- BJT biasing and Amplifier

- Unit-1 and 2

Prepared by
S.Vijayakumar, AP/ECE
Ramco Institute of Technology

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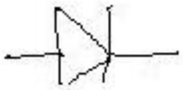
Chap. 4 BJT transistors

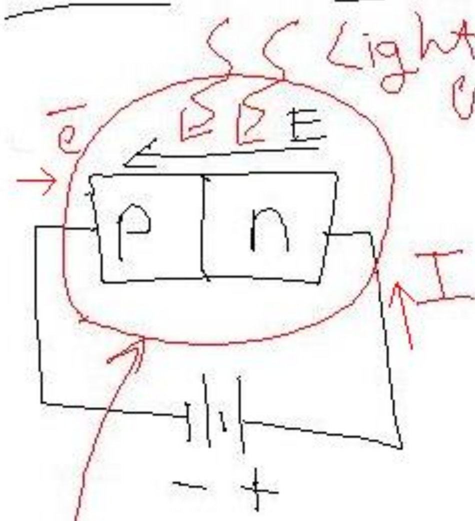
- Widely used in amplifier circuits
- Formed by junction of 3 materials
- npn or pnp structure

Photodiode or Solar Cell



Large area device

reversed biased



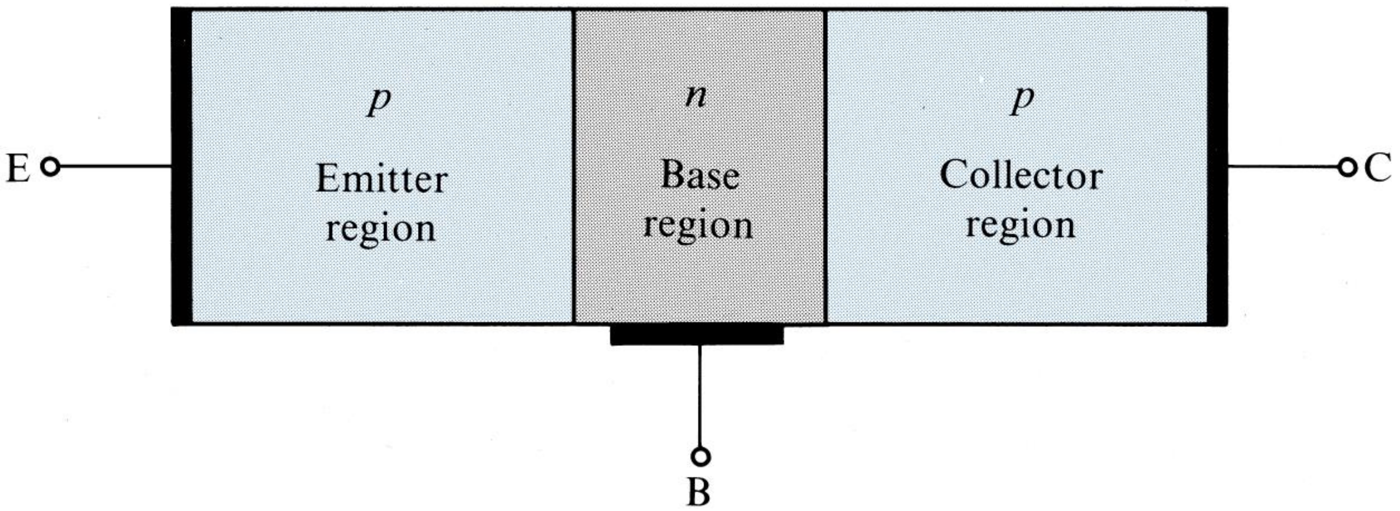
Light creates an electron-hole pair

- the E-field separates the hole & electron before recombination takes places

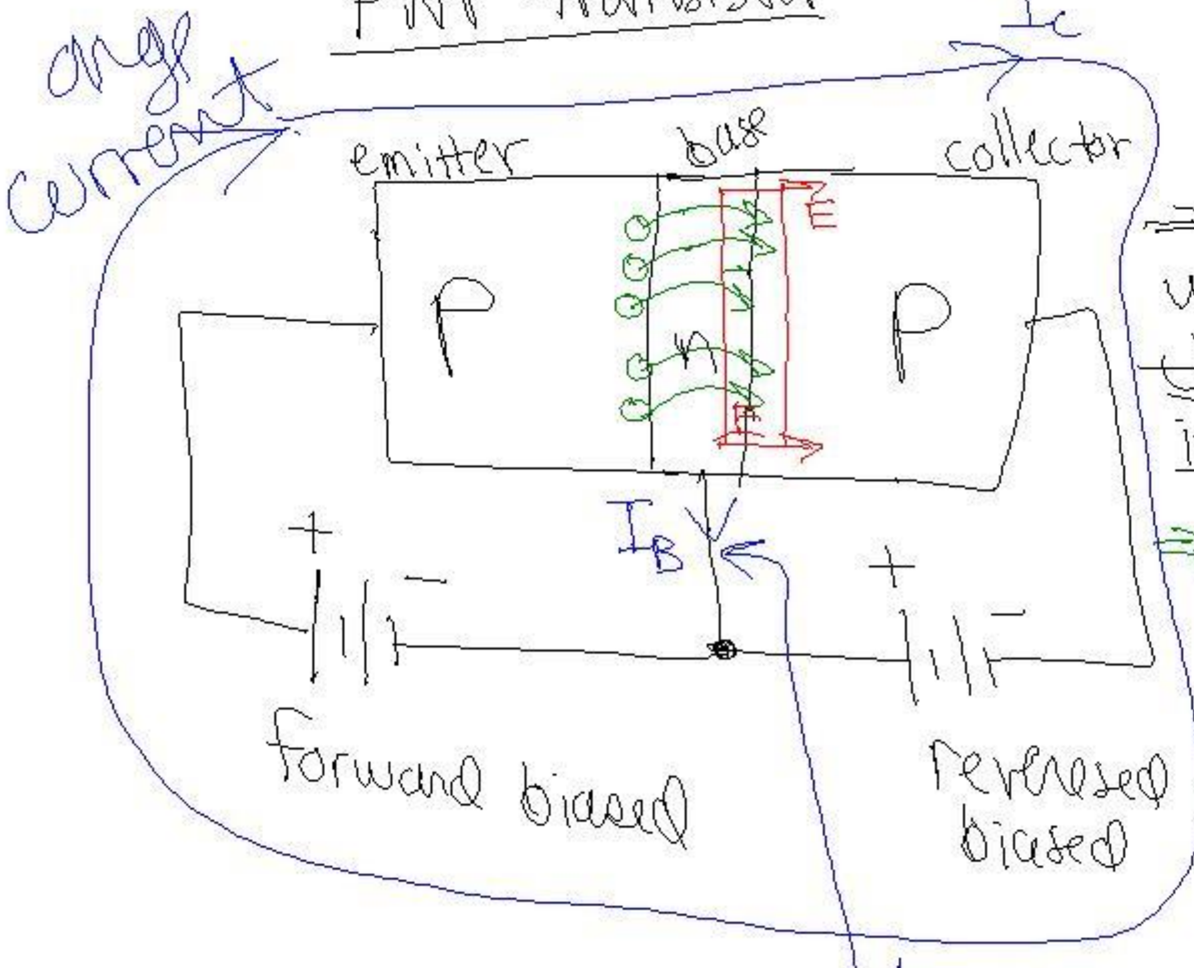
acts as a current source

⇒ A current flows

pnp transistor



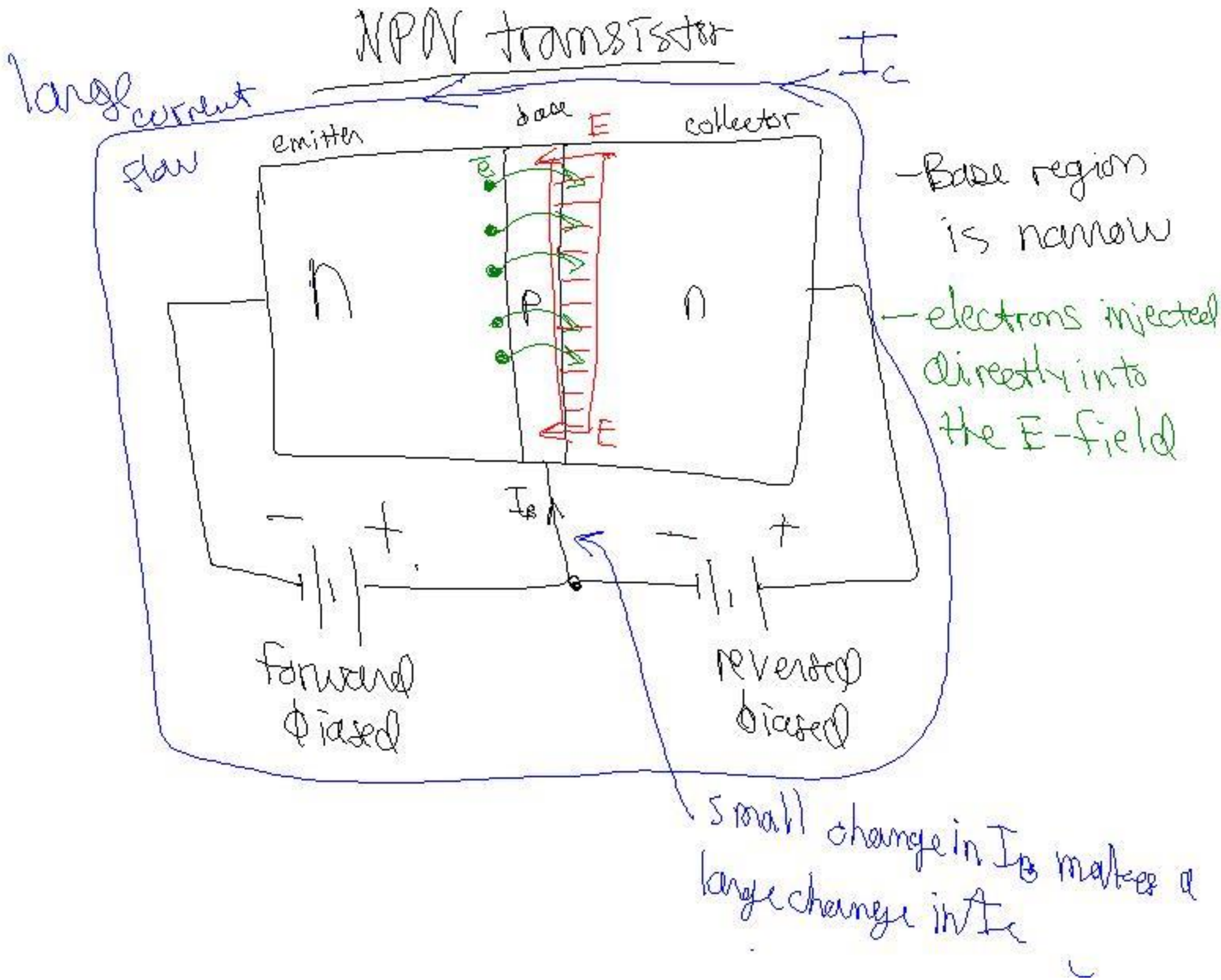
PNP transistor



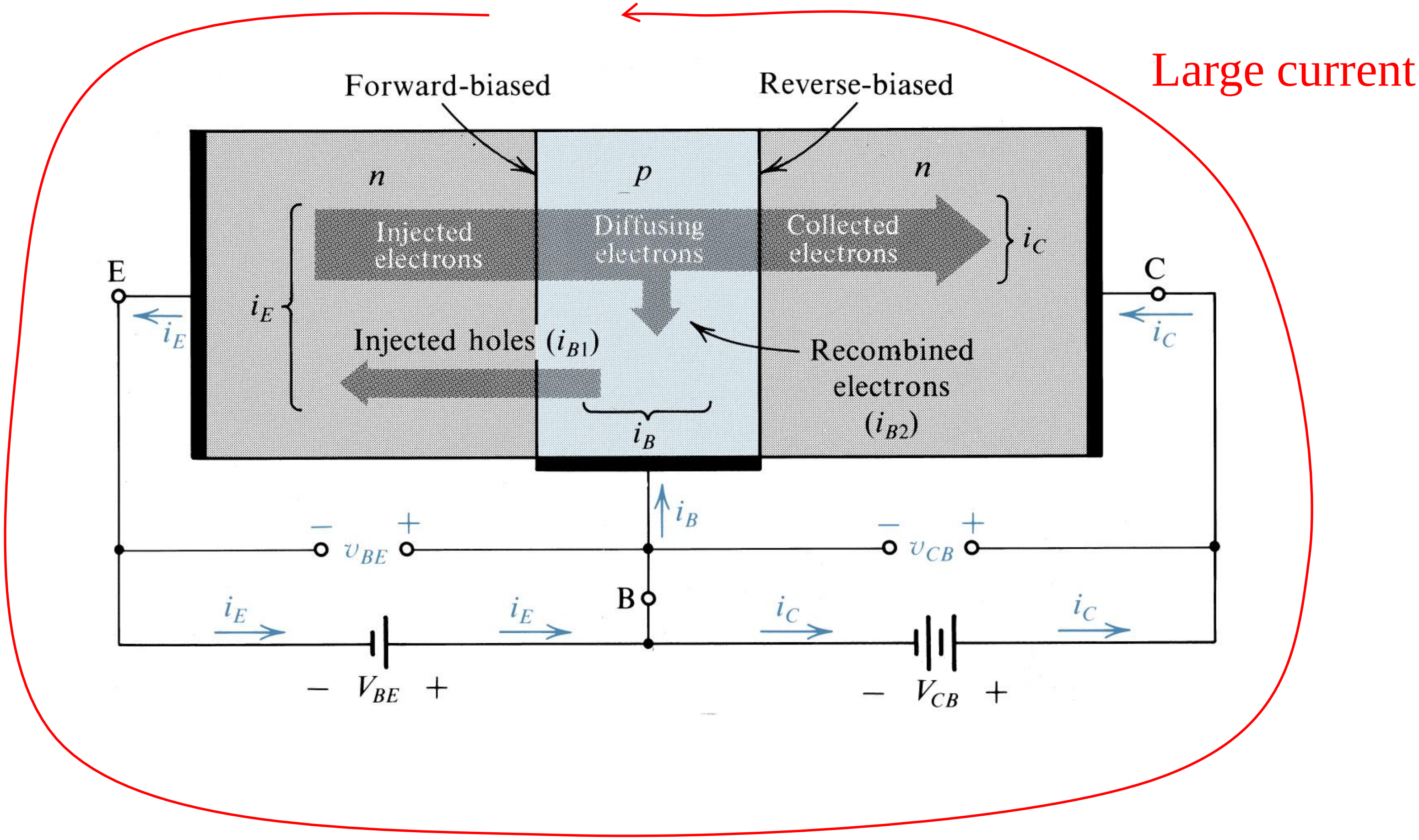
⇒ A transistors works because <u>the base region is narrow</u>

⇒ Holes from the emitter are being <u>injected</u> into the E-field.

A small change in I_B makes a large change in I_C


NPN transistor
large current flow
I_C
emitter
base
collector
E
n
p
n
I_B
- +
- +
forward biased
reversed biased
-Base region is narrow
-electrons injected directly into the E-field
small change in I_B makes a large change in I_C

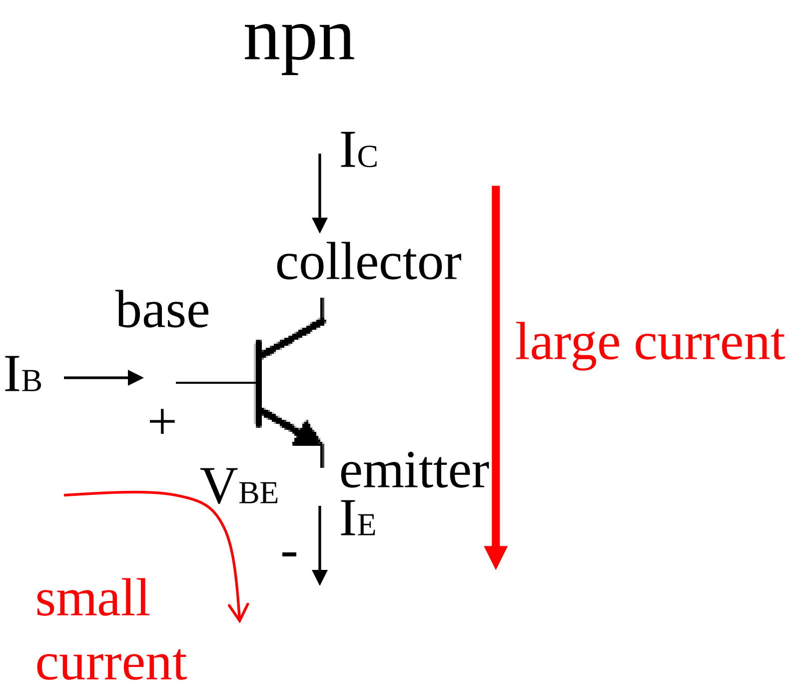
Operation of npn transistor



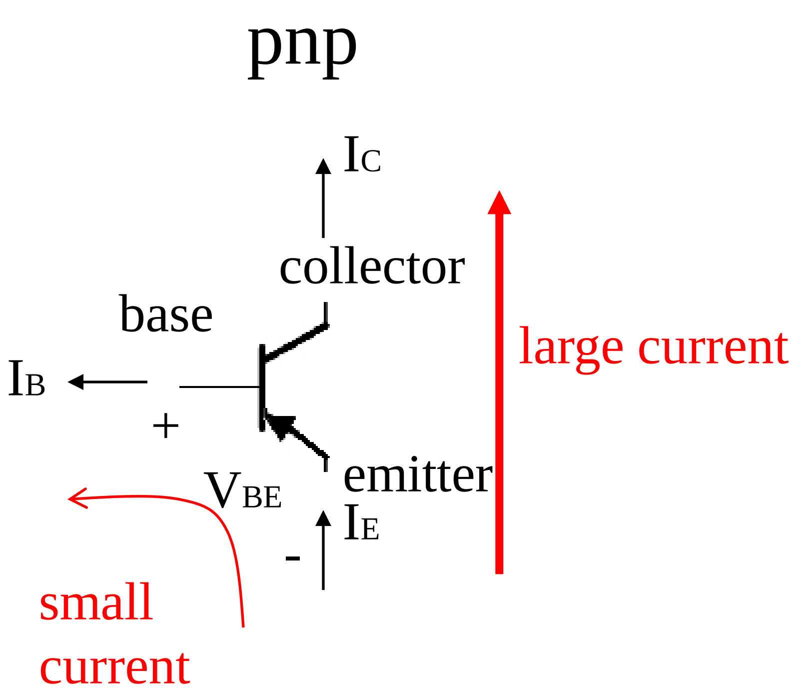
Modes of operation of a BJT transistor

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

$I_E \approx I_C$

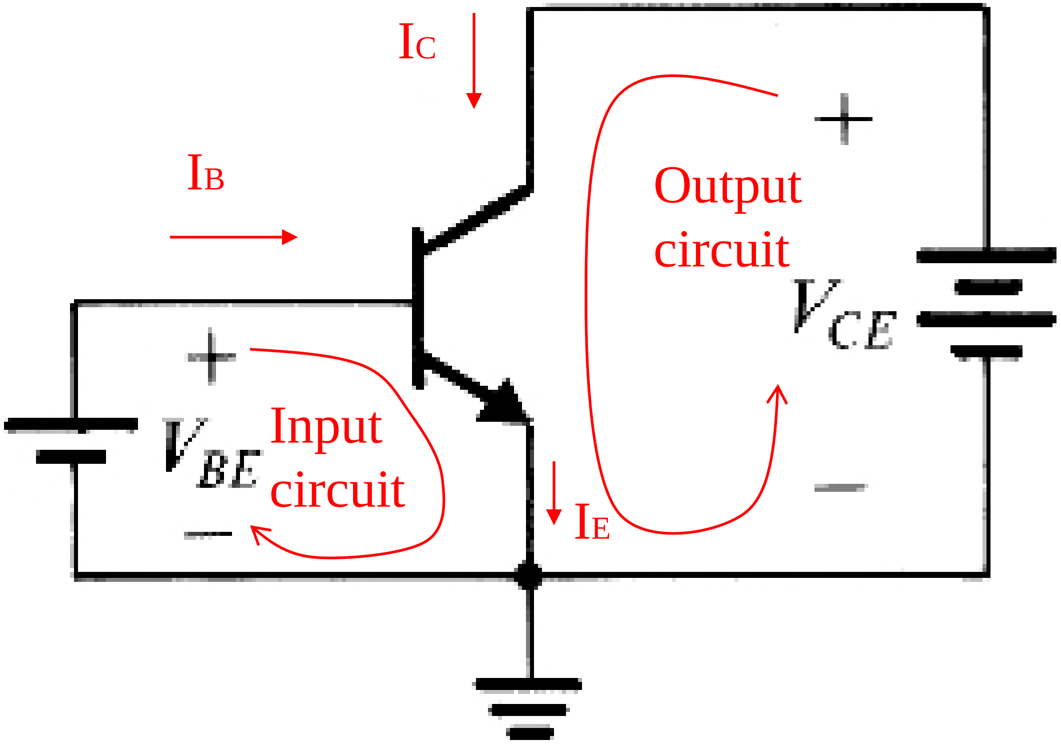
$I_C = \beta I_B$

β is the current gain of the transistor ≈ 100

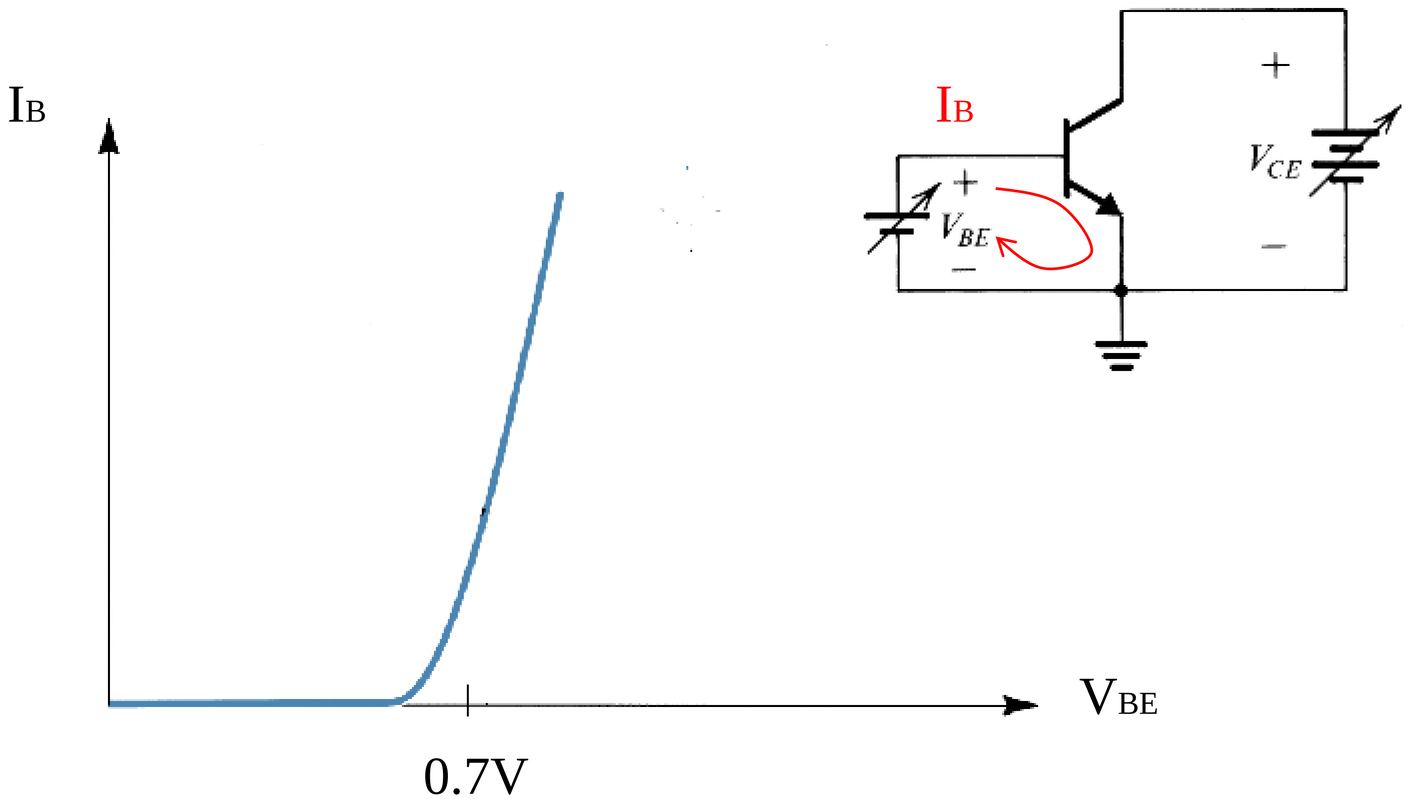
$V_{BE} = 0.7V$(npn)

