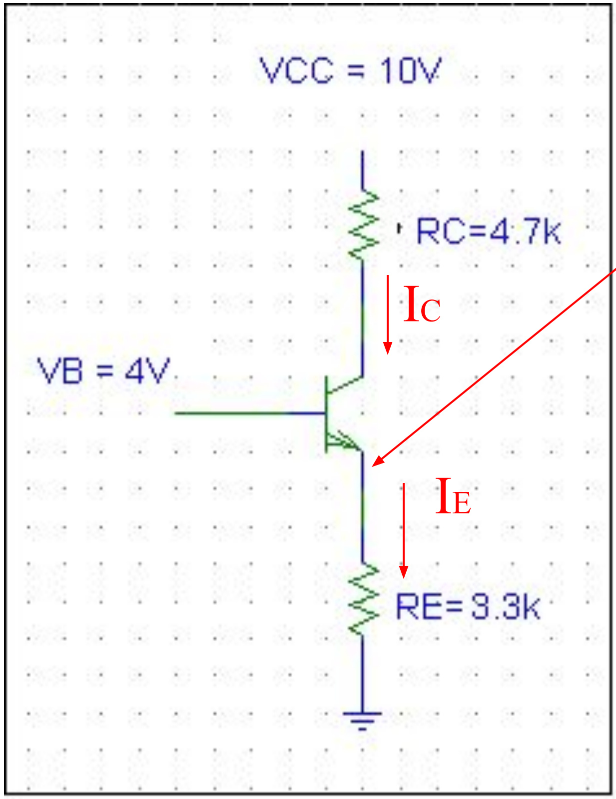


A small ac signal v_{be} is superimposed on the DC voltage V_{BE}. It gives rise to a collector signal current i_c, superimposed on the dc current I_C.

The slope of the i_c - v_{BE} curve at the bias point Q is the transconductance g_m: the amount of ac current produced by an ac voltage.

Analysis of transistor circuits at DC

For all circuits: assume transistor operates in linear region
write B-E voltage loop
write C-E voltage loop



Example -1

B-E junction acts like a diode

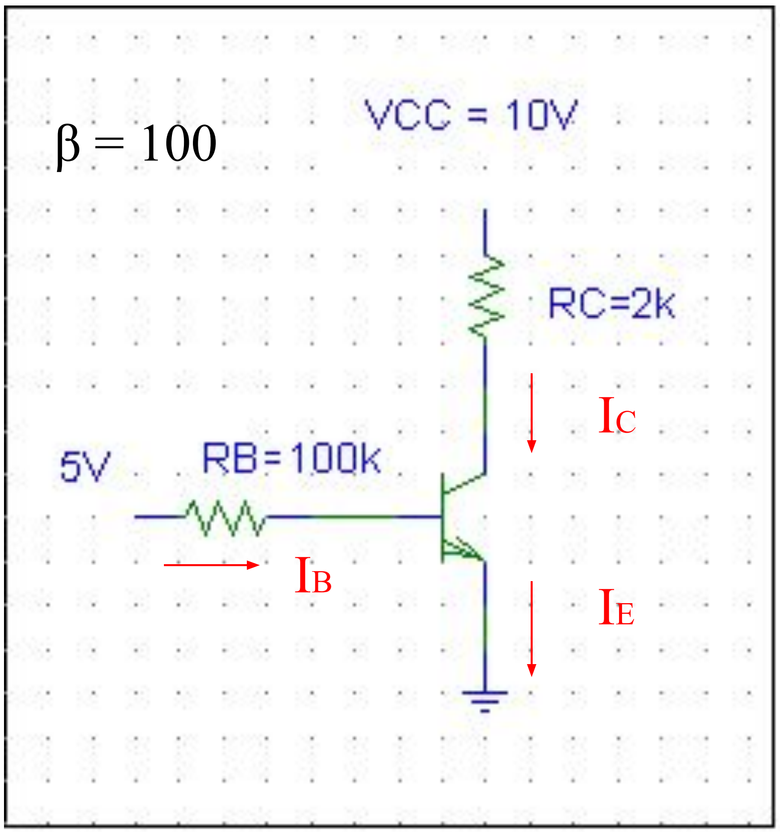
$V_E = V_B - V_{BE} = 4V - 0.7V = 3.3V$

$I_E = (V_E - 0)/R_E = 3.3/3.3K = 1mA$

$I_C \approx I_E = 1mA$

$V_C = 10 - I_C R_C = 10 - 1(4.7) = 5.3V$

Example-2



B-E Voltage loop

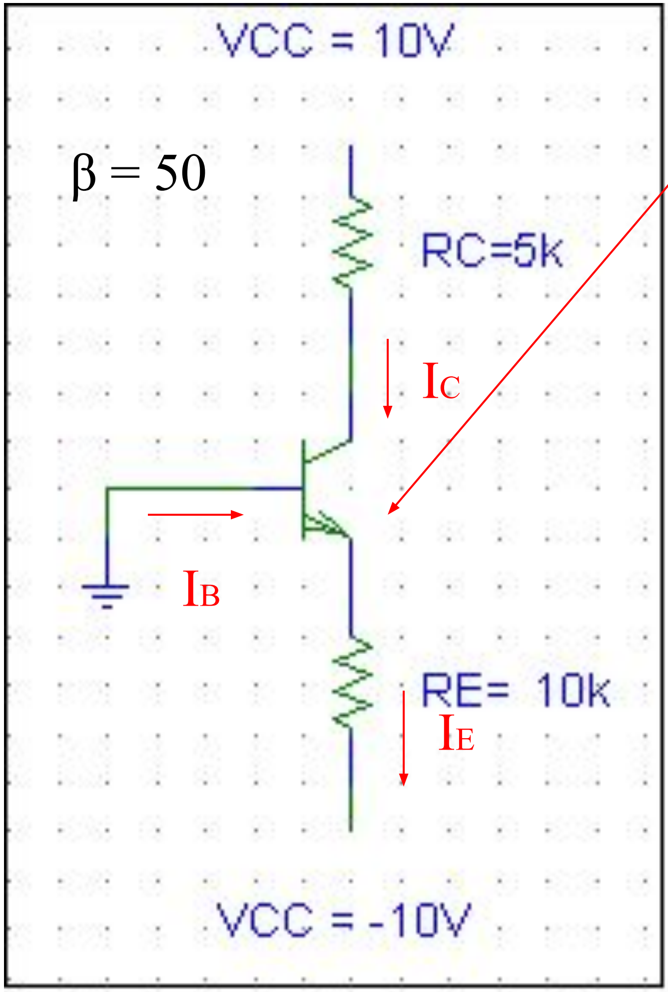
$5 = I_B R_B + V_{BE}$, solve for I_B

$I_B = (5 - V_{BE})/R_B = (5-.7)/100k = 0.043mA$

$I_C = \beta I_B = (100)0.043mA = 4.3mA$

$V_C = 10 - I_C R_C = 10 - 4.3(2) = 1.4V$

Exercise-3



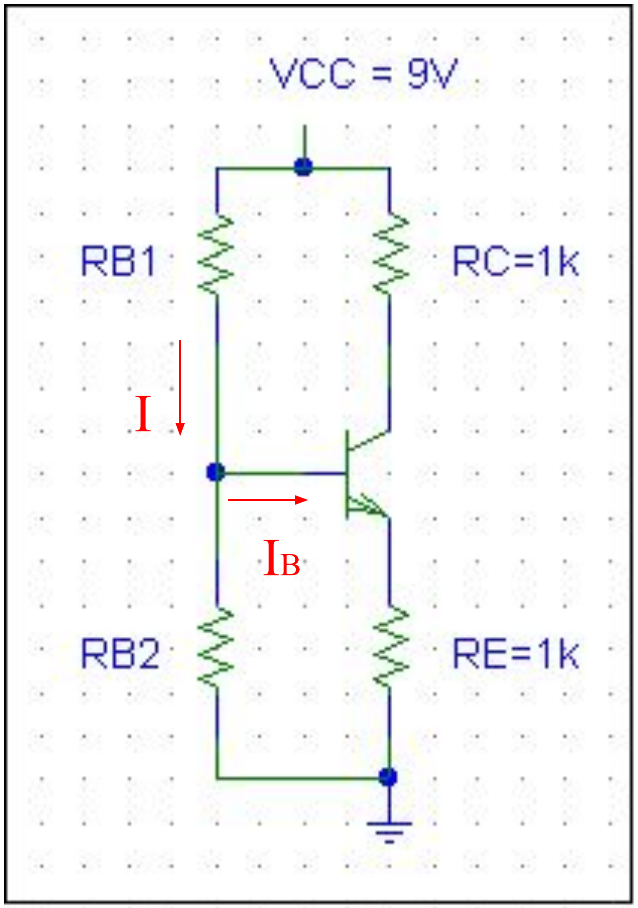
$V_E = 0 - .7 = -0.7V$

$I_E = (V_E - -10)/R_E = (-.7 + 10)/10K =$ 0.93mA

$I_C \approx I_E =$ 0.93mA

$I_B = I_B/\beta = .93mA/50 =$ 18.6μA

$V_C = 10 - I_C R_C = 10 - .93(5) =$ 5.35V



Prob.

- Use a voltage divider, R_{B1} and R_{B2} to bias V_B to avoid two power supplies.
- Make the current in the voltage divider about 10 times I_B to simplify the analysis. Use $V_B = 3V$ and $I = 0.2mA$.

(a) R_{B1} and R_{B2} form a voltage divider.

Assume $I >> I_B$ $I = V_{CC}/(R_{B1} + R_{B2})$

$$.2mA = 9 /(R_{B1} + R_{B2})$$

AND

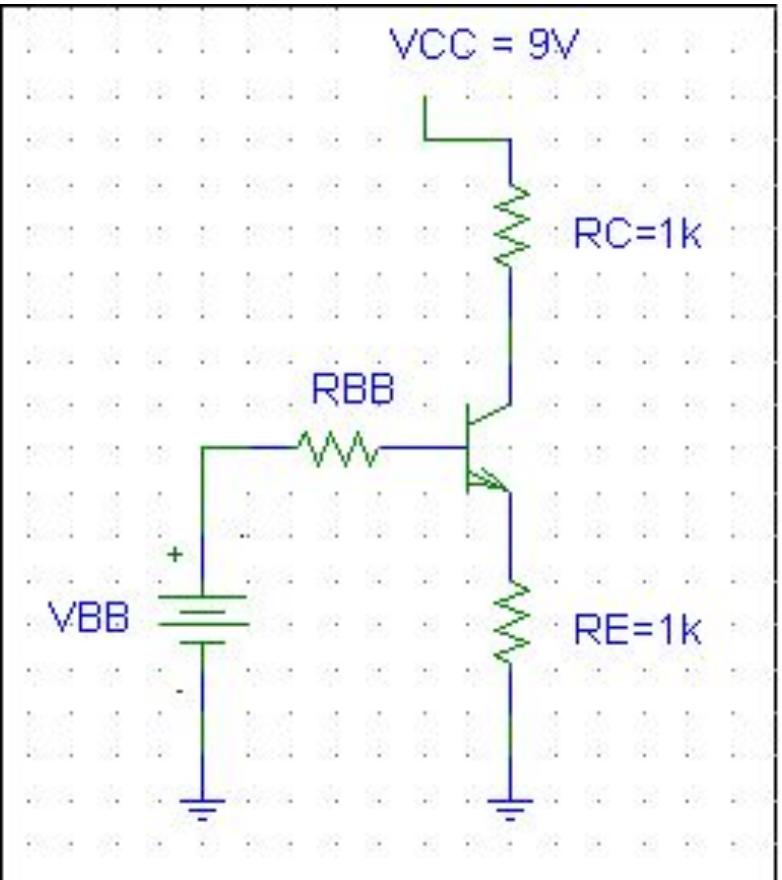
$V_B = V_{CC}[R_{B2}/(R_{B1} + R_{B2})]$

$3 = 9 [R_{B2}/(R_{B1} + R_{B2})]$, Solve for R_{B1} and R_{B2}.

$R_{B1} = 30K\Omega$, and $R_{B2} = 15K\Omega$.

Prob.

Find the operating point



•Use the Thevenin equivalent circuit for the base

•Makes the circuit simpler

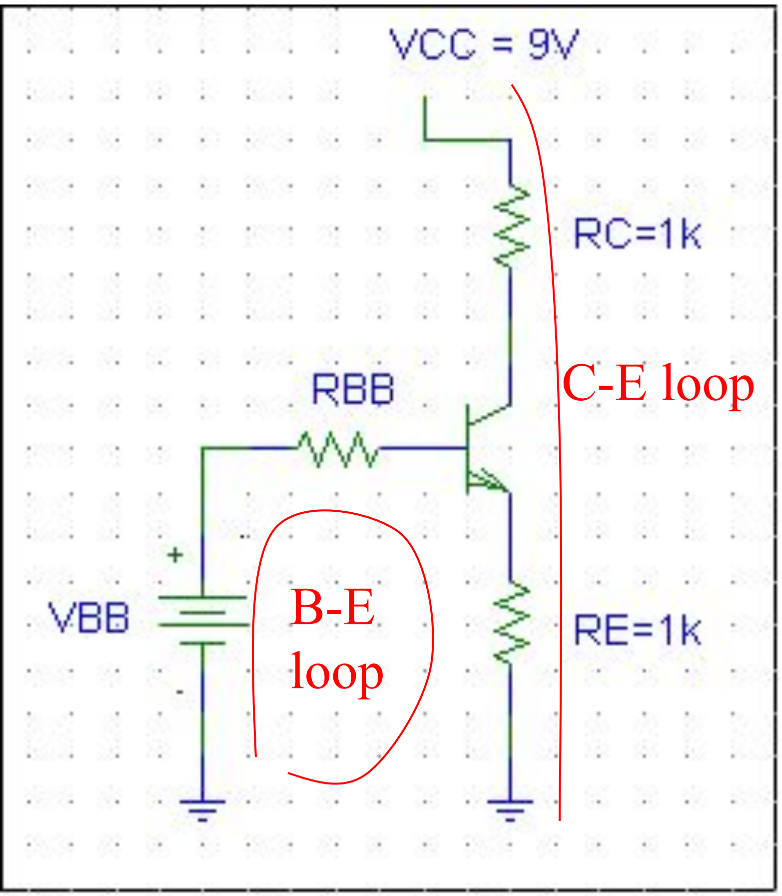
•$V_{BB} = V_B = 3V$

•R_{BB} is measured with voltage sources grounded

•$R_{BB} = R_{B1} \| R_{B2} = 30K\Omega \| 15K\Omega = 10K\Omega$

Prob.

Write B-E loop and C-E loop



B-E loop

$V_{BB} = I_B R_{BB} + V_{BE} + I_E R_E$

$I_E = 2.09$ mA

C-E loop

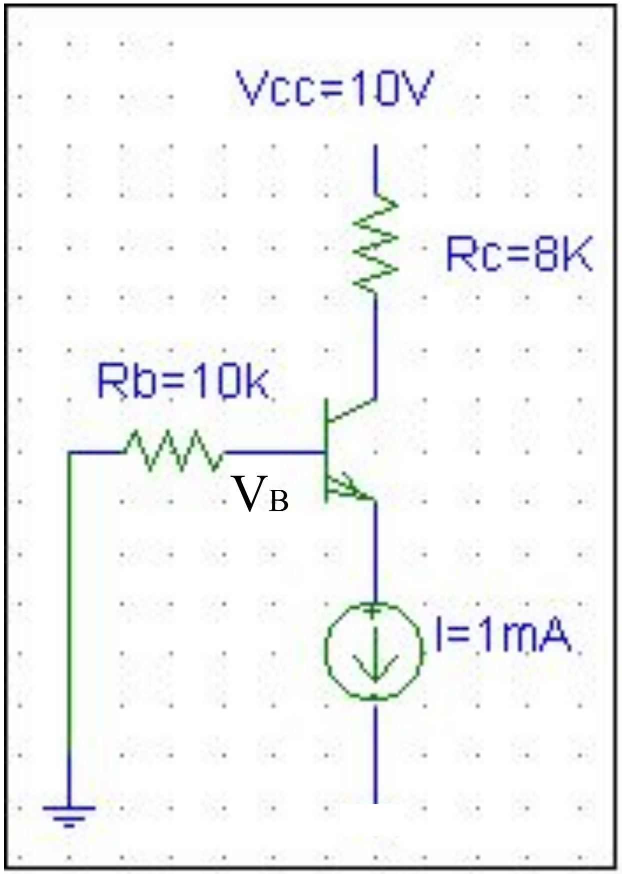
$V_{CC} = I_C R_C + V_{CE} + I_E R_E$

$V_{CE} = 4.8$ V

This is how all DC circuits are analyzed and designed!

Exercise-4

(a) Find V_C, V_B, and V_E, given: $\beta = 100$, $V_A = 100V$



$I_E = 1\ mA$

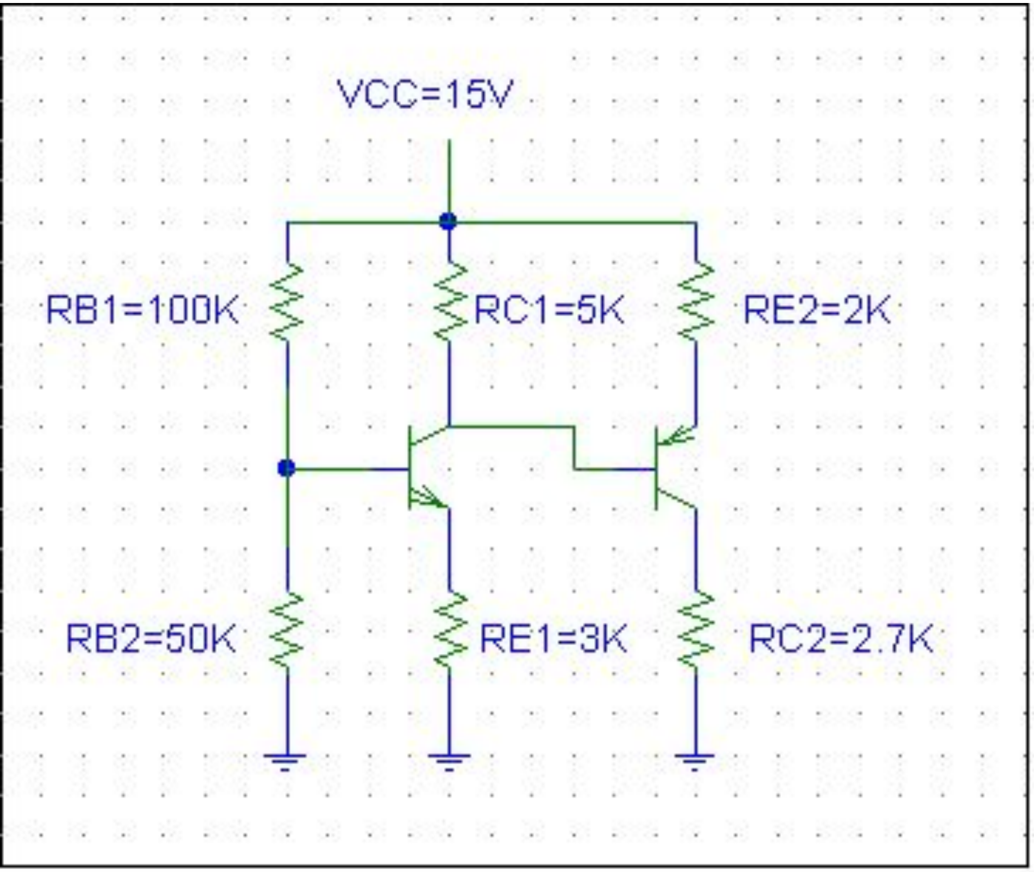
$I_B \approx I_E/\beta = 0.01mA$

$V_B = 0 - I_B 10K = -0.1V$

$V_E = V_B - V_{BE} = -0.1 - 0.7 = -0.8V$

$V_C = 10V - I_C 8K = 10 - 1(8) = 2V$

Example-5



- 2-stage amplifier, 1st stage has an npn transistor; 2nd stage has an pnp transistor.

$I_C = \beta I_B$

$I_C \approx I_E$

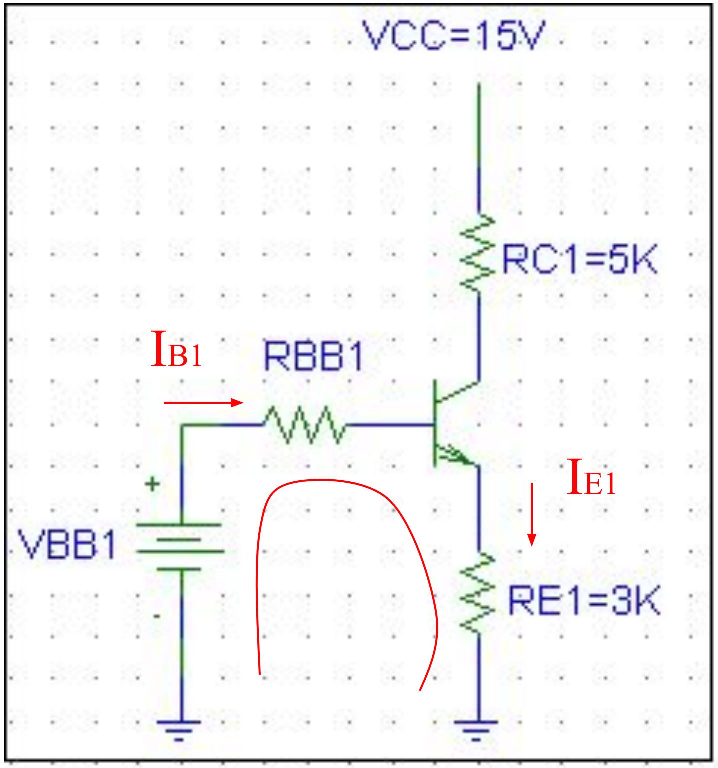
$V_{BE} = 0.7_{(npn)} = -0.7_{(pnp)}$

$\beta = 100$

Find I_{C1}, I_{C2}, V_{CE1}, V_{CE2}

- Use Thevenin circuits.

Example -5



- $R_{BB1} = R_{B1} || R_{B2} = 33K$
- $V_{BB1} = V_{CC}[R_{B2}/(R_{B1}+R_{B2})]$

$V_{BB1} = 15[50K/150K] = 5V$

Stage 1

- B-E loop

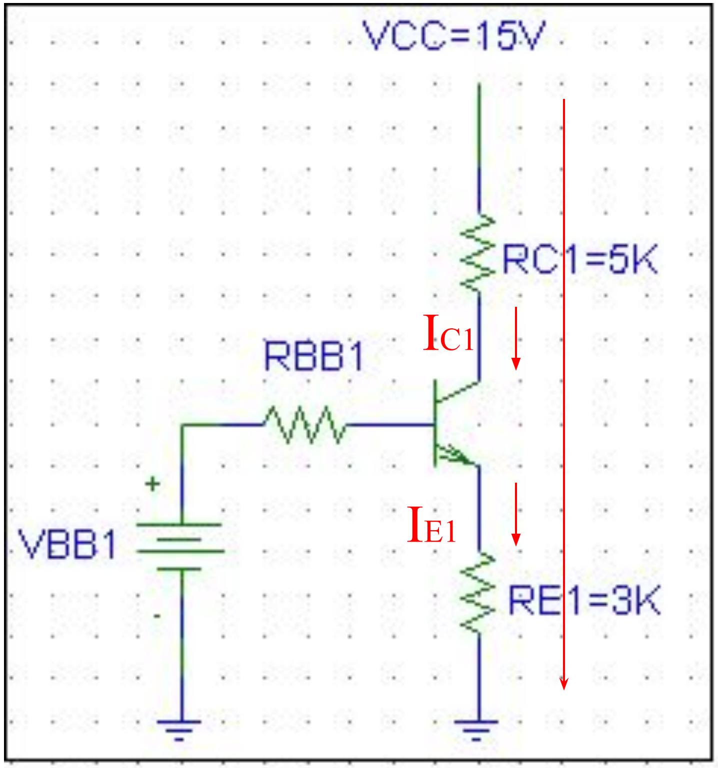
$V_{BB1} = I_{B1}R_{BB1} + V_{BE} + I_{E1}R_{E1}$

Use $I_{B1} \approx I_{E1}/ \beta$

$5 = I_{E1}33K / 100 + .7 + I_{E1}3K$

$I_{E1} = 1.3mA$

Example -5



C-E loop

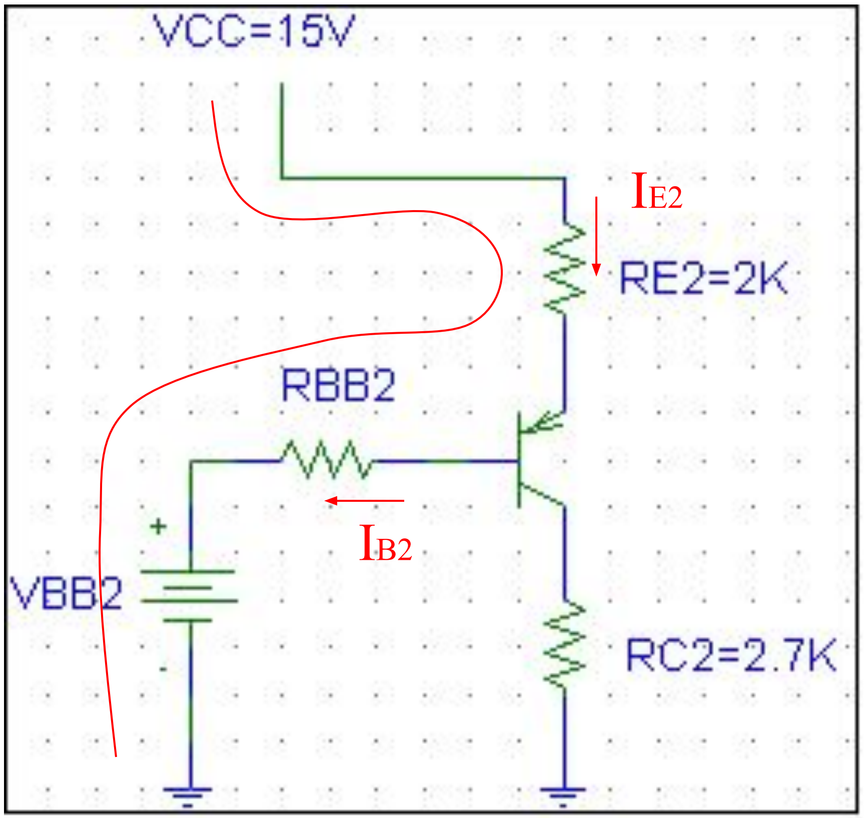
neglect IB2 because it is IB2 << IC1

$$V_{CC} = I_{C1}R_{C1} + V_{CE1} + I_{E1}R_{E1}$$

$$15 = 1.3(5) + V_{CE1} + 1.3(3)$$

$V_{CE1} = 4.87V$

Example-5



Stage 2

- B-E loop

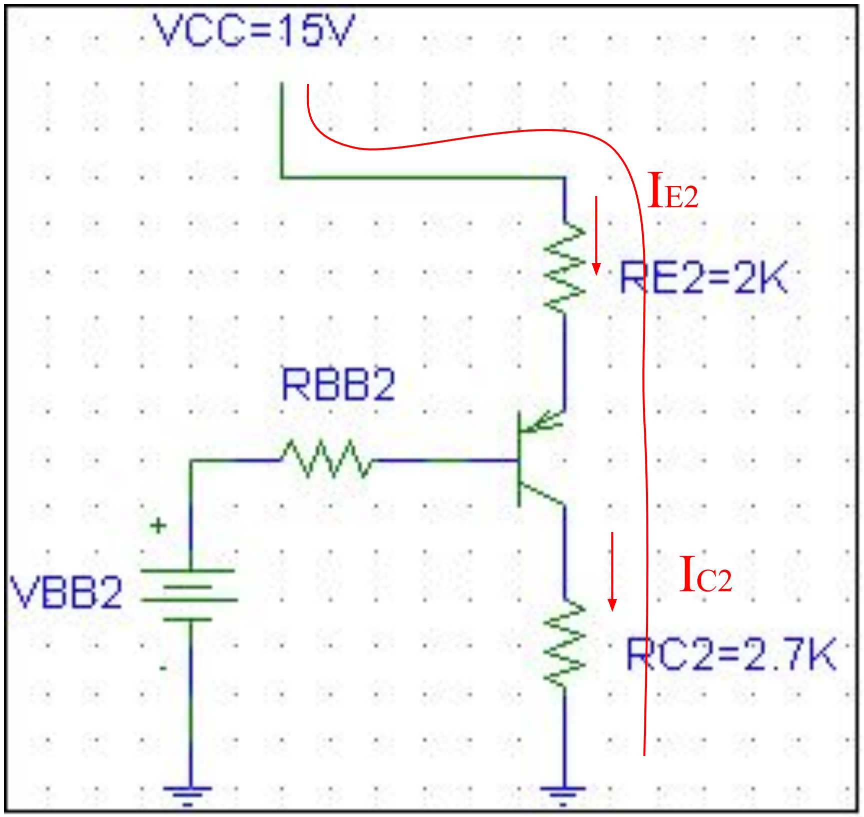
$V_{CC} = I_{E2}R_{E2} + V_{EB} + I_{B2}R_{BB2} + V_{BB2}$

$15 = I_{E2}(2K) + .7 + I_{B2}(5K) + 4.87 + 1.3(3)$

Use $I_{B2} \approx I_{E2}/\beta$, solve for I_{E2}

$I_{E2} = 2.8mA$

Example-5



Stage 2

- C-E loop

$$V_{CC} = I_{E2}R_{E2} + V_{EC2} + I_{C2}R_{C2}$$

$$15 = 2.8(2) + V_{EC2} + 2.8\,(2.7)$$

solve for V_{EC2}

$V_{CE2} = 1.84V$

Summary of DC problem

- Bias transistors so that they operate in the linear region B-E junction forward biased, C-E junction reversed biased

- Use $V_{BE} = 0.7$ (npn), $I_C \approx I_E$, $I_C = \beta I_B$

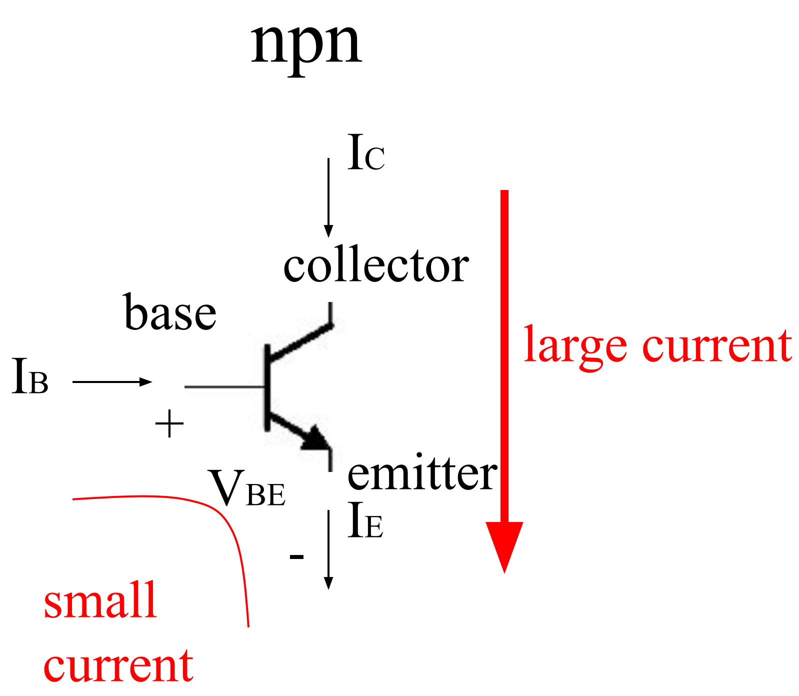
- Represent base portion of circuit by the Thevenin circuit

- Write B-E, and C-E voltage loops.