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

4.5 Graphical representation of transistor characteristics

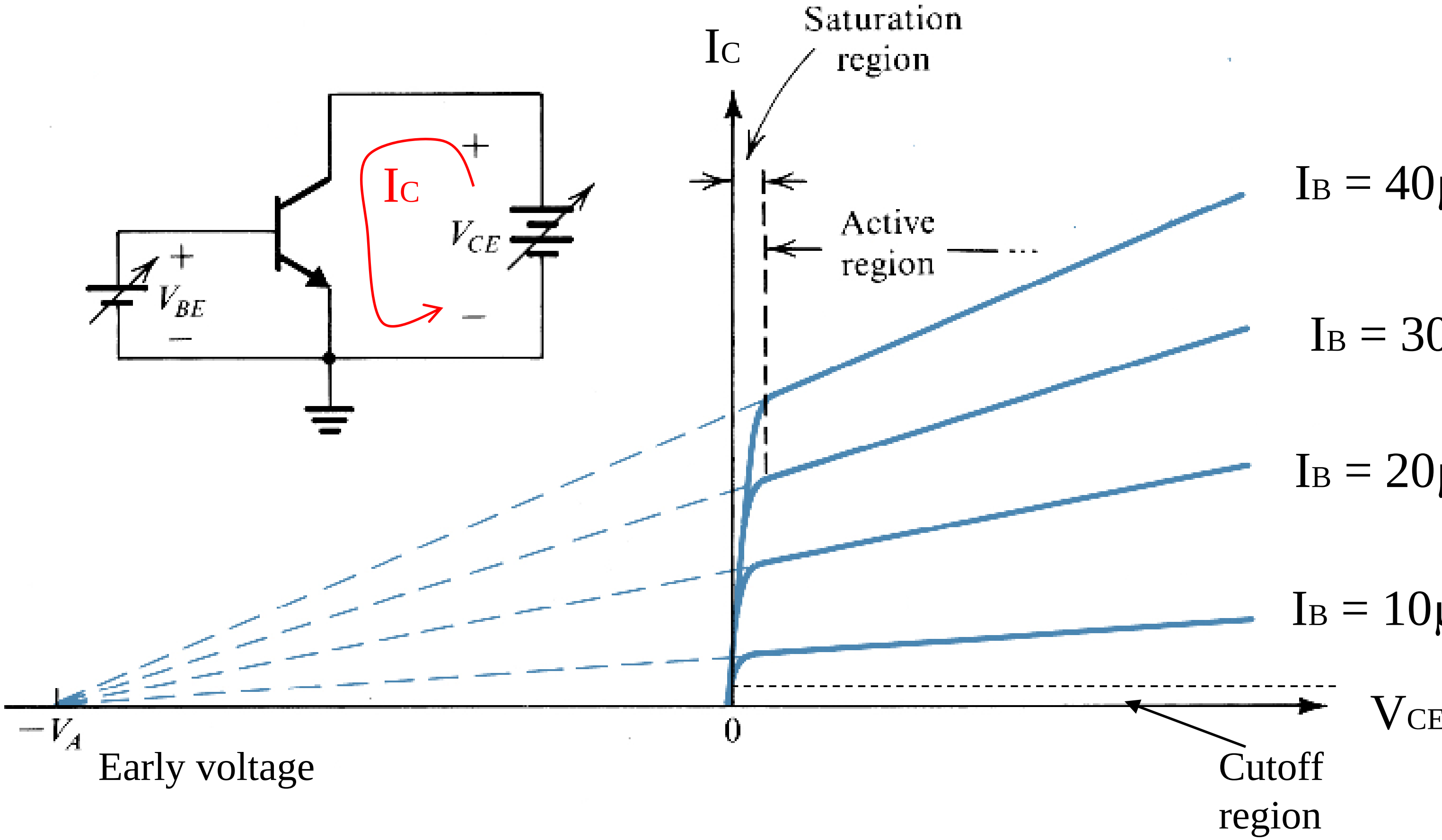


Input characteristics



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

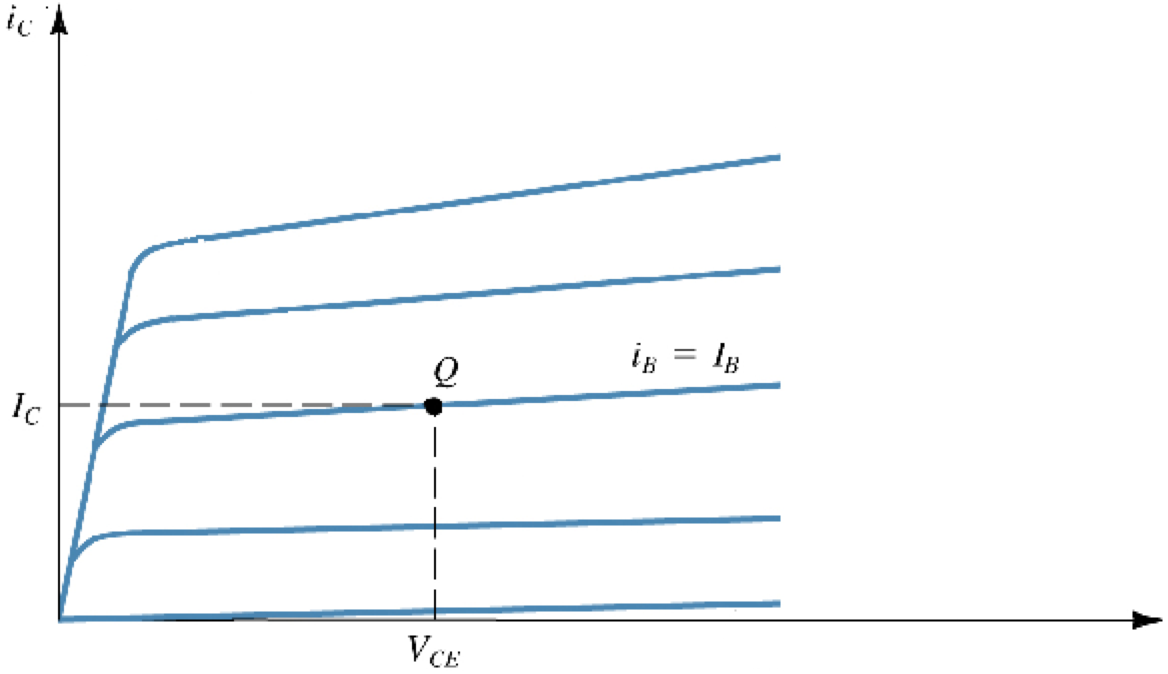
Output characteristics



- 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)

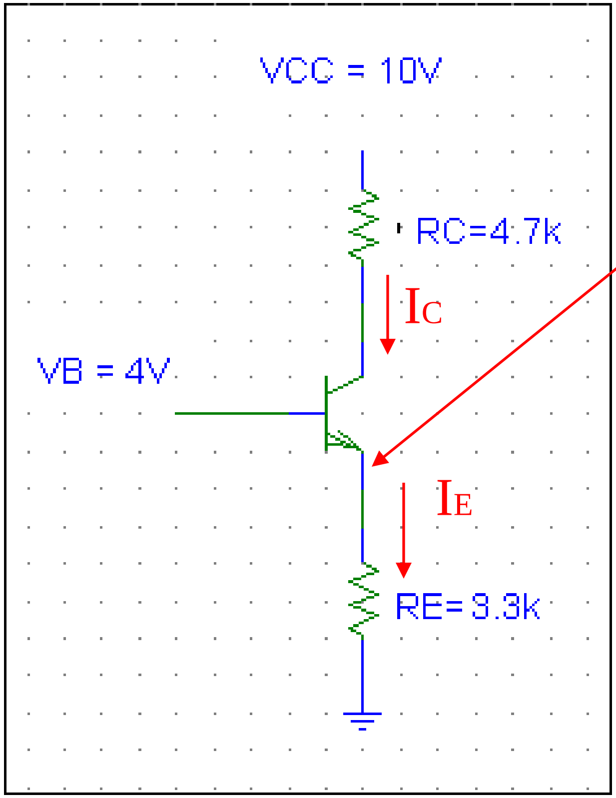
Biasing a transistor

- 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.



4.6 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 4.2

B-E junction acts like a diode

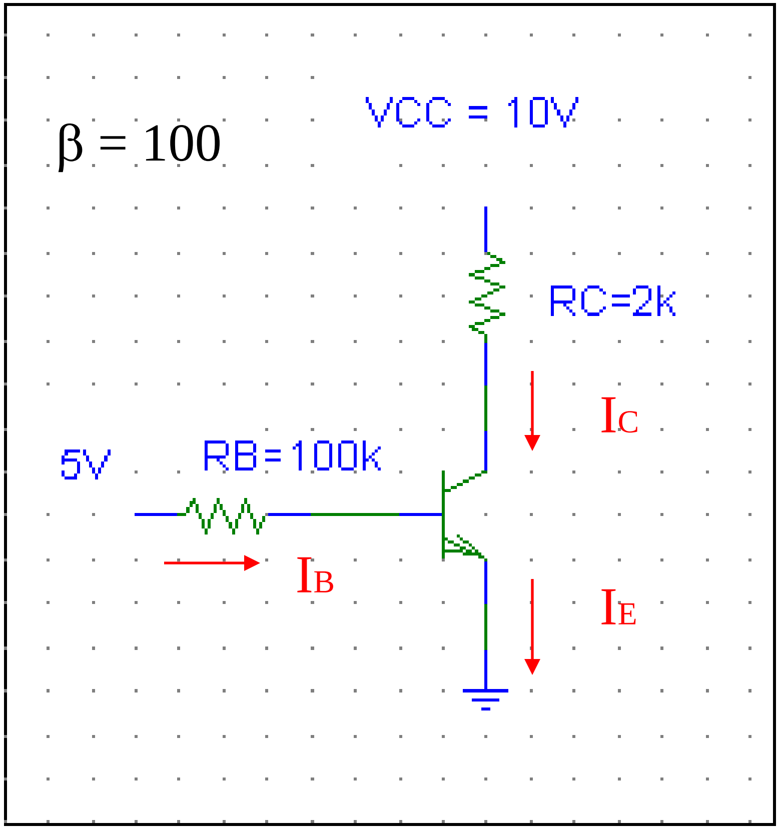
$V_E = V_B - V_{BE} = 4V - 0.7V = 3.3V$

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

$I_C \approx I_E = 1mA$

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

Example 4.6



B-E Voltage loop

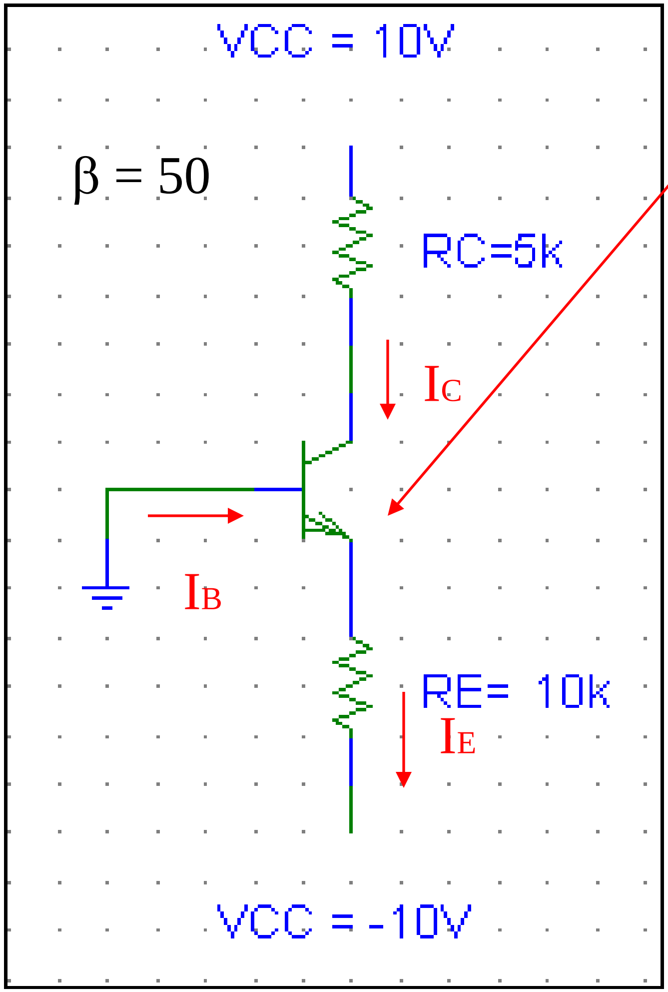
$5 = I_B R_B + V_{BE}$, solve for I_B

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

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

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

Exercise 4.8



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

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

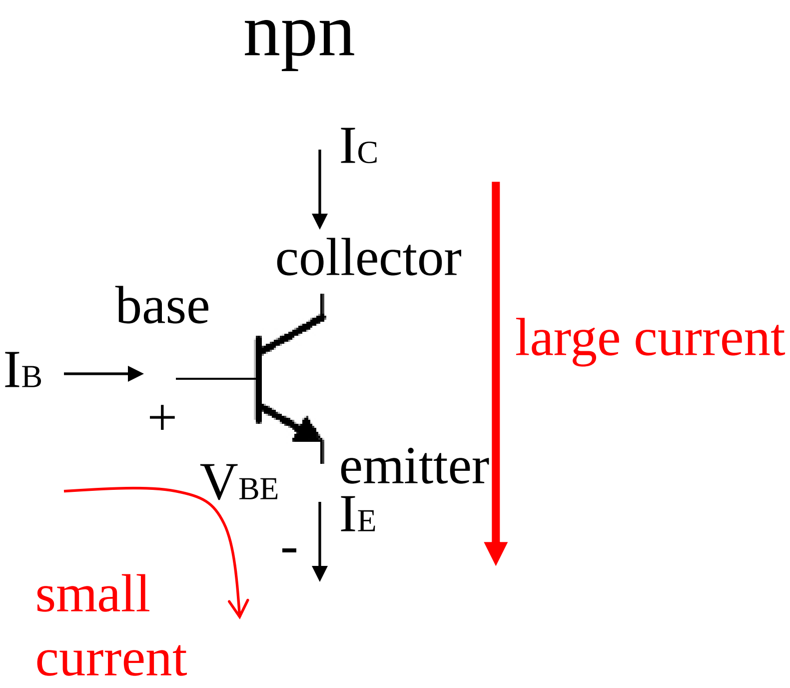
$I_C \approx I_E =$ 0.93mA

$I_B = I_C/\beta = .93mA/50 =$ 18.6μA

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

$V_{CE} = 5.35 - -0.7 =$ 6.05V

Summary of npn 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)

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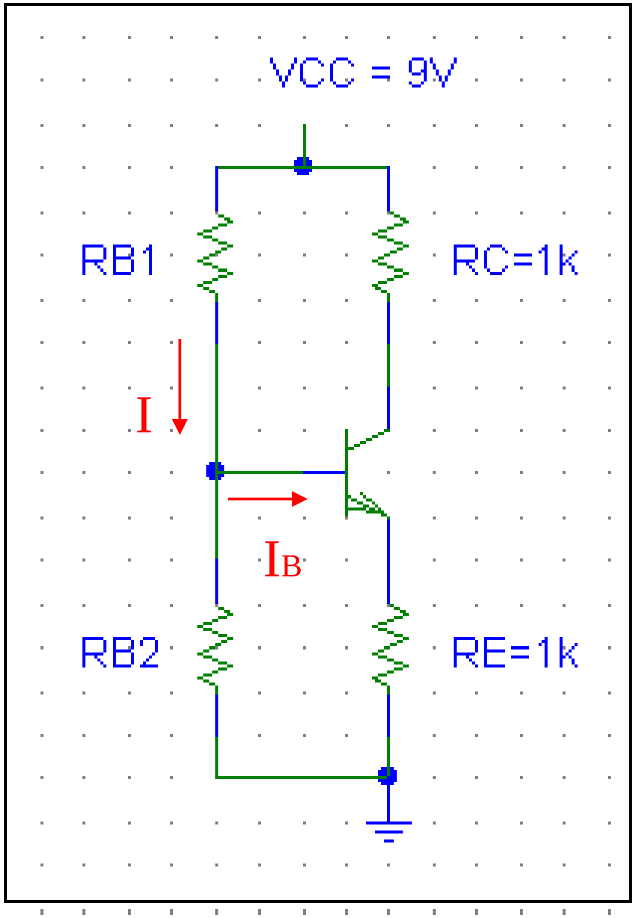
Prob. 4.32



•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

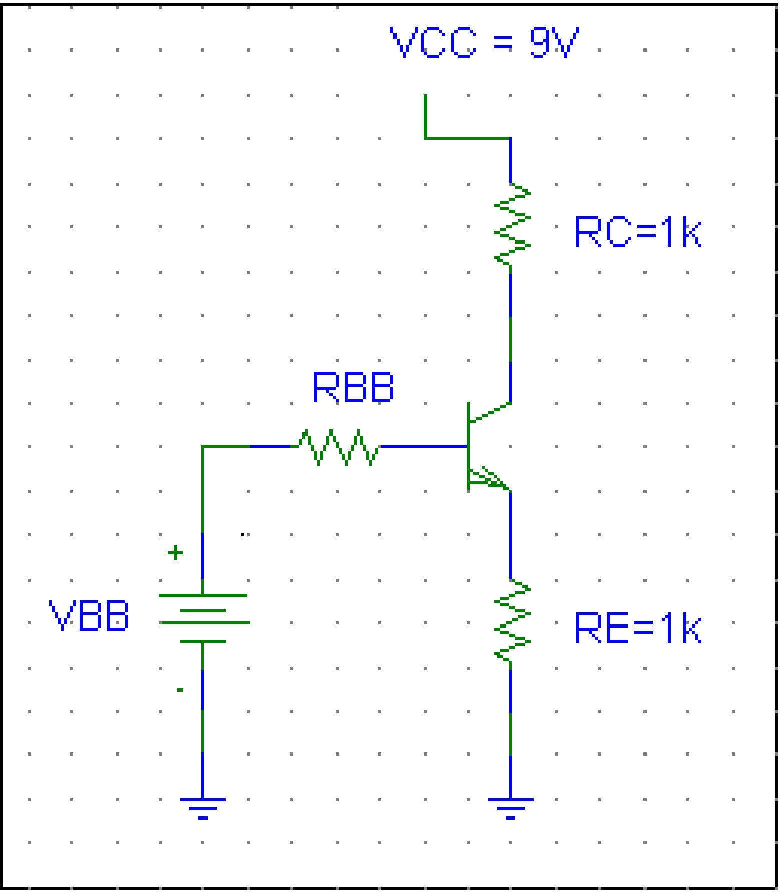
$V_B = V_{CC}[R_{B2}/(R_{B1} + R_{B2})]$

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

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

Prob. 4.32

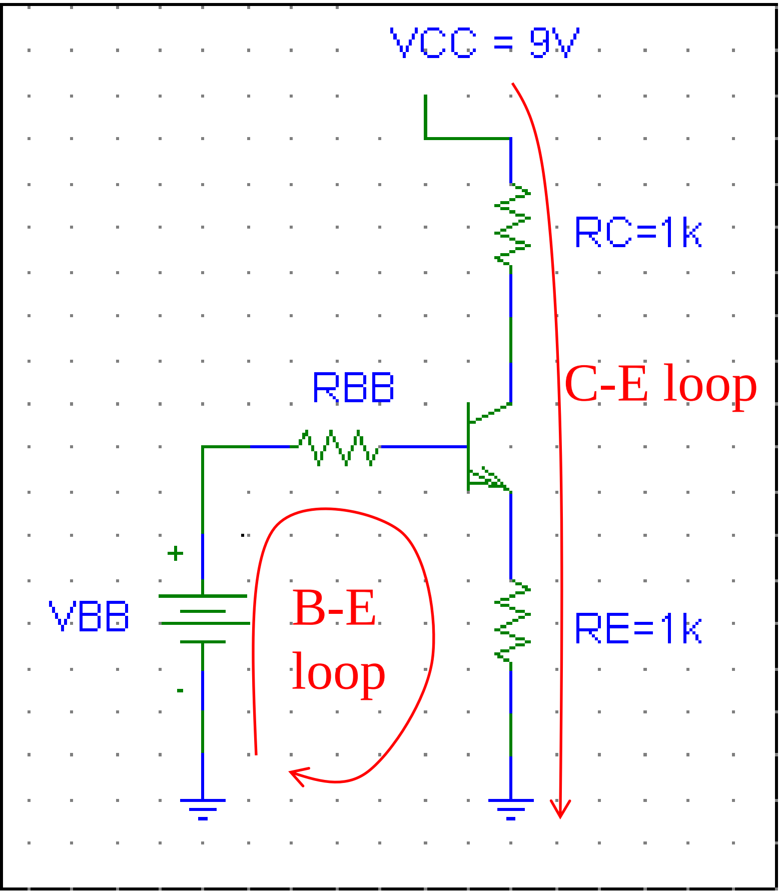
Find the operating point



- 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. 4.32

Write B-E loop and C-E loop



B-E loop

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

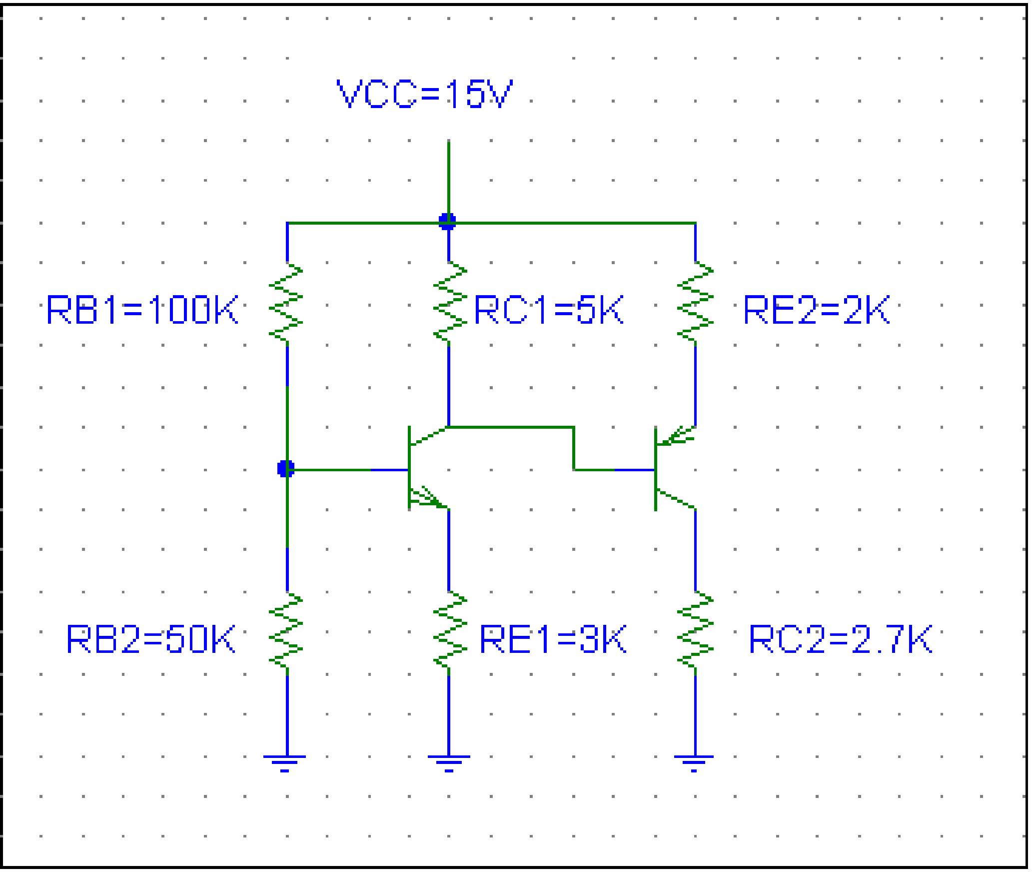
C-E loop

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

Solve for, I_C, V_{CE}, and I_B.

This is how all DC circuits are analyzed and designed!

Example 4.8



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

$I_C = \beta I_B$

$I_C \approx I_E$

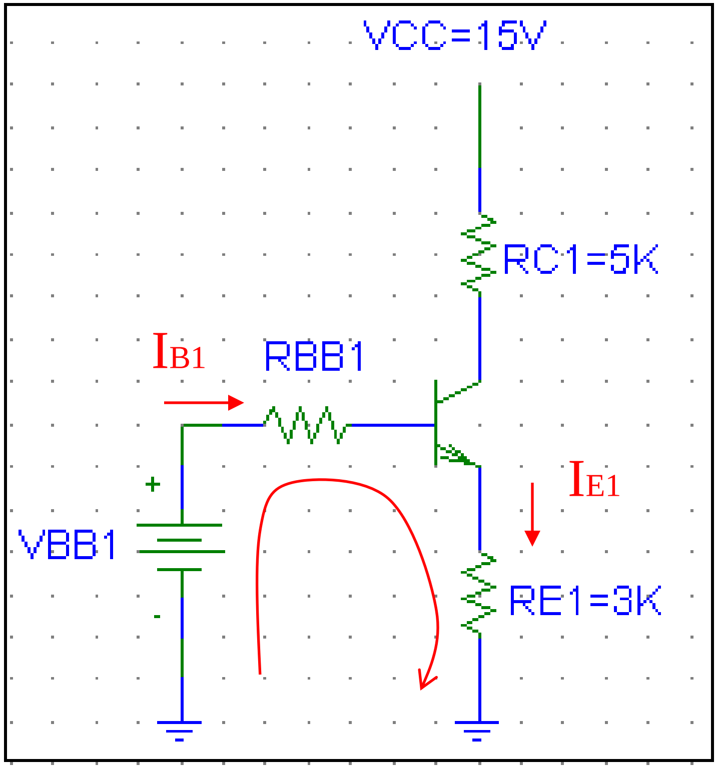
$V_{BE} = 0.7_{(npn)} = -0.7_{(pnp)}$

$\beta = 100$

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

- Use Thevenin circuits.