- For analysis, solve for I_C, and V_{CE}.

- For design, solve for resistor values (I_C and V_{CE} specified).

Summary of npn transistor behavior



Transistor as an amplifier

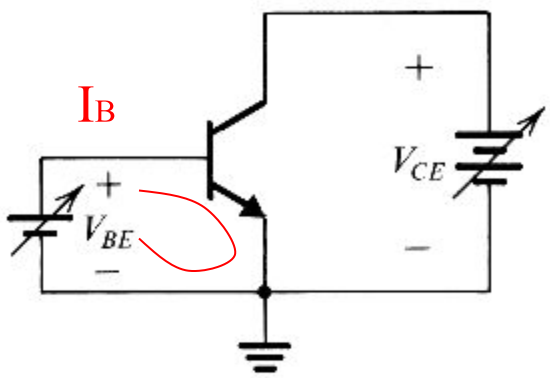
- Transistor circuits are analyzed and designed in terms of DC and ac versions of the same circuit.

- An ac signal is usually superimposed on the DC circuit.

- The location of the operating point (values of I_C and V_{CE}) of the transistor affects the ac operation of the circuit.

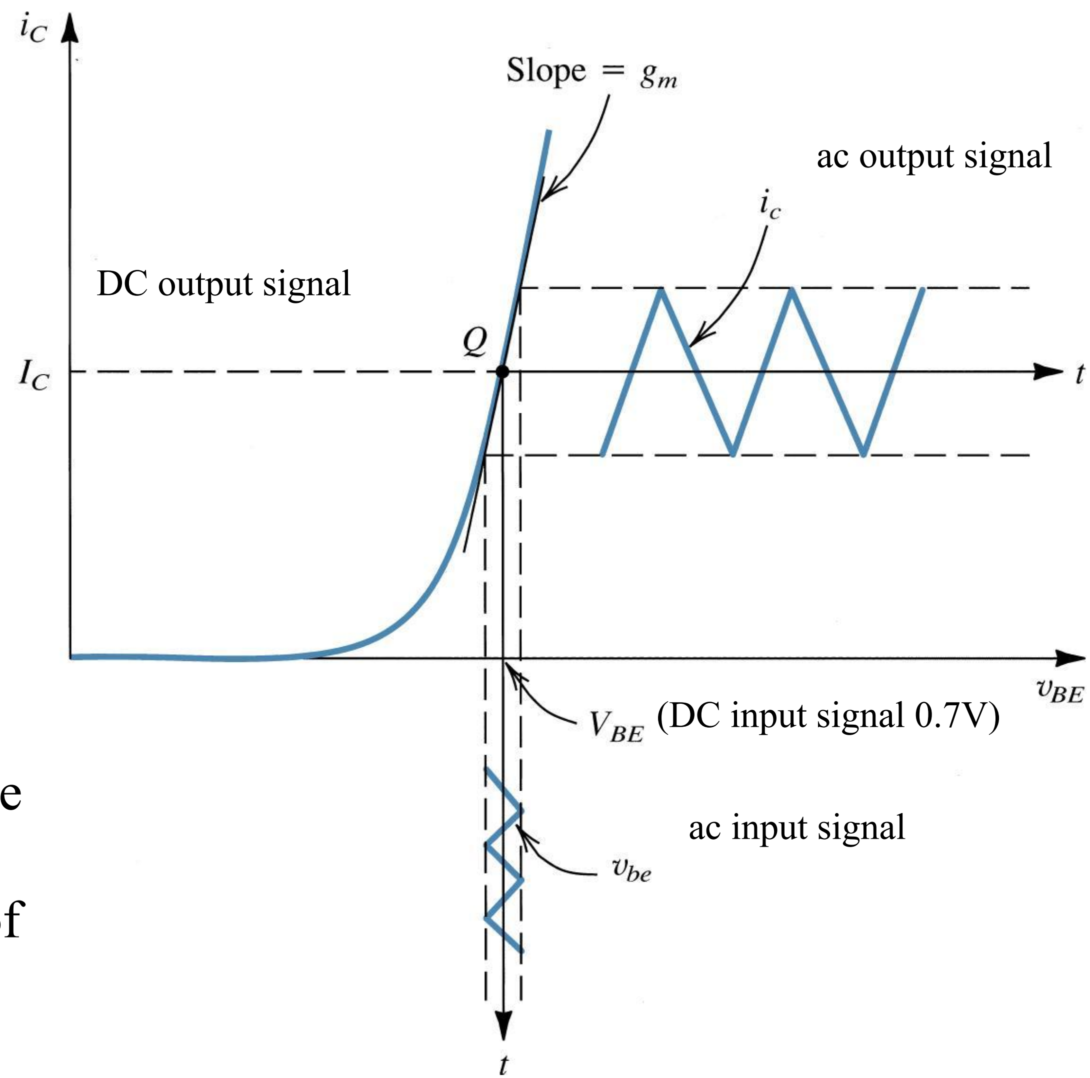
- There are at least two ac parameters determined from DC quantities.

Transconductance



A small ac signal v_{be} is superimposed on the DC voltage V_{BE}. It gives rise to a collector signal current i_c, superimposed on the dc current I_C.

The slope of the i_c - v_{BE} curve at the bias point Q is the transconductance g_m: the amount of ac current produced by an ac voltage.



Transconductance

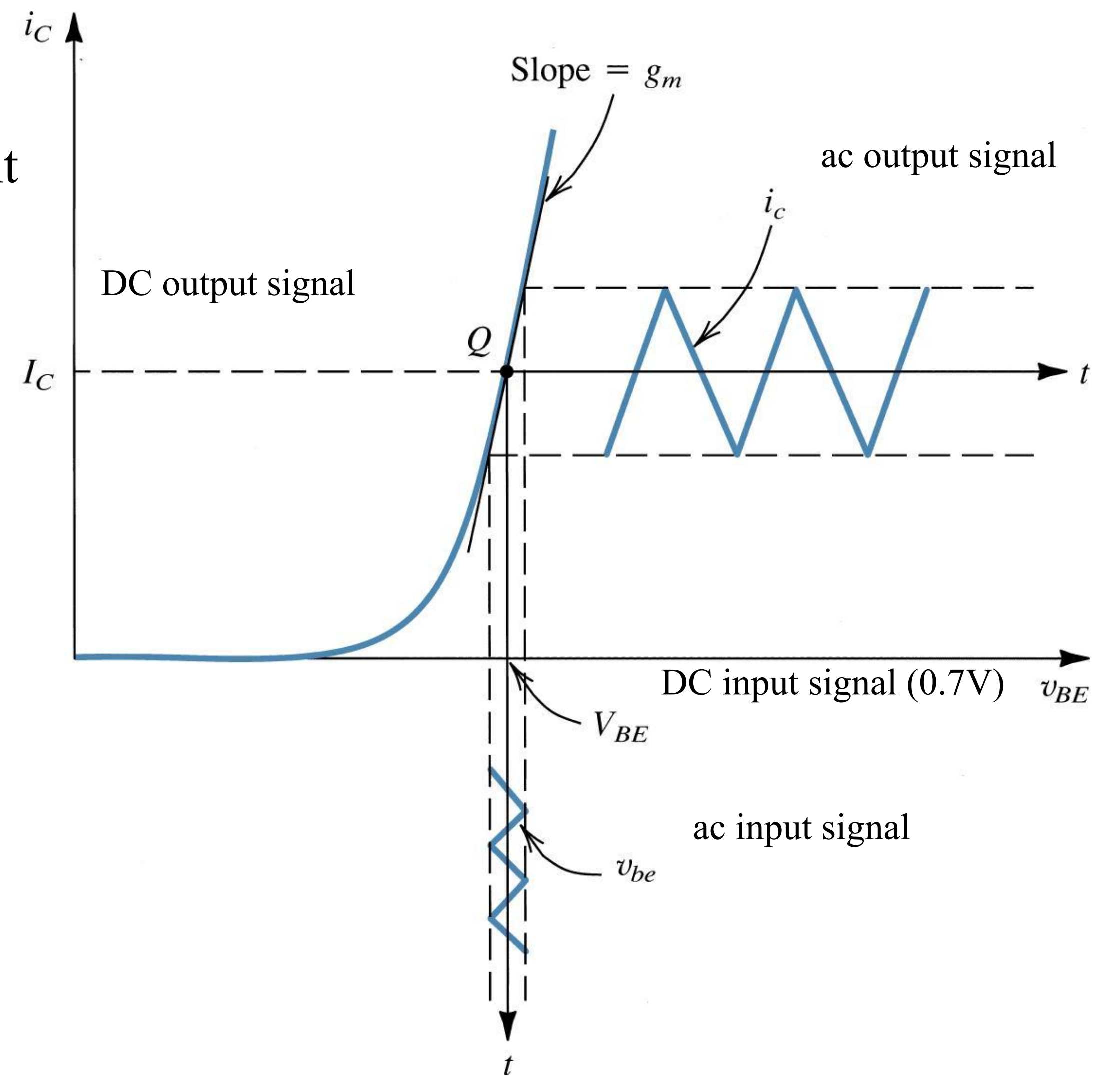
Transconductance = slope at Q point

$g_m = di_c/dv_{BE}|_{ic = ICQ}$

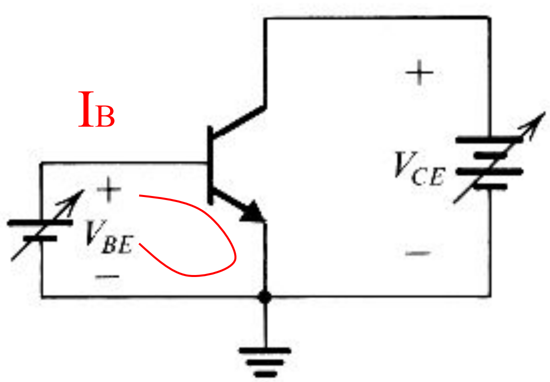
where $I_C = I_S[\exp(-V_{BE}/V_T)-1]$; the equation for a diode.

$g_m = I_S \exp(-V_{BE}/V_T)\,(1/V_T)$

$g_m \approx I_C/V_T$ (A/V)



ac input resistance of transistor

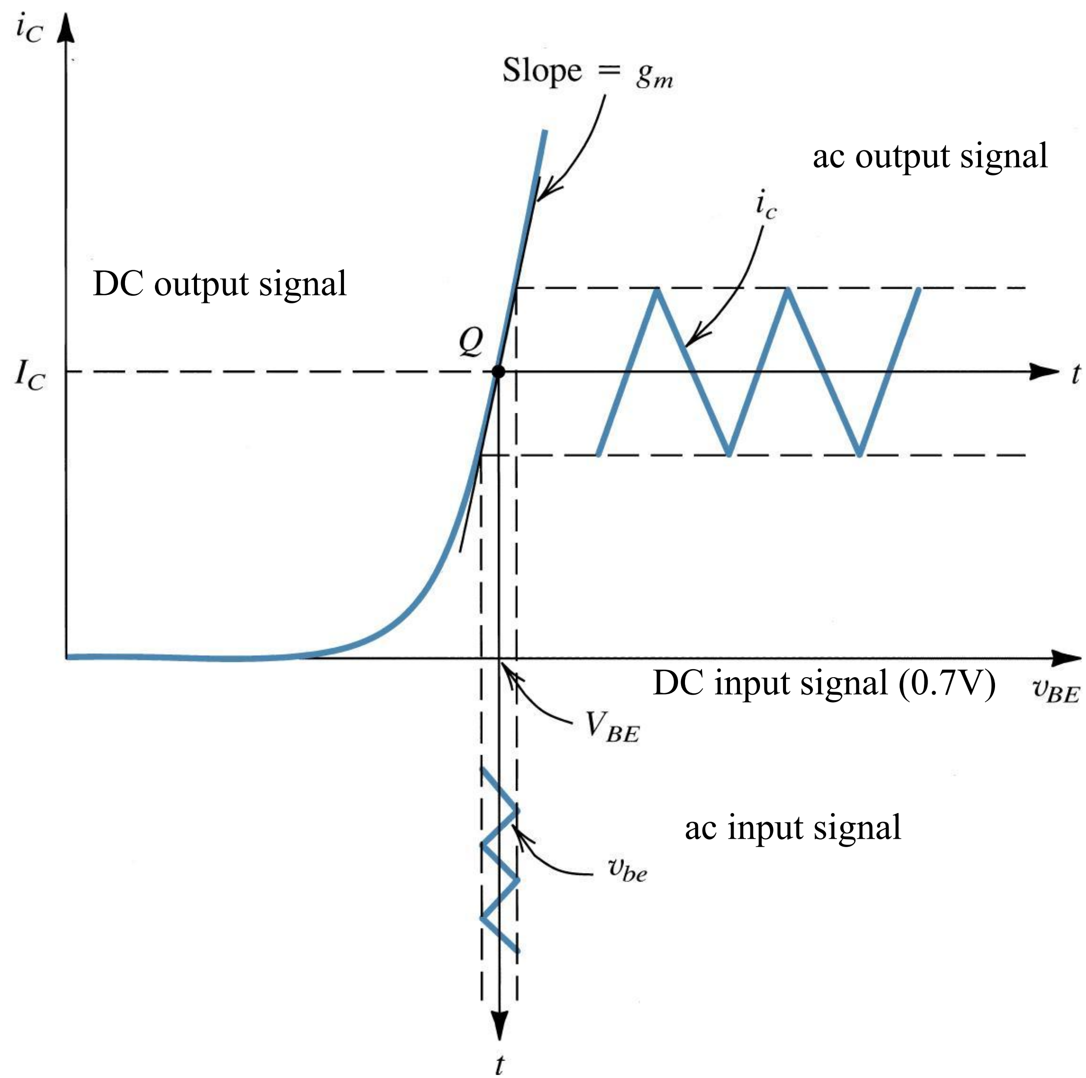


ac input resistance ∝ 1/slope at Q point

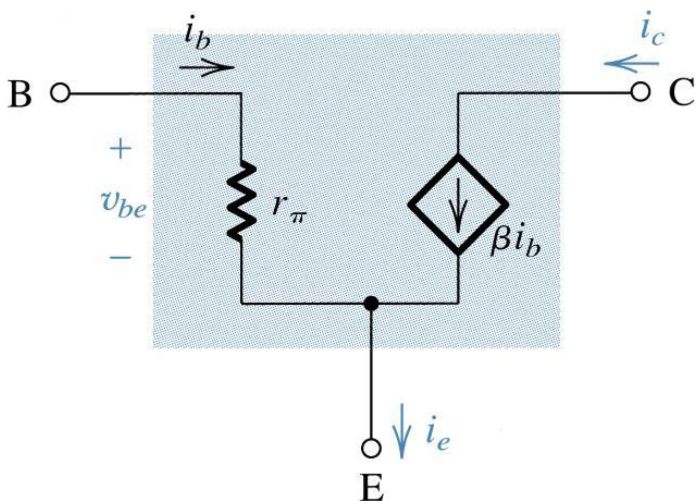
$r_\pi = dv_{BE}/di_b|_{i_c = I_{CQ}}$

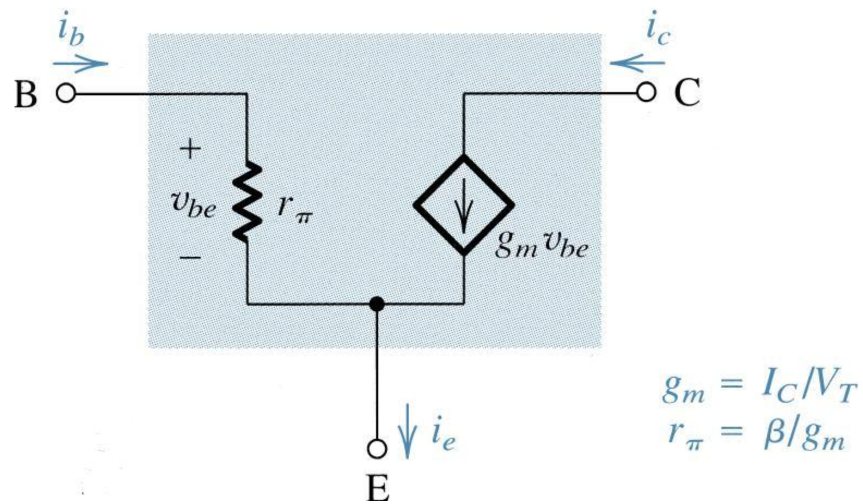
$r_\pi \approx V_T / I_B$

$r_e \approx V_T / I_E$



Small-signal equivalent circuit models





- ac model
- Hybrid-π model
- They are equivalent
- Works in linear region only

Steps to analyze a transistor circuit

1 DC problem

Set ac sources to zero, solve for DC quantities, I_C and V_{CE}.

2 Determine ac quantities from DC parameters

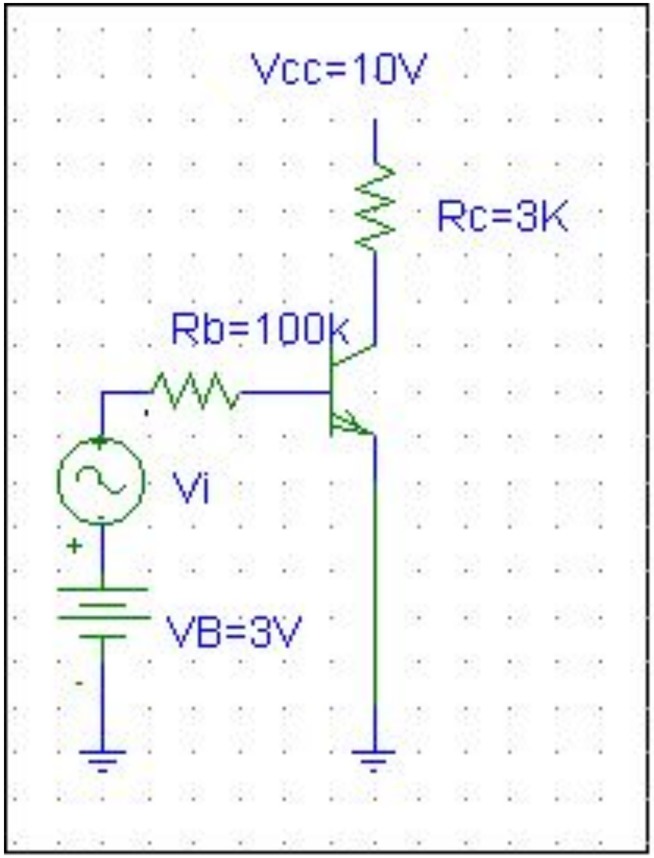
Find g_m, r_π, and r_e.

3 ac problem

Set DC sources to zero, replace transistor by hybrid-π model, find ac quantites, Rin, Rout, Av, and Ai.

Example-6

Find v_{out}/v_{in}, ($\beta = 100$)



DC problem

Short v_i, determine I_C and V_{CE}

B-E voltage loop

$3 = I_B R_B + V_{BE}$

$I_B = (3 - .7)/R_B = 0.023\text{mA}$

C-E voltage loop

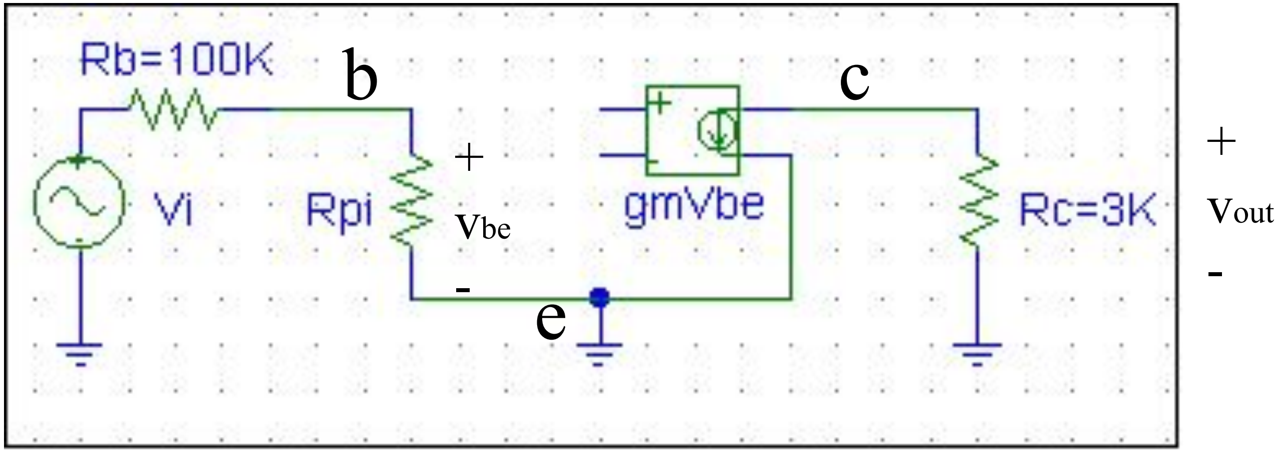
$V_{CE} = 10 - I_C R_C$

$V_{CE} = 10 - (2.3)(3)$

$V_{CE} = 3.1\text{V}$

Q point: $V_{CE} = 3.1\text{V}$, $I_C = 2.3\text{mA}$

Example -6



ac problem

Short DC sources, input and output circuits are separate, only coupled mathematically

$g_m = I_C/V_T = 2.3mA/25mV = 92mA/V$

$r_\pi = V_T/ I_B = 25mV/.023mA = 1.1K$

$v_{be}= v_i\ [r_\pi\ /\ (100K + r_\pi)] = 0.011v_i$

$v_{out} = -\ g_m\ v_{be}R_C$

$v_{out} = -\ 92\,(0.011v_i)3K$

$v_{out}/v_i = -3.04$

Exercise-7

Find g_m, r_π, and r_0, given: $\beta = 100$, $V_A = 100V, I_C = 1\ mA$

$g_m = I_C/V_T = 1\ mA/25mV =$ 40 mA/V

$r_\pi = V_T/\ I_B = 25mV/.01mA =$ 2.5K

$r_0 =$ output resistance of transistor

$r_0 =$ 1/slope of transistor output characteristics

$r_0 = |\ V_A|/I_C =$ 100K

Summary of transistor analysis

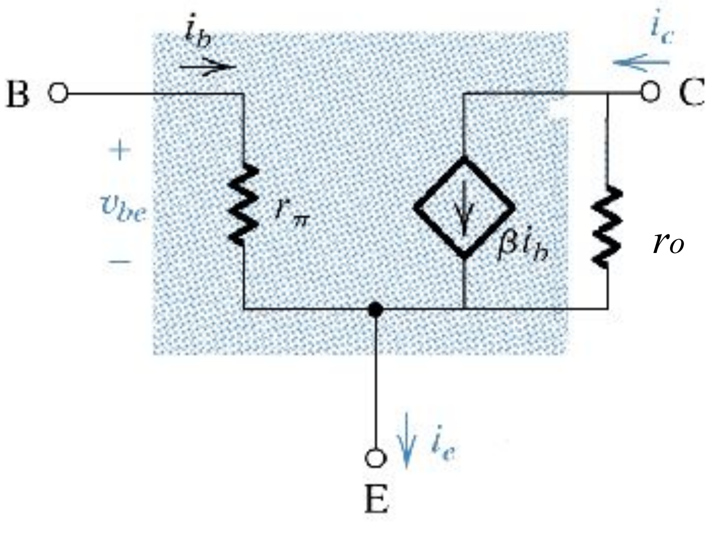
- Transistor circuits are analyzed and designed in terms of DC and ac versions of the same circuit.
- An ac signal is usually superimposed on the DC circuit.
- The location of the operating point (values of I_C and V_{CE}) of the transistor affects the ac operation of the circuit.
- There are at least two ac parameters determined from DC quantities.

Steps to analyze a transistor circuit

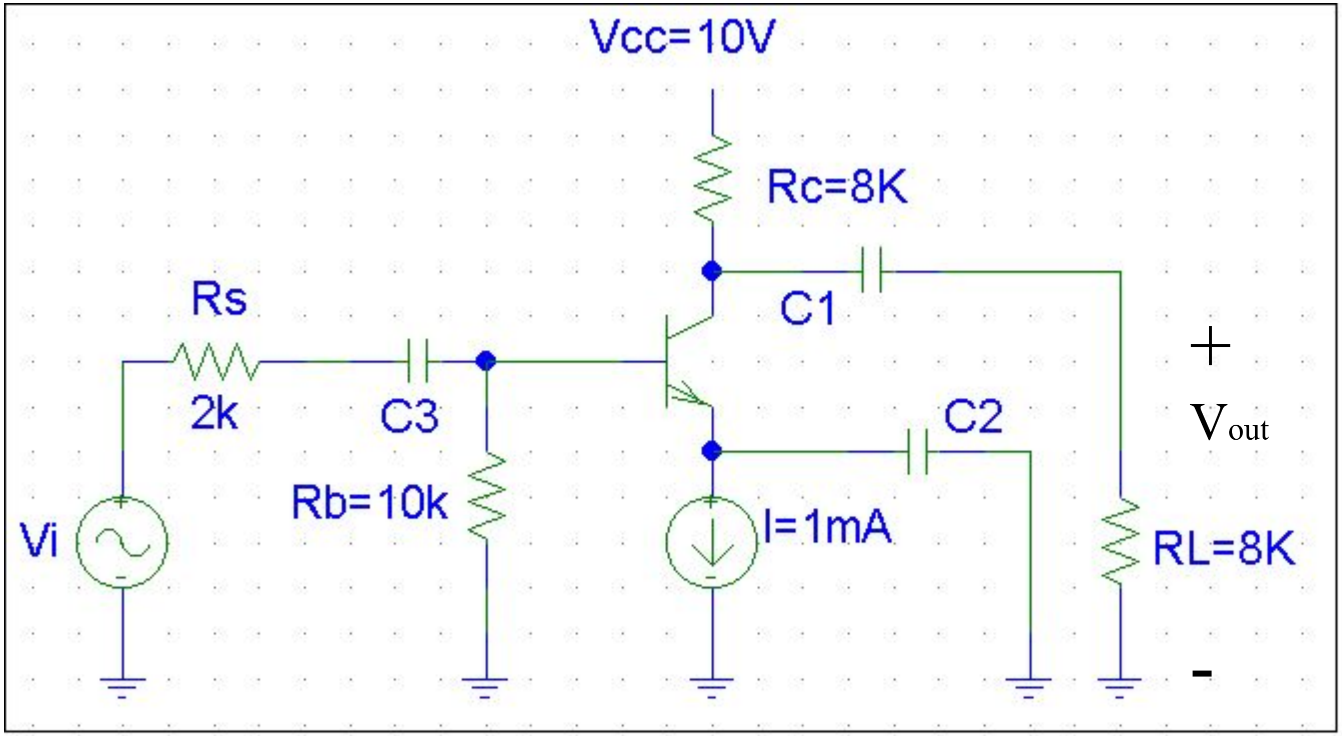
1 DC Analysis Set ac sources to zero, solve for DC quantities, I_C and V_{CE}.

2 Determine ac quantities from DC parameters
Find g_m, r_π, and r_o.

3 AC Analysis
Set DC sources to zero, replace transistor by hybrid-π model, find ac quantities, Rin, Rout, Av, and Ai.



Circuit



$I_E = 1\ mA$

$I_B \approx I_E/\beta = 0.01mA$

$V_B = 0 - I_B 10K = -0.1V$

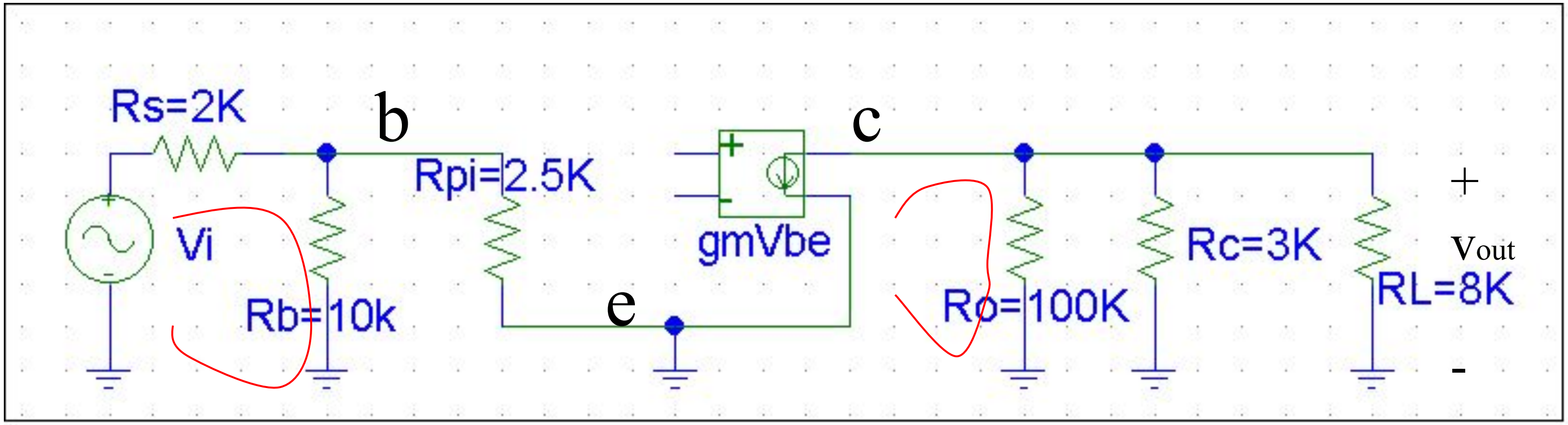
$V_E = V_B - V_{BE} = -0.1 - 0.7 = -0.8V$

$V_C = 10V - I_C 8K = 10 - 1(8) = 2V$

$g_m = I_C/V_T = 1\ mA/25mV = 40\ mA/V$

$r_\pi = V_T/\ I_B = 25mV/.01mA = 2.5K$

ac equivalent circuit



$v_{be} = (R_b||R_{pi})/ [(R_b||R_{pi}) + R_s]v_i$

$v_{be} = 0.5v_i$

$v_{out} = -(g_m v_{be})||(R_o||R_c||R_L)$

$v_{out} = -154v_{be}$

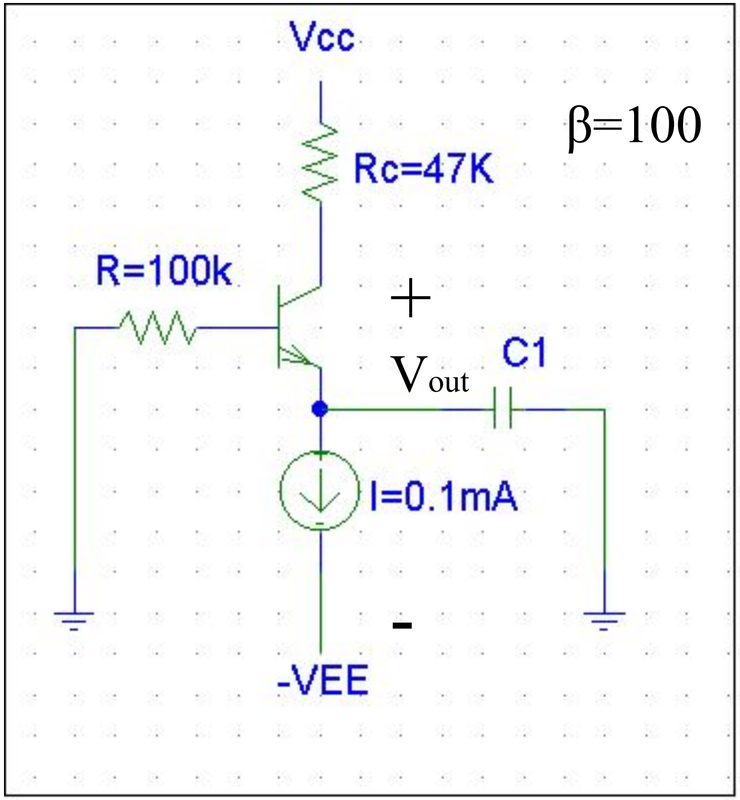
$A_v = v_{out}/v_i = -77$

Neglecting R_o

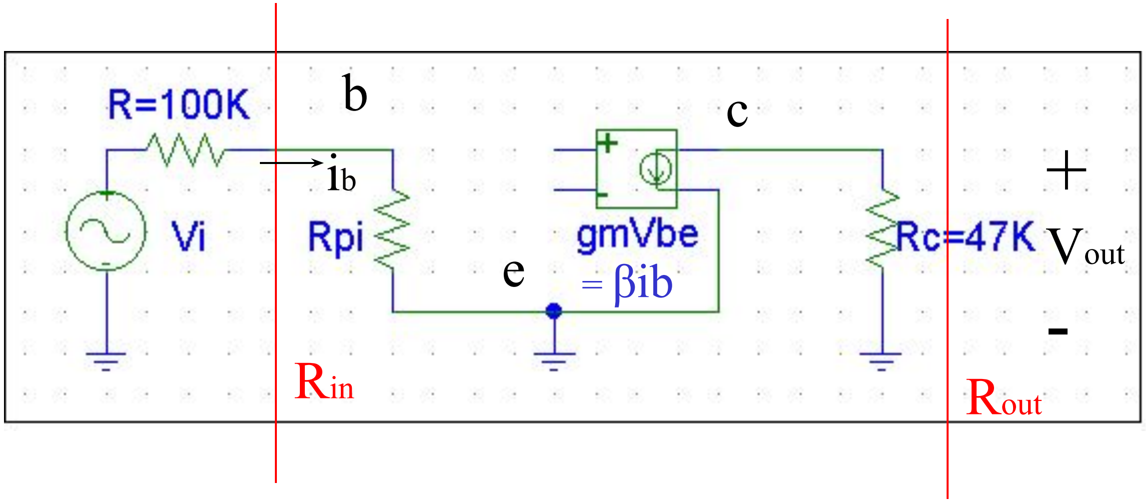
$v_{out} = -(g_m v_{be})||(R_c||R_L)$

$A_v = v_{out}/v_i = -80$

Prob.



Prob.



(a) Find R_{in}

$R_{in} = R_{pi} = V_T/I_B = (25mV)100/.1 = 2.5K\Omega$

(c) Find R_{out}

$R_{out} = R_c = 47K\Omega$

(b) Find $A_v = v_{out}/v_{in}$

$v_{out} = -\beta i_b R_c$

$v_{in} = i_b (R + R_{pi})$

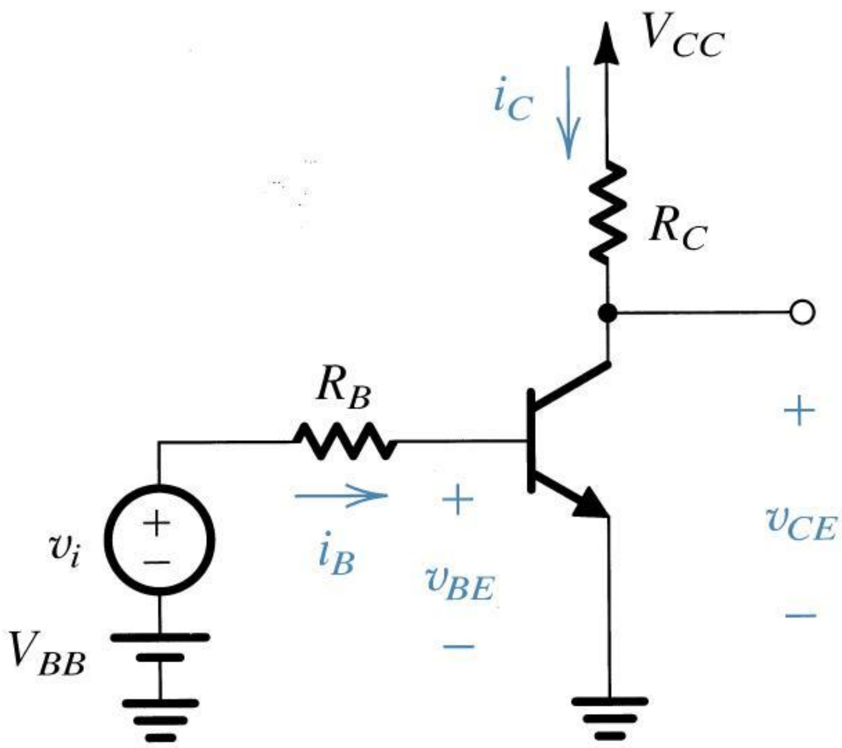
$A_v = v_{out}/v_{in} = -\beta i_b R_c / i_b (R + R_{pi}$

$= -\beta R_c/(R + R_{pi})$

$= -100(47K)/(100K + 2.5K)$

$= -37.6$

Graphical analysis



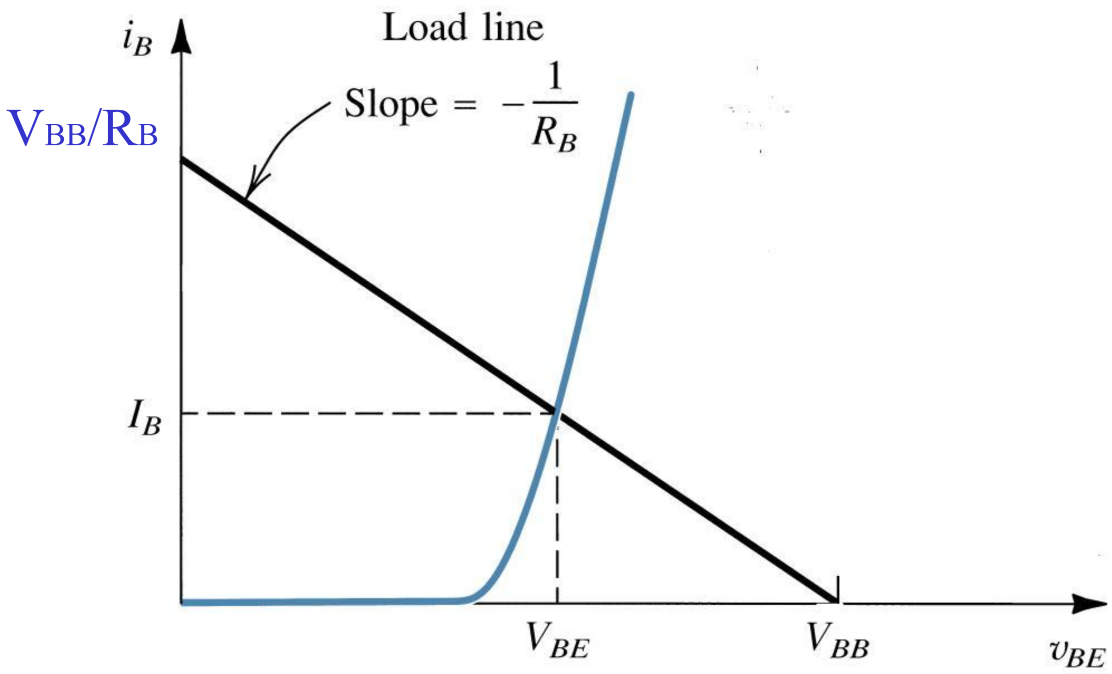
Input circuit

B-E voltage loop

$V_{BB} = I_B R_B + V_{BE}$

$I_B = (V_{BB} - V_{BE})/R_B$

Graphical construction of I_B and V_{BE}

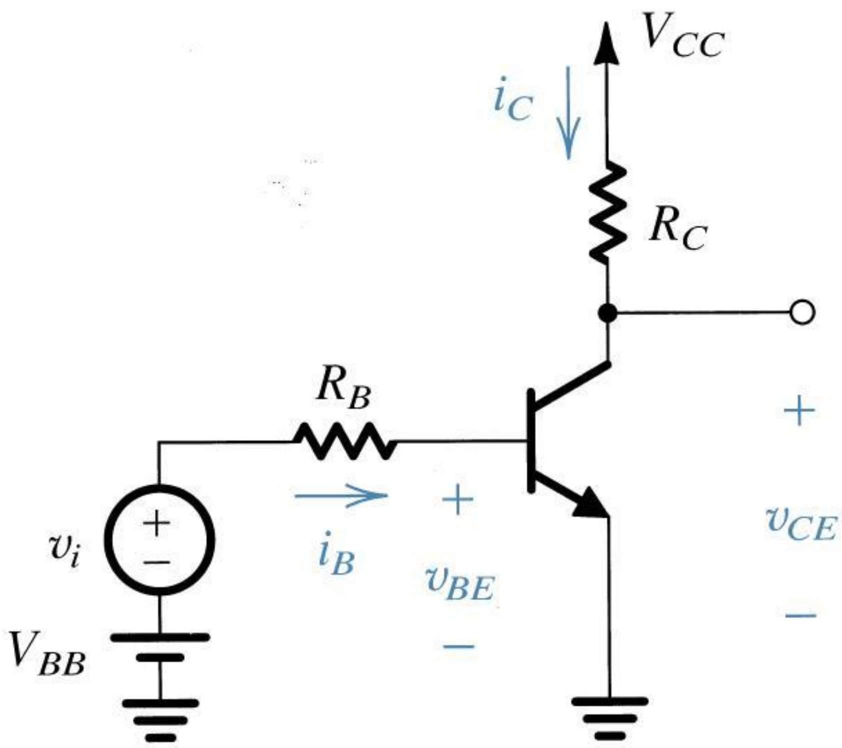


$I_B = (V_{BB} - V_{BE})/R_B$

If $V_{BE} = 0$, $I_B = V_{BB}/R_B$

If $I_B = 0$, $V_{BE} = V_{BB}$

Load line



Output circuit

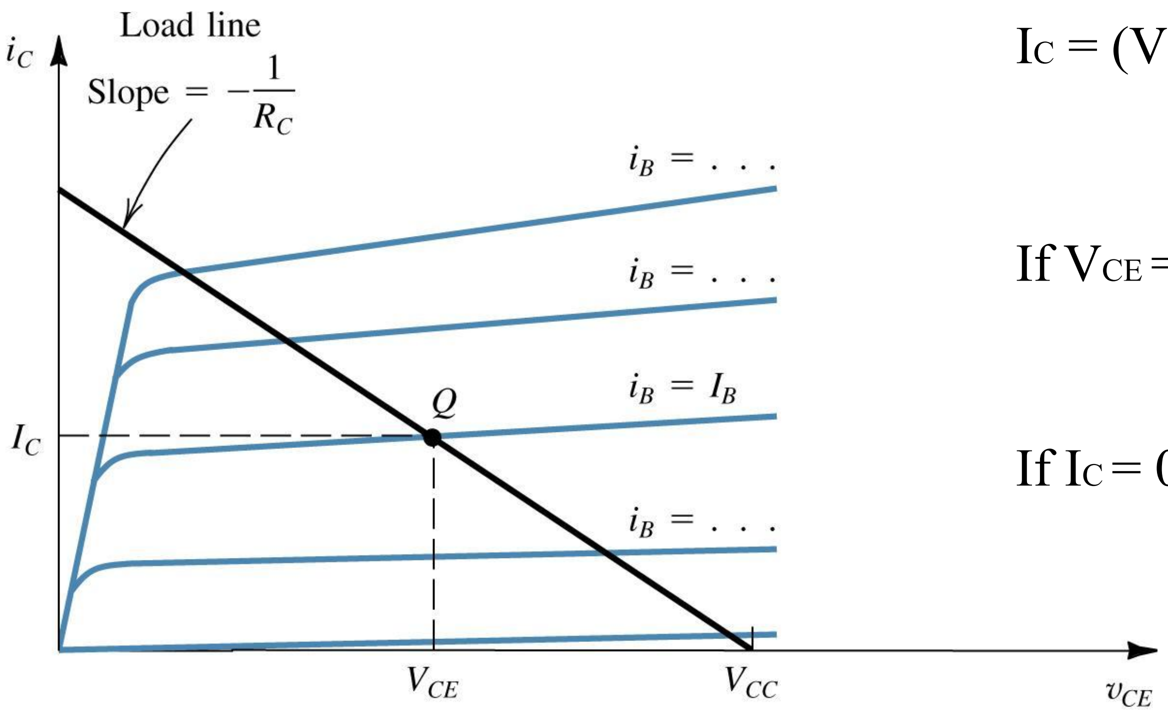
C-E voltage loop

$V_{CC} = I_C R_C + V_{CE}$

$I_C = (V_{CC} - V_{CE})/R_C$

Graphical construction of I_C and V_{CE}

V_{CC}/R_C

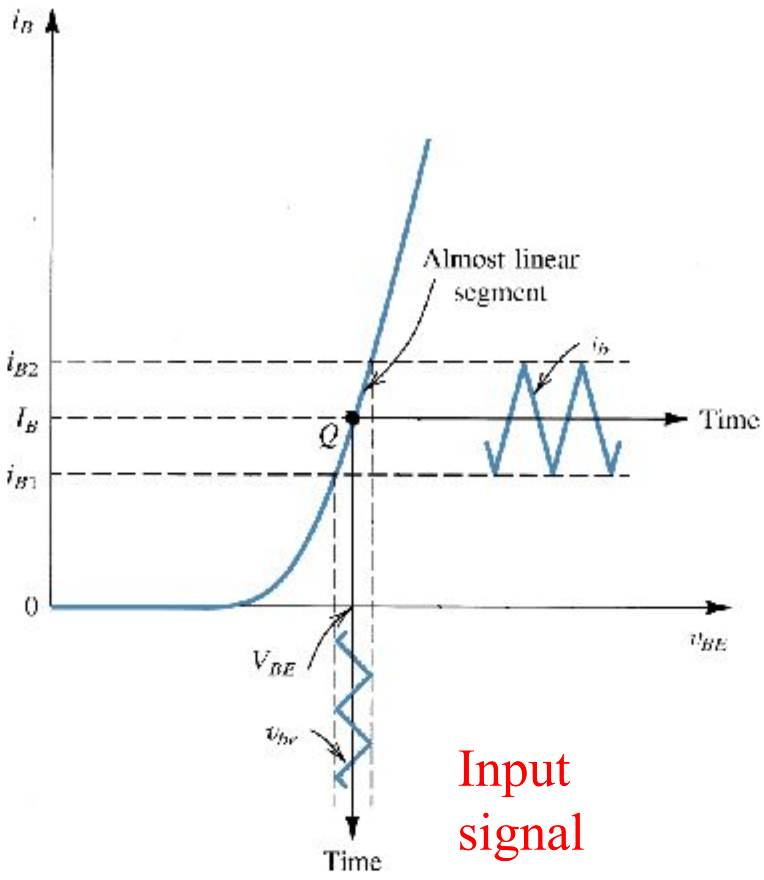


$I_C = (V_{CC} - V_{CE})/R_C$

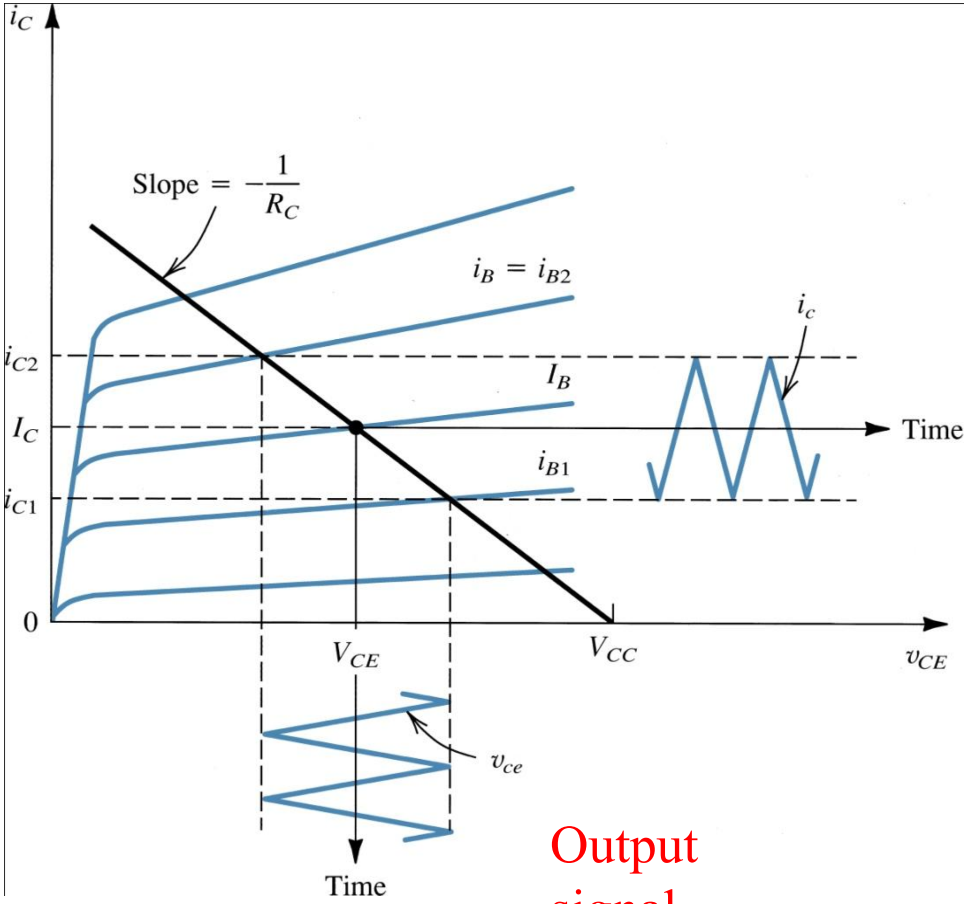
If $V_{CE} = 0$, $I_C = V_{CC}/R_C$

If $I_C = 0$, $V_{CE} = V_{CC}$

Graphical analysis

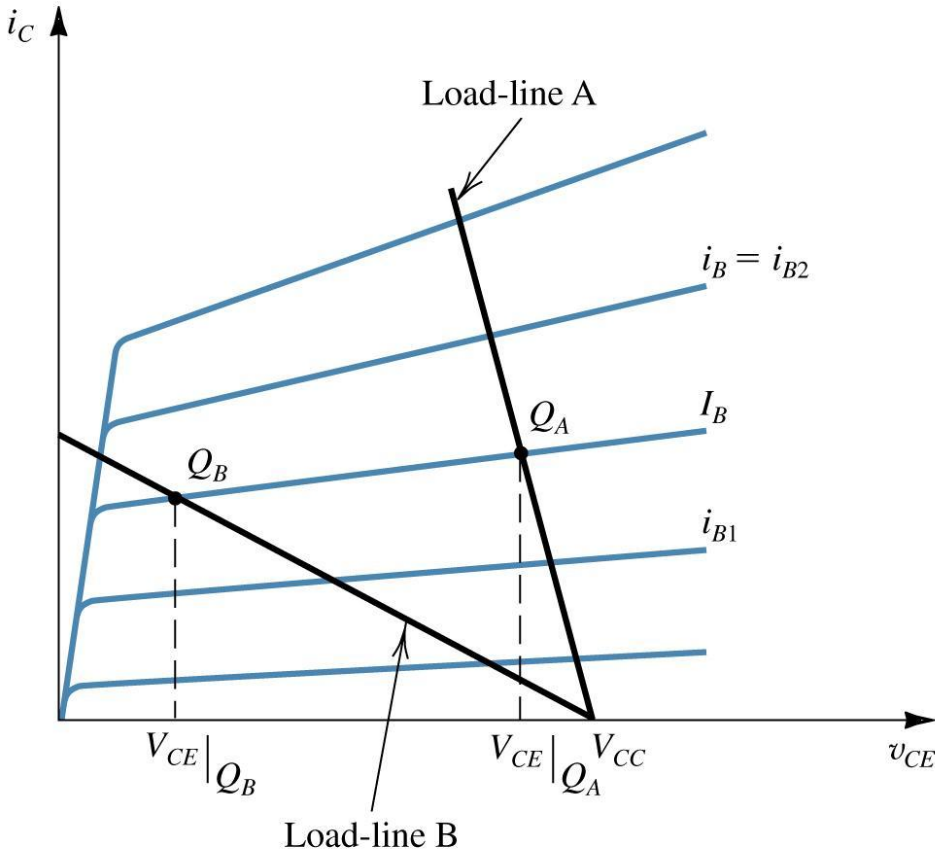


Input signal



Output signal

Bias point location effects



- Load-line A results in bias point Q_A which is too close to V_{CC} and thus limits the positive swing of v_{CE}.
- Load-line B results in an operating point too close to the saturation region, thus limiting the negative swing of v_{CE}.