Example 4.8



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

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

Stage 1

- B-E loop

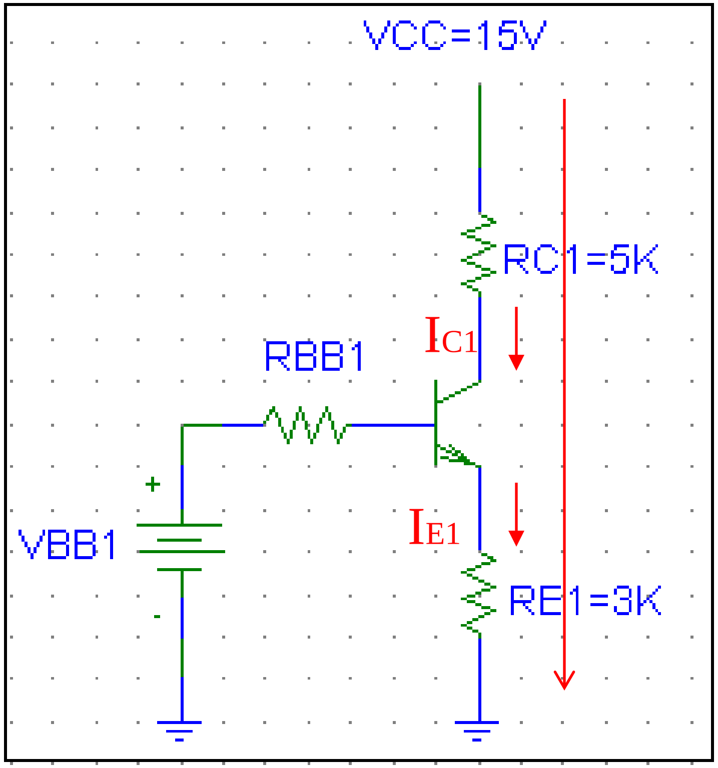
$V_{BB1} = I_{B1}R_{BB1} + V_{BE} + I_{E1}R_{E1}$

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

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

$I_{E1} = 1.3mA$

Example 4.8



C-E loop

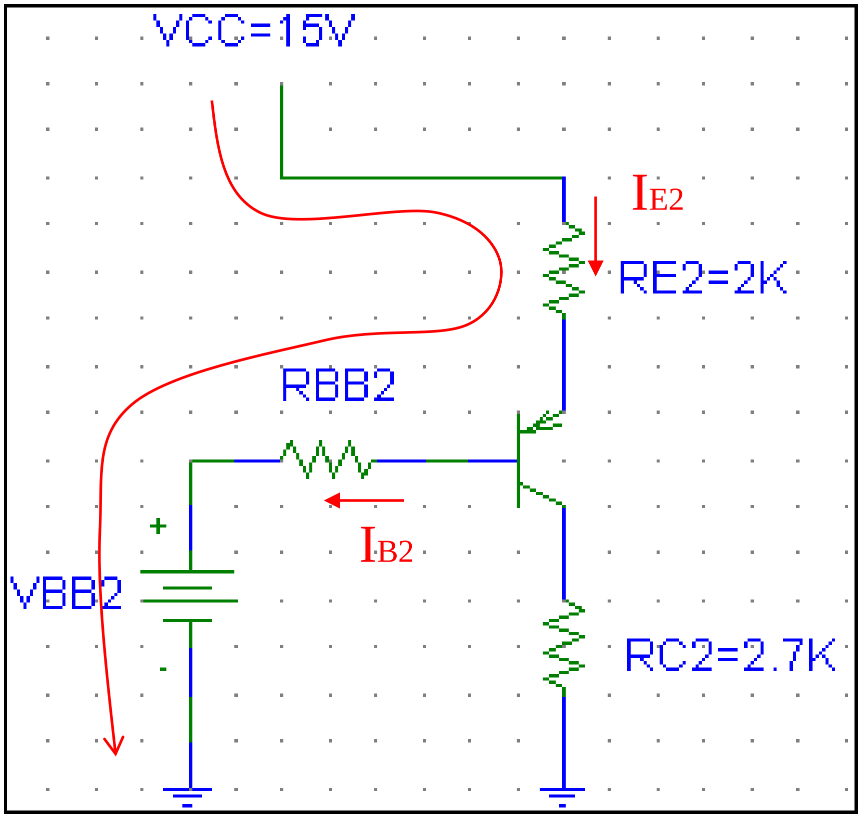
neglect IB2 because it is IB2 << IC1

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

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

$V_{CE1} = 4.87V$

Example 4.8



Stage 2

•B-E loop

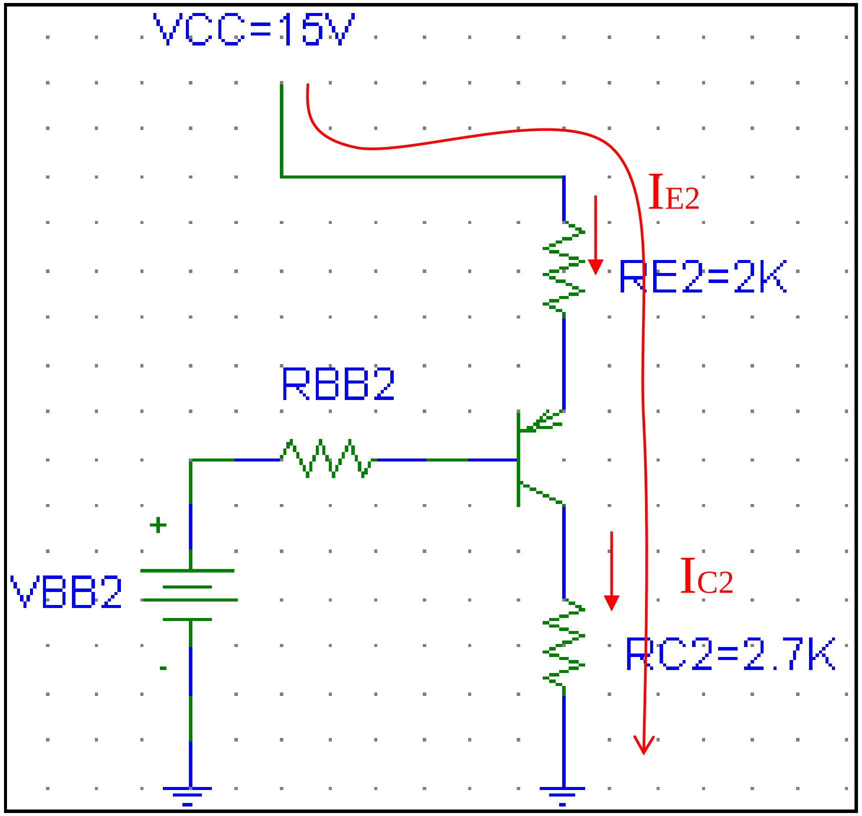
$$V_{CC} = I_{E2}R_{E2} + V_{EB} + I_{B2}R_{BB2} + V_{BB2}$$

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

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

$I_{E2} = 2.8mA$

Example 4.8



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).

4.7 Transistor as an amplifier

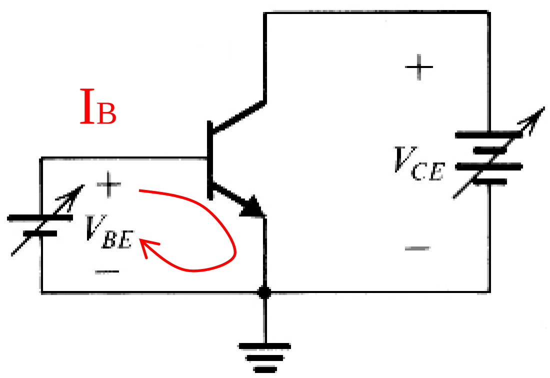
•Transistor circuits are analyzed and designed in terms of DC and ac versions of the same circuit.

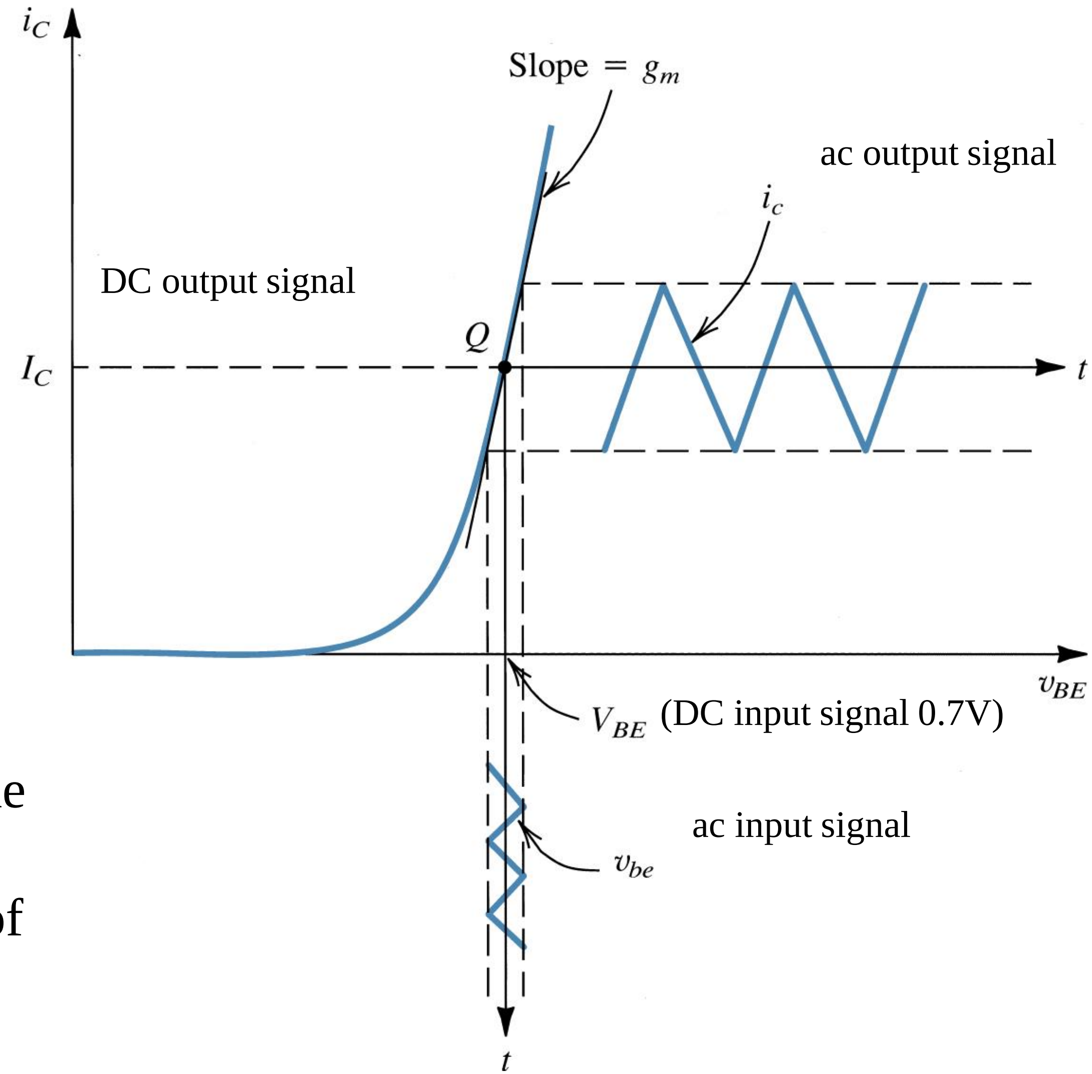
•An ac signal is usually superimposed on the DC circuit.

•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

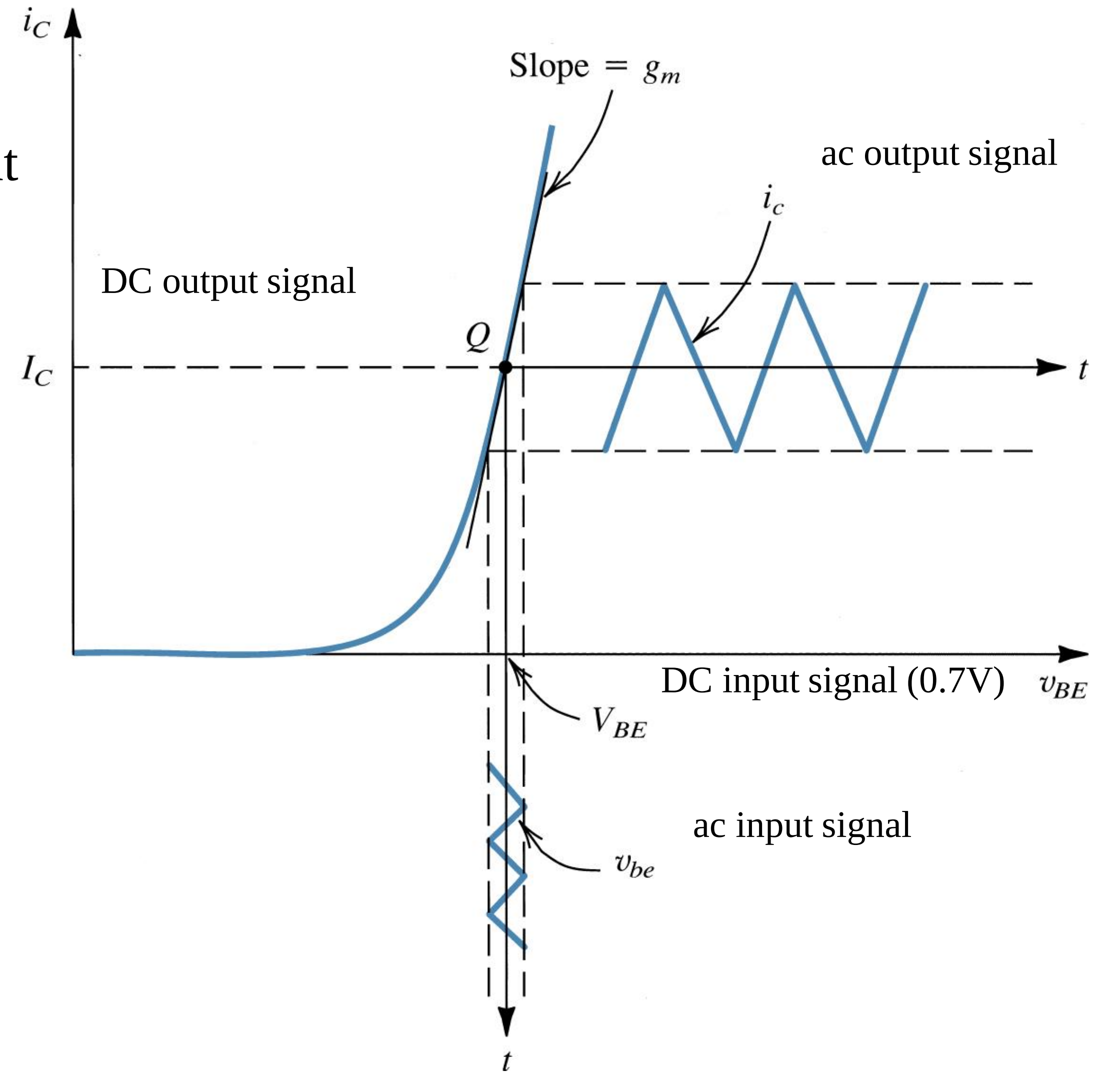
Transconductance = slope at Q point

$g_m = di_c/dv_{BE}|_{i_c = I_{CQ}}$

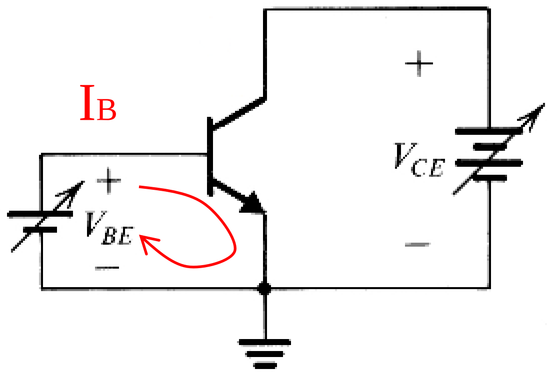
where $I_C = I_S[\exp(-V_{BE}/V_T)-1]$; the equation for a diode.

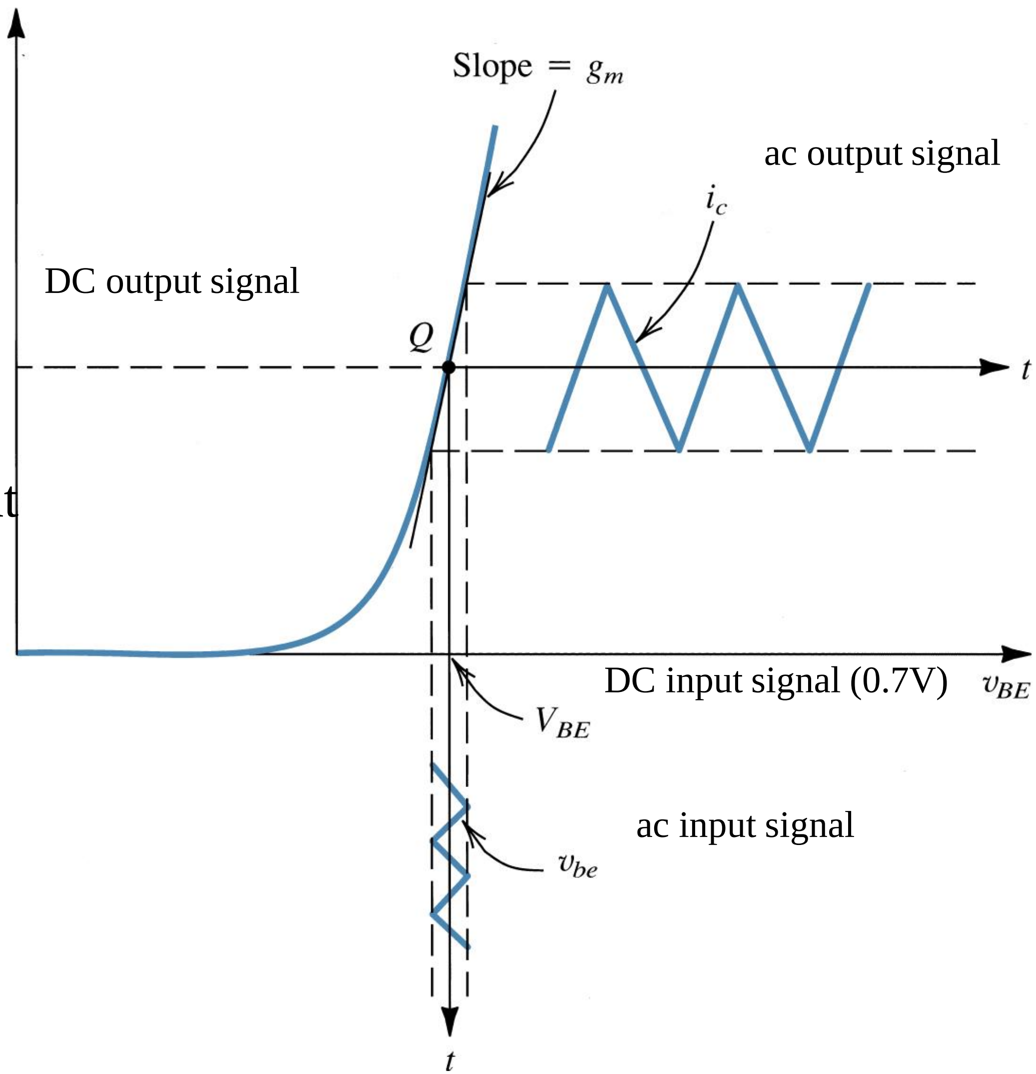
$g_m = I_S\exp(-V_{BE}/V_T)\ (1/V_T)$

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



ac input resistance of transistor





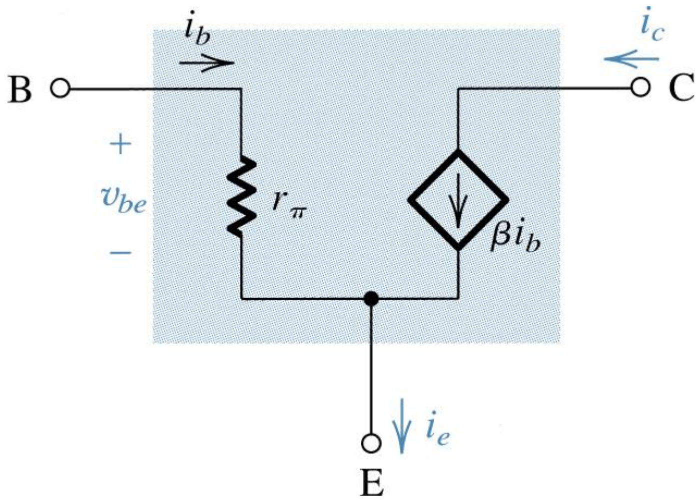
ac input resistance $\propto$ 1/slope at Q point

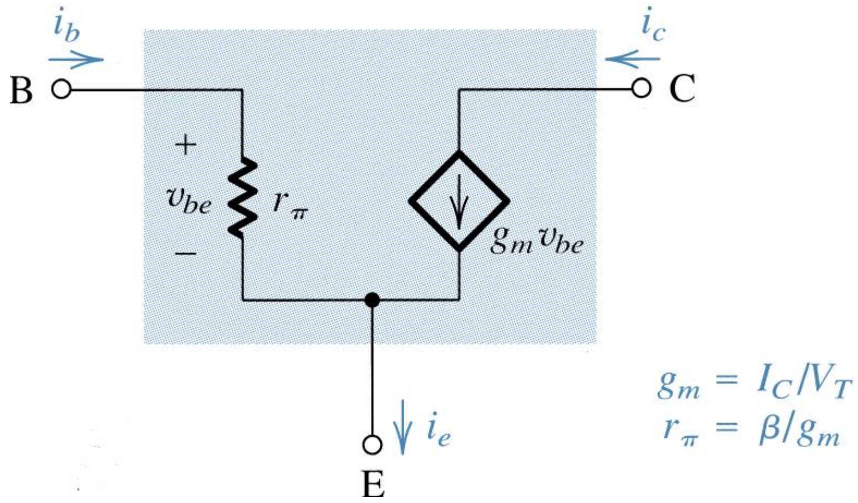
$r_\pi = dv_{BE}/di_b|_{i_c\, =\, I_{CQ}}$

$r_\pi \approx V_T / I_B$

$r_e \approx V_T / I_E$

4.8 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

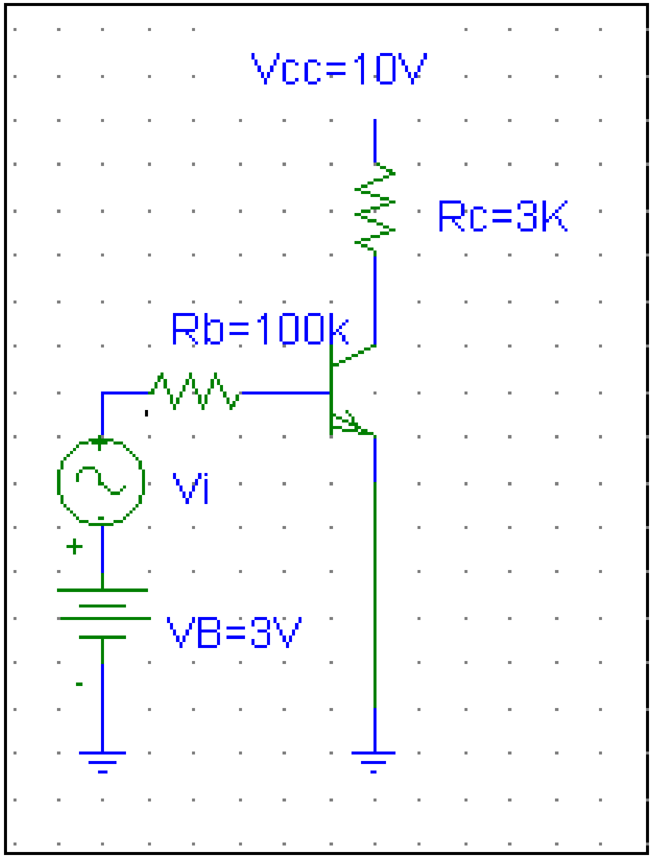
Find g_m, r_π, and r_e.