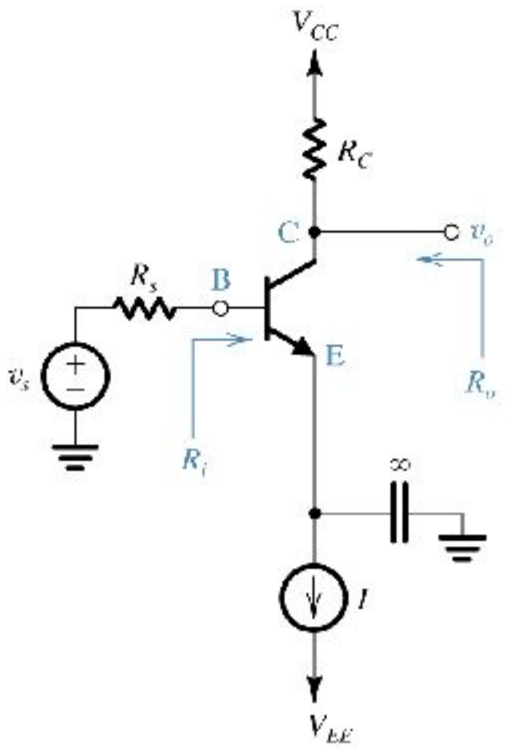
Basic single-stage BJT amplifier configurations

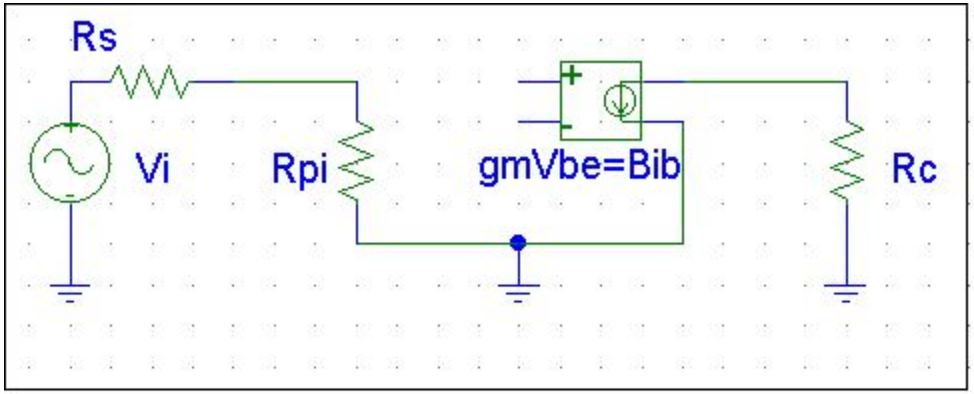
We will study 3 types of BJT amplifiers

- **CE - common emitter,** used for A_v, A_i, and general purpose
- **CE with R_E - common emitter with R_E**, same as CE but more stable
- **CC common collector,** used for A_i, low output resistance, used as an output stage

CB common base (not covered)

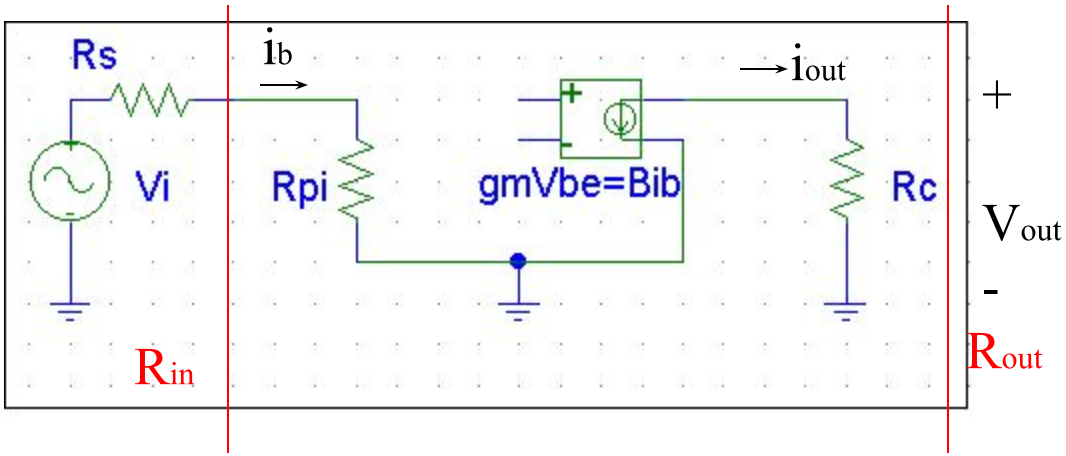
Common emitter amplifier





ac equivalent circuit

Common emitter amplifier



R_{in}
(Does not include source)
$R_{in} = R_{pi}$

R_{out}
(Does not include load)
$R_{out} = R_C$

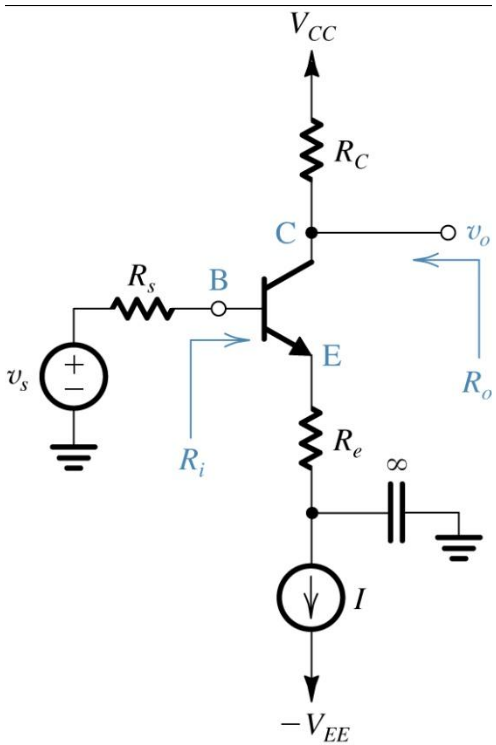
A_V
$= V_{out}/V_{in}$
$V_{out} = - \beta i_b R_C$
$V_{in} = i_b(R_s + R_{pi})$

$A_V = - \beta R_C / (R_s + R_{pi})$

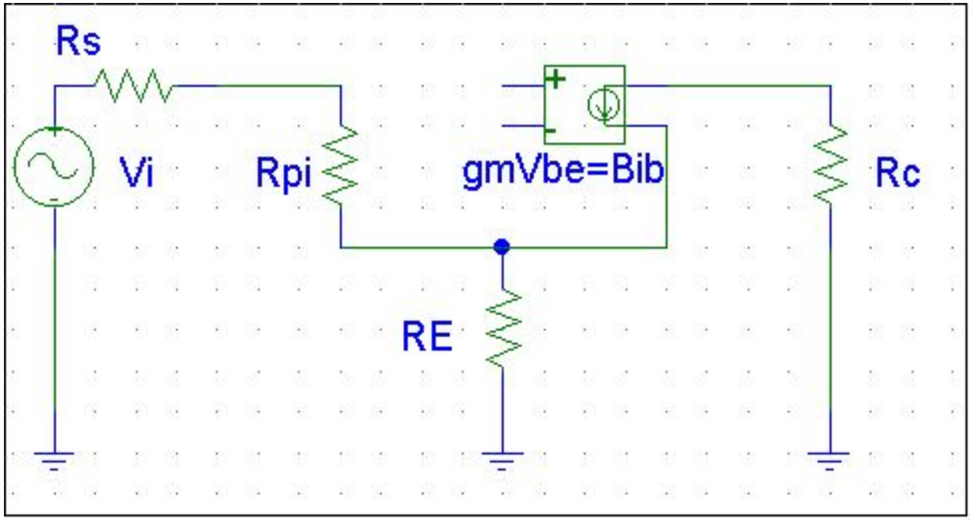
A_i
$= i_{out}/i_{in}$
$i_{out} = - \beta i_b$
$i_{in} = i_b$

$A_i = - \beta$

Common emitter with R_E amplifier



(a)



ac equivalent circuit

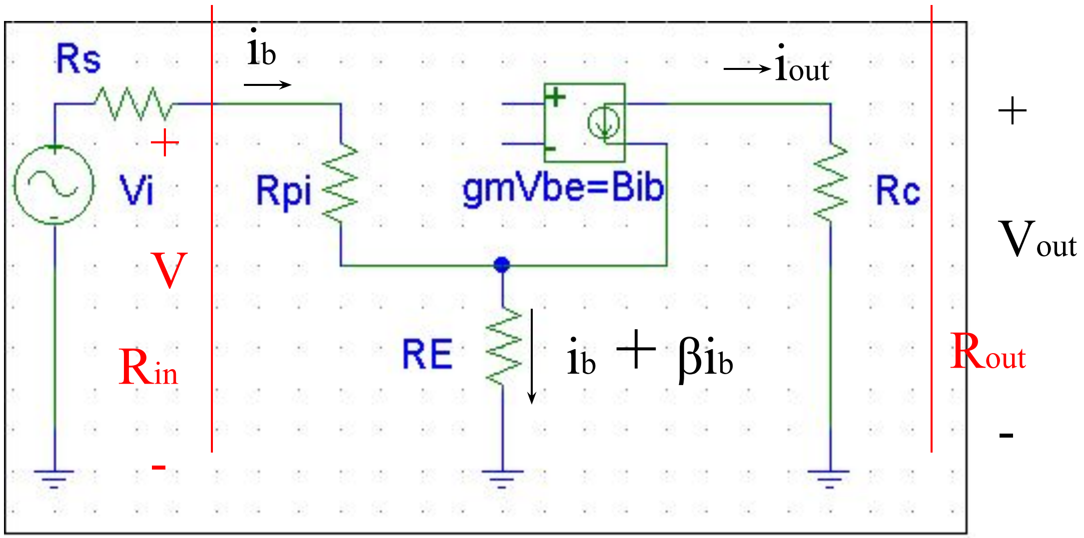
Common emitter with R_E amplifier

R_{in}

$R_{in} = V/i_b$

$V = i_b R_{pi} + (i_b + \beta i_b)R_E$

$R_{in} = R_{pi} + (1 + \beta)R_E$
(usually large)



R_{out}

$R_{out} = R_C$

A_v

$= V_{out}/V_{in}$

$V_{out} = - \beta i_b R_C$

$V_{in} = i_b R_s + i_b R_{pi} + (i_b + \beta i_b)R_E$

$A_V = - \beta R_C / (R_s + R_{pi} + (1 + \beta)R_E)$

(less than CE, but less sensitive to β variations)

A_i

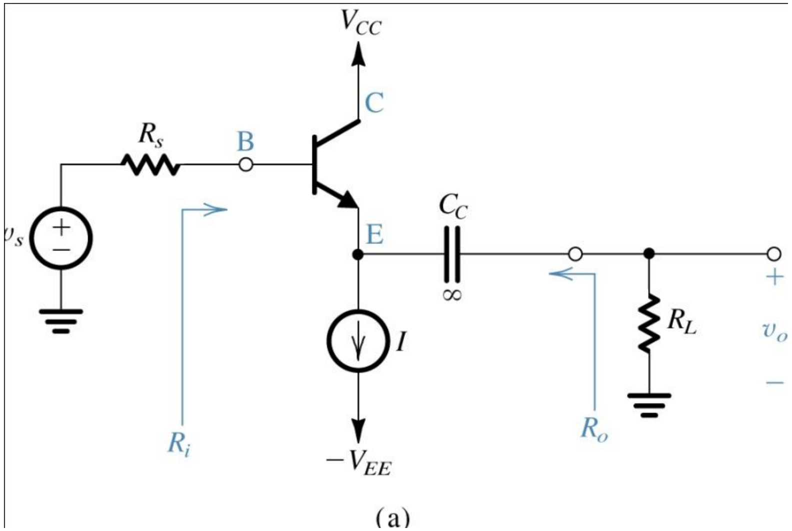
$= i_{out}/i_{in}$

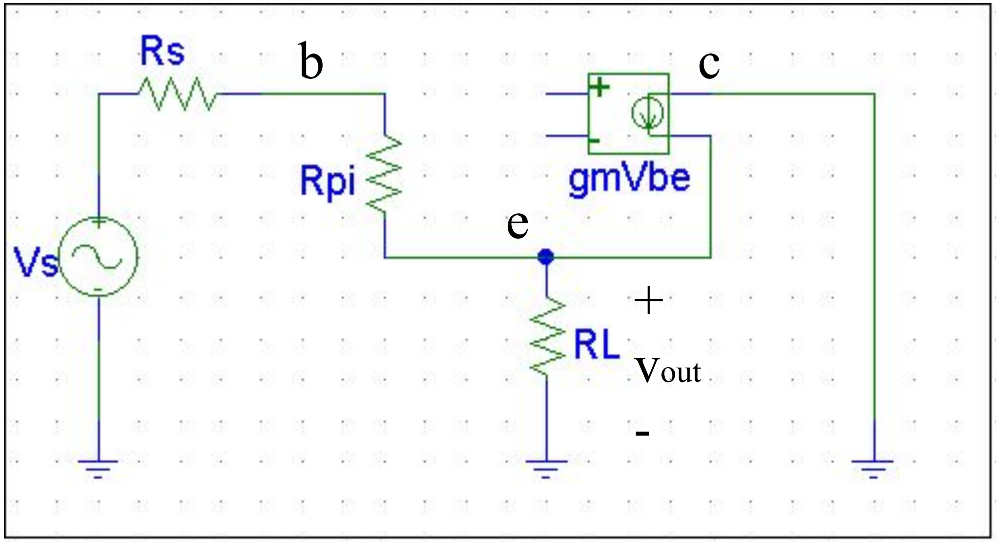
$i_{out} = - \beta i_b$

$i_{in} = i_b$

$A_i = - \beta$

Common collector (emitter follower) amplifier

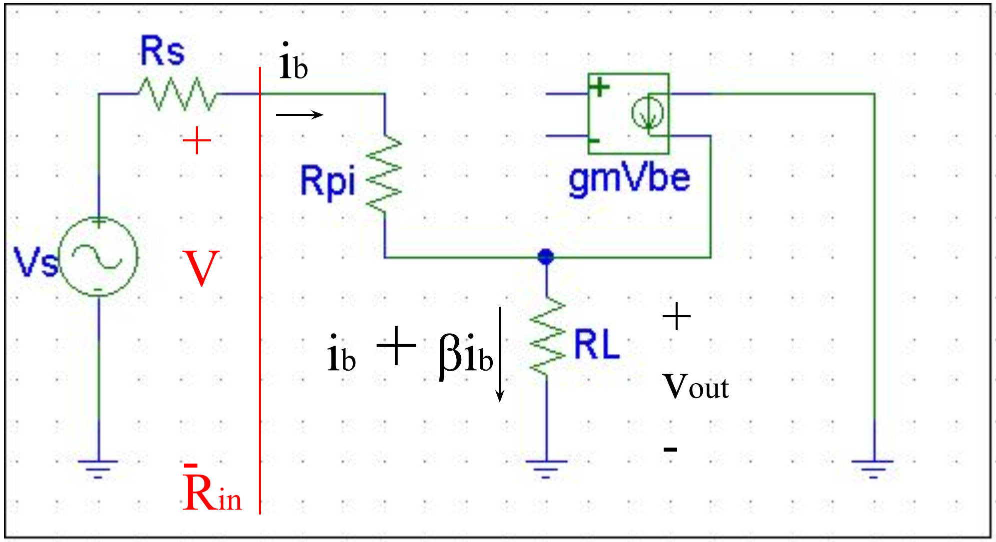




(Vout at emitter)

ac equivalent circuit

Common collector amplifier



R_{in}

$R_{in} = V/i_b$

$V = i_b R_{pi} + (i_b + \beta i_b)R_L$

$R_{in} = R_{pi} + (1 + \beta)R_L$

A_V

$= v_{out}/v_s$

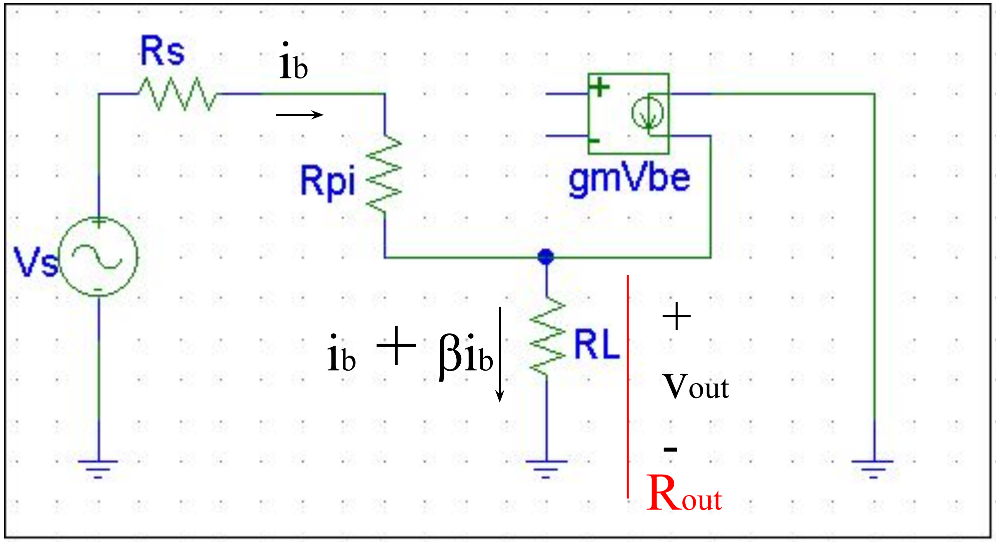
$v_{out} = (i_b + \beta i_b)R_L$

$v_s = i_b R_s + i_b R_{pi} + (i_b + \beta i_b)R_L$

$A_V = (1+ \beta)R_L / (R_s + R_{pi} + (1 + \beta)R_L)$

(always ≤ 1)

Common collector amplifier



A_i

$= i_{out}/i_{in}$

$i_{out} = i_b + \beta i_b$

$i_{in} = i_b$

$A_i = \beta + 1$

R_{out}

(don't include RL, set Vs = 0)

$R_{out} = v_{out} / -(i_b + \beta i_b)$

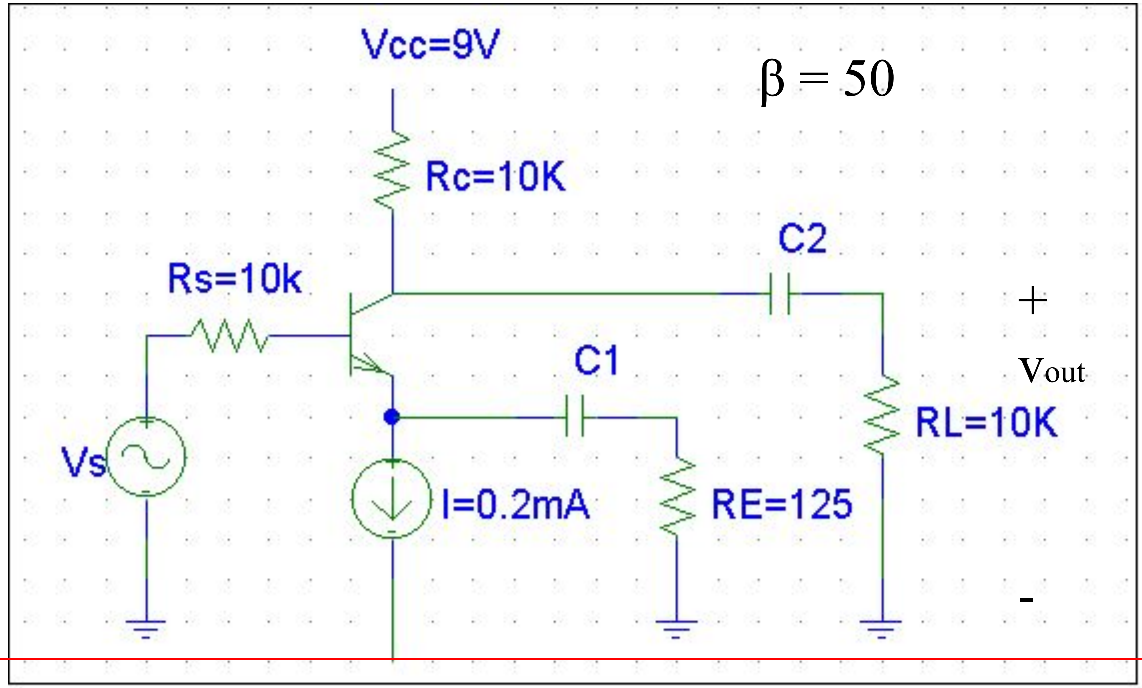
$v_{out} = -i_b R_{pi} + -i_b R_s$

$R_{out} = (R_{pi} + R_s) / (1 + \beta)$

(usually low)

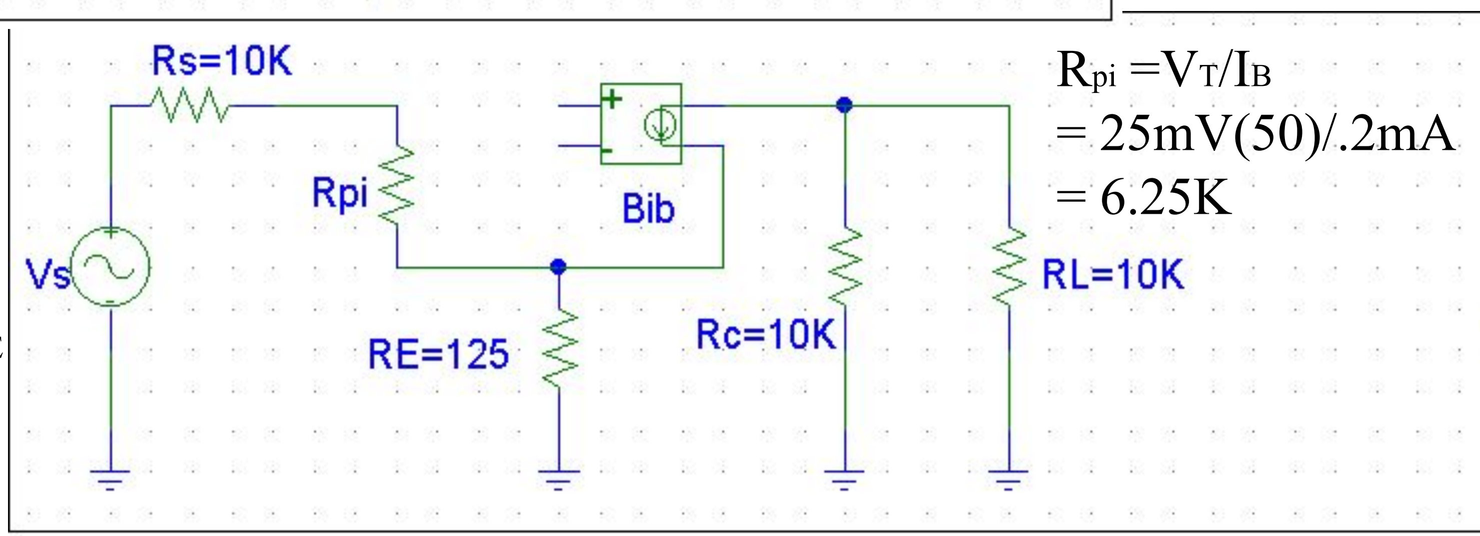
Prob

Given



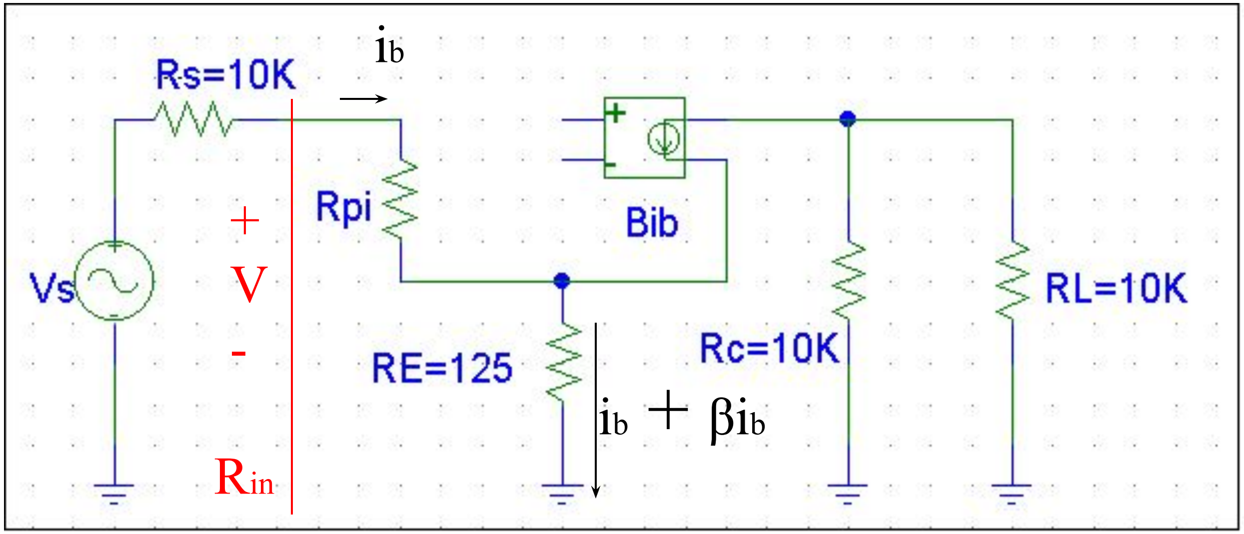
ac circuit

CE with R_E amp, because R_E is in ac circuit



$R_{pi} = V_T/I_B$
$= 25mV(50)/.2mA$
$= 6.25K$

Prob.



(a) Find Rin

$R_{in} = V/i_b$

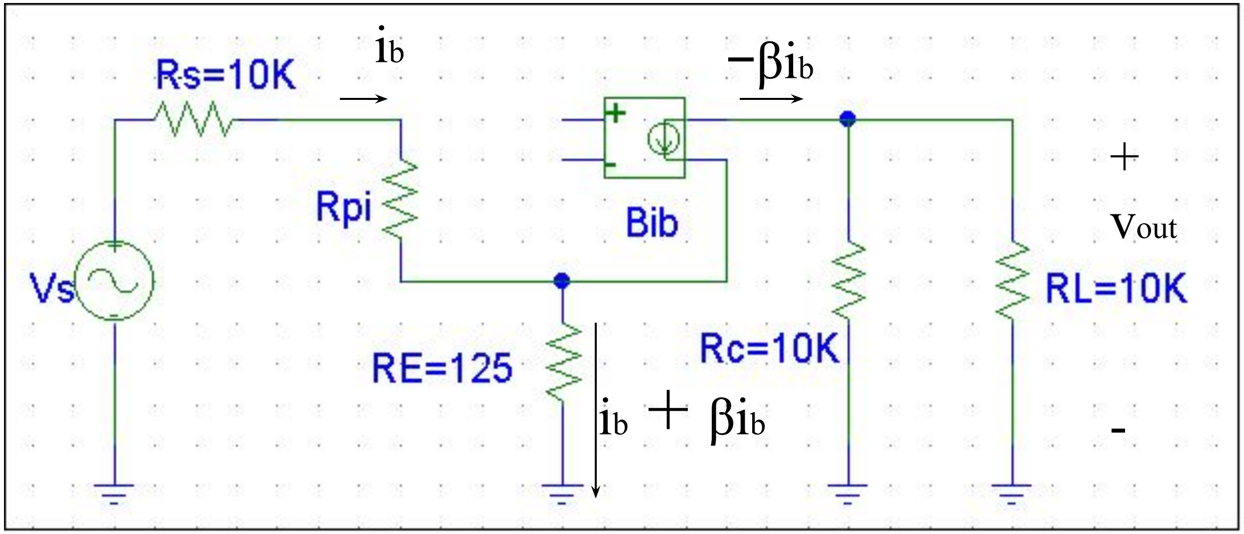
$V = i_b R_{pi} + (i_b + \beta i_b)R_E$

$R_{in} = R_{pi} + (1 + \beta)R_E$

$R_{in} = 6.25K + (1 + 50)125$

$R_{in} \approx 12.62K$

Prob.



(b) Find $A_V = v_{out}/v_s$

$v_{out} = -\beta i_b(R_C||R_L)$

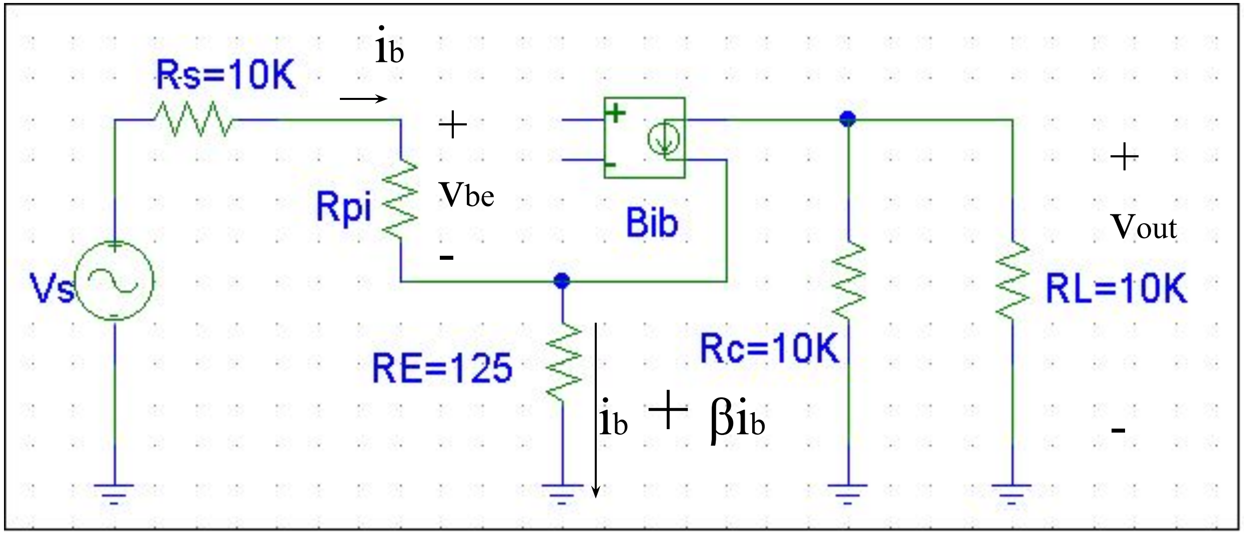
$v_s = i_b R_s + i_b R_{pi} + (i_b + \beta i_b)R_E$

$A_V = -\beta\ (R_C||R_L) / (R_s + R_{pi} + (1 + \beta)R_E)$

$A_V = -50\ (10K||10K)/(10K + 6.25K_i + (1 + 50)125)$

$A_V \approx -11$

Prob.



(c) If v_{be} is limited to 5mV, what is the largest signal at input and output?

$v_{be} = i_b R_{pi} = 5\text{mV}$

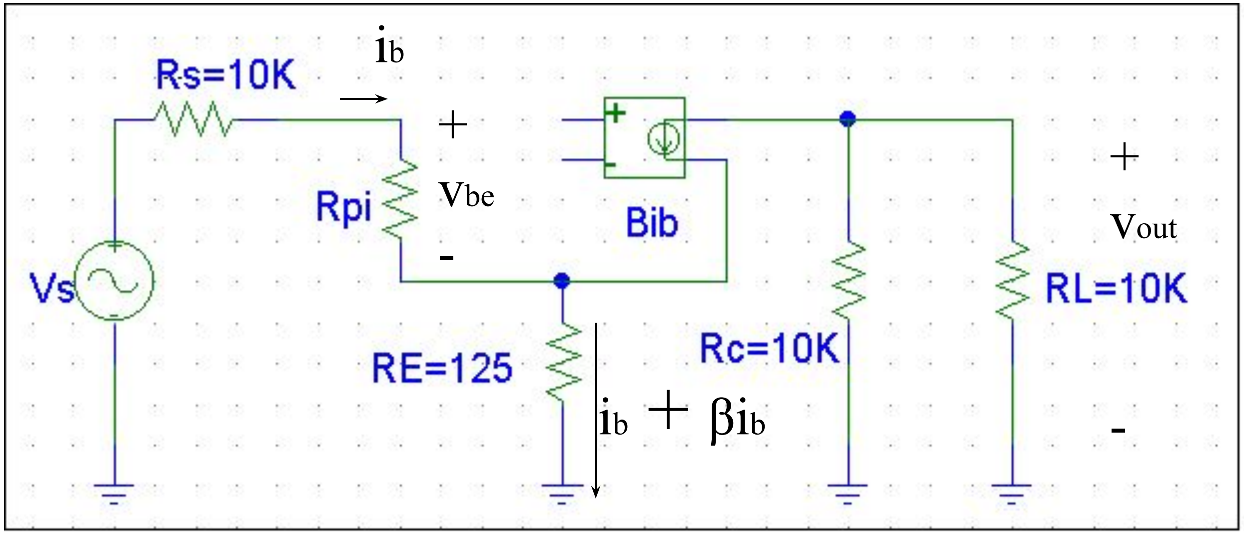
$i_b = v_{be}/R_{pi} = 5\text{mV}/6.25\text{K} =$ $0.8\mu\text{A}$ (ac value)

$v_s = i_b R_s + i_b R_{pi} + (i_b + \beta i_b)R_E$

$v_s = (0.8\mu\text{A})10\text{K} + (0.8\mu\text{A})\ 6.25\text{K} + (0.8\mu\text{A} + (50)0.8\mu\text{A})125$

$v_s \approx 18\text{mV}$

Prob.



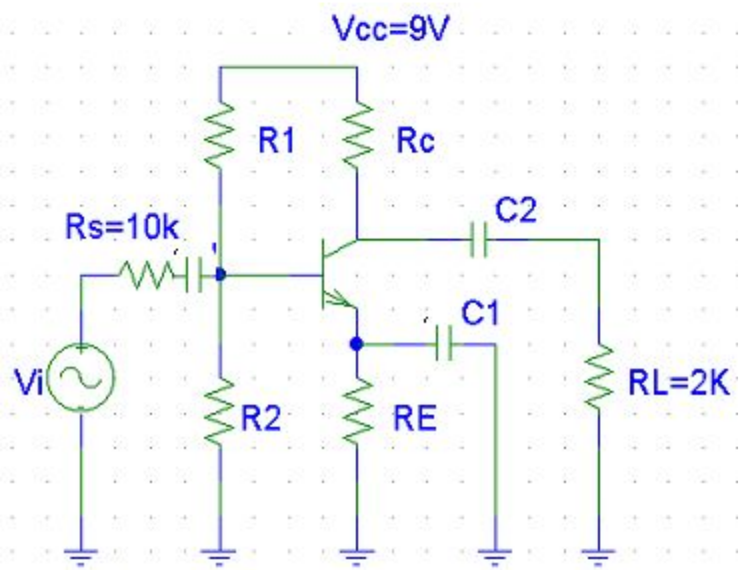
(c) If v_{be} is limited to 5mV, what is the largest signal at input and output?

$v_{out} = v_s A_V$

$v_{out} = 17.4\text{mV}(-11)$

$v_{out} \approx -191\text{mV}$ (ac value)

Prob.



$\beta = 100$

Using this circuit, design an amp with:

$I_E = 2mA$
$A_V = -8$
current in voltage divider $I = 0.2mA$

(CE amp because RE is not in ac circuit)

Voltage divider
$Vcc/I = 9/0.2mA = 45K$
$45K = R_1 + R_2$

Choose $V_B \approx 1/3$ Vcc to put operating point near the center of the transistor characteristics
$R_2/(R_1 + R_2) = 3V$

Combining gives, $R_1 = 30K$, $R_2 = 15K$

Prob.

Find RE (input circuit)

Use Thevenin equivalent

B-E loop

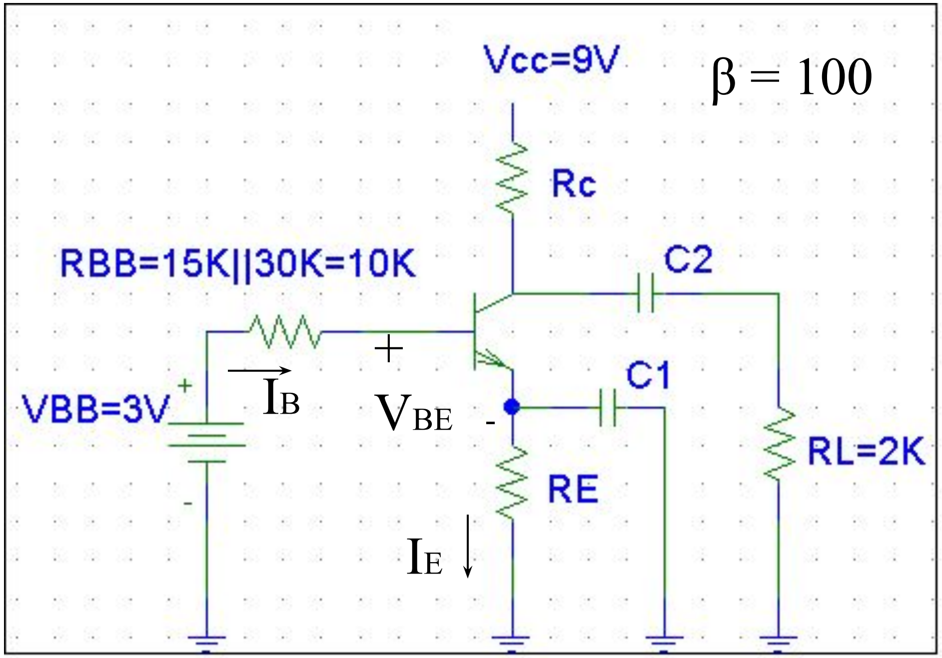
$V_{BB} = I_B R_{BB} + V_{BE} + I_E R_E$

using $I_B \approx I_E/\beta$

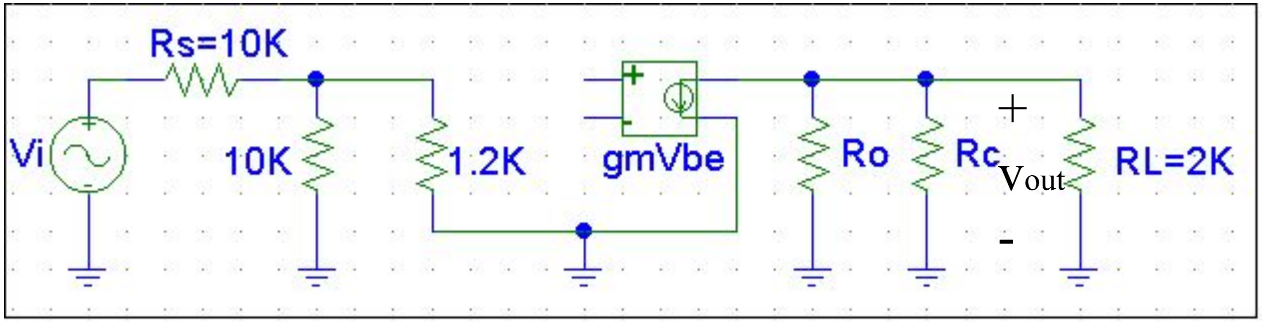
$R_E = [V_{BB} - V_{BE} - (I_E/\beta)R_{BB}]/I_E$

$R_E = [3 - .7 - (2mA/100)10K]/2mA$

$R_E = 1.05K\Omega$



Prob.



Find Rc (ac circuit)

$R_{pi} = V_T/I_B = 25mV(100)/2mA = 1.25K$

$R_o = V_A/I_C = 100/2mA = 50K$

$A_v = v_{out}/v_{in}$

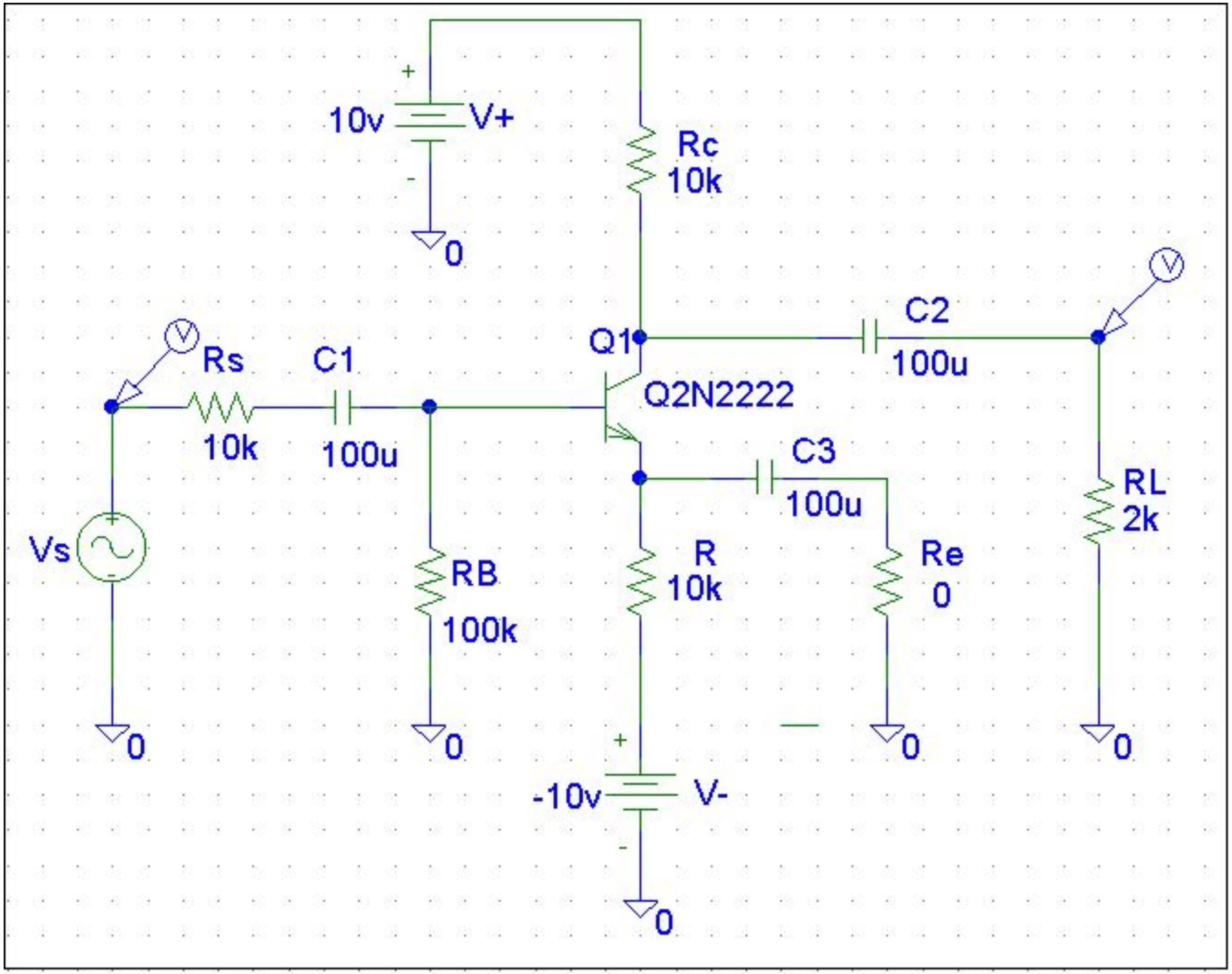
$v_{out} = -g_m v_{be}\,(Ro||Rc||RL)$

$v_{be} = 10K||1.2K\ /\ [10K+ 10K||1.2K]v_i$

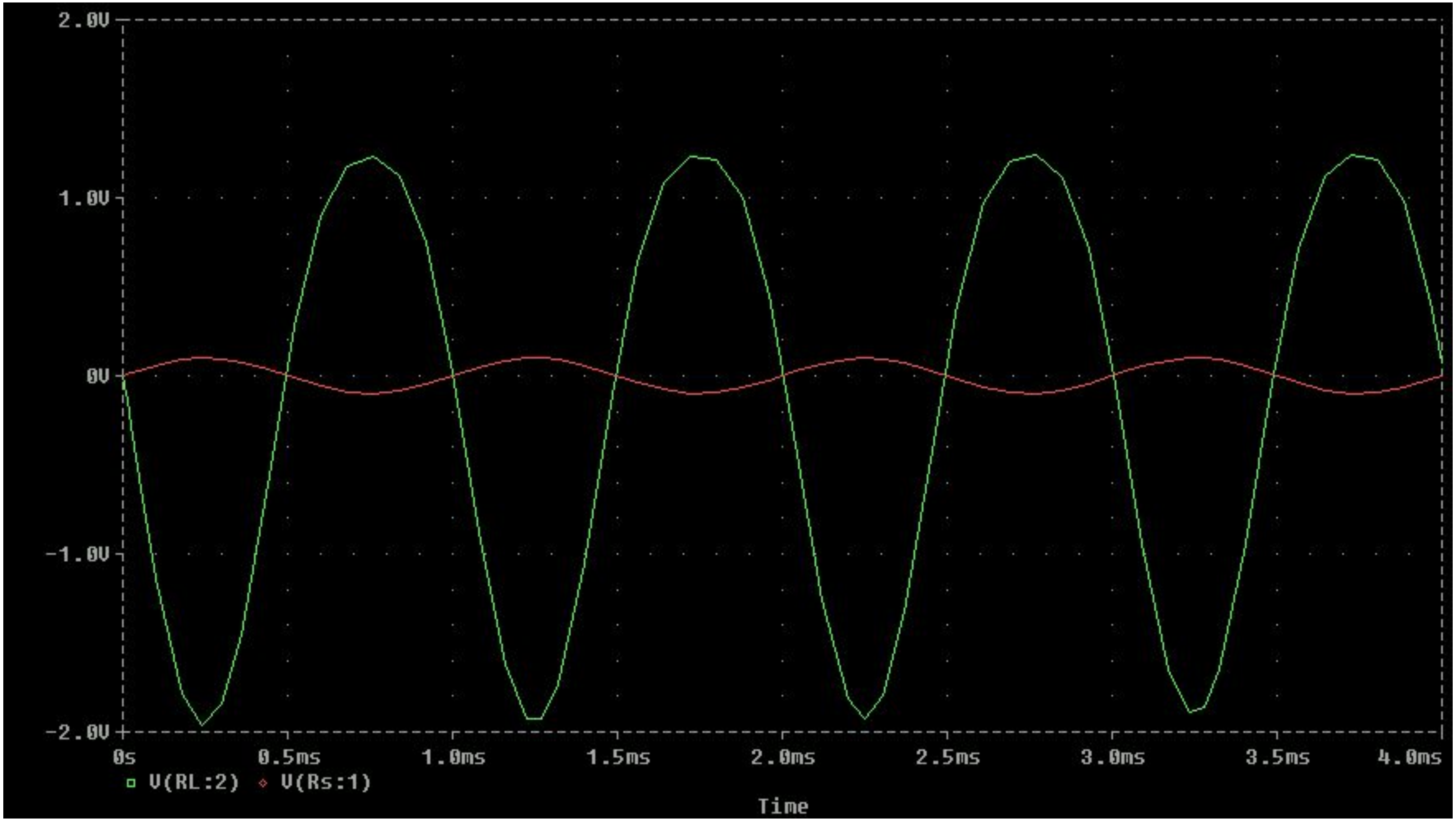
$A_v = -g_m(Ro||Rc||RL)(10K||1.2K)\ /\ [10K||1.2K +Rs]$

Set Av = -8, and solve for Rc, Rc ≈ 2K

CE amplifier



CE amplifier



Av ≈ -12.2

CE amplifier

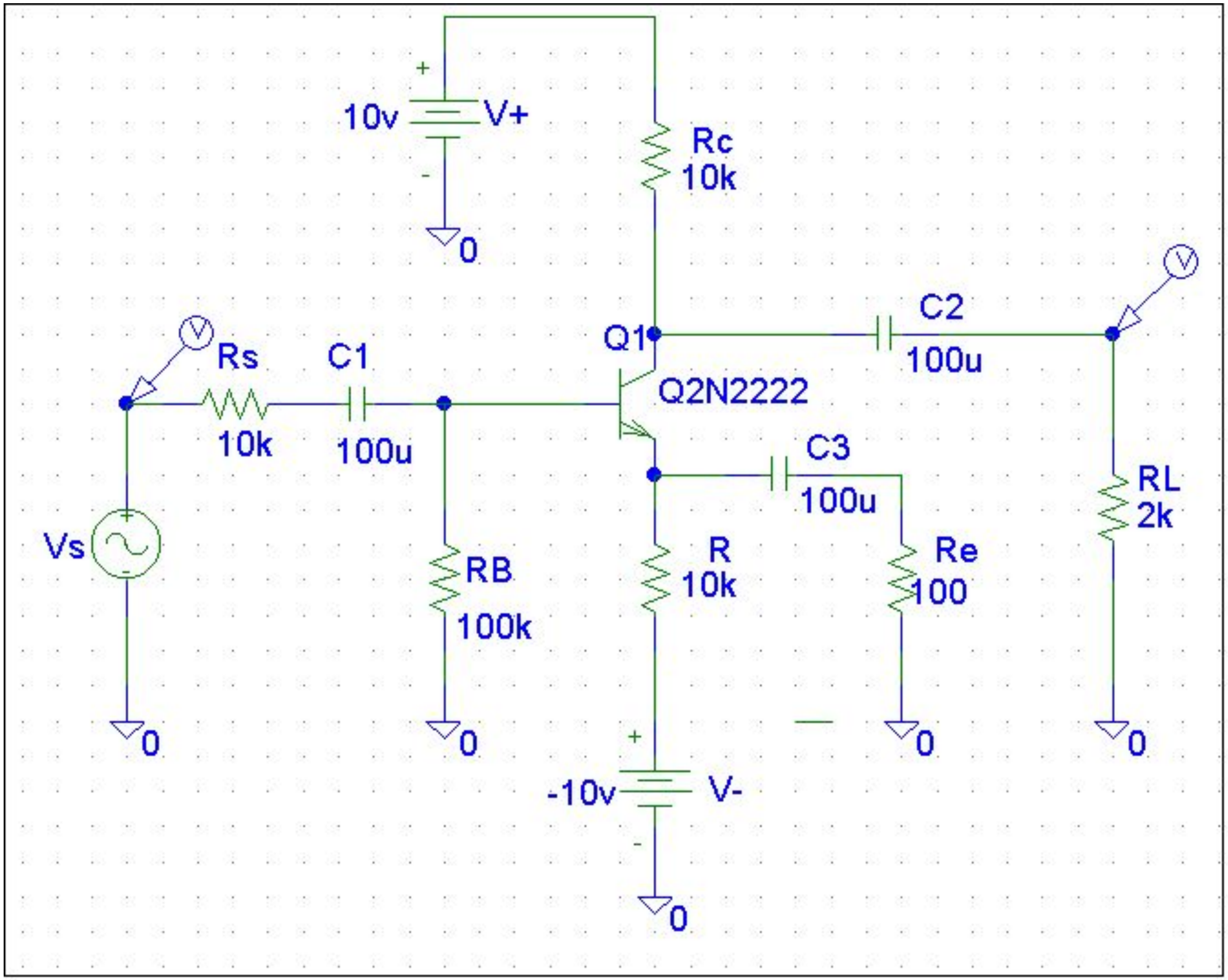
FOURIER COMPONENTS OF TRANSIENT RESPONSE V($N_0009)

DC COMPONENT = -1.226074E-01

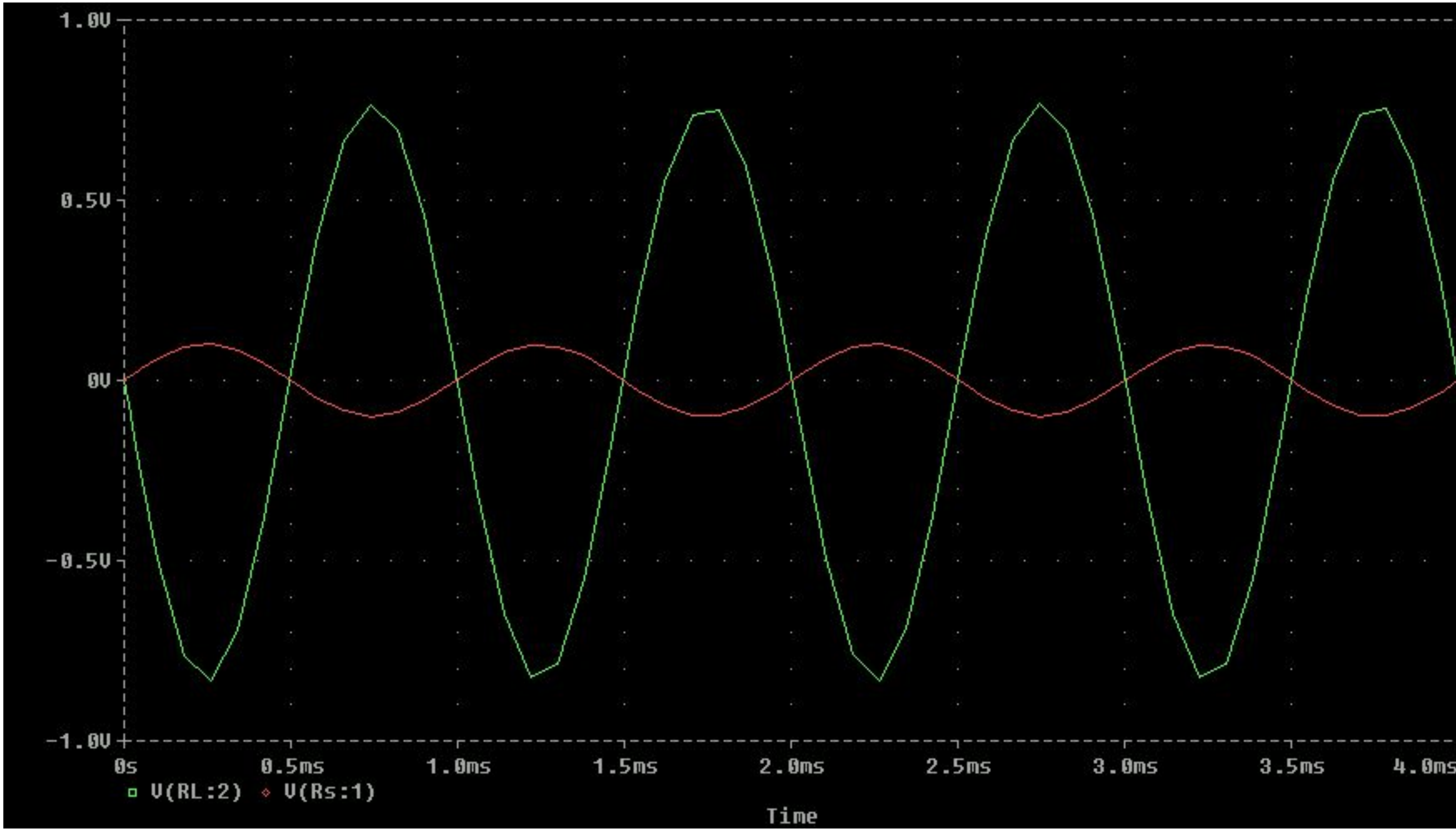
HARMONIC NO	FREQUENCY (HZ)	FOURIER COMPONENT	NORMALIZED COMPONENT	PHASE (DEG)	NORMALIZED PHASE (DEG)
1	1.000E+03	1.581E+00	1.000E+00	-1.795E+02	0.000E+00
2	2.000E+03	1.992E-01	1.260E-01	9.111E+01	2.706E+02
3	3.000E+03	2.171E-02	1.374E-02	-1.778E+02	1.668E+00
4	4.000E+03	3.376E-03	2.136E-03	-1.441E+02	3.533E+01

TOTAL HARMONIC DISTORTION = 1.267478E+01 PERCENT

CE amplifier with R_E



CE amplifier with R_E



$Av \approx - 7.5$

FOURIER COMPONENTS OF TRANSIENT RESPONSE V($N_0009)

DC COMPONENT = -1.353568E-02

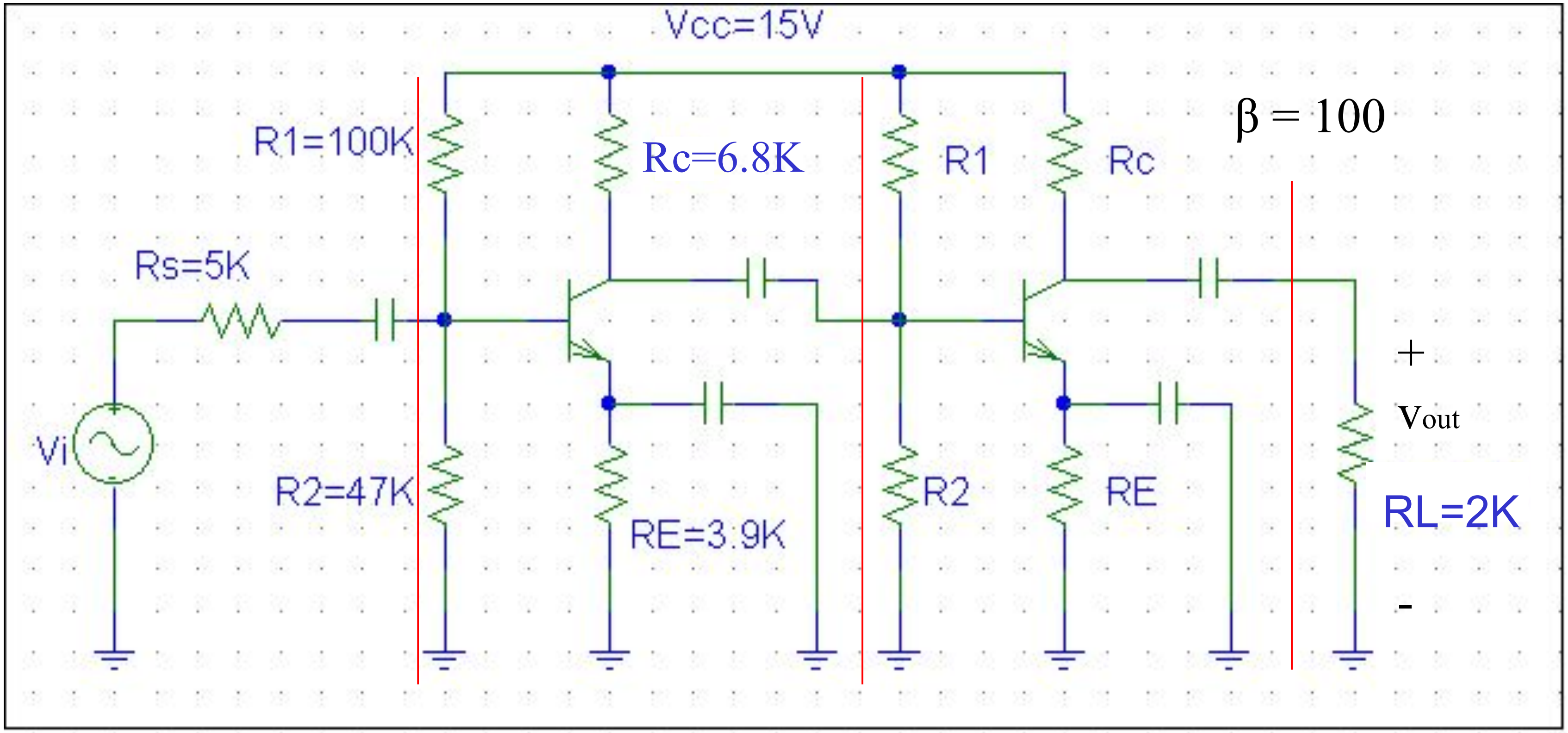
HARMONIC NO	FREQUENCY (HZ)	FOURIER COMPONENT	NORMALIZED COMPONENT	PHASE (DEG)	NORMALIZED PHASE (DEG)
1	1.000E+03	7.879E-01	1.000E+00	-1.794E+02	0.000E+00
2	2.000E+03	1.604E-02	2.036E-02	9.400E+01	2.734E+02
3	3.000E+03	5.210E-03	6.612E-03	-1.389E+02	4.056E+01
4	4.000E+03	3.824E-03	4.854E-03	-1.171E+02	6.231E+01

TOTAL HARMONIC DISTORTION = 2.194882E+00 PERCENT

Summary

	Av	THD
CE	-12.2	12.7%
CE w/R_E (R_E = 100)	-7.5	2.19%

Prob.



- 2 stage amplifier
- Both stages are the same
- Capacitively coupled

(a) Find I_C and V_C of each transistor (same for each stage)

Prob.