3 ac problem

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

Example 4.9

Find v_{out}/v_{in}, (β = 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

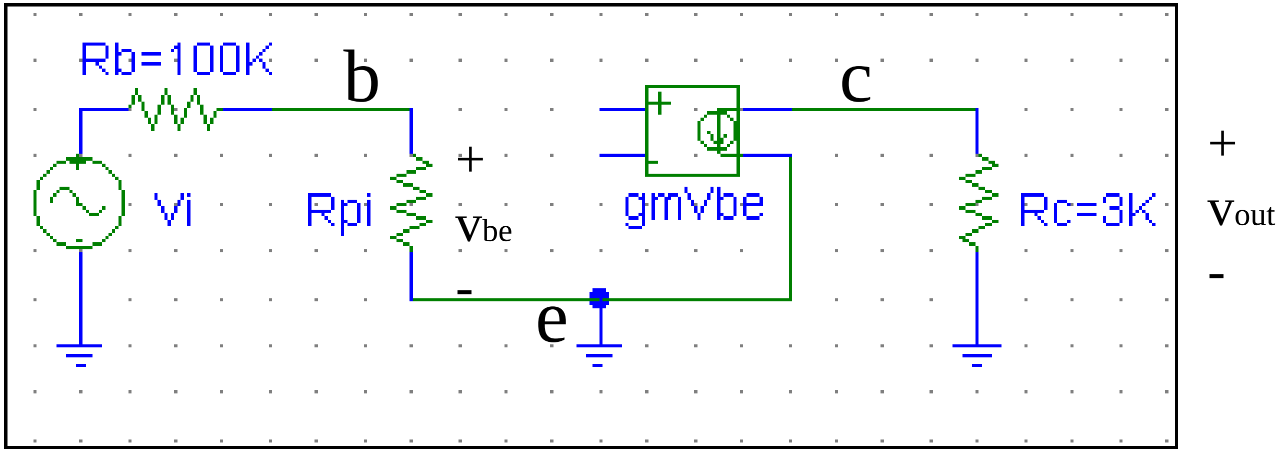
$V_{CE} = 10 - I_C R_C$

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

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

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

Example 4.9



ac problem

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

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

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

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

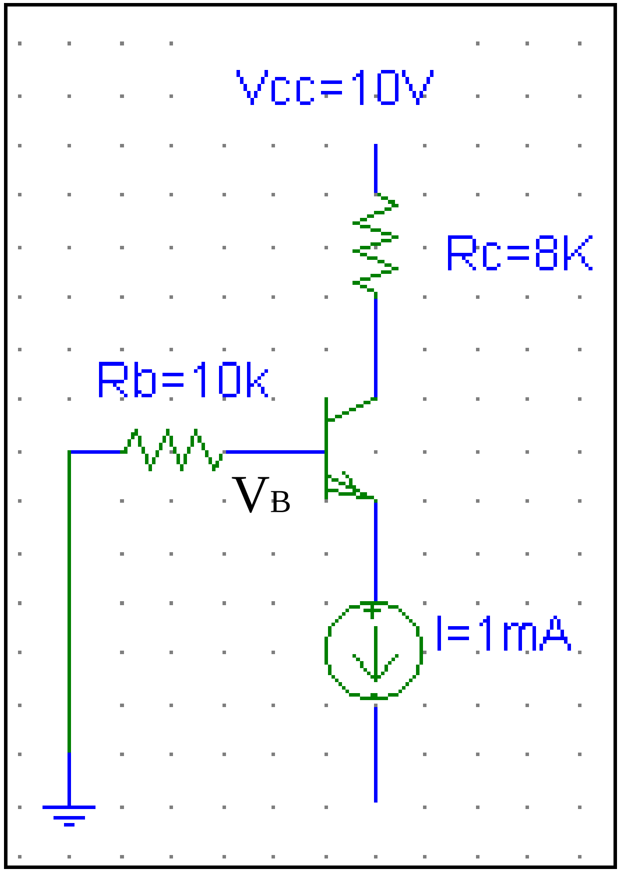
$v_{out} = -\, g_m\, v_{be} R_C$

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

$v_{out}/v_i = -3.04$

Exercise 4.24

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



$I_E = 1\ mA$

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

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

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

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

Exercise 4.24

(b) Find g_m, r_π, and r_0, given: $\beta = 100$, $V_A = 100V$

$g_m = I_C/V_T = 1\ mA/25mV =$ 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.

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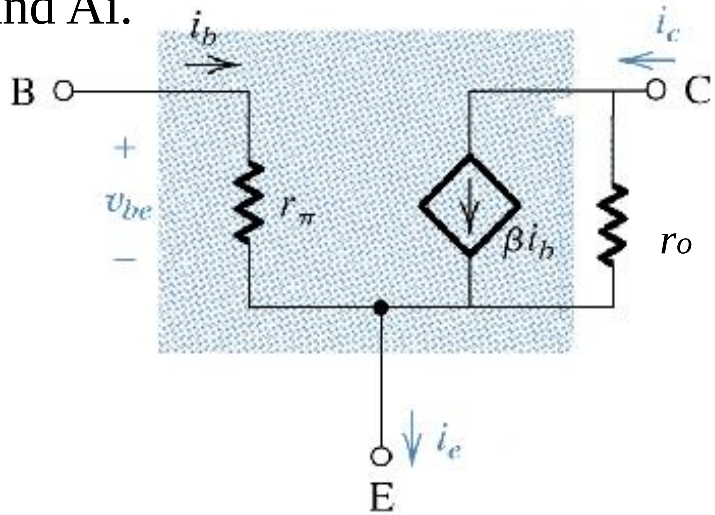
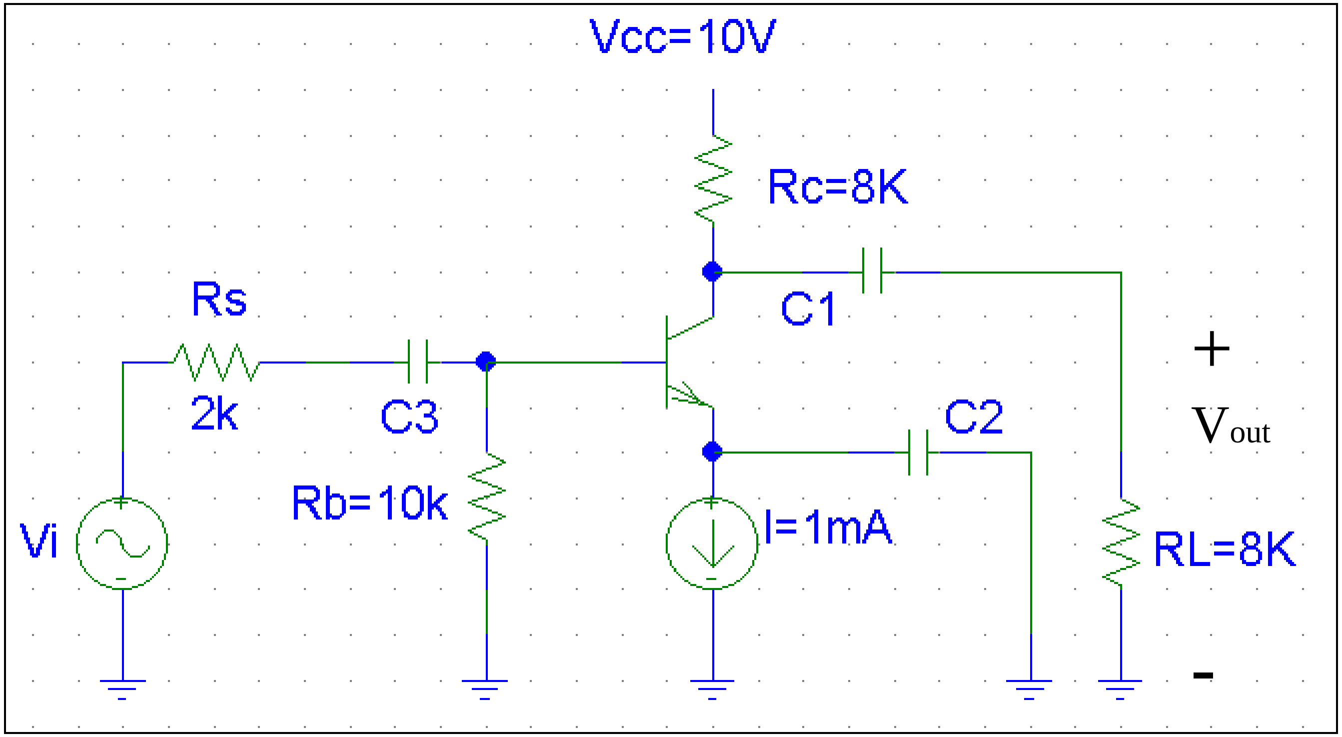
Set DC sources to zero, replace transistor by hybrid-π model, find ac quantites, Rin, Rout, Av, and Ai.



Circuit from Exercise 4.24



$I_E = 1 \text{ mA}$

$I_B \approx I_E/\beta = 0.01\text{mA}$

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

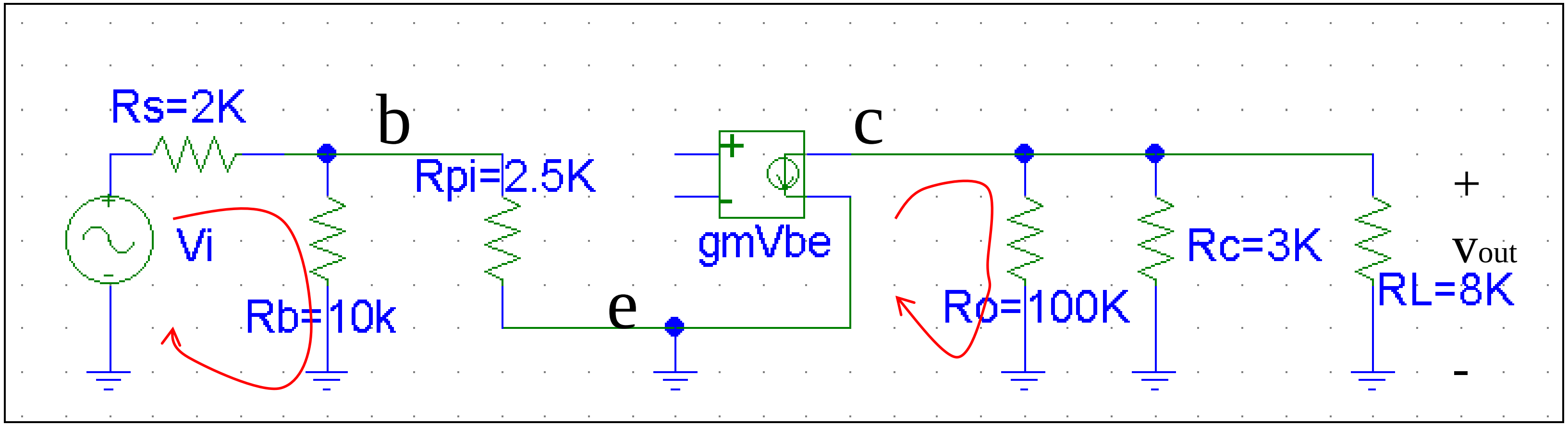
$V_E = V_B - V_{BE} = -0.1 - 0.7 = -0.8V$

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

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

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

ac equivalent circuit



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

$v_{be} = 0.5v_i$

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

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

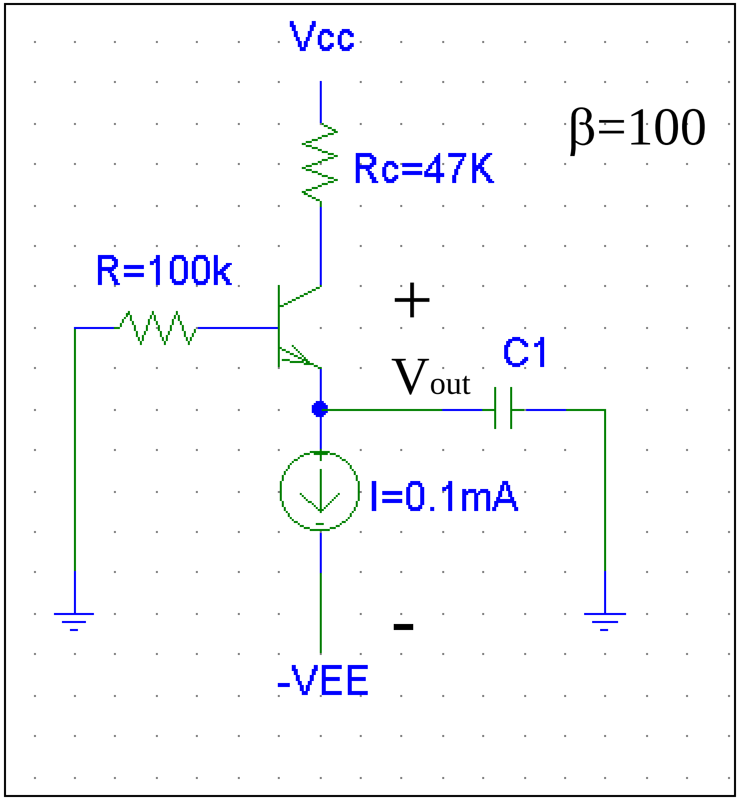
$A_v = v_{out}/v_i = -77$

Neglecting R_o

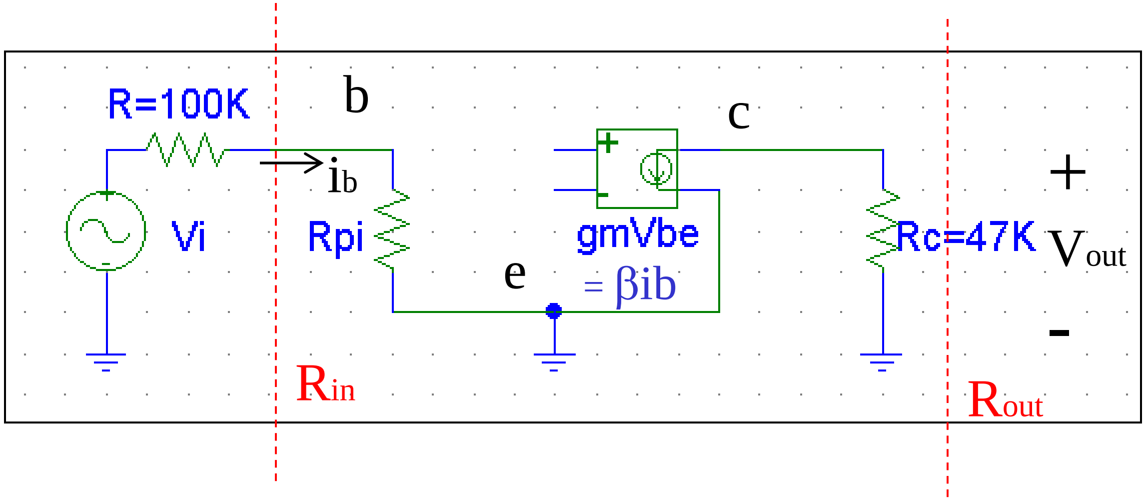
$v_{out} = -(g_m v_{be})(R_c||R_L)$

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

Prob. 4.76



Prob. 4.76



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

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

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

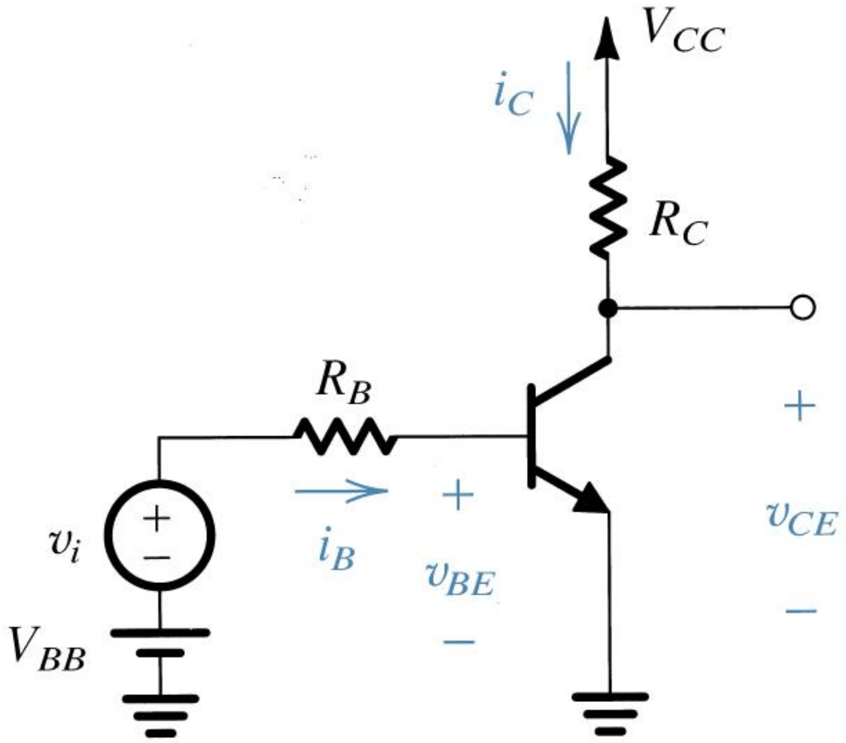
$A_v = v_{out}/v_{in} = -\beta i_b R_c/\ i_b (R + R_{pi})$