(a) Find I_C and V_C of each transistor (same for each stage)

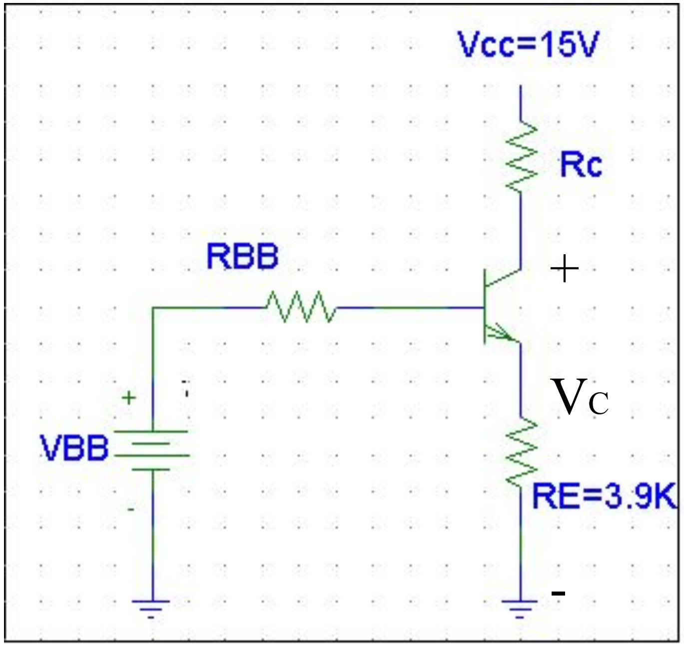
B-E voltage loop

$V_{BB} = I_B R_{BB} + V_{BE} + I_E R_E$

where $R_{BB} = R_1||R_2 = 32K$
$V_{BB} = V_{CC}R_2/(R_1+R_2) = 4.8V$, and
$I_B \approx I_E/\beta$

$I_E = [V_{BB} - V_{BE}]/[R_{BB}/\beta + R_E]$

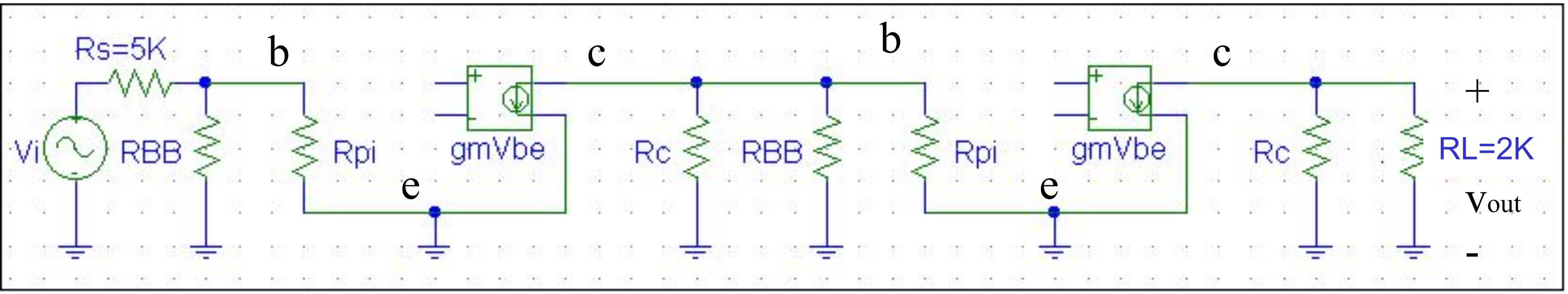
$I_E = 0.97mA$



$V_C = V_{CC} - I_C R_C$
$V_C = 15 - .97(6.8)$
$V_C = 8.39V$

Prob.

(b) find ac circuit

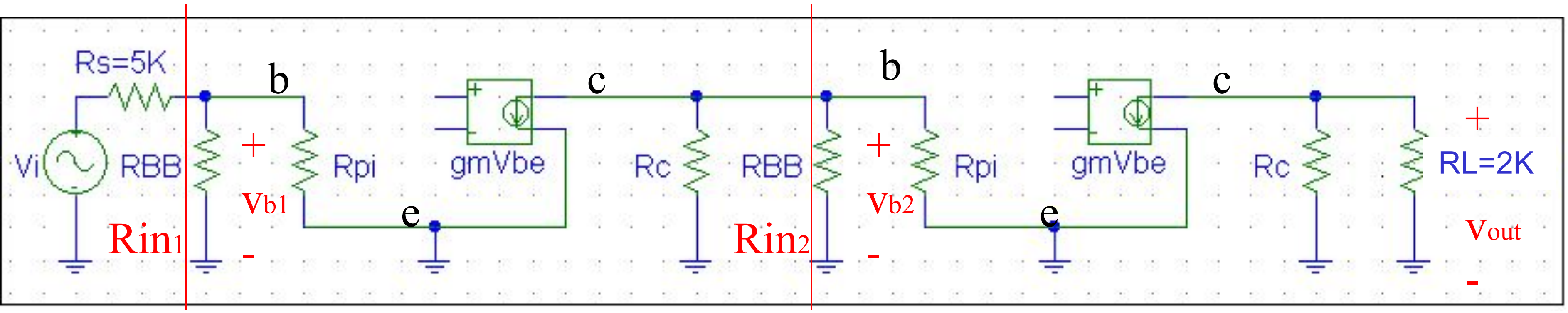


$R_{BB} = R_1||R_2 = 100K||47K = 32K\Omega$

$Rpi = V_T/I_B = 25mV(100)/.97mA \approx 2.6K\Omega$

$g_m = I_C/V_T = .97mA/25mV \approx 39mA/V$

Prob.



(c) find R_{in1}

$R_{in1} = R_{BB}||R_{pi}$

$= 32K||2.6K$

$= 2.4K\Omega$

find v_{b1}/v_i

$= R_{in1}/[R_{in1} + R_S]$

$= 2.4K/[2.4K + 5K]$

$= 0.32$

(d) find R_{in2}

$R_{in2} = R_{BB}||R_{pi}$

$= 2.4K\Omega$

find v_{b2}/v_{b1}

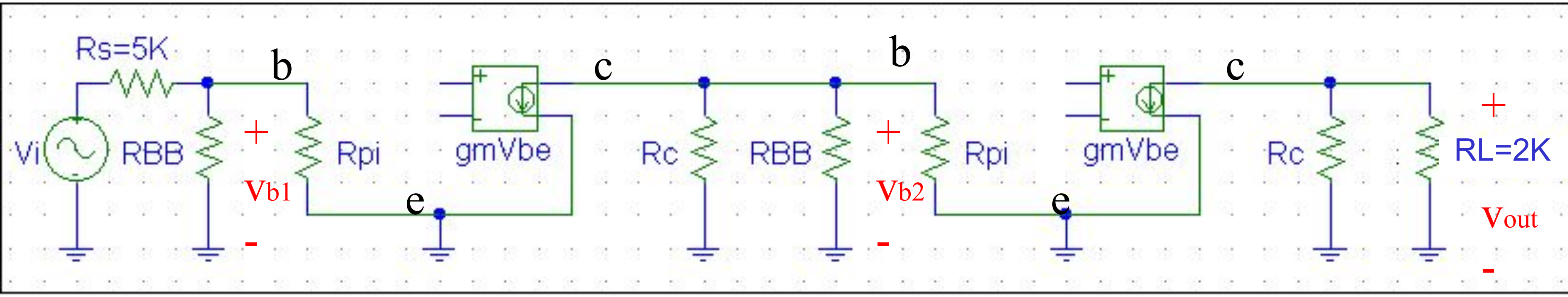
$v_{b2} = -g_m v_{be1}[R_C||R_{BB}||R_{pi}]$

$v_{b2}/v_{be1} = -g_m[R_C||R_{BB}||R_{pi}]$

$v_{b2}/v_{b1} = -(39mA/V)[6.8||32K||2.6K]$

$= -69.1$

Prob.



(e) find v_{out}/v_{b2}

$v_{out} = -g_m v_{be2}[R_C||R_L]$

$v_{out}/v_{be2} = -g_m[R_C||R_L]$

$v_{b2}/v_{b1} = -(39mA/V)[6.8K||2K]$

$= -60.3$

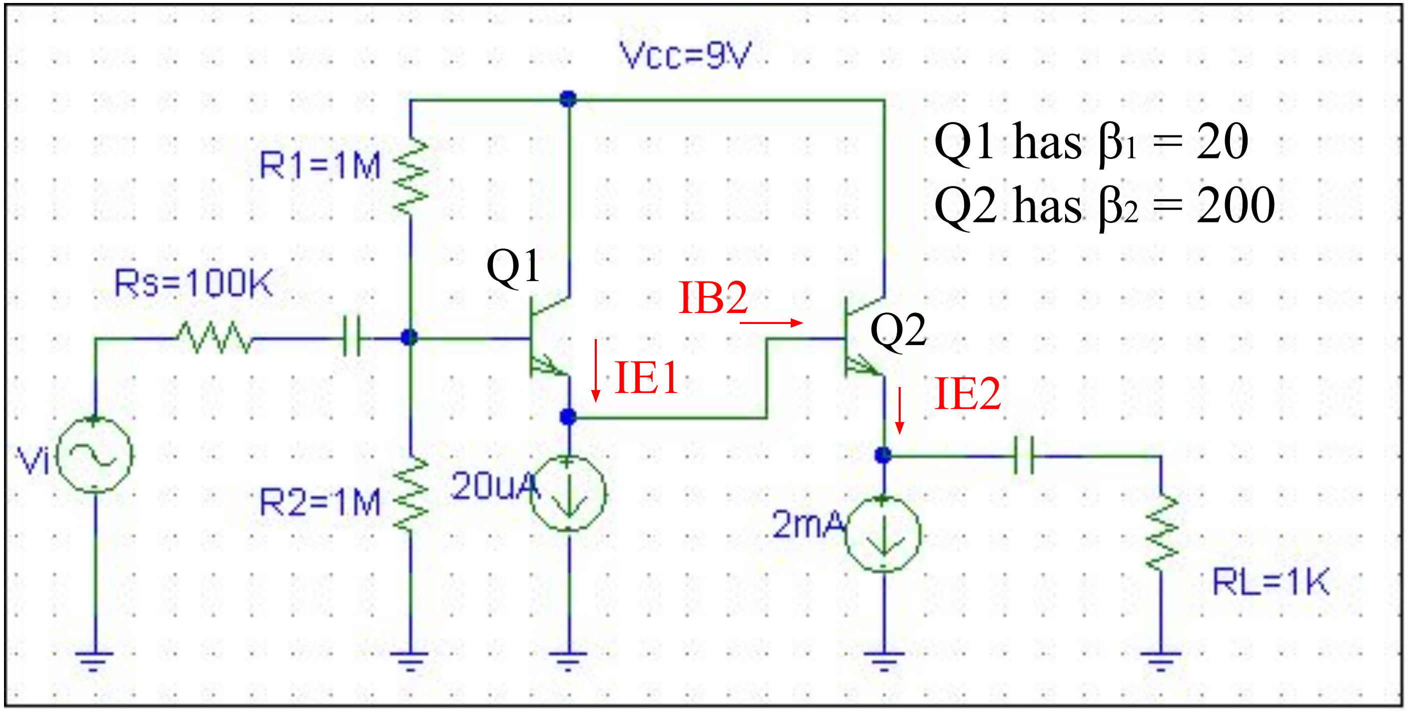
(f) find overall voltage gain

$v_{out}/v_i = (v_{b1}/v_i)\,(v_{b2}/v_{b1})\,(v_{out}/v_{b2})$

$v_{out}/v_i = (0.32)\,(-69.1)\,(-60.3)$

$v_{out}/v_i = 1332$

Prob.



Find I_{E1}, I_{E2}, V_{B1}, and V_{B2}

$I_{E2} = 2mA$

$I_{E1} = I_{20\mu A} + I_{B2}$

$I_{E1} = I_{20\mu A} + I_{E2}/\beta_2$

$I_{E1} = 20\mu A + 10\mu A$

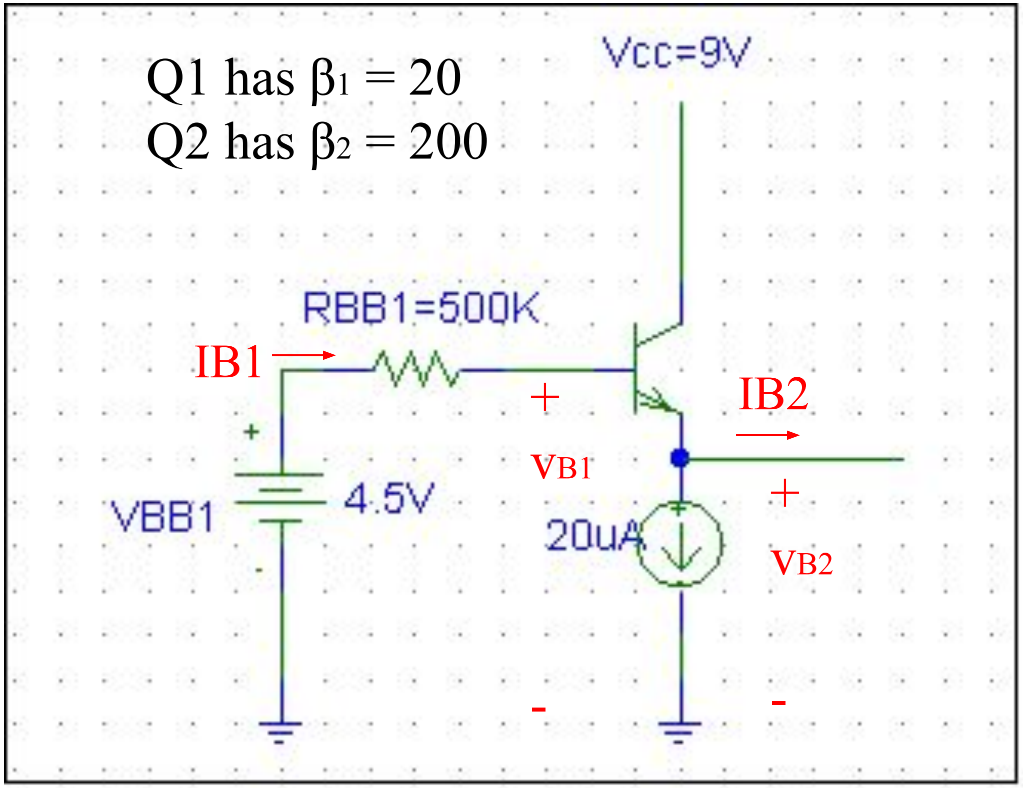
$I_{E1} = 30\mu A$

Prob.

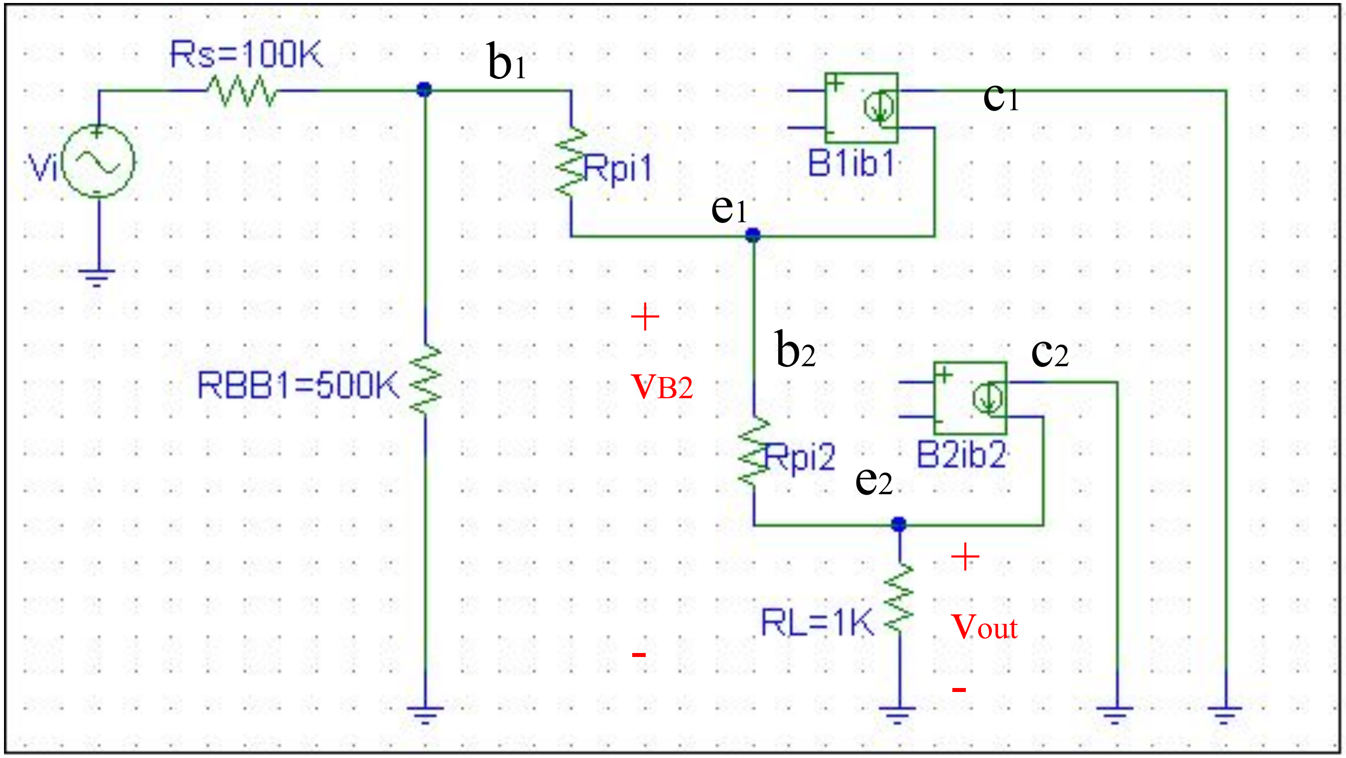
Find V_{B1}, and V_{B2}
Use Thevenin equivalent

$V_{B1} = V_{BB1} - I_{B1}(R_{BB2})$
$= 4.5 - (30\mu A/20)500K$
$= 3.8V$

$V_{B2} = V_{B1} - V_{BE}$
$= 3.8V - 0.7$
$= 3.1V$



Prob.



$R_{pi2} = V_T/I_{B2}$

$= V_T\, \beta_2/I_{E2}$

$= 25mV(200)/2mA$

$= 2.5K\Omega$

(b) find v_{out}/v_{b2}

$v_{out} = (i_{b2} + \beta_2 i_{b2})R_L$

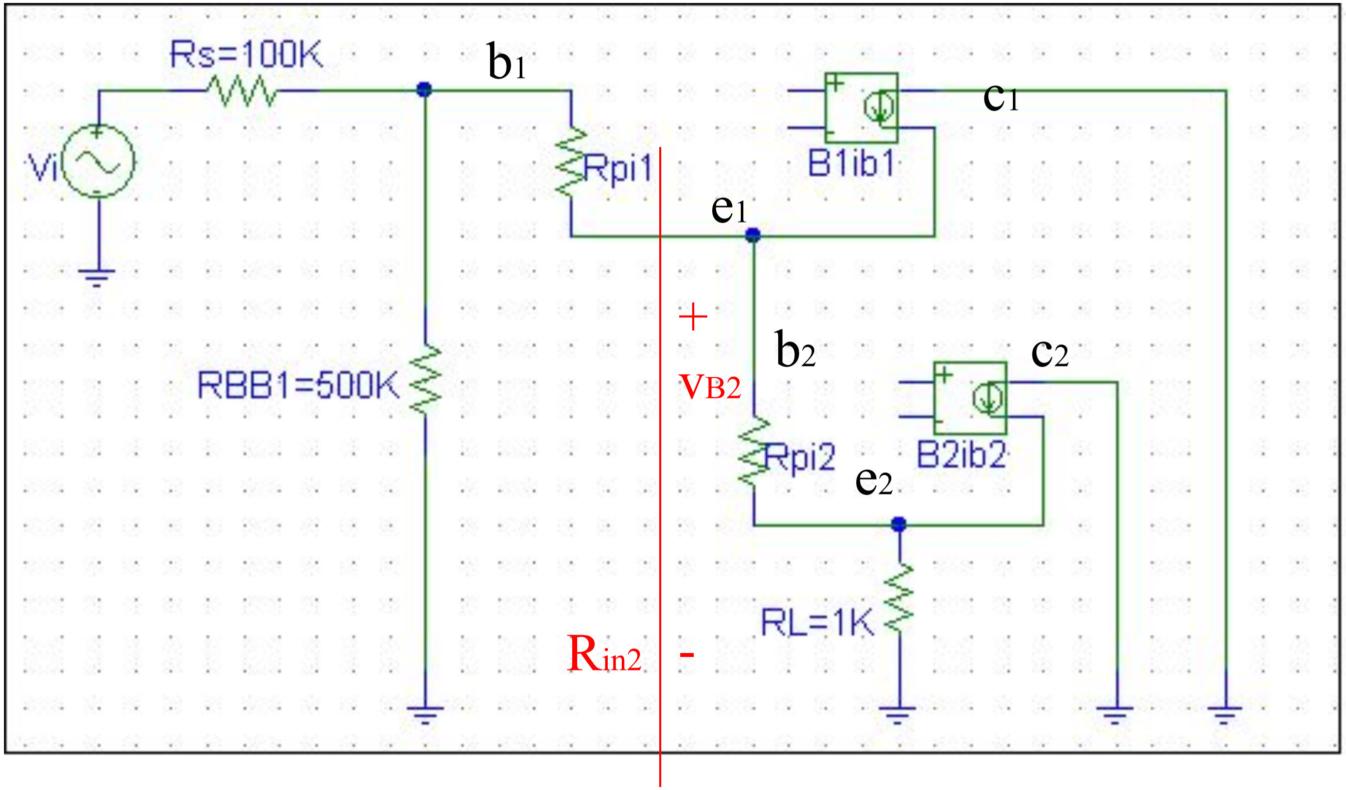
$v_{b2} = (i_{b2} + \beta_2 i_{b2})R_L + i_{b2}R_{pi2}$

$v_{out}/v_{b2} = (1 + \beta_2)R_L/[(1 + \beta_2)R_L + R_{pi2}]$

$= (1 + 200)1K/[(1 + 200)1K + 2.5K]$

≈ 0.988

Prob.

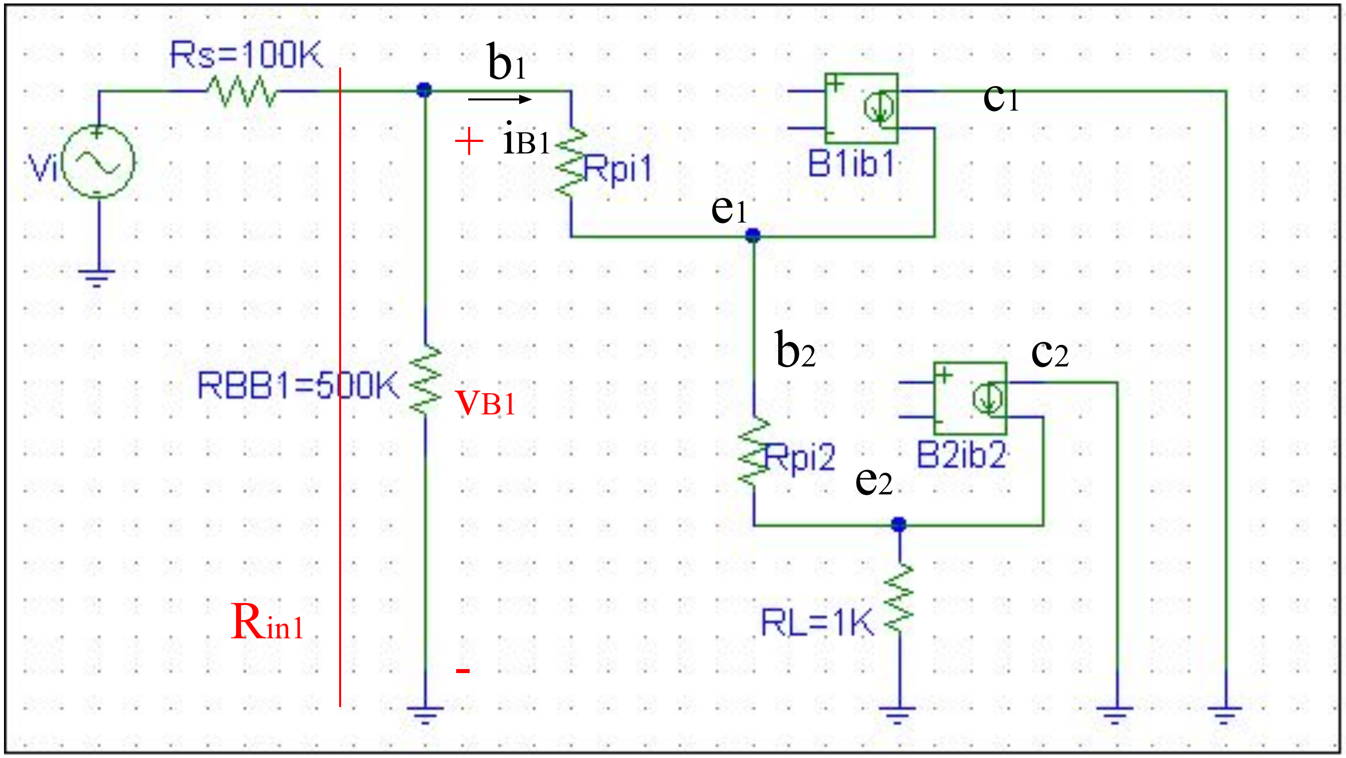


(b) find $R_{in2} = v_{b2}/i_{b2}$

$v_{b2} = (i_{b2} + \beta_2 i_{b2})R_L + i_{b2}Rpi_2$

$$R_{in2} = v_{b2}/i_{b2} = (1 + \beta_2)R_L + Rp$$
$$= (1 + 200)1K + 2.5K$$
$$\approx 204K$$

Prob.



(c) find $R_{in1} = R_{BB1} || (v_{b1}/i_{b1})$

$= R_{BB1} || [i_{b1}Rpi_1 + (i_{b1} + \beta_1 i_{b1})R_{in2}]/i_{b1}$

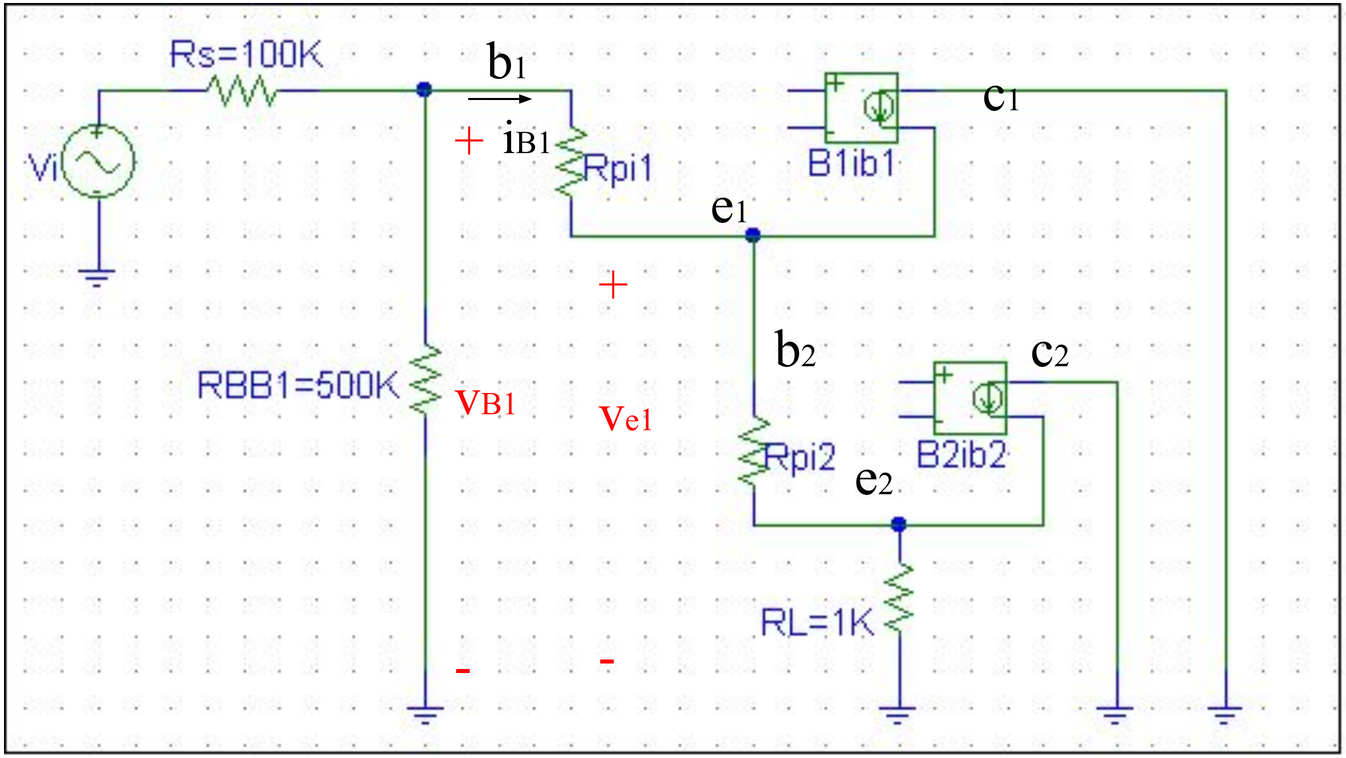
$= R_{BB1} || [Rpi_1 + (1+ \beta_1)R_{in2}]$,

where $Rpi_1 = V_T\, \beta_1/I_{E1} = 25mV(20)/30\mu A = 16.7K$

$= 500K||[16.7K + (1+ 20)204K]$

$\approx 500K\Omega$

Prob.



(c) find v_{e1}/v_{b1}

$$v_{e1} = (i_{b1} + \beta_1 i_{b1})R_{in2}$$

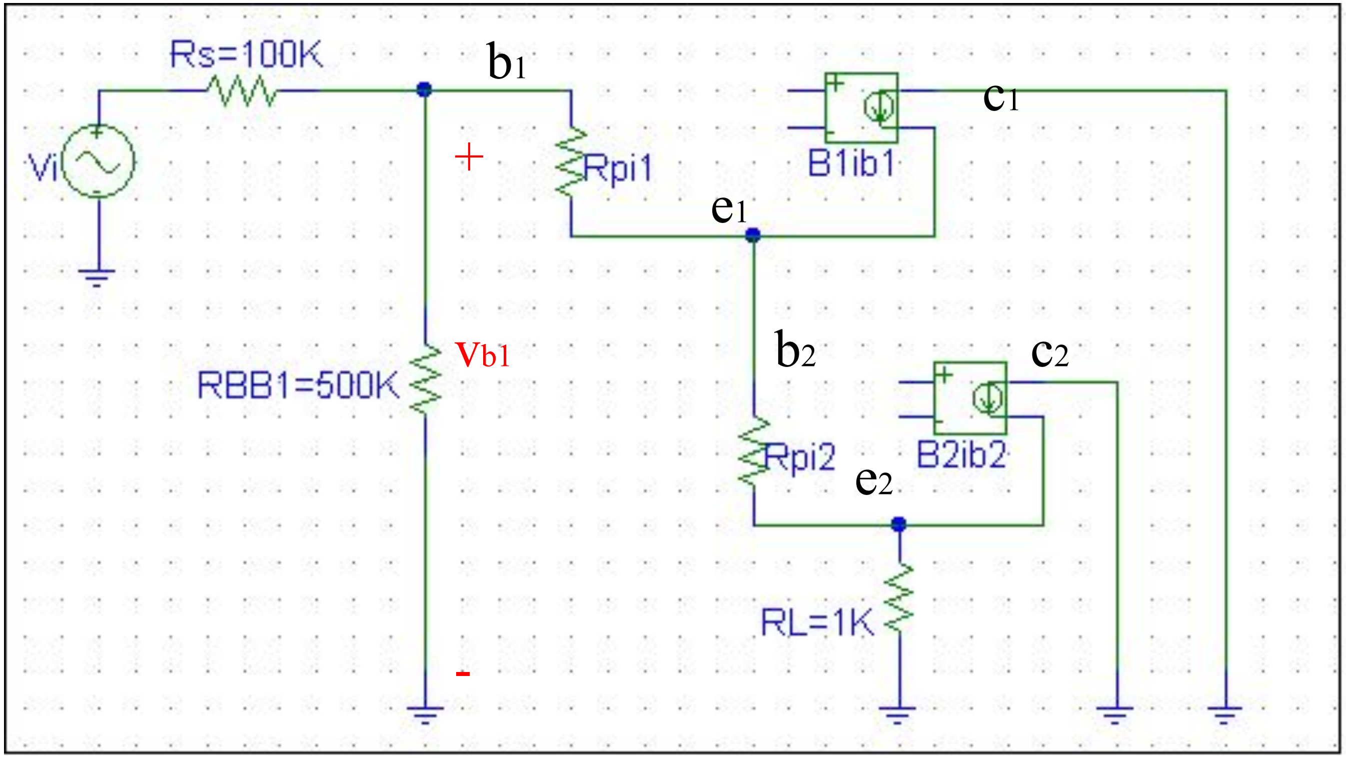
$$v_{b1} = (i_{b1} + \beta_1 i_{b1})R_{in2} + i_{b1}Rpi_1$$

$$v_{e1}/v_{b1} = (1 + \beta_1)\, R_{in2} /[(1 + \beta_1)\, R_{in2} + Rpi_1]$$

$$= (1 + 20)204K/[(1 + 20)204K + 16.7K]$$

$$\approx 0.996$$

Prob.



(d) find v_{b1}/v_i

$v_{b1}/v_i = R_{in1}/[R_S + R_{in1}]$

$= 0.82$

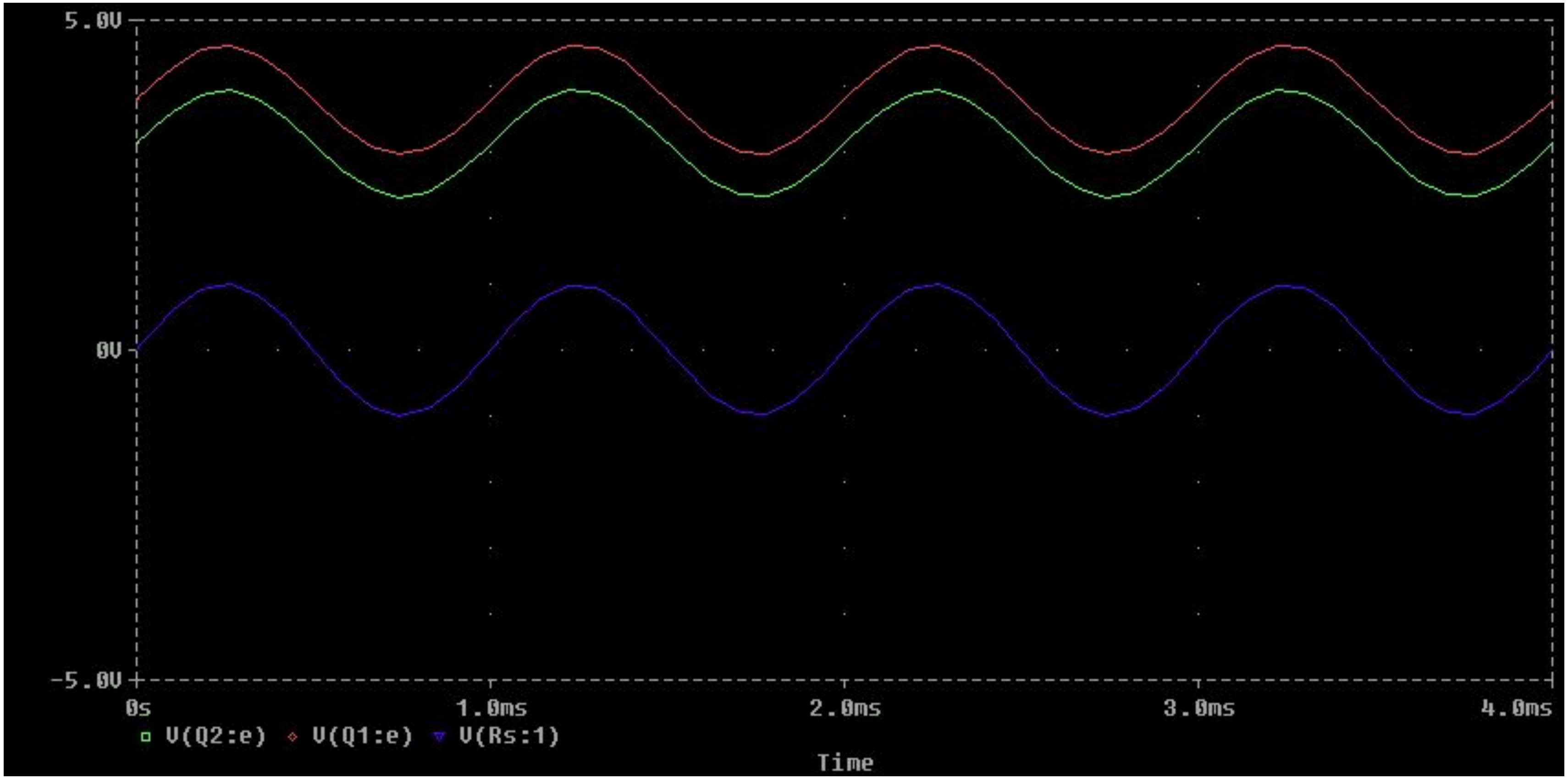
(e) find overall voltage gain

$v_{out}/v_i = (v_{b1}/v_i)\ (v_{e1}/v_{b1})\ (v_{out}/v_{e1})$

$v_{out}/v_i = (0.82)\ (0.99)\ (0.99)$

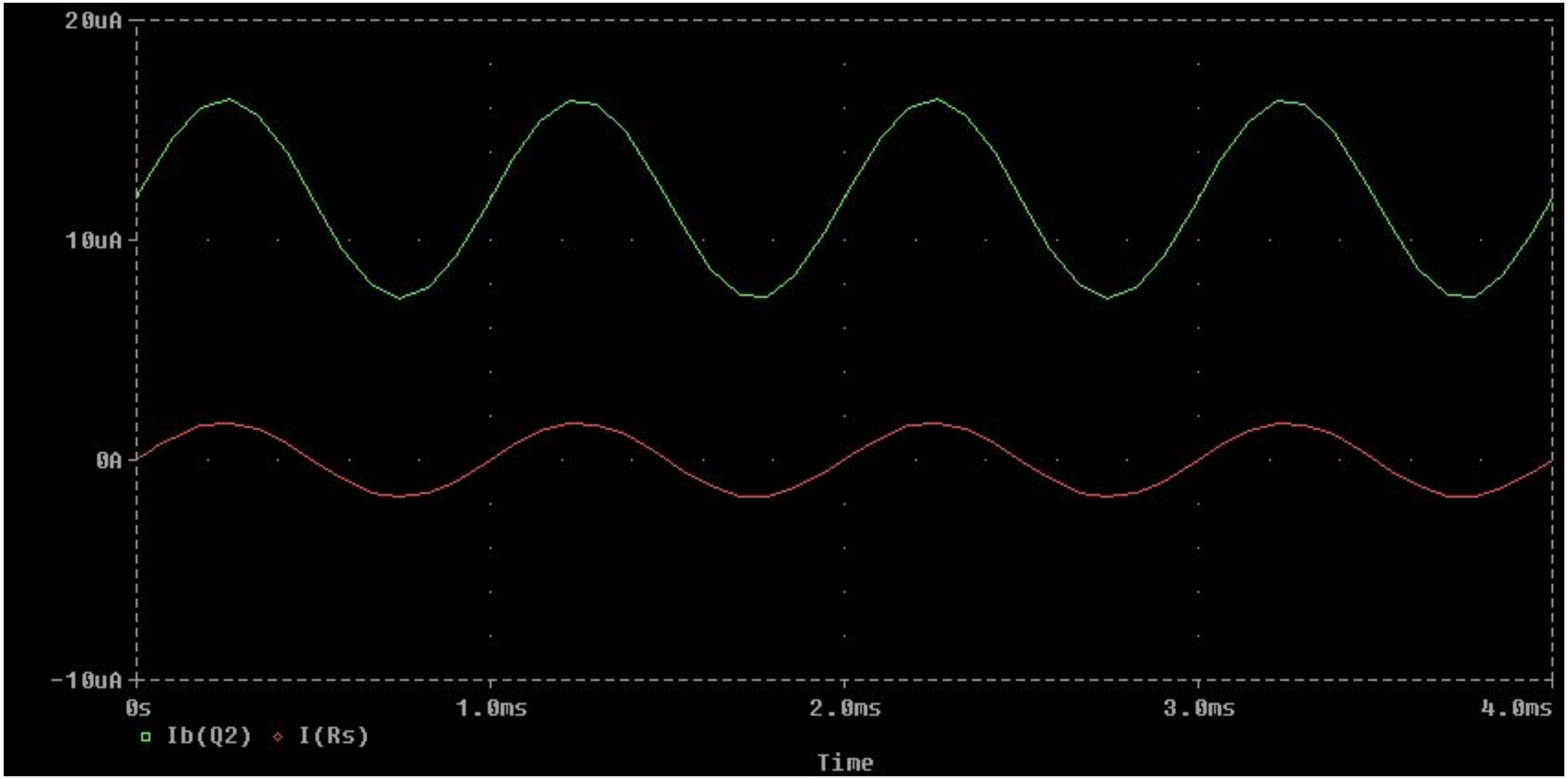
$v_{out}/v_i = 0.81$

Voltage outputs at each stage



Output of stage 2 | Output of stage 1 | Input

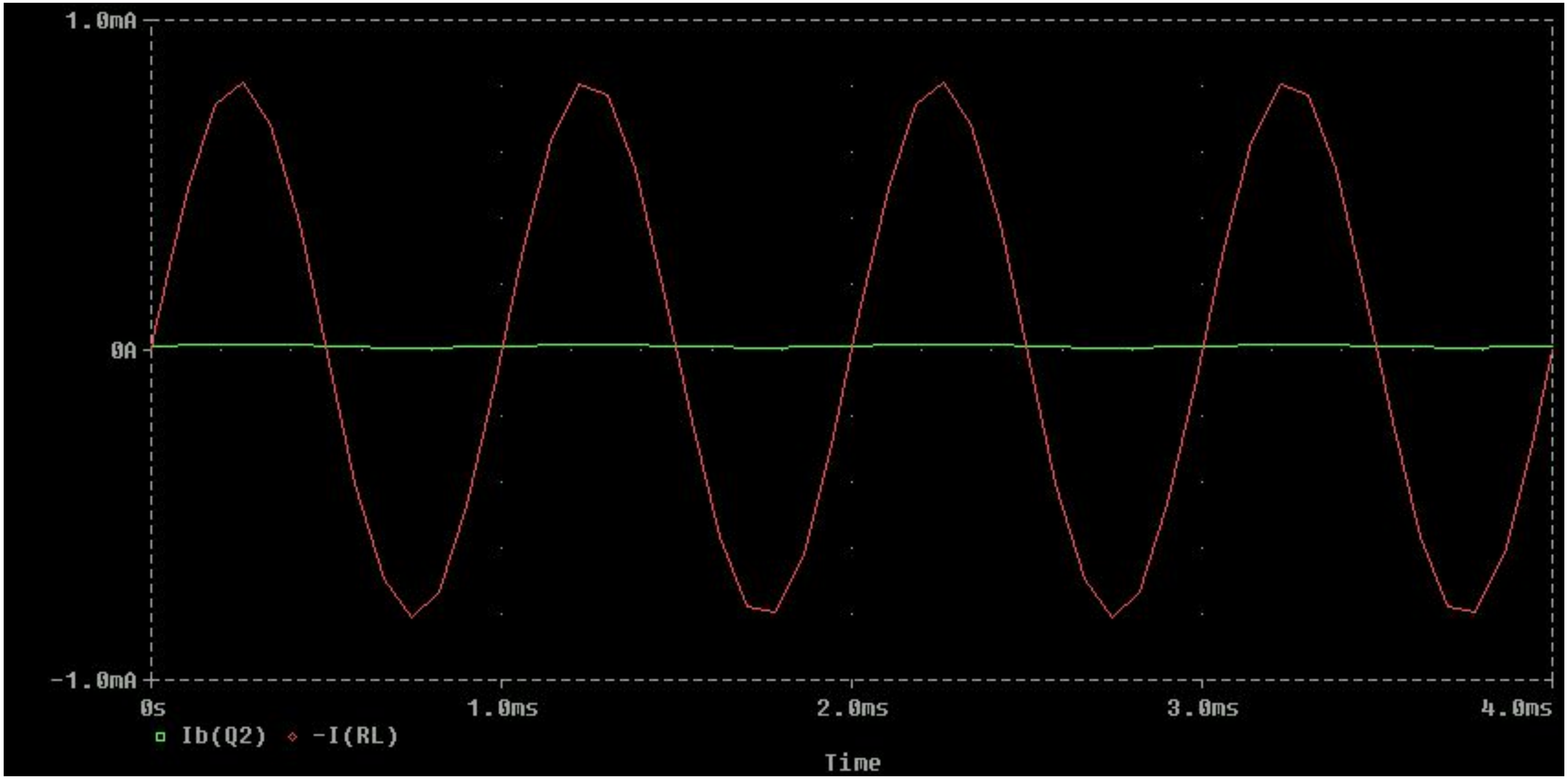
Current



Input to stage 2 (ib2)

Input current

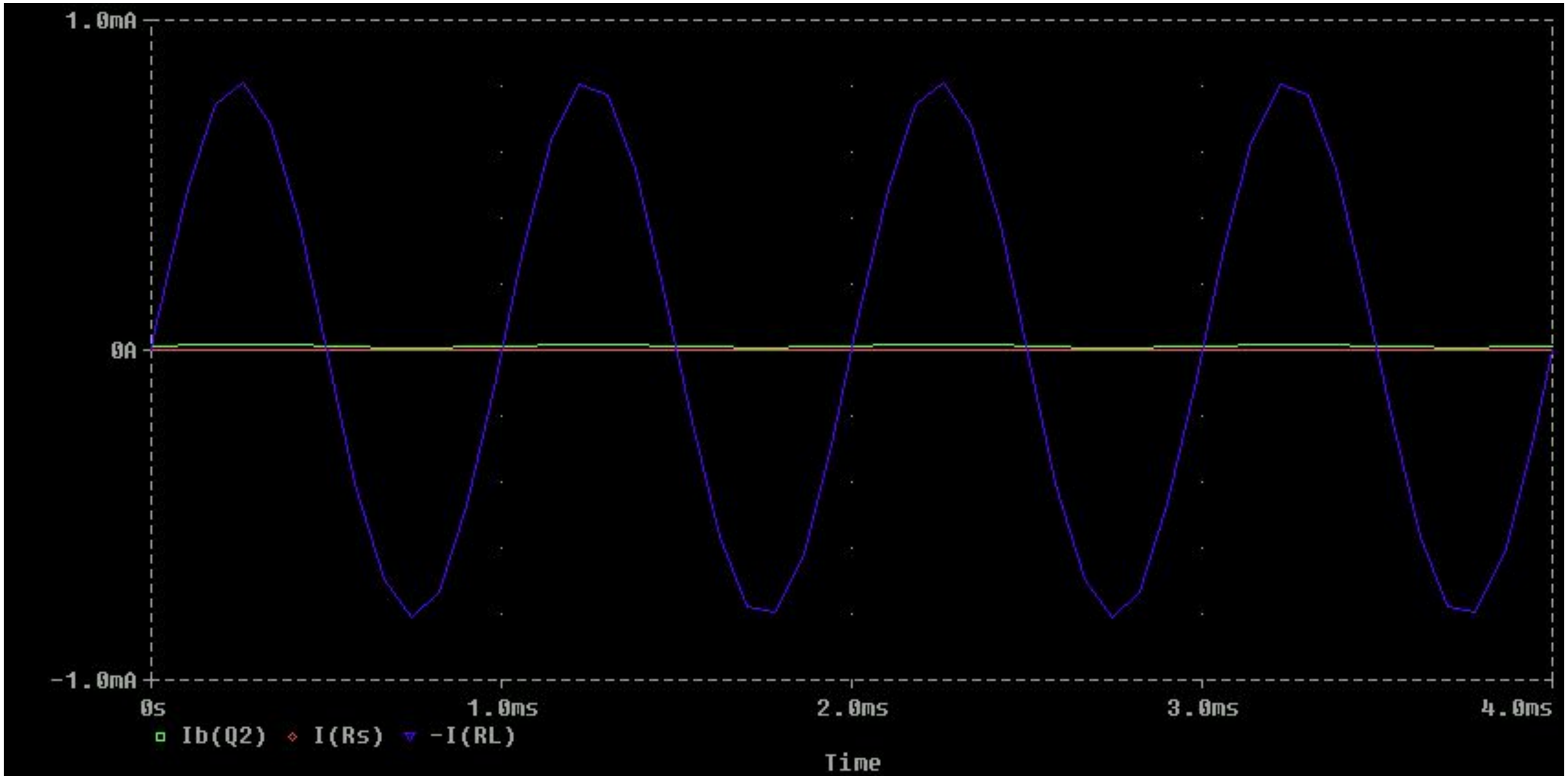
Current



Input to
stage 2 (ib2)

output
current

Current



Input to stage 2 (ib2)

Input current

output current

Power and current gain

Input current = (Vi)/R_{in} = 1/500K = 2.0μA

output current= (Vout)/R_L = (0.81V)/1K= 0.81mA

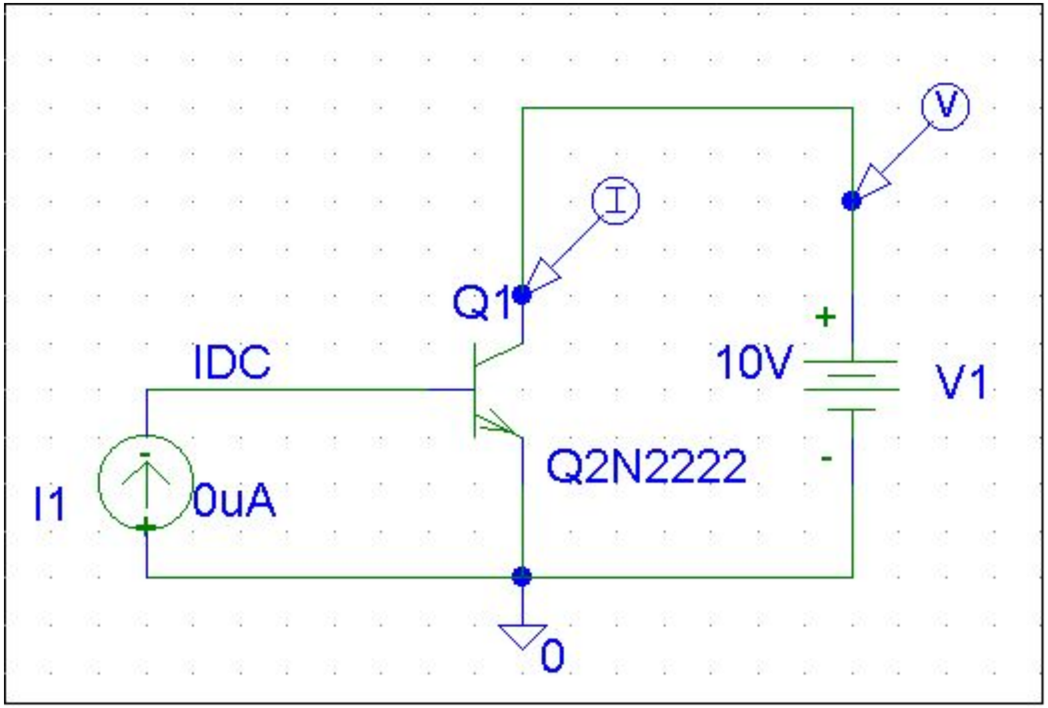
current gain = 0.81mA/ 2.0μA = 405

Input power = (Vi) (Vi)/R_{in} = 1 x 1/500K = 2.0μW

output power = (Vout) (Vout)/R_L = (0.81V) (0.81V)/1K= 656μW

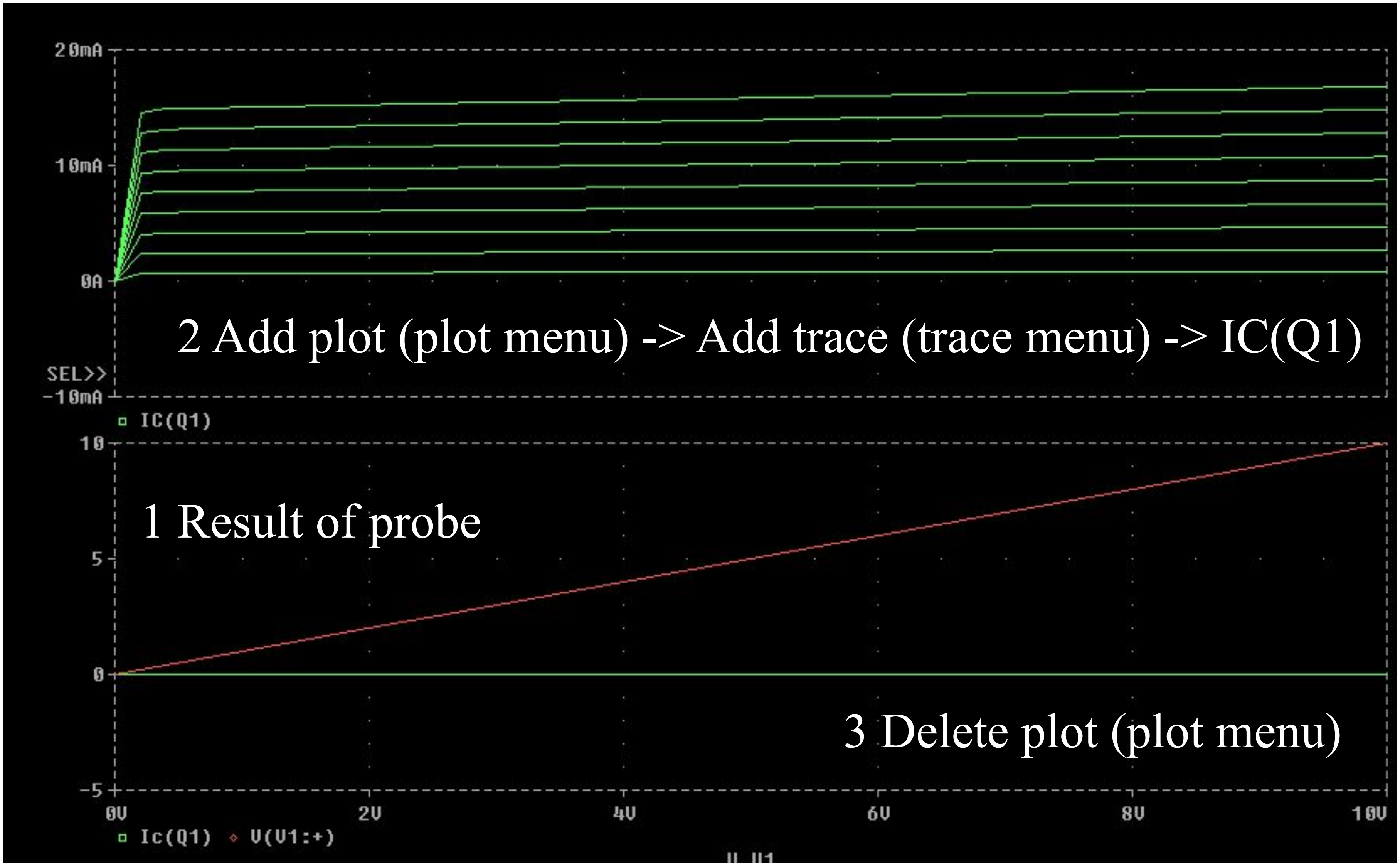
power gain = 656μW/2μW = 329

BJT Output Characteristics

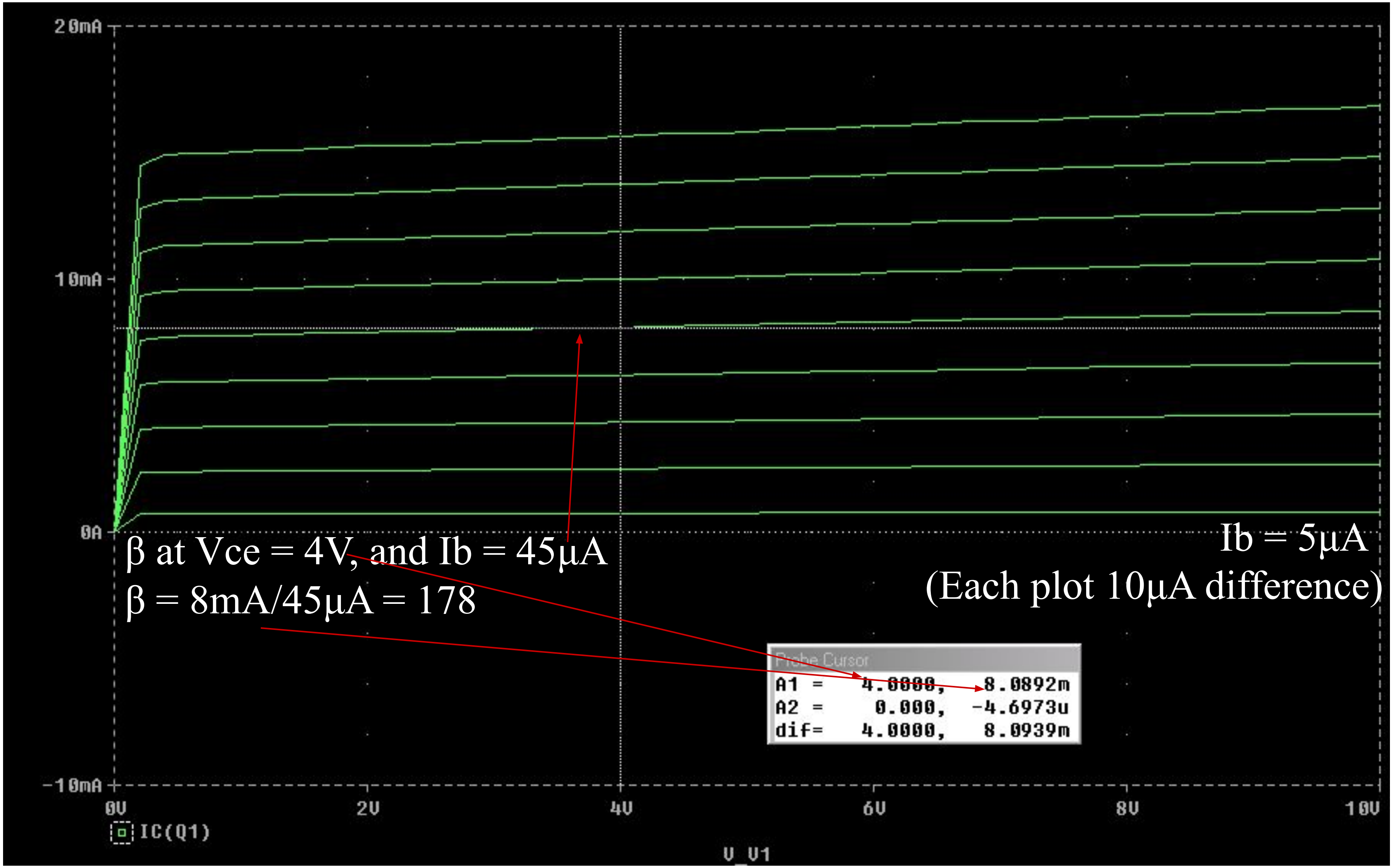


- Plot Ic vs. Vce for multiple values of Vce and Ib
- From Analysis menu use DC Sweep
- Use Nested sweep in DC Sweep section