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

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

$= -37.6$

4.9 Graphical analysis



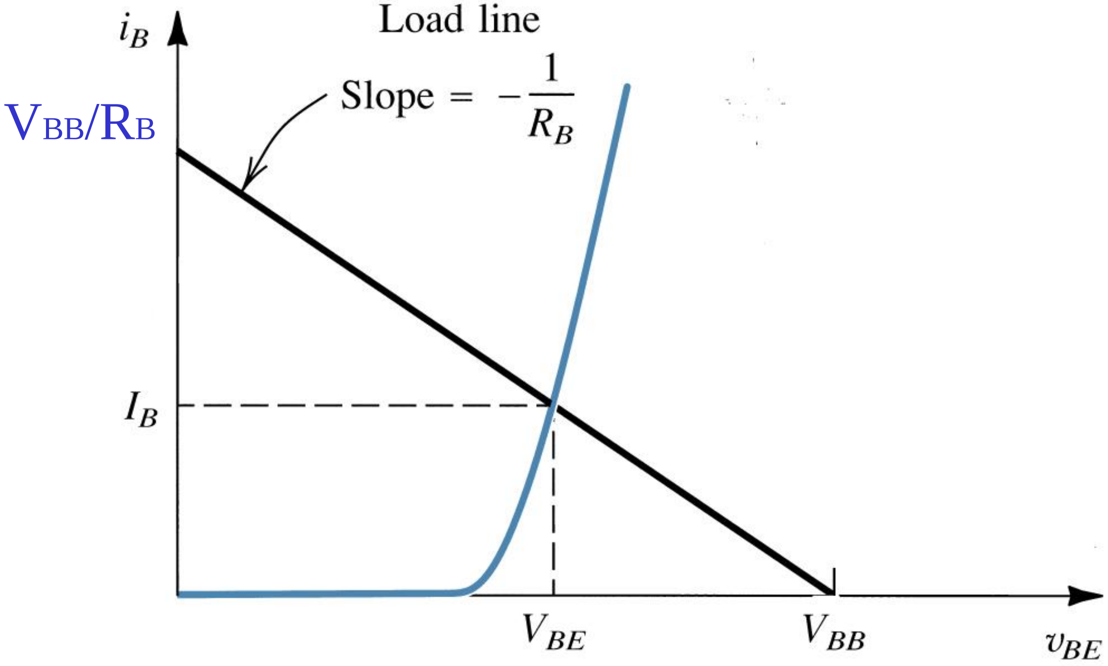
Input circuit

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}

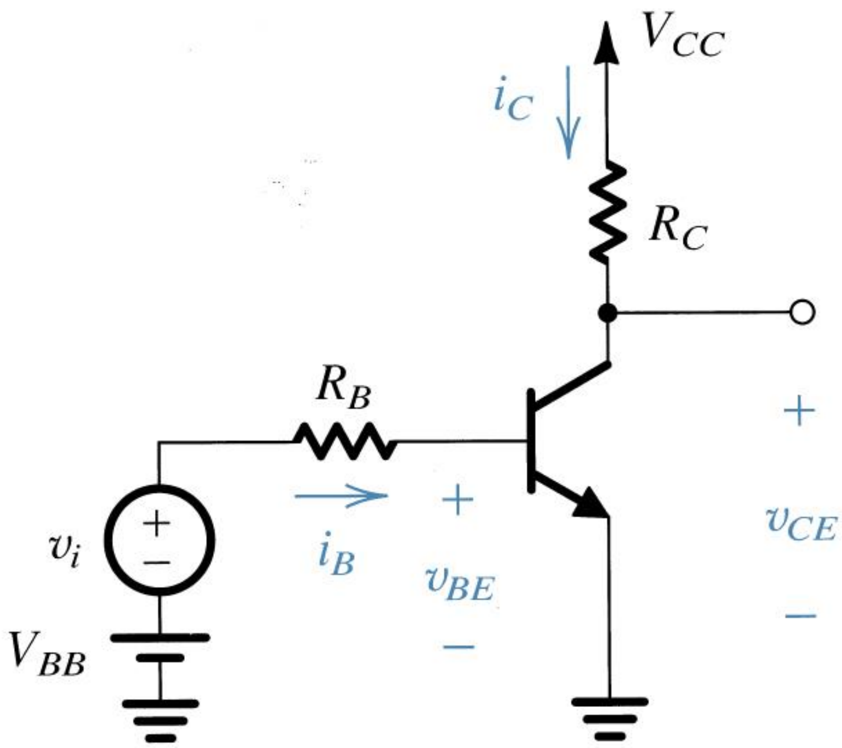


$I_B = (V_{BB} - V_{BE})/R_B$

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

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

Load line



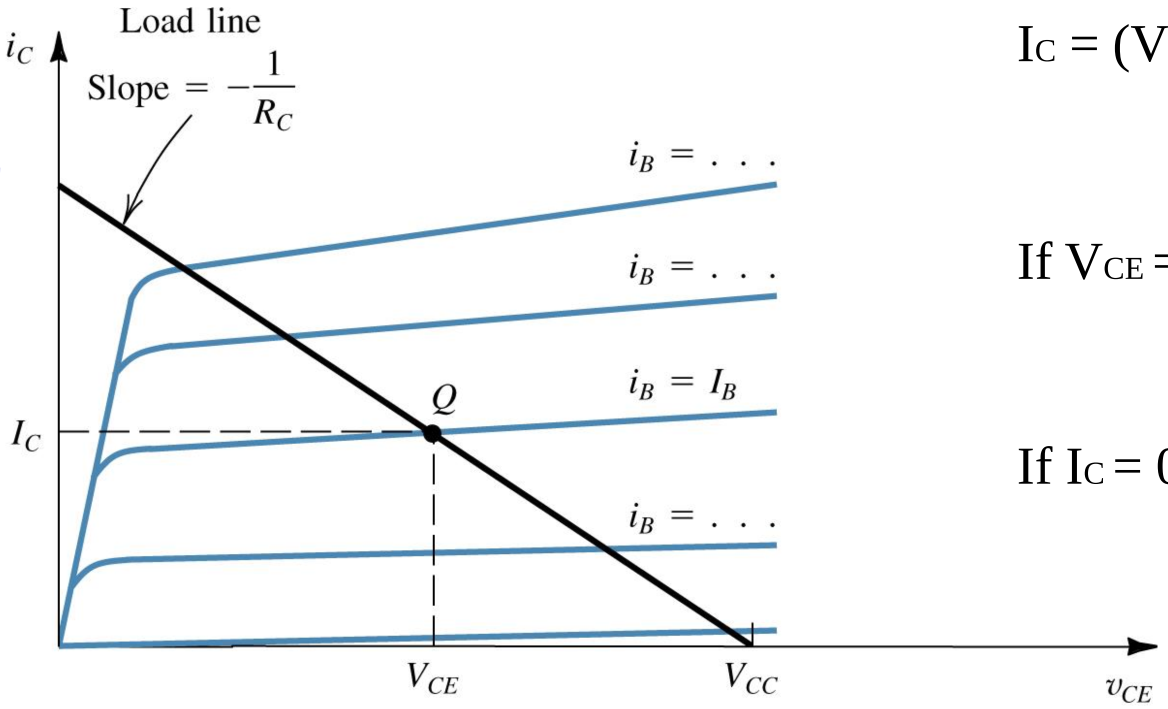
Output circuit
C-E voltage loop

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

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

Graphical construction of I_C and V_{CE}

V_{CC}/R_C

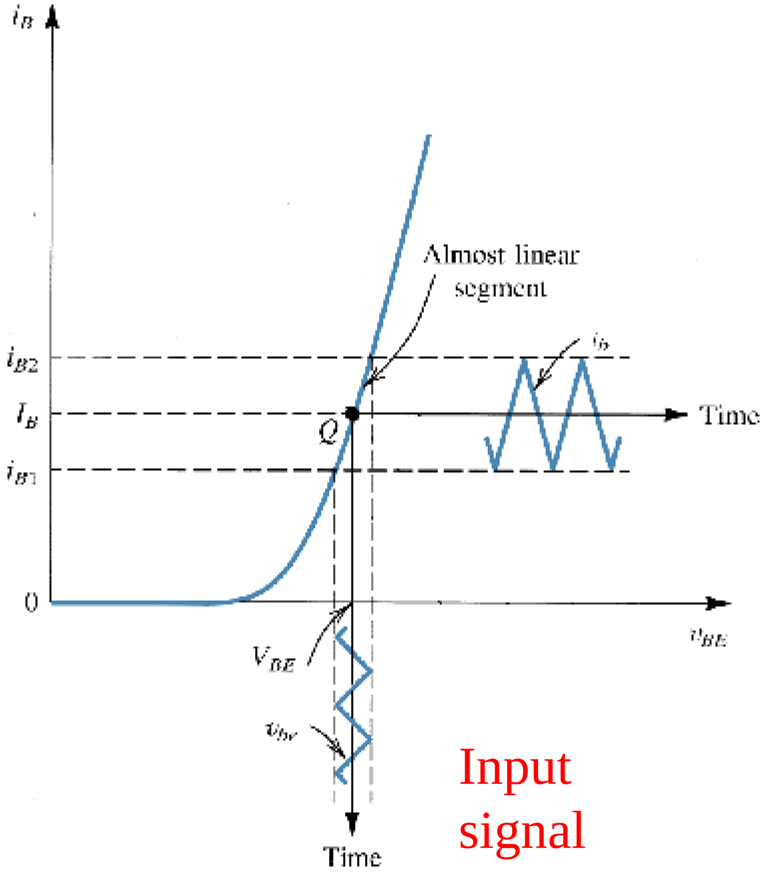


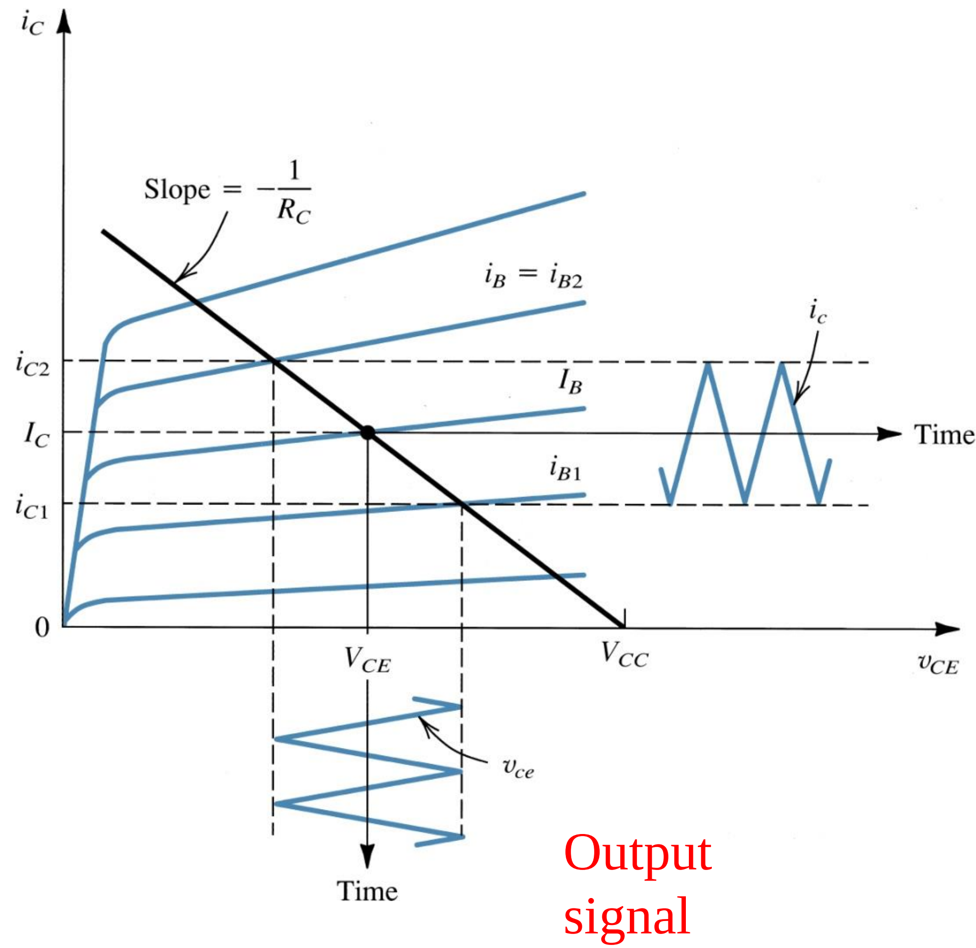
$I_C = (V_{CC} - V_{CE})/R_C$

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

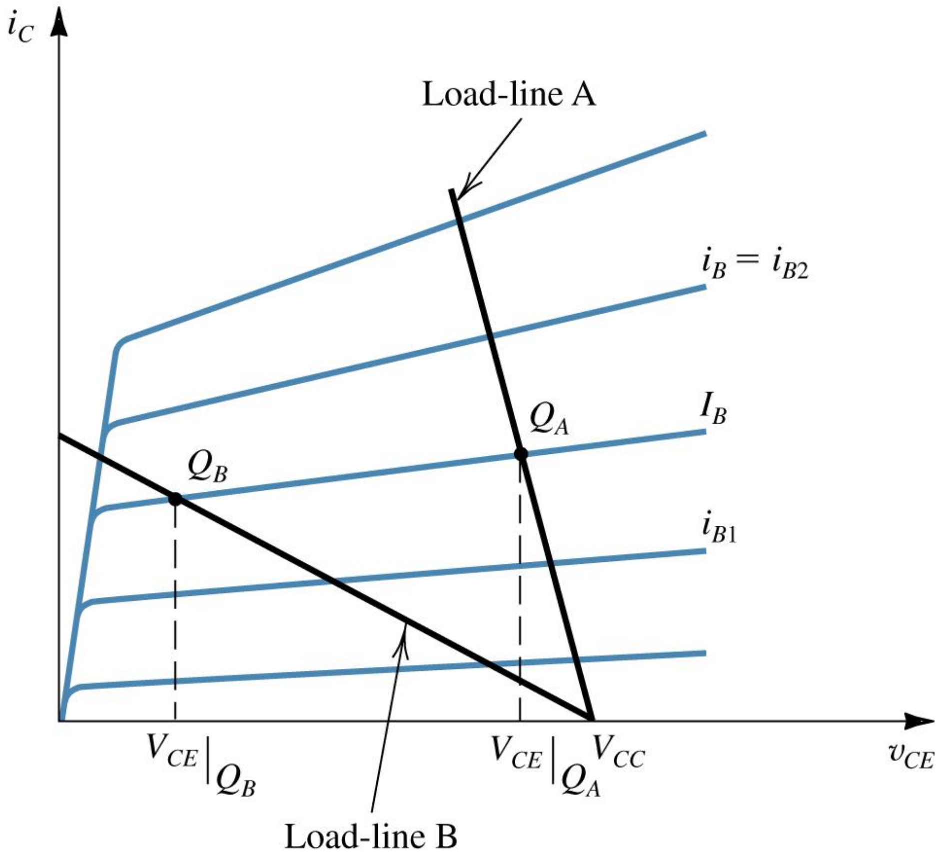
If $I_C = 0$, $V_{CE} = V_{CC}$

Graphical analysis





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}.

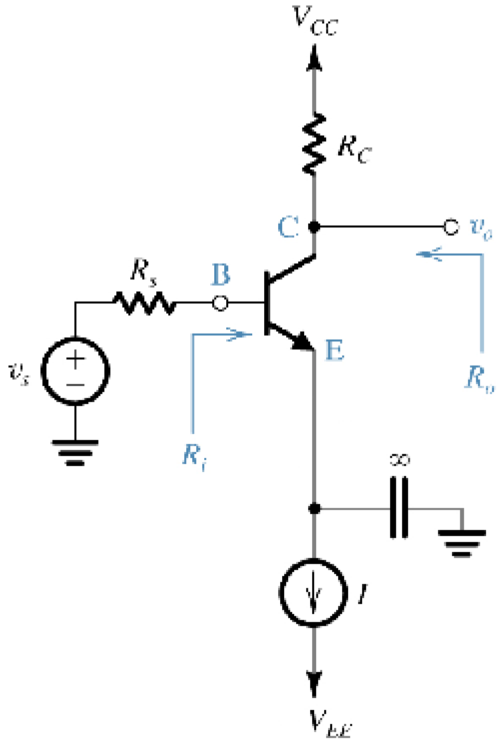
4.11 Basic single-stage BJT amplifier configurations

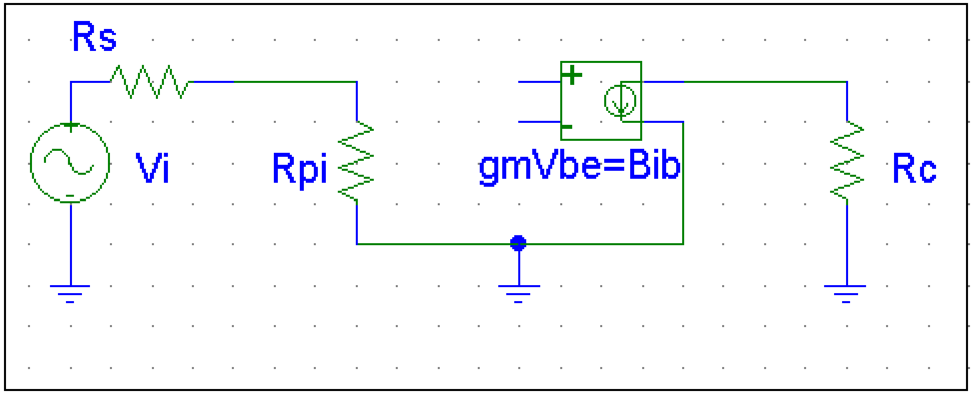
We will study 3 types of BJT amplifiers

- **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

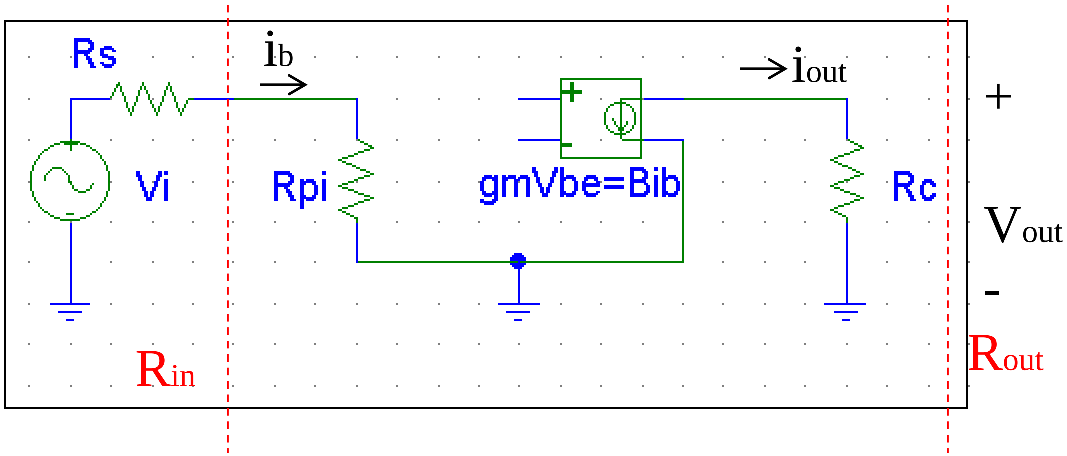




ac equivalent circuit

Common emitter amplifier

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



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

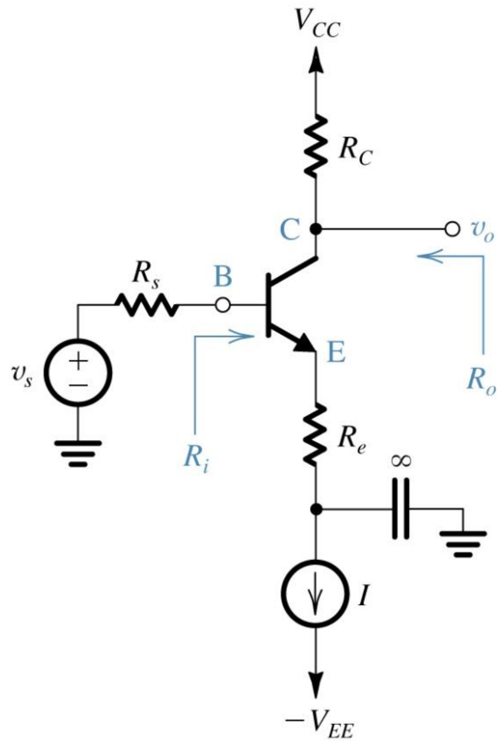
A_V
$= V_{out}/V_{in}$
$V_{out} = -\beta i_b R_C$
$V_{in} = i_b(R_s + R_{pi})$

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

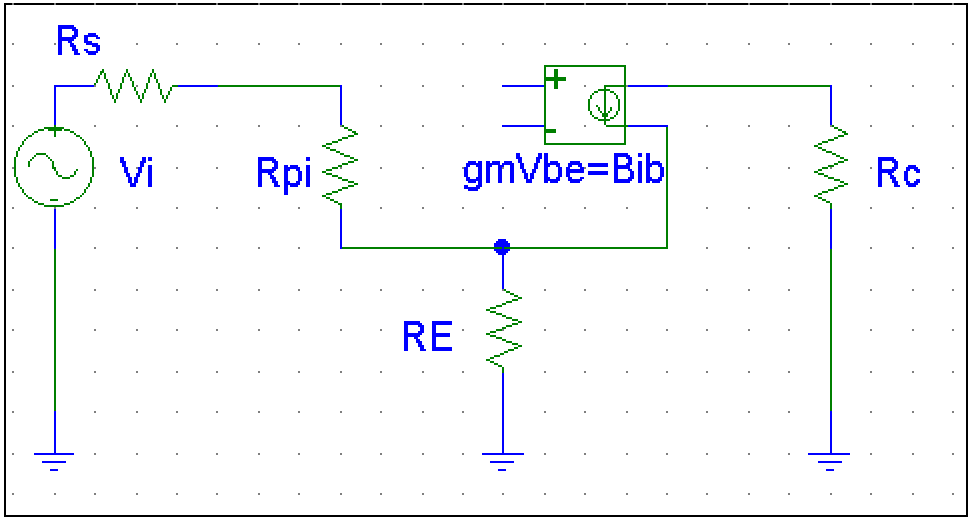
A_i
$= i_{out}/i_{in}$
$i_{out} = -\beta i_b$
$i_{in} = i_b$

$A_i = -\beta$

Common emitter with R_E amplifier

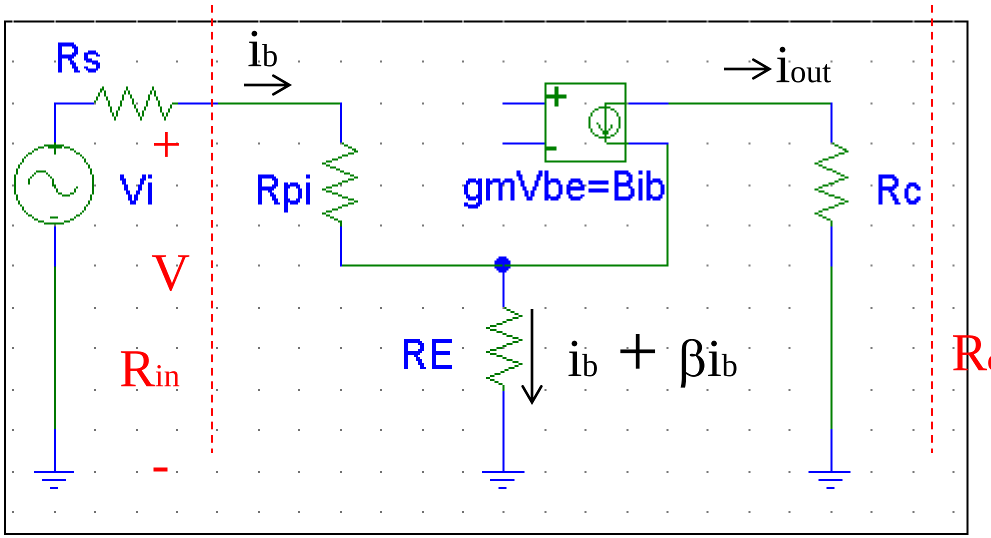


(a)



ac equivalent circuit

Common emitter with R_E amplifier



+

V_{out}

R_{out}

-

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

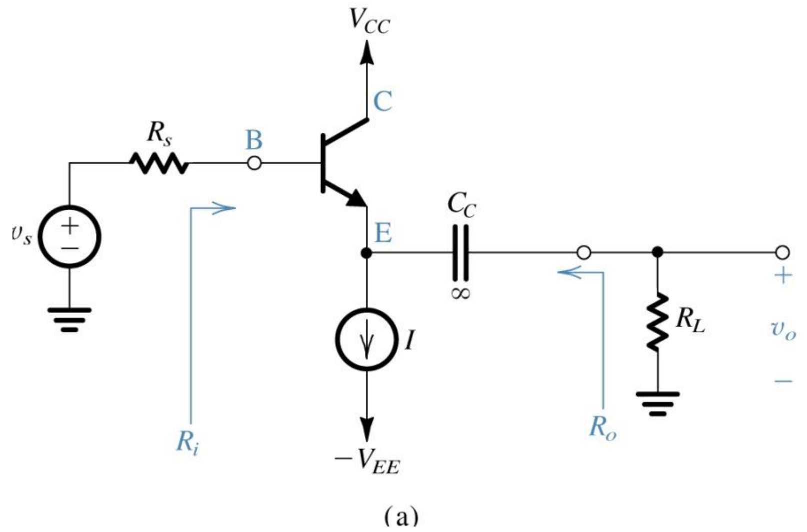
$= i_{out}/i_{in}$

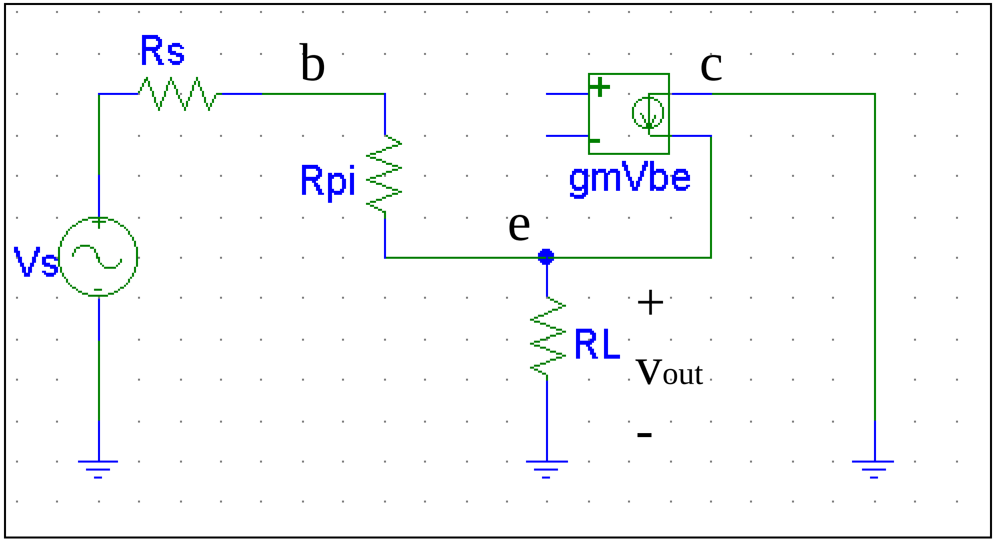
$i_{out} = -\beta i_b$

$i_{in} = i_b$

$A_i = -\beta$

Common collector (emitter follower) amplifier

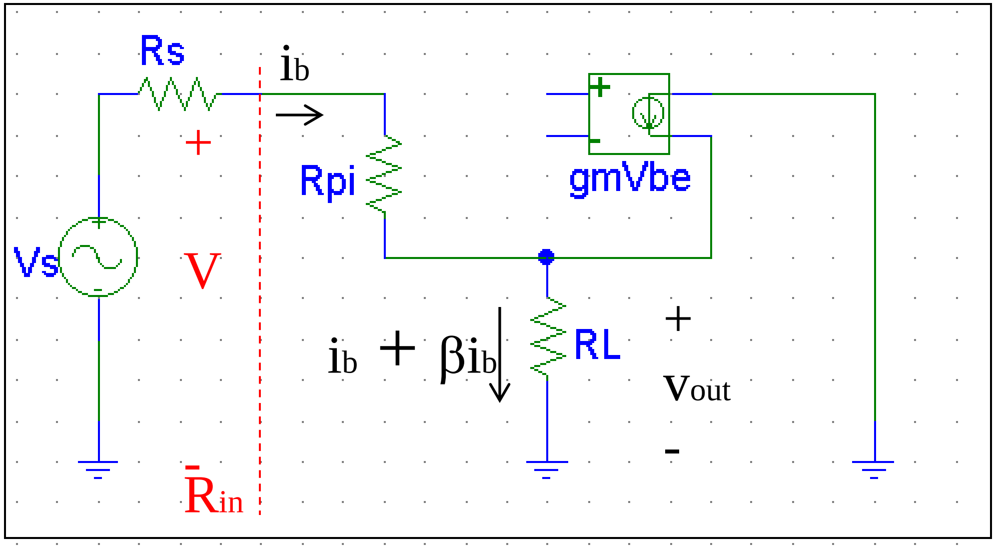




(Vout at emitter)

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

$= v_{out}/v_s$

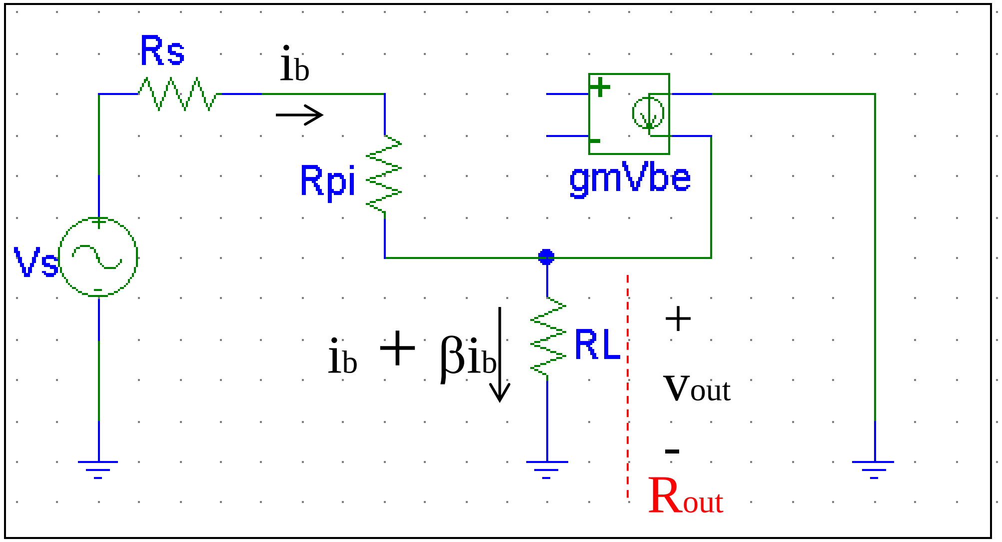
$v_{out} = (i_b + \beta i_b)R_L$

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

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

(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)

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

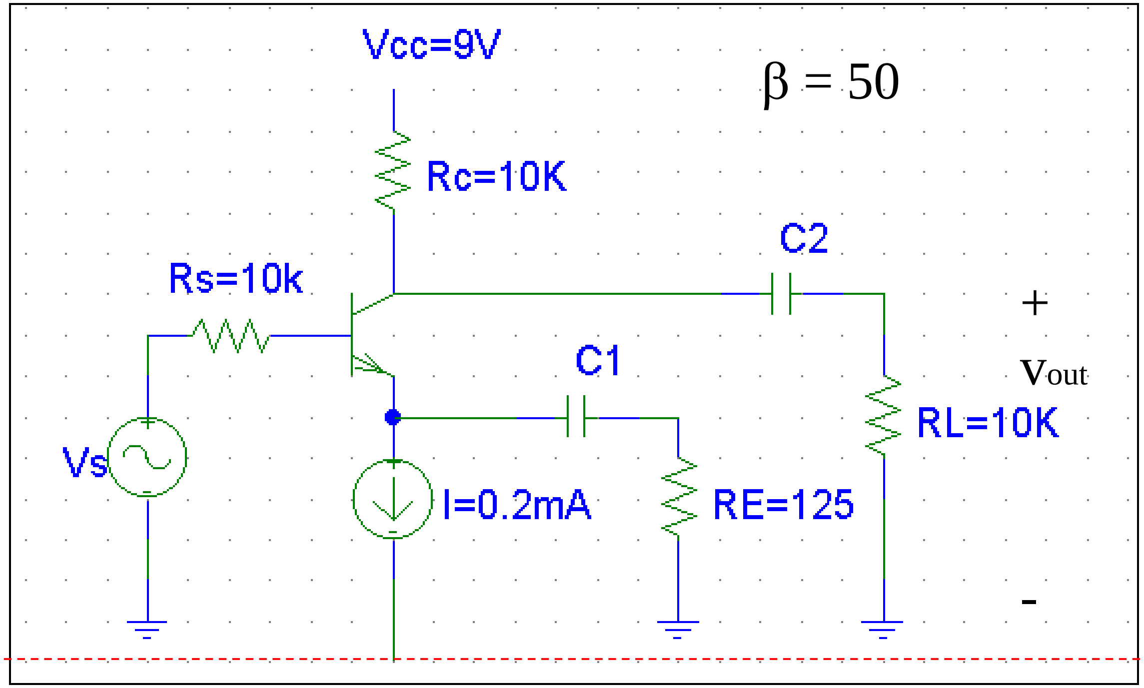
$v_{out} = -i_b R_{pi} + -i_b R_s$

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

(usually low)