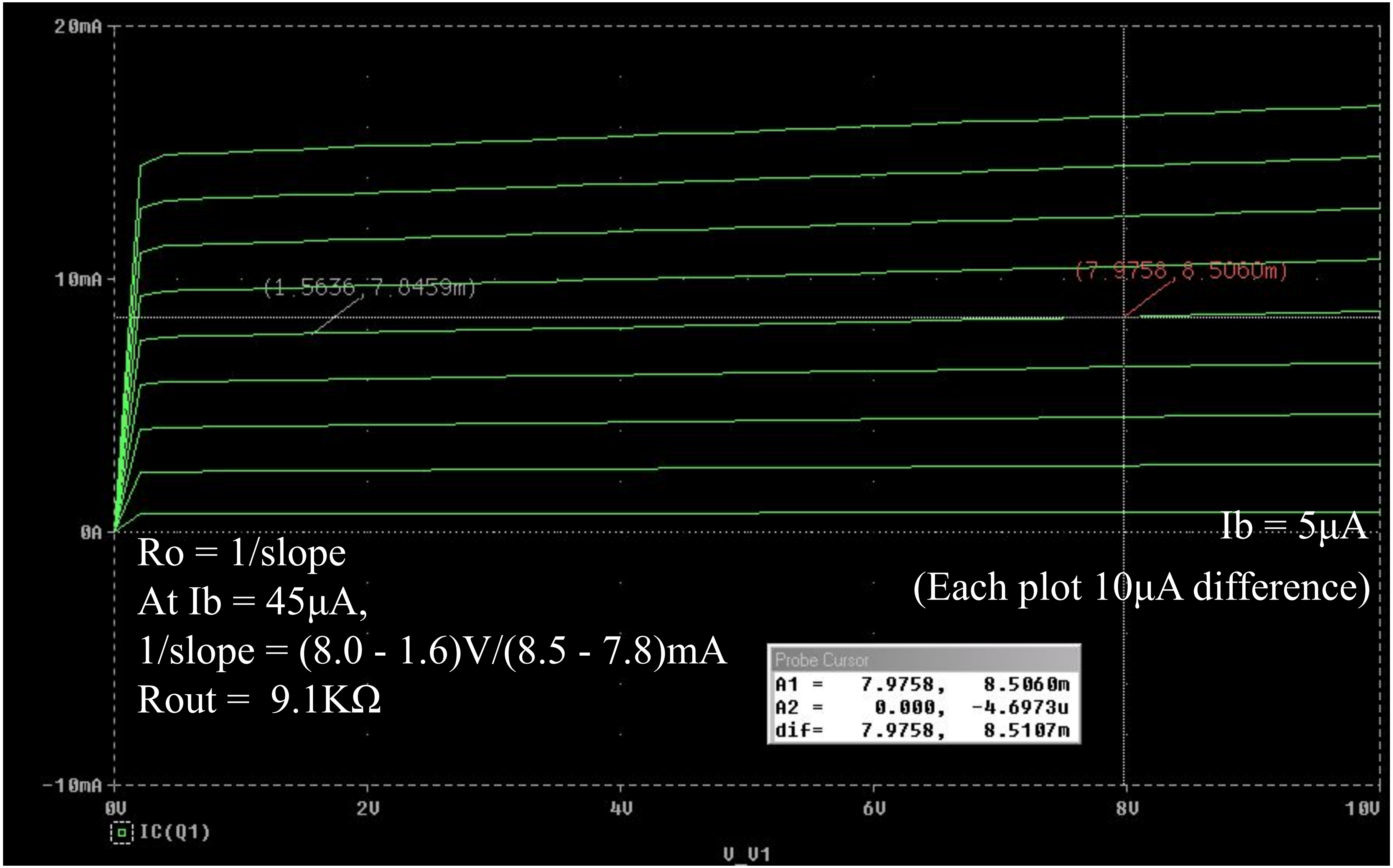
Probe: BJT Output Characteristics



BJT Output Characteristics: current gain



BJT Output Characteristics: transistor output resistance



Ib = 5µA

(Each plot 10µA difference)

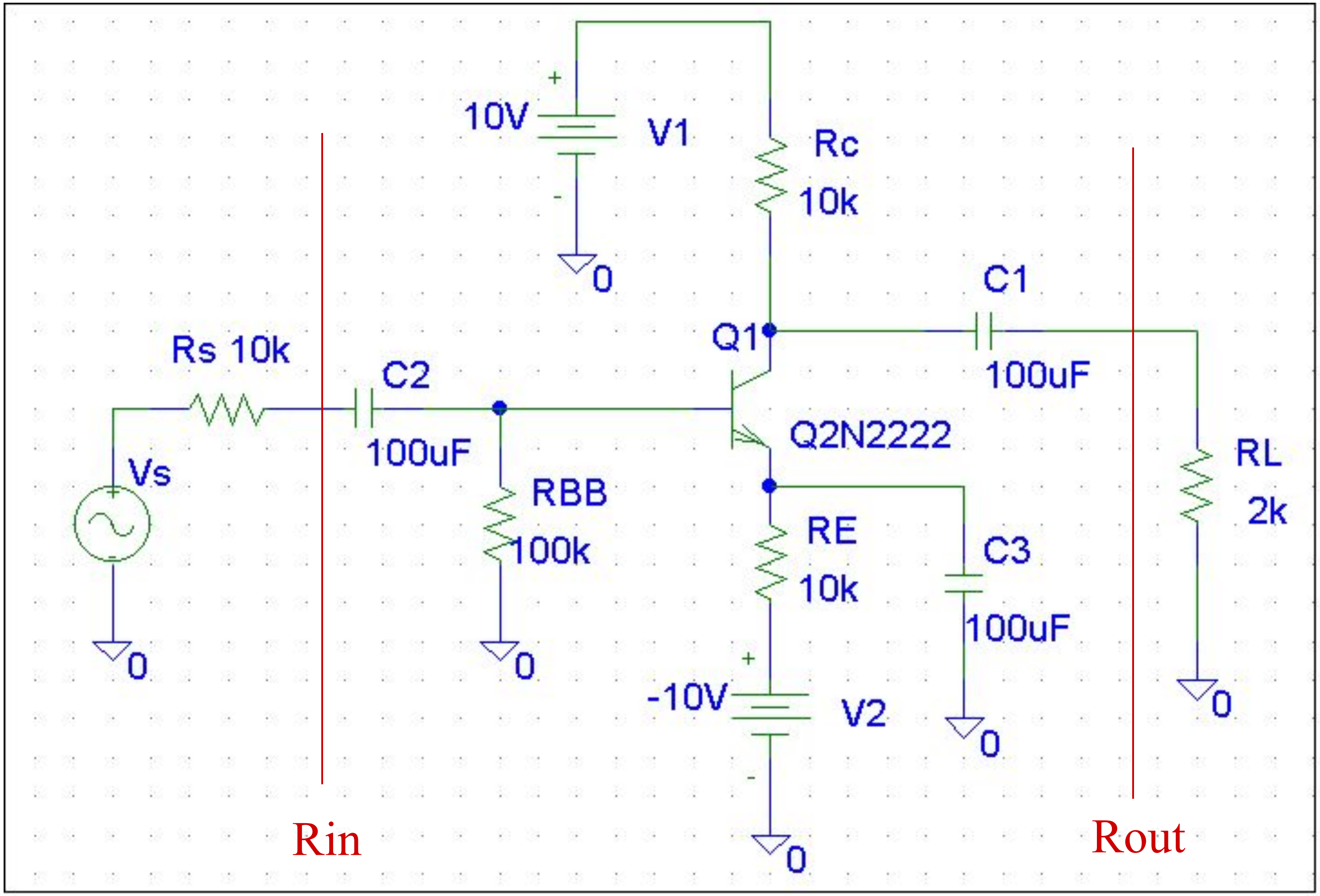
Ro = 1/slope

At Ib = 45µA,

1/slope = (8.0 - 1.6)V/(8.5 - 7.8)mA

Rout = 9.1KΩ

CE Amplifier: Measurements with Spice



Input Resistance Measurement Using SPICE

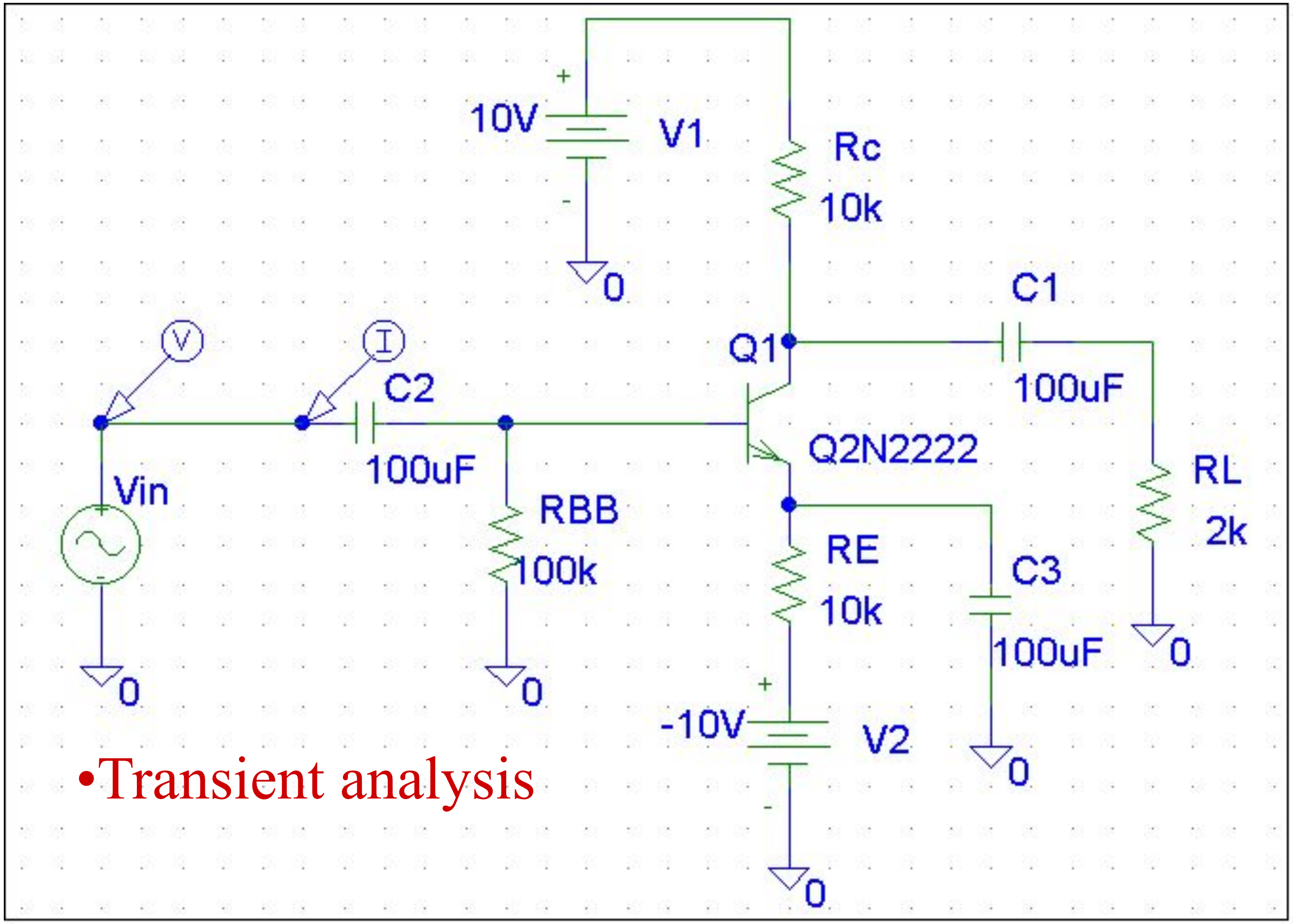
- Replace source, Vs and Rs with Vin, measure
  Rin = Vin/Iin

- Do not change DC problem: keep capacitive coupling
  if present

- Source (Vin) should be a high enough frequency so that
  capacitors act as shorts: Rcap = $|1/\omega C|$. For C = 100µF,
  ω = 1KHz, Rcap = $1/2\pi(1K)(100E\text{-}6) \cong 1.6\Omega$

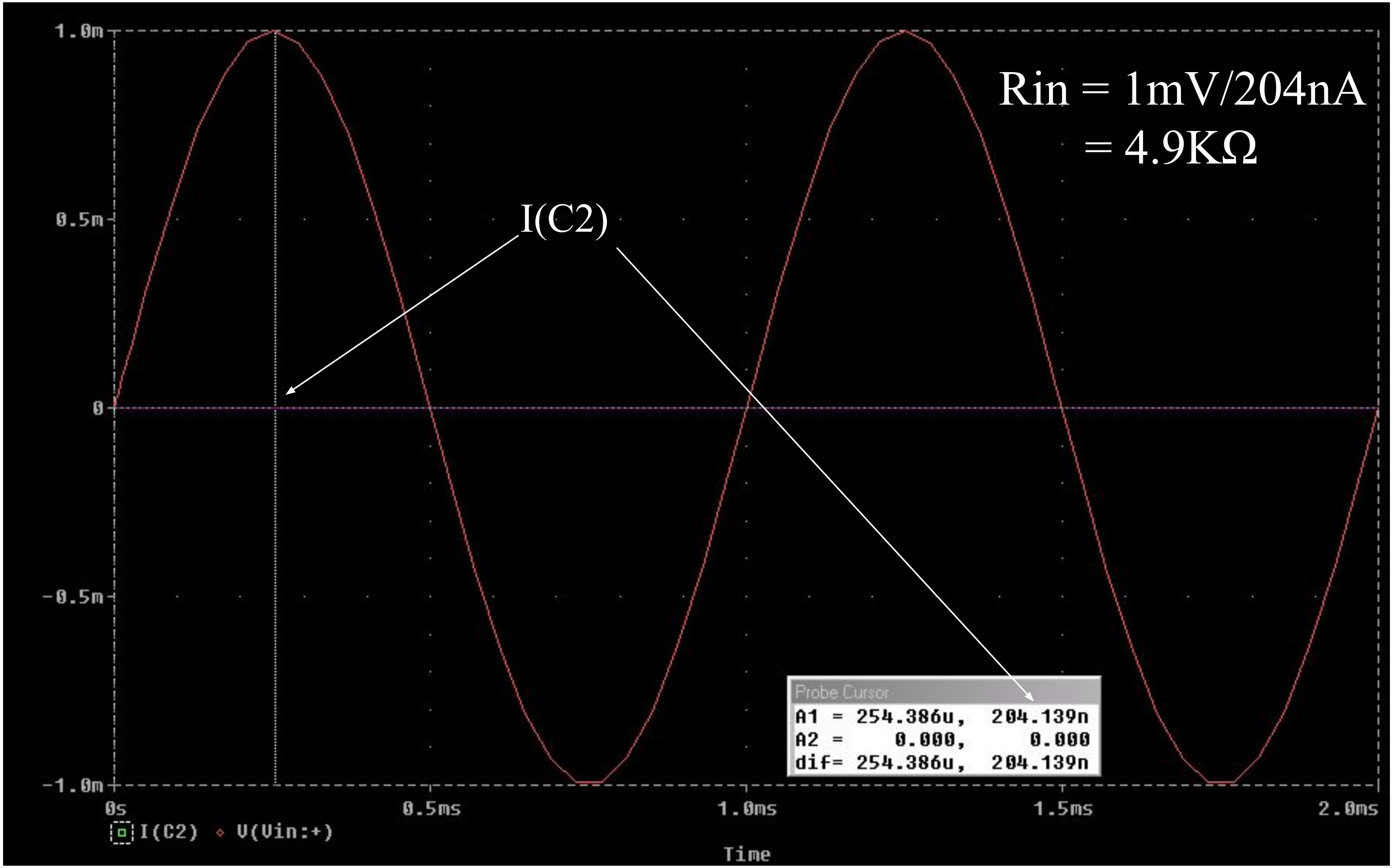
- Vin should have a small value so operating point does not change
  Vin $\cong$ 1mV

Rin Measurement



•Transient analysis

Probe results



Output Resistance Measurement Using SPICE

- Replace load, RL with Vin, measure Rin = Vin/Iin

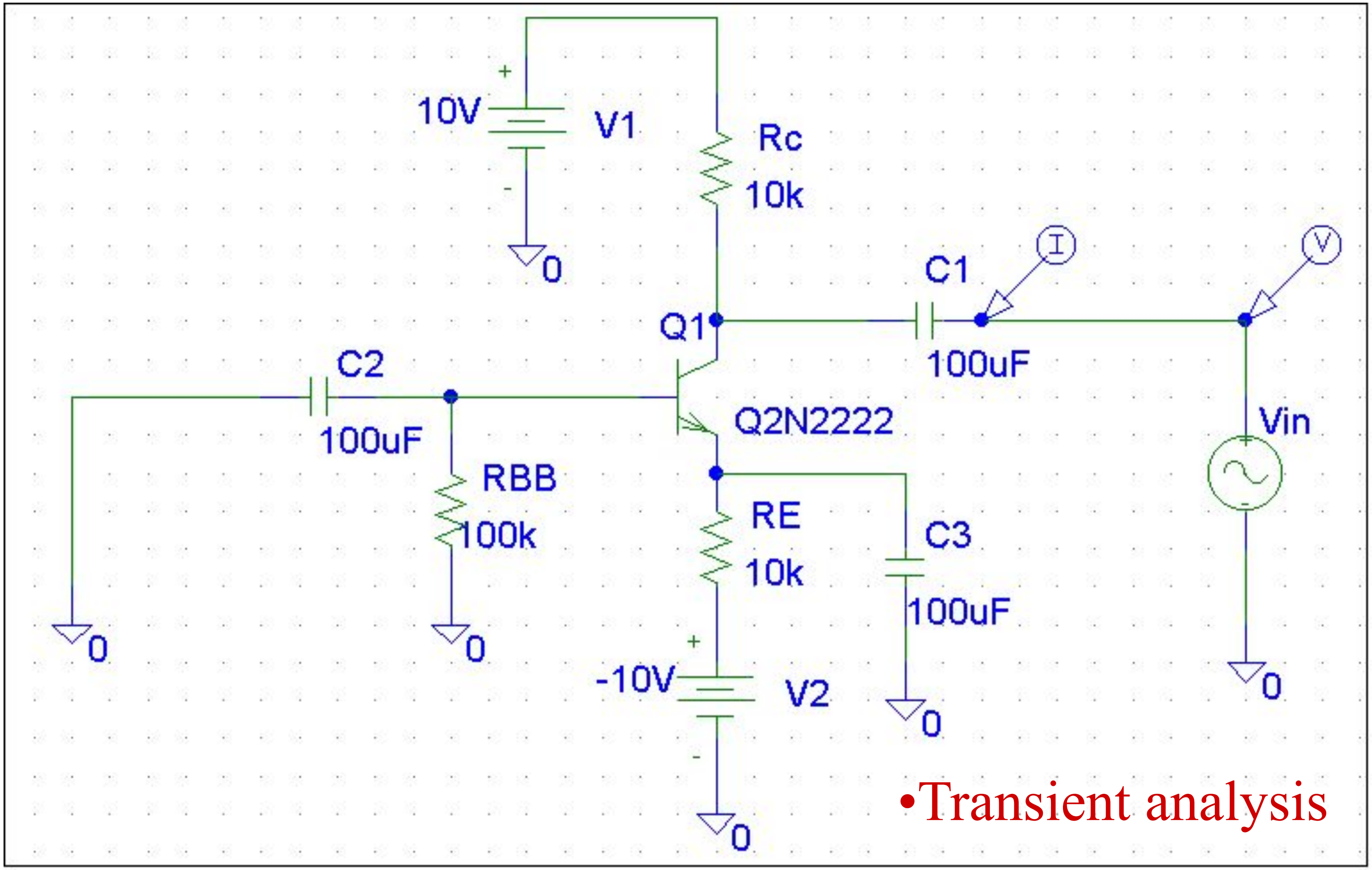
- Set Vs = 0

- Do not change DC problem: keep capacitive coupling if present

- Source (Vin) should be a high enough frequency so that capacitors act as shorts: Rcap = $|1/\omega C|$. For C = 100μF, ω = 1KHz, Rcap = $1/2\pi(1K)(100E-6) \cong 1.6\Omega$

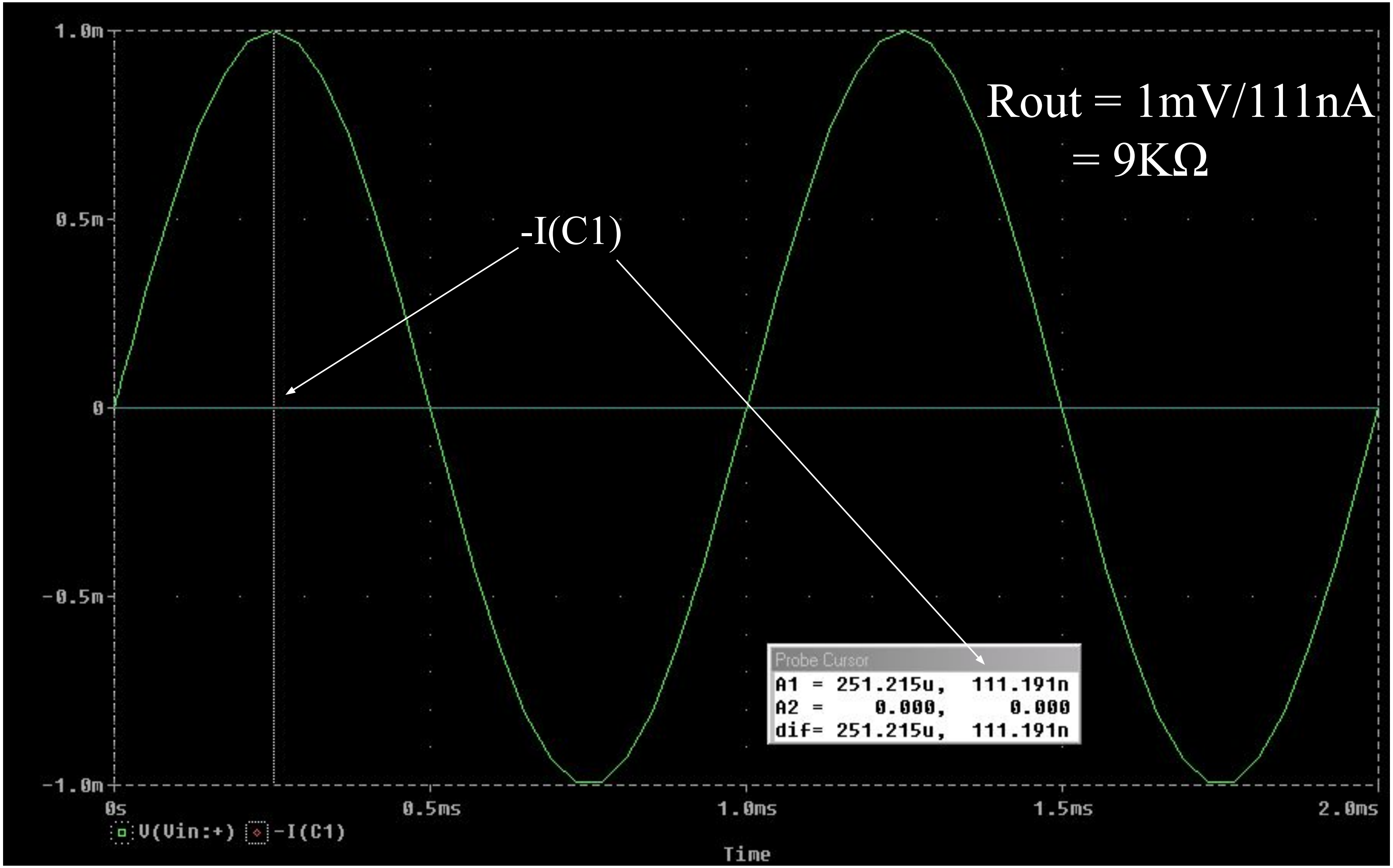
- Vin should have a small value so operating point does not change Vin $\cong$ 1mV

Rout Measurement



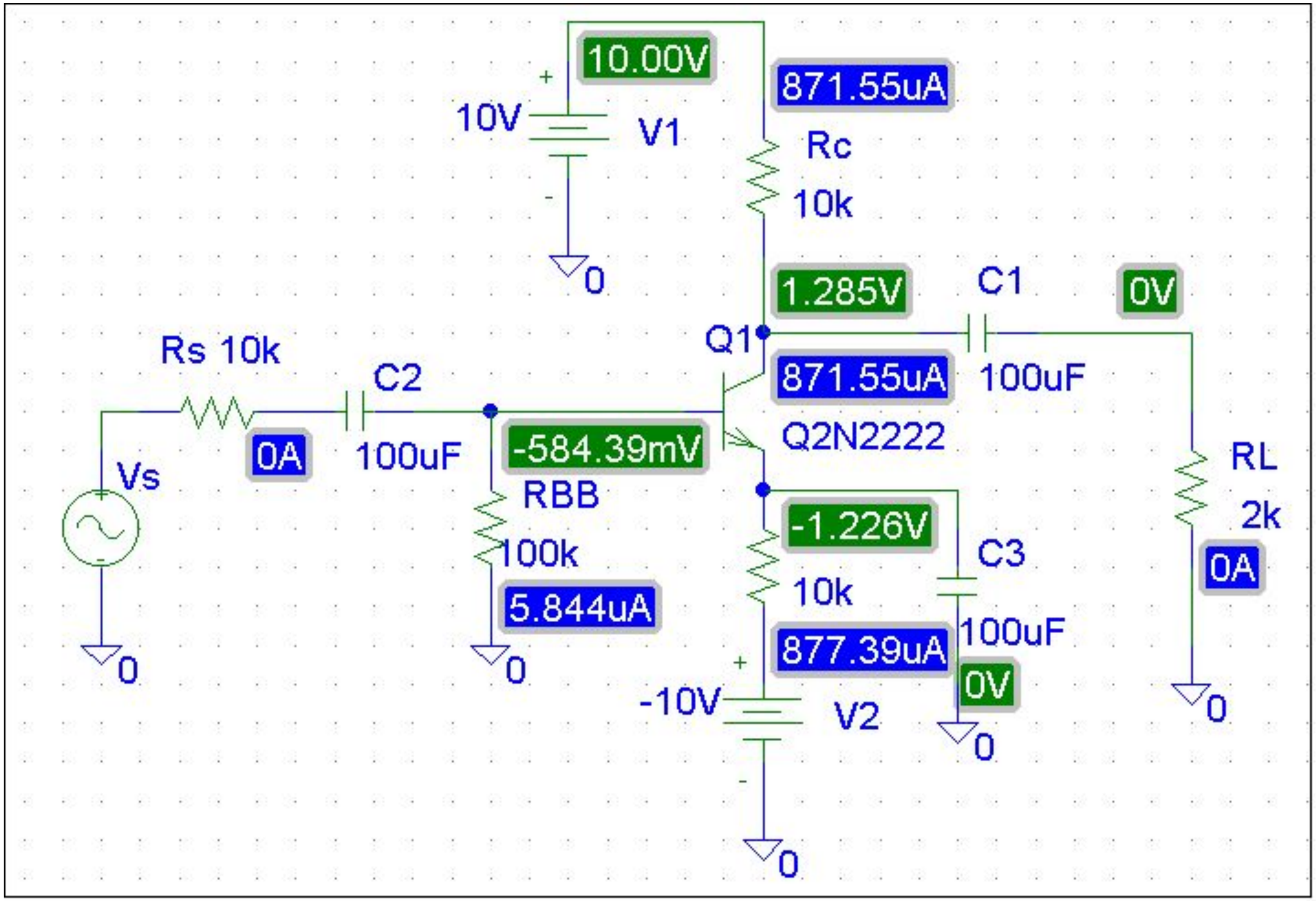
•Transient analysis

Probe results



-I(C1) is current in Vin flowing out of + terminal

DC Power measurements



Power delivered by $\pm$ 10 sources:

(10)(872μA) + (10)(877μA) = 8.72mW + 8.77mW = 17.4mW

ac Power Measurements of Load