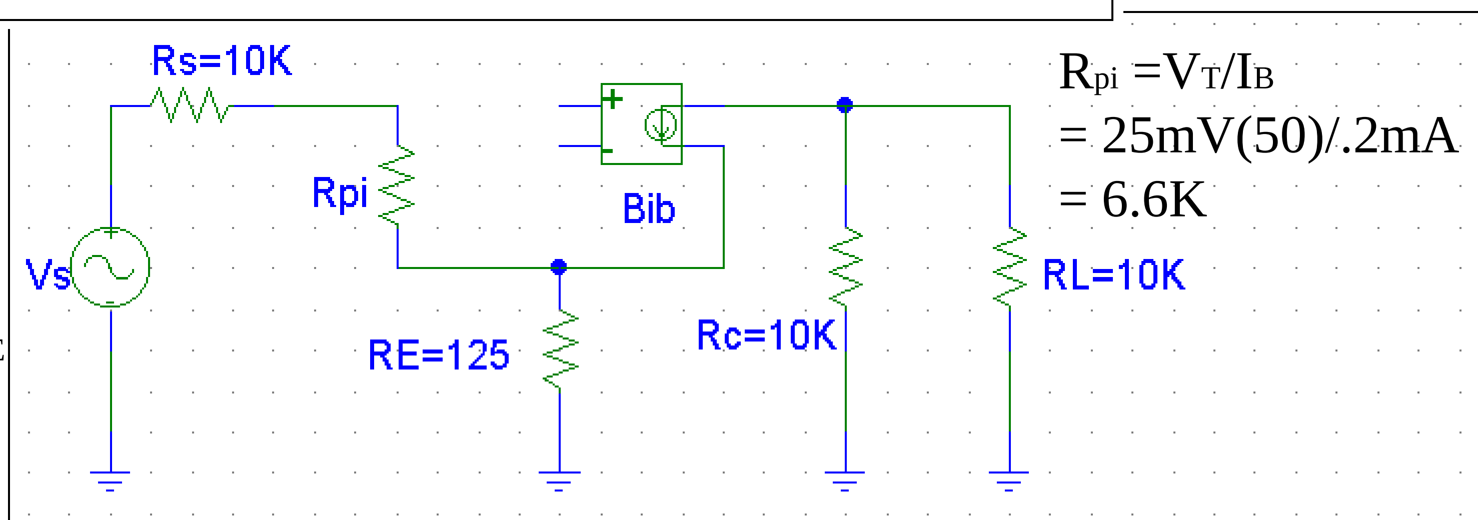
Prob. 4.84

Given



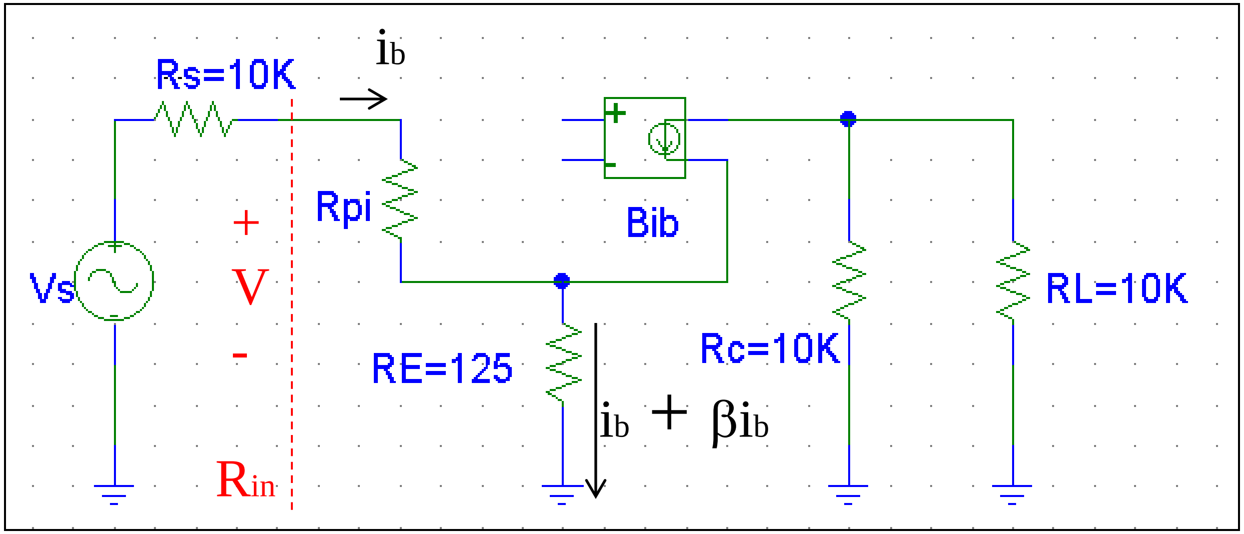
ac
circuit

CE with R_E
amp, because R_E
is in ac circuit



$R_{pi} = V_T/I_B$
$= 25\text{mV}(50)/.2\text{mA}$
$= 6.6\text{K}$

Prob. 4.84



(a) Find Rin

$R_{in} = V/i_b$

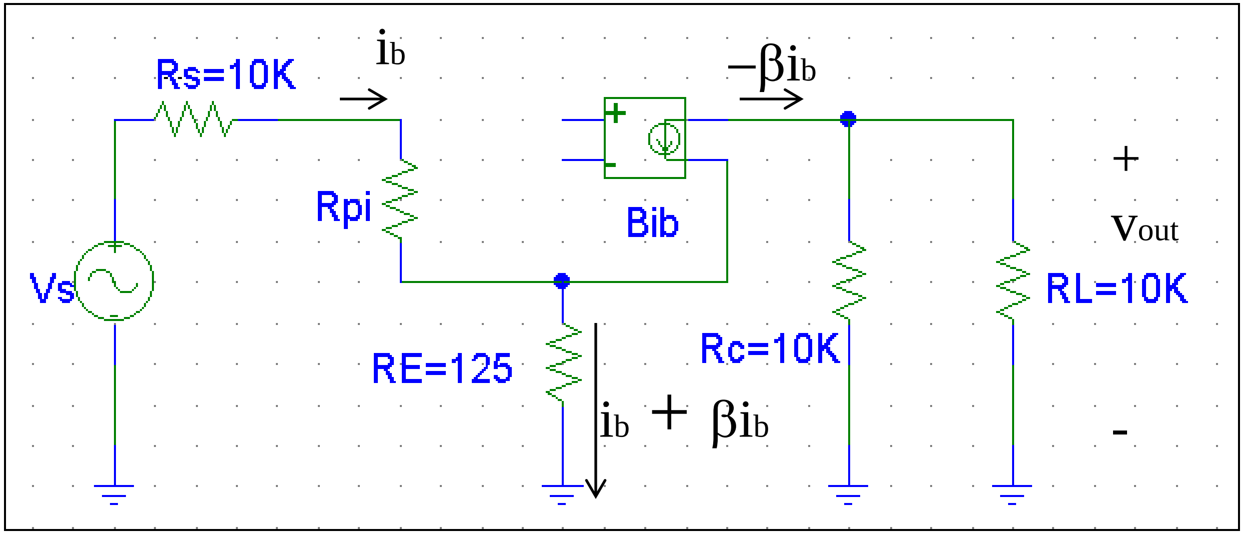
$V = i_b R_{pi} + (i_b + \beta i_b)R_E$

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

$R_{in} = 6.6K + (1 + 50)125$

$R_{in} \approx 13K$

Prob. 4.84



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

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

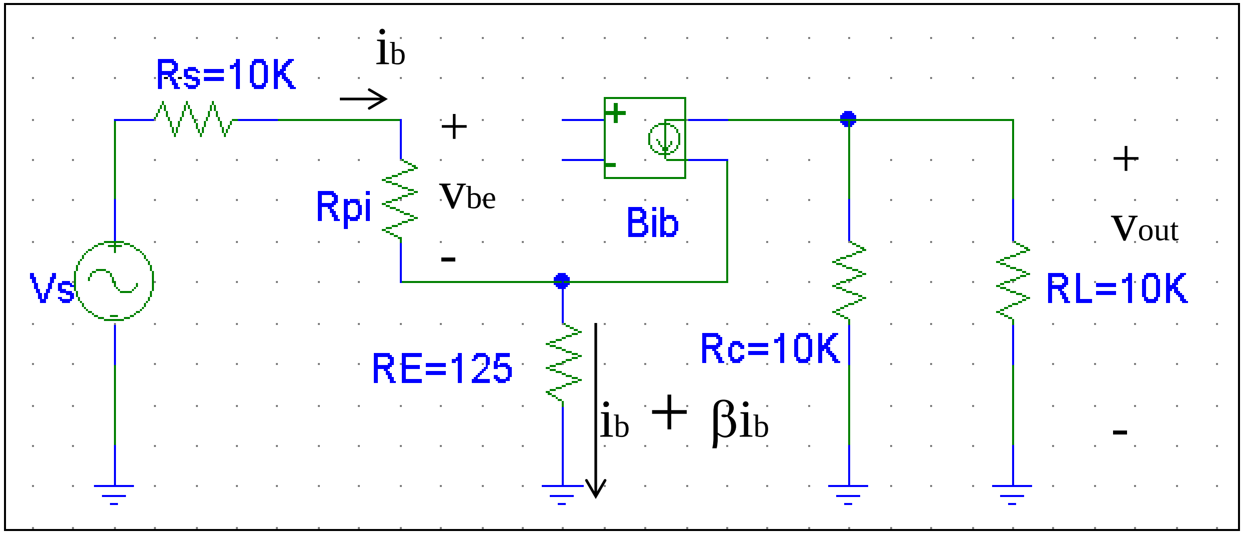
$v_s = i_b R_s + i_b R_{pi} + (i_b + \beta i_b)R_E$

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

$A_V = -50\,(10K||10K)/(10K + 6.6K_i + (1 + 50)125)$

$A_V \approx -11$

Prob. 4.84



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

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

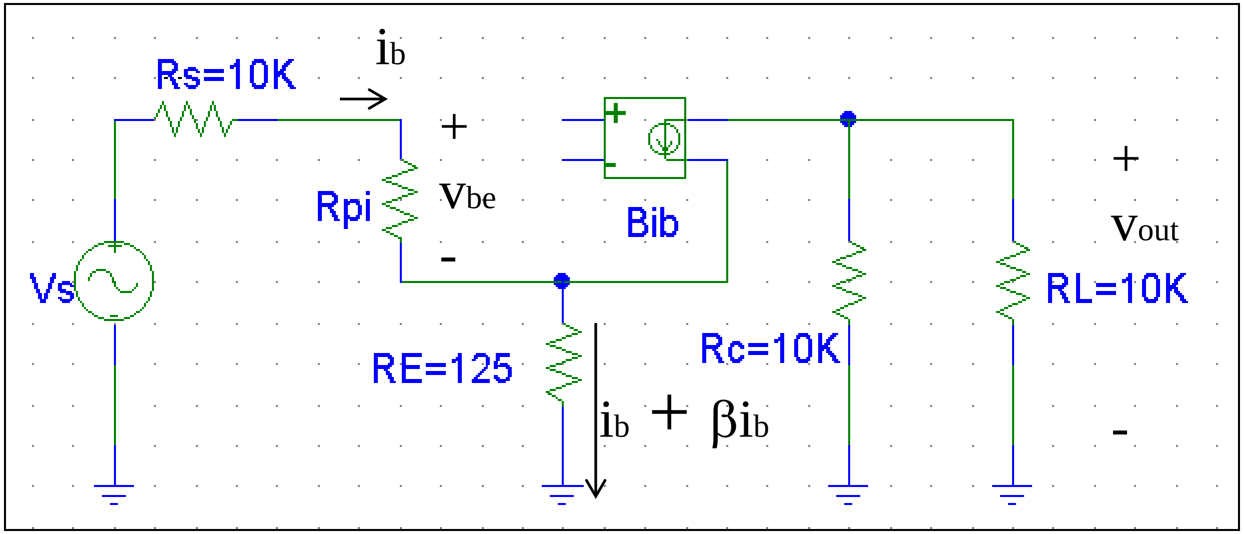
$i_b = v_{be} / R_{pi} = 5\text{mV}/6.6\text{K} = 0.76\mu\text{A (ac value)}$

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

$v_s = (0.76\mu\text{A})10\text{K} + (0.76\mu\text{A})\ 6.6\text{K} + (0.76\mu\text{A} + (50)0.76\mu\text{A})125$

$v_s \approx 17.4\text{mV}$

Prob. 4.84



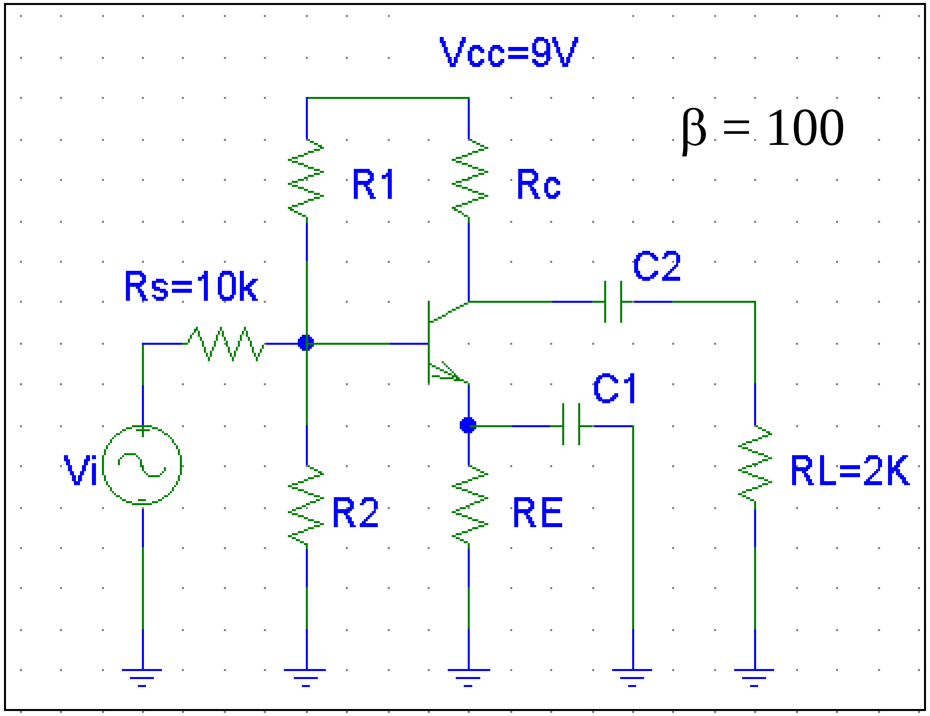
(c) If v_{be} is limited to 5mV, what is the largest signal at input and output?

$v_{out} = v_s A_V$

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

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

Prob. 4.79



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. 4.79

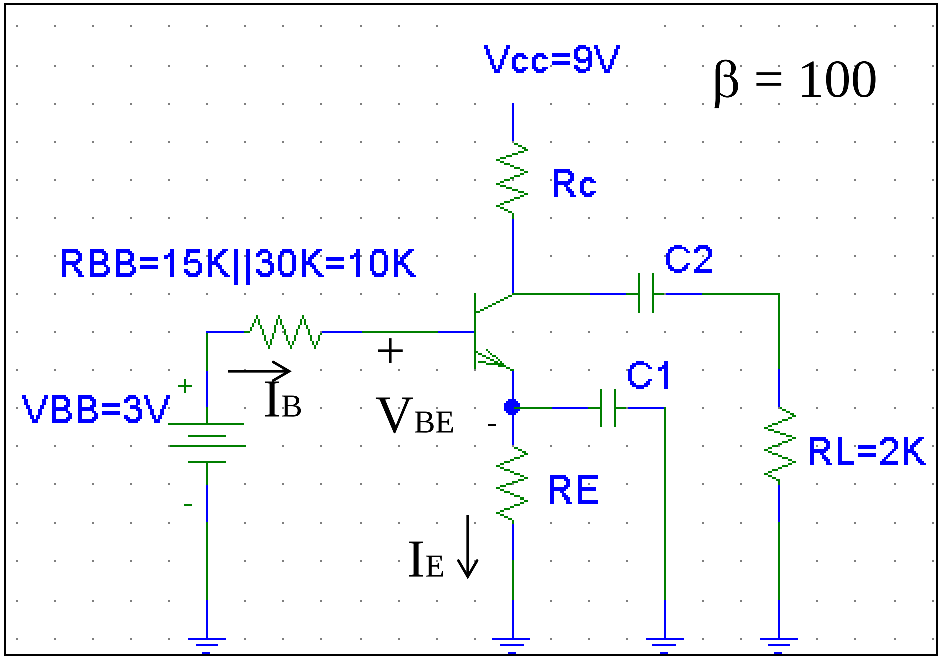
Find RE (input circuit)
Use Thevenin equivalent

B-E loop
$V_{BB}=I_BR_{BB}+V_{BE}+I_ER_E$

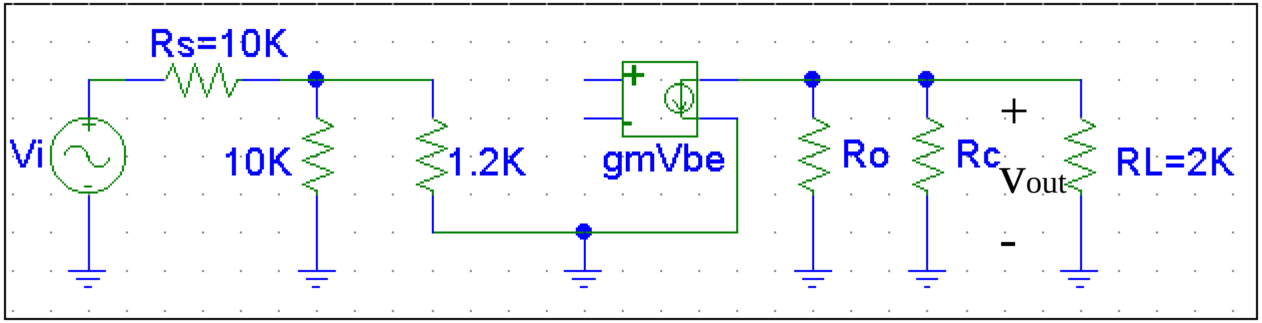
using $I_B \approx I_E/\beta$
$R_E = [V_{BB} - V_{BE} - (I_E/\beta)R_{BB}]/I_E$

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

$R_E = 1.05K\Omega$



Prob. 4.79



Find Rc (ac circuit)

Rpi = V_T/I_B = 25mV(100)/2mA = 1.25K

Ro = V_A/I_C = 100/2mA = 50K

Av = v_{out}/v_{in}

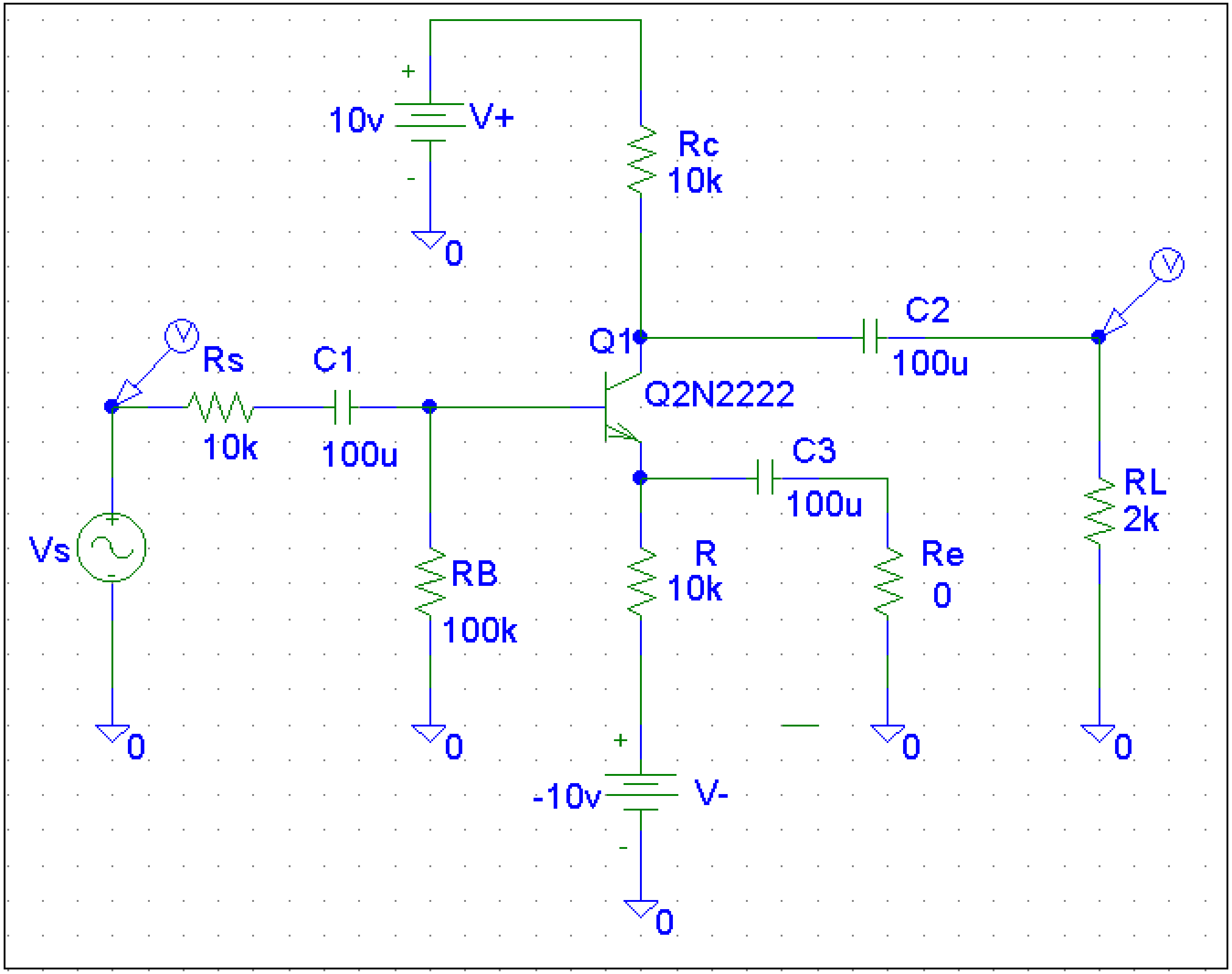
v_{out} = $-g_m v_{be}$ (Ro||Rc||RL)

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

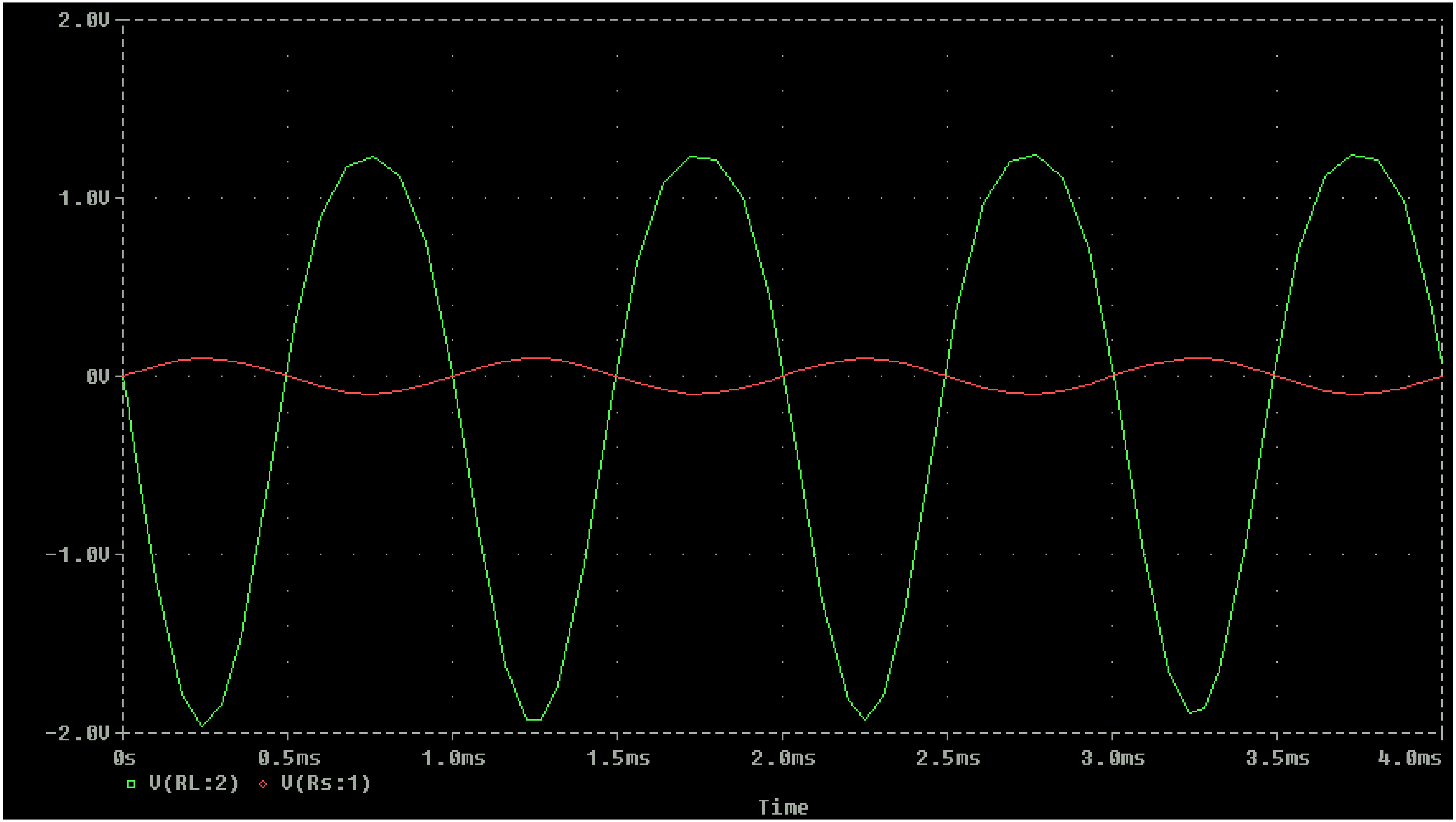
Av = $-g_m$(Ro||Rc||RL)(10K||1.2K) / [10K||1.2K +Rs]

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

CE amplifier



CE amplifier



Av ≈ -12.2

CE amplifier

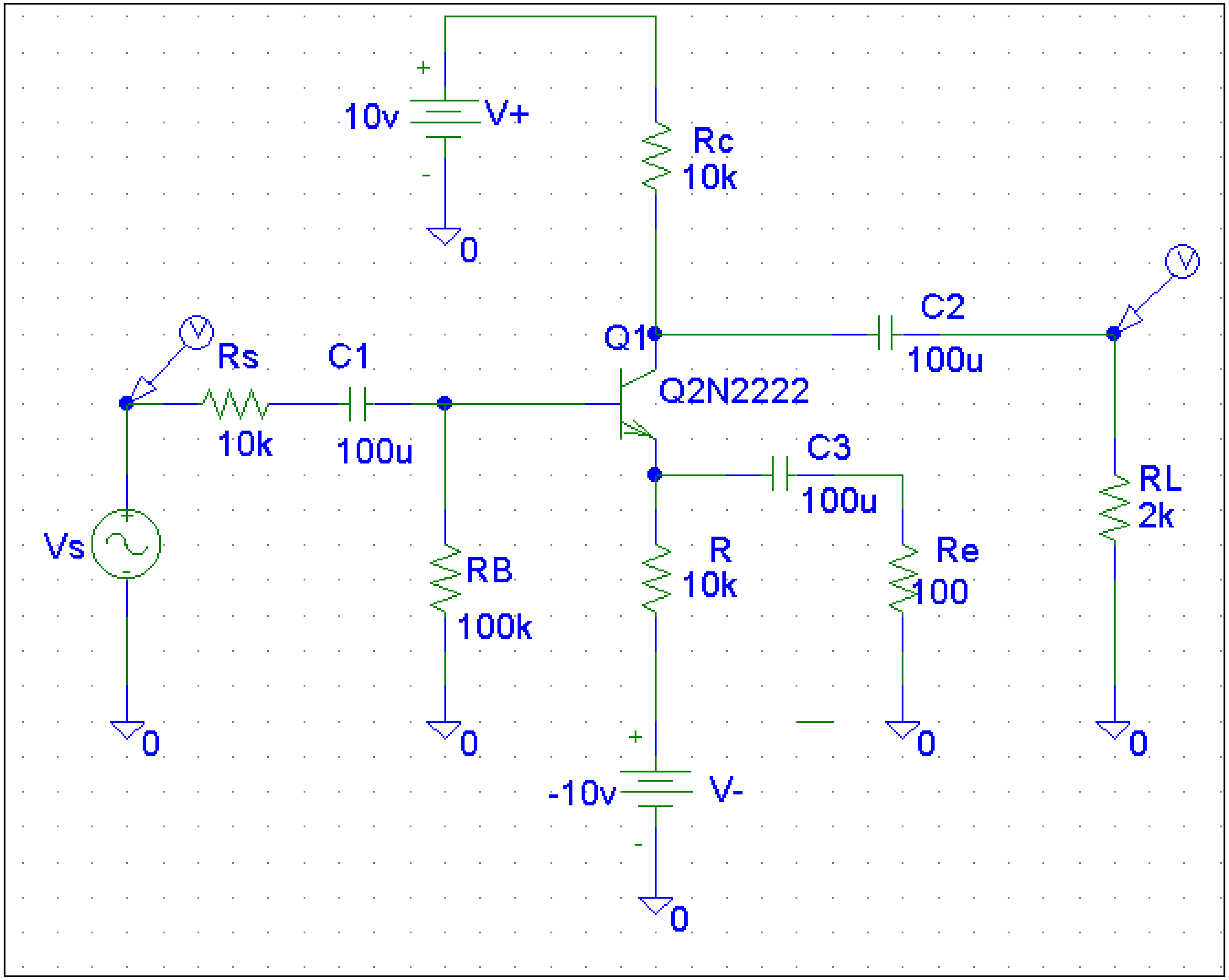
FOURIER COMPONENTS OF TRANSIENT RESPONSE V($N_0009)

DC COMPONENT = -1.226074E-01

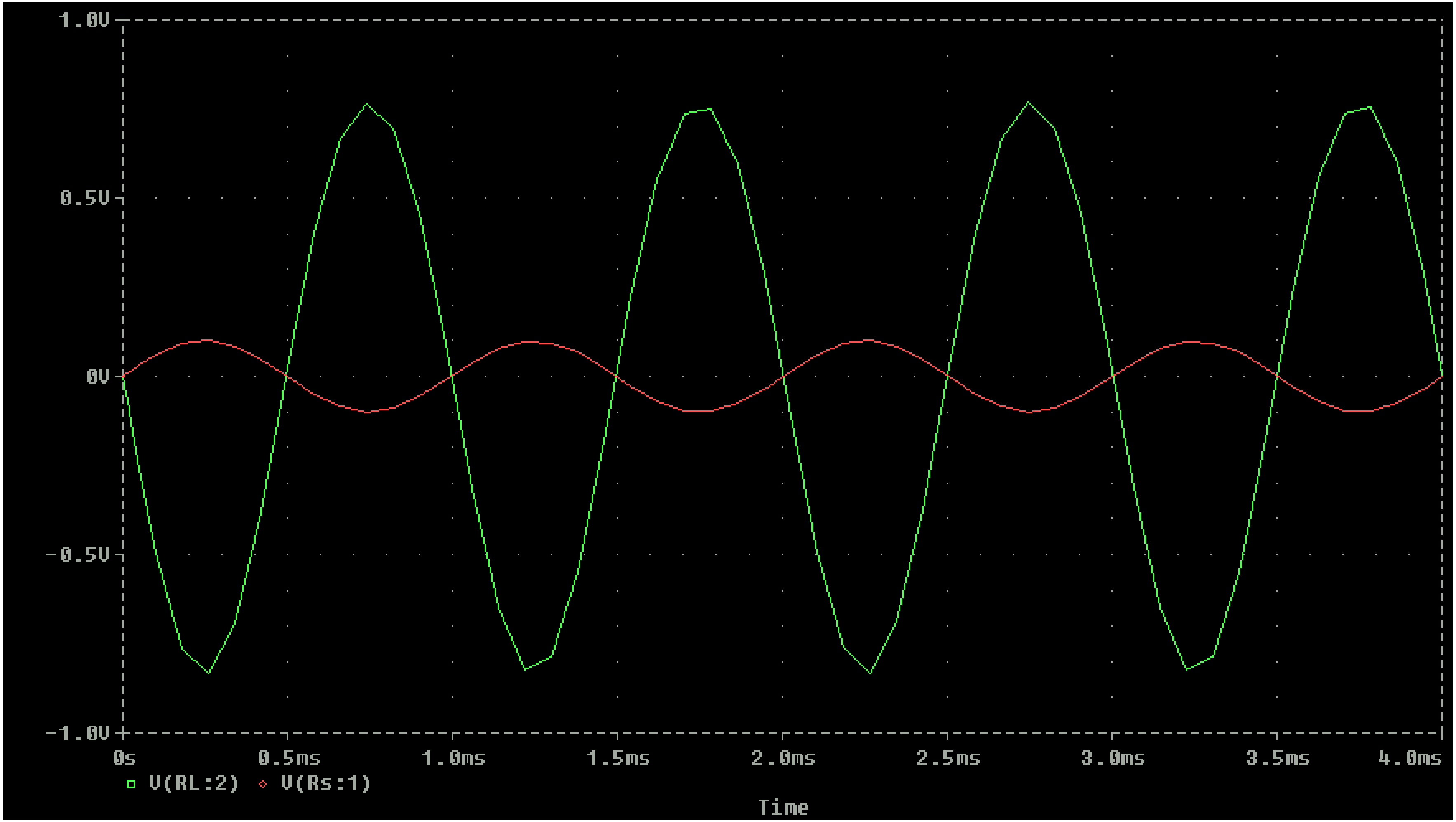
HARMONIC NO	FREQUENCY (HZ)	FOURIER COMPONENT	NORMALIZED COMPONENT	PHASE (DEG)	NORMALIZED PHASE (DEG)
1	1.000E+03	1.581E+00	1.000E+00	-1.795E+02	0.000E+00
2	2.000E+03	1.992E-01	1.260E-01	9.111E+01	2.706E+02
3	3.000E+03	2.171E-02	1.374E-02	-1.778E+02	1.668E+00
4	4.000E+03	3.376E-03	2.136E-03	-1.441E+02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

TOTAL HARMONIC DISTORTION = 1.267478E+01 PERCENT

CE amplifier with RE



CE amplifier with R_E



$Av \approx -7.5$

FOURIER COMPONENTS OF TRANSIENT RESPONSE V($N_0009)

DC COMPONENT = -1.353568E-02

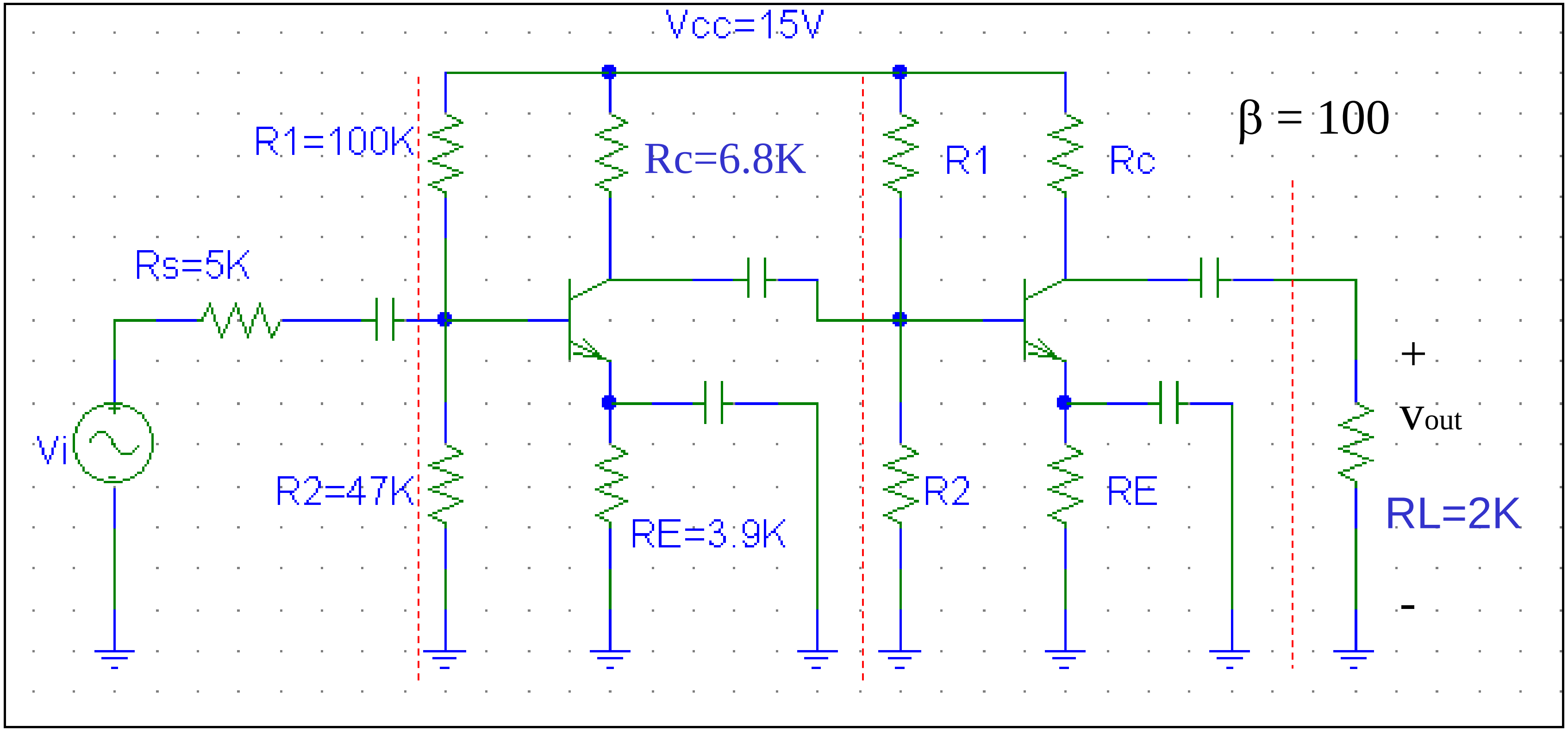
HARMONIC NO	FREQUENCY (HZ)	FOURIER COMPONENT	NORMALIZED COMPONENT	PHASE (DEG)	NORMALIZED PHASE (DEG)
1	1.000E+03	7.879E-01	1.000E+00	-1.794E+02	0.000E+00
2	2.000E+03	1.604E-02	2.036E-02	9.400E+01	2.734E+02
3	3.000E+03	5.210E-03	6.612E-03	-1.389E+02	4.056E+01
4	4.000E+03	3.824E-03	4.854E-03	-1.171E+02	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. 4.83

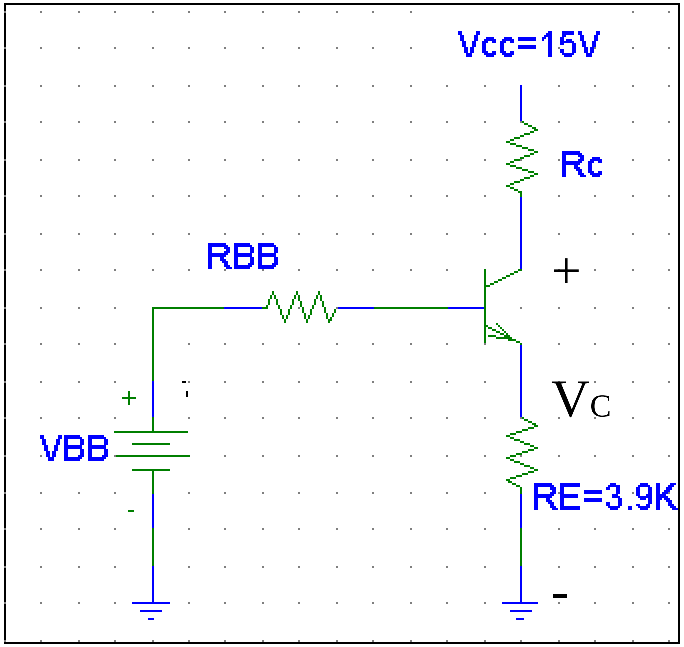


- 2 stage amplifier
- Both stages are the same
- Capacitively coupled

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

Prob. 4.83

(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
$I_B \approx I_E/\beta$

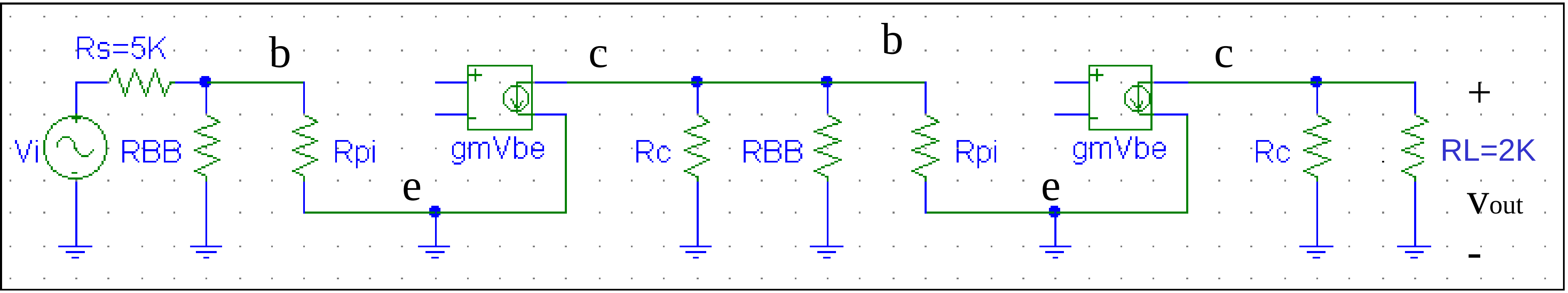
$I_E = [V_{BB} - V_{BE}]/[R_{BB}/\beta + R_E]$

$I_E = 0.97mA$

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

Prob. 4.83

(b) find ac circuit

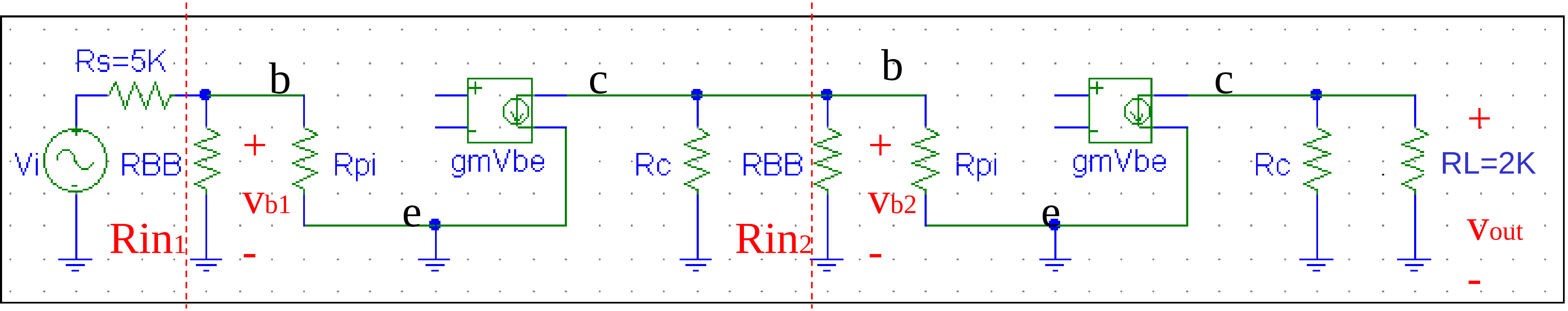


$R_{BB} = R_1||R_2 = 100K||47K = 32K\Omega$

$R_{pi} = V_T/I_B = 25mV(100)/.97mA \approx 2.6K\Omega$

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

Prob. 4.83



(c) find R_{in1}

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

$= 32K||2.6K$

$= 2.4K\Omega$

(d) find R_{in2}

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

$= 2.4K\Omega$

find v_{b1}/v_i

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

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

$= 0.32$

find v_{b2}/v_{b1}

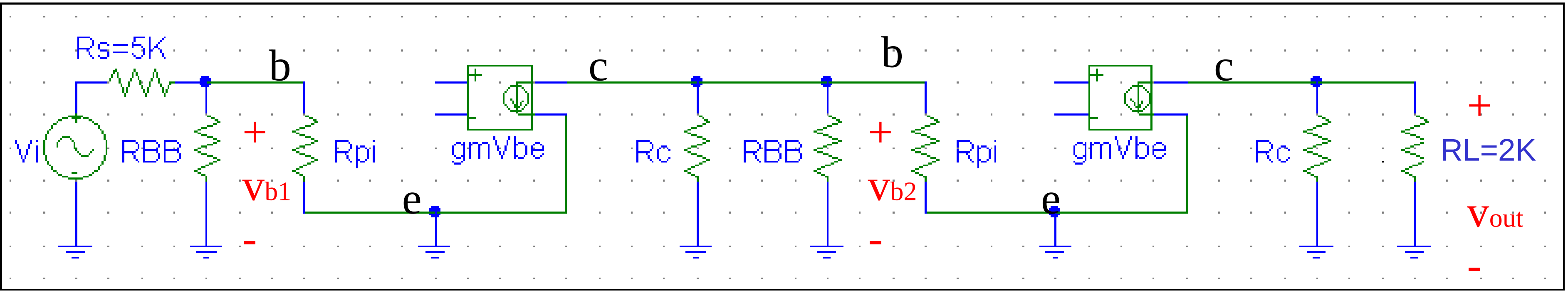
$v_{b2} = -g_m v_{be1}[R_C||R_{BB}||R_{pi}]$

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

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

$= -69.1$

Prob. 4.83



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

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

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

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

$= -60.3$

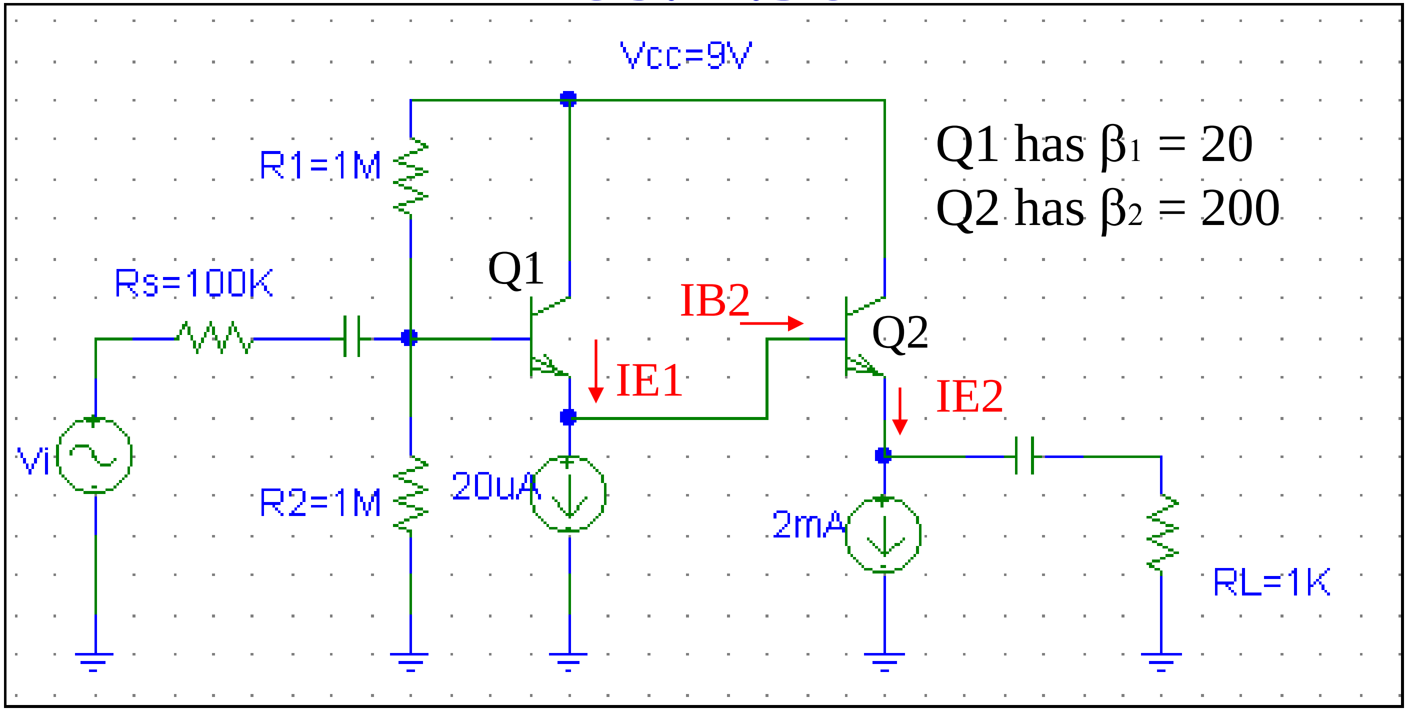
(f) find overall voltage gain

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

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

$v_{out}/v_i = 1332$

Prob. 4.96



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

$I_{E2} = 2mA$

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

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

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

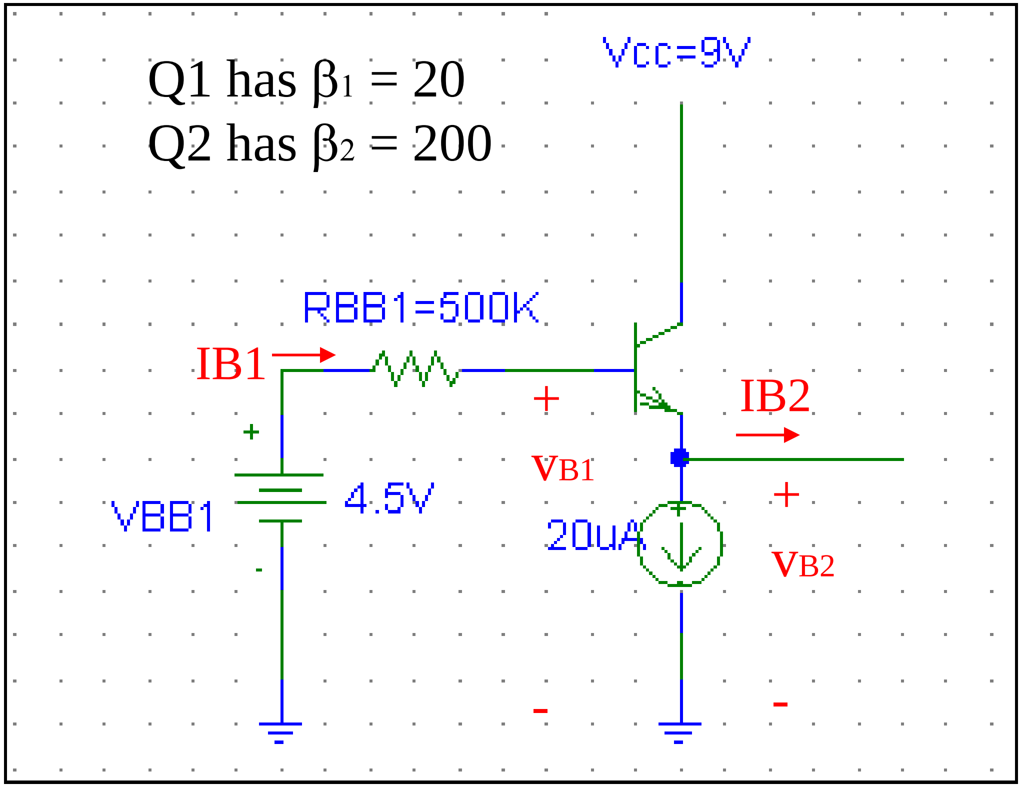
$I_{E1} = 30\mu A$

Prob. 4.96

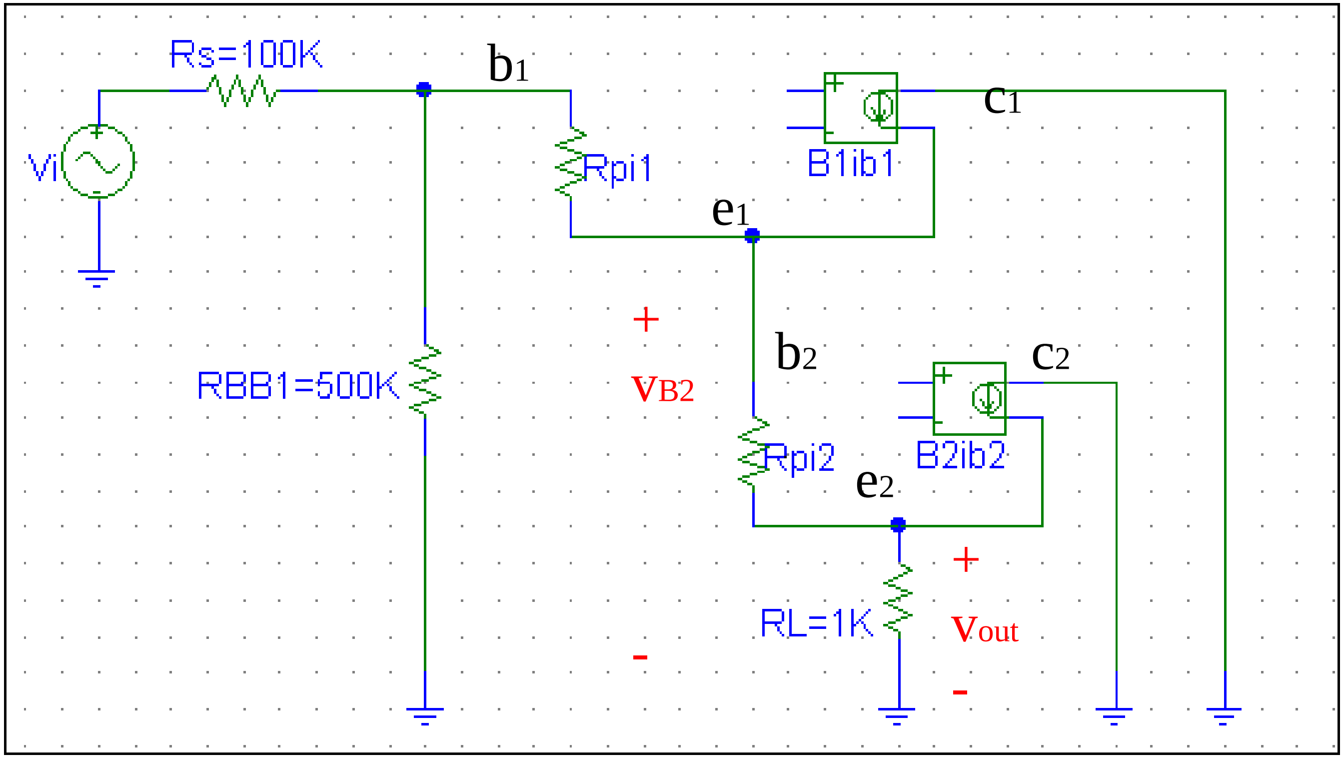
Find V_{B1}, and V_{B2}
Use Thevenin equivalent

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

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



Prob. 4.96



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

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

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

$= 25mV(200)/2mA$

$= 2.5K\Omega$

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

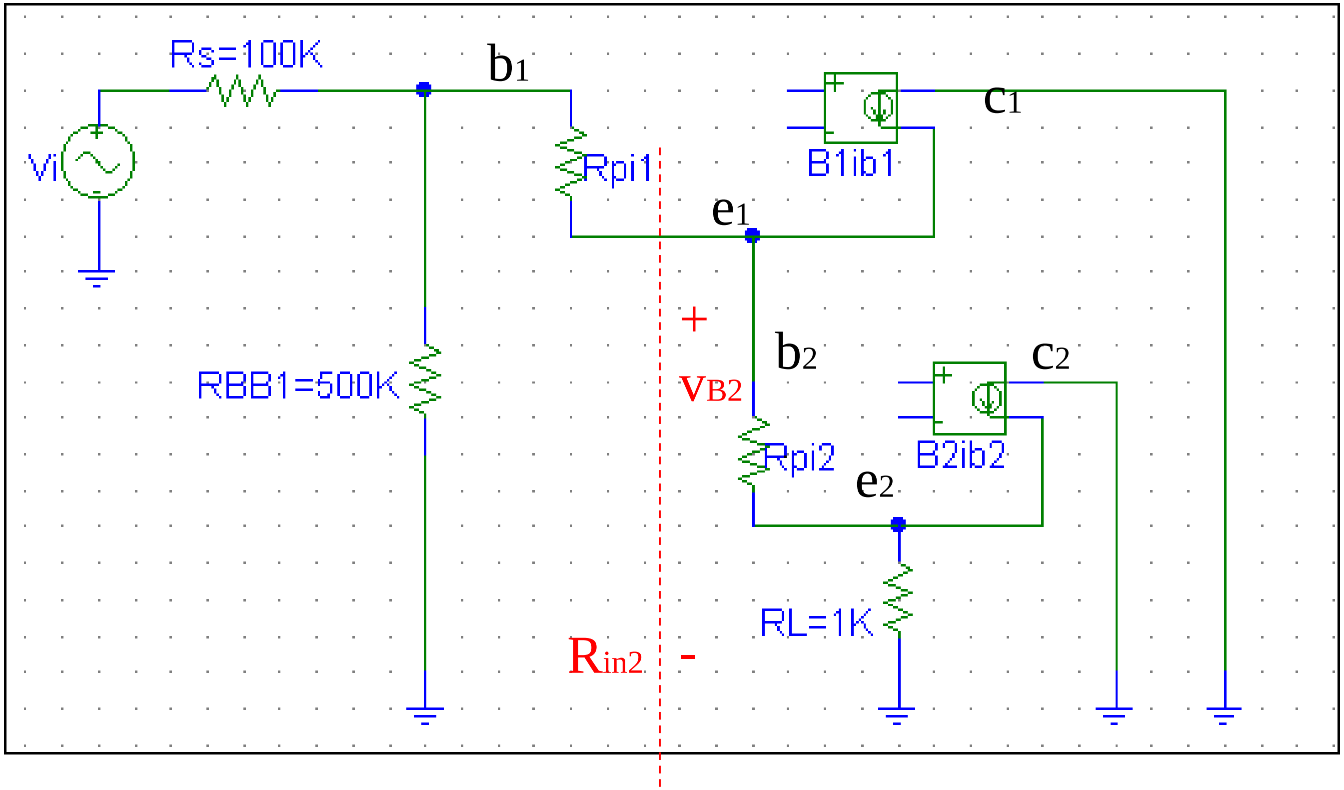
$v_{b2} = (i_{b2} + \beta_2 i_{b2})R_L + i_{b2}R_{pi2}$

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

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

≈ 0.988

Prob. 4.96

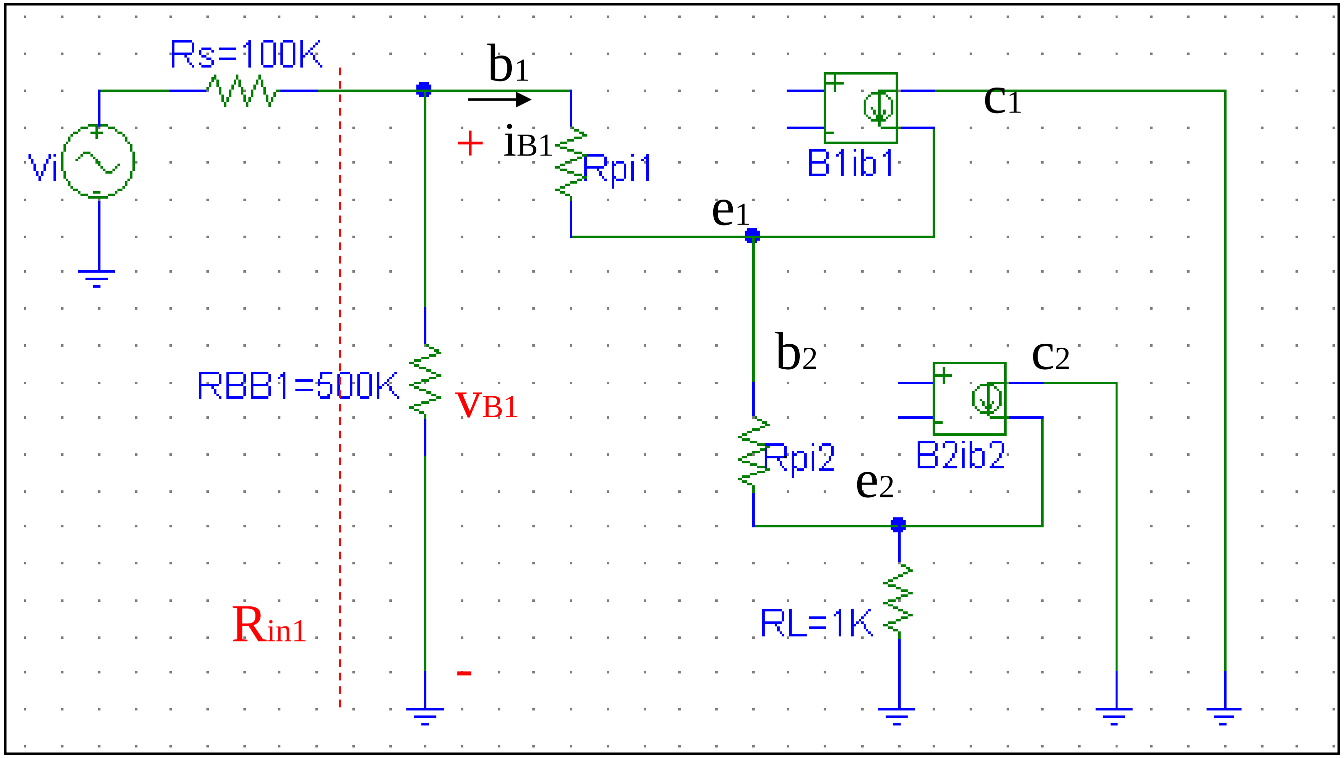


(b) find $R_{in2} = v_{b2}/i_{b2}$

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

$$R_{in2} = v_{b2}/i_{b2} = (1 + \beta_2)R_L + Rpi_2$$
$$= (1 + 200)1K + 2.5K$$
$$\approx 204K$$

Prob. 4.96



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

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

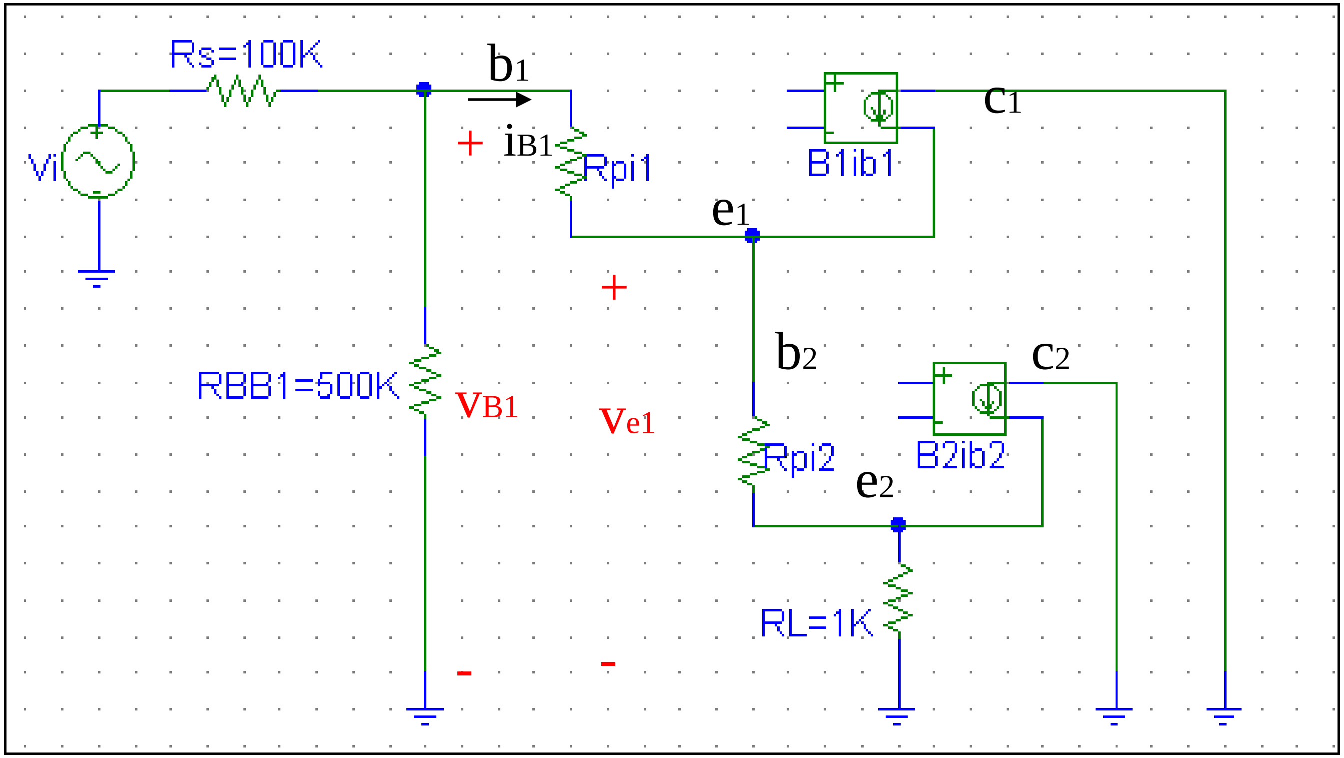
$= R_{BB1} ||\ [Rpi_1 + (1+ \beta_1)R_{in2}]$,

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. 4.96



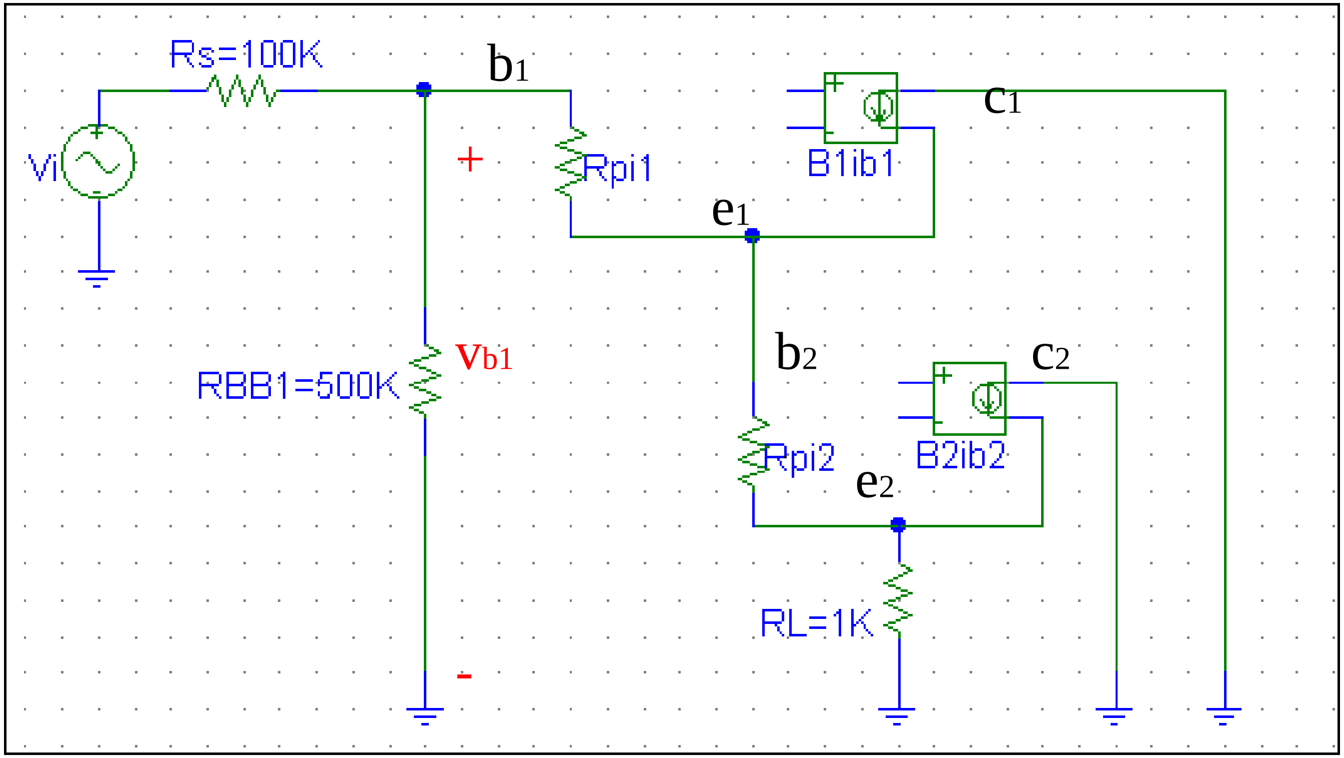
(c) find v_{e1}/v_{b1}

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

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

$$v_{e1}/v_{b1} = (1+\beta_1)\,R_{in2}/[(1+\beta_1)\,R_{in2} + Rpi_1]$$
$$= (1+20)204K/[(1+20)204K + 16.7K]$$
$$\approx 0.996$$

Prob. 4.96



(d) find v_{b1}/v_i

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

$= 0.82$

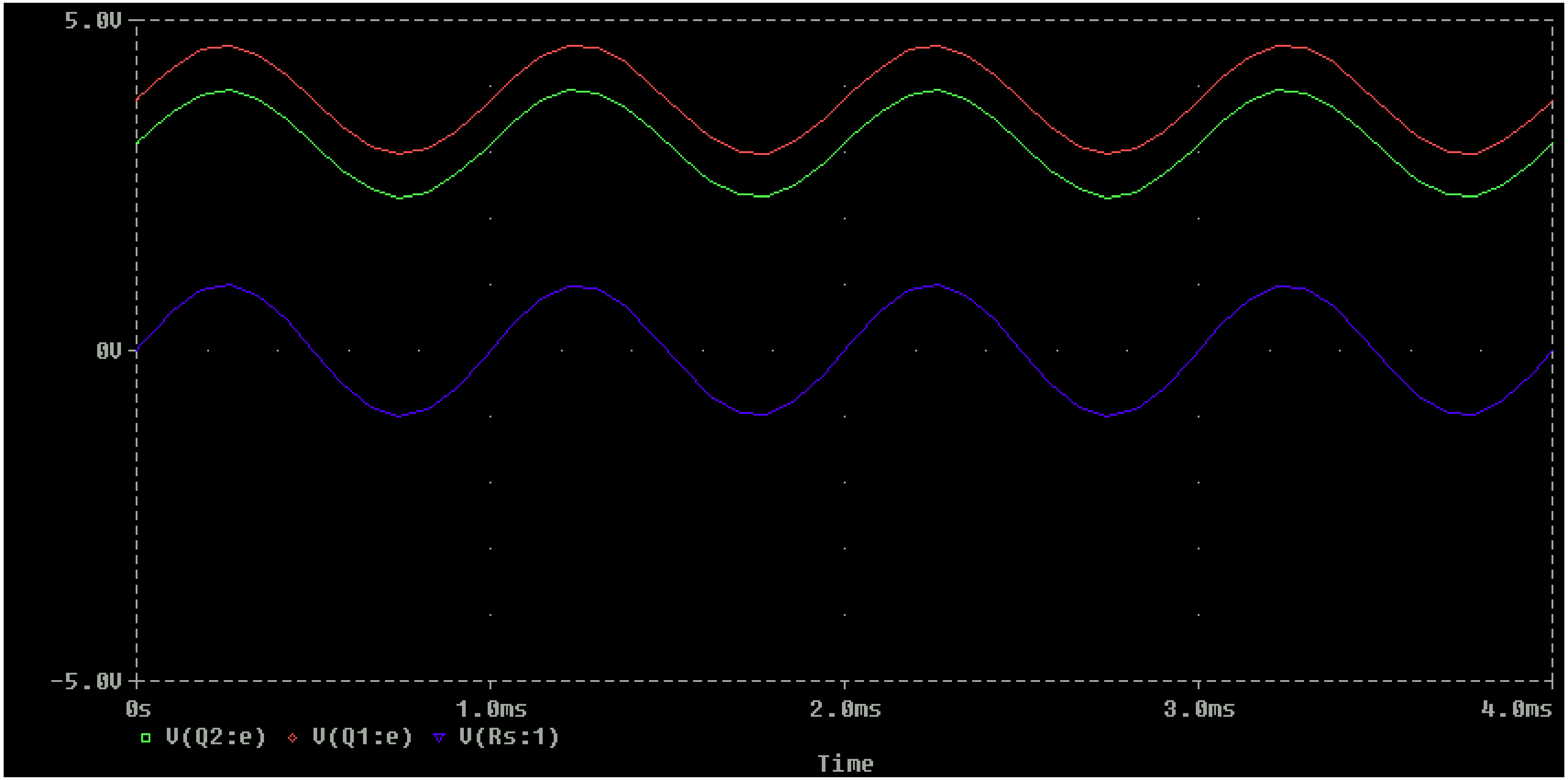
(e) find overall voltage gain

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

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

$v_{out}/v_i = 0.81$

(Prob. 4.96) Voltage outputs at each stage

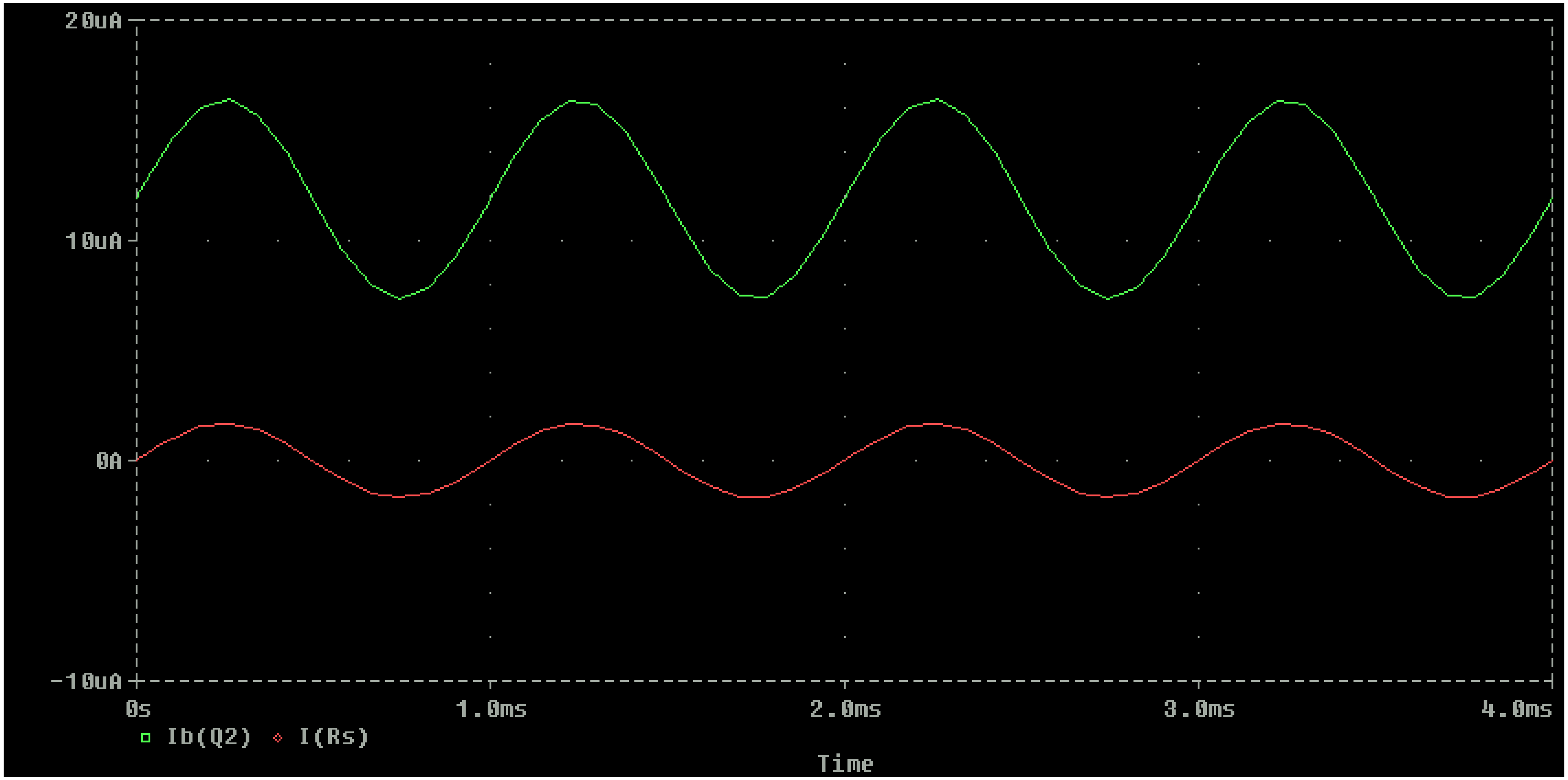


Output of stage 2

Output of stage 1

Input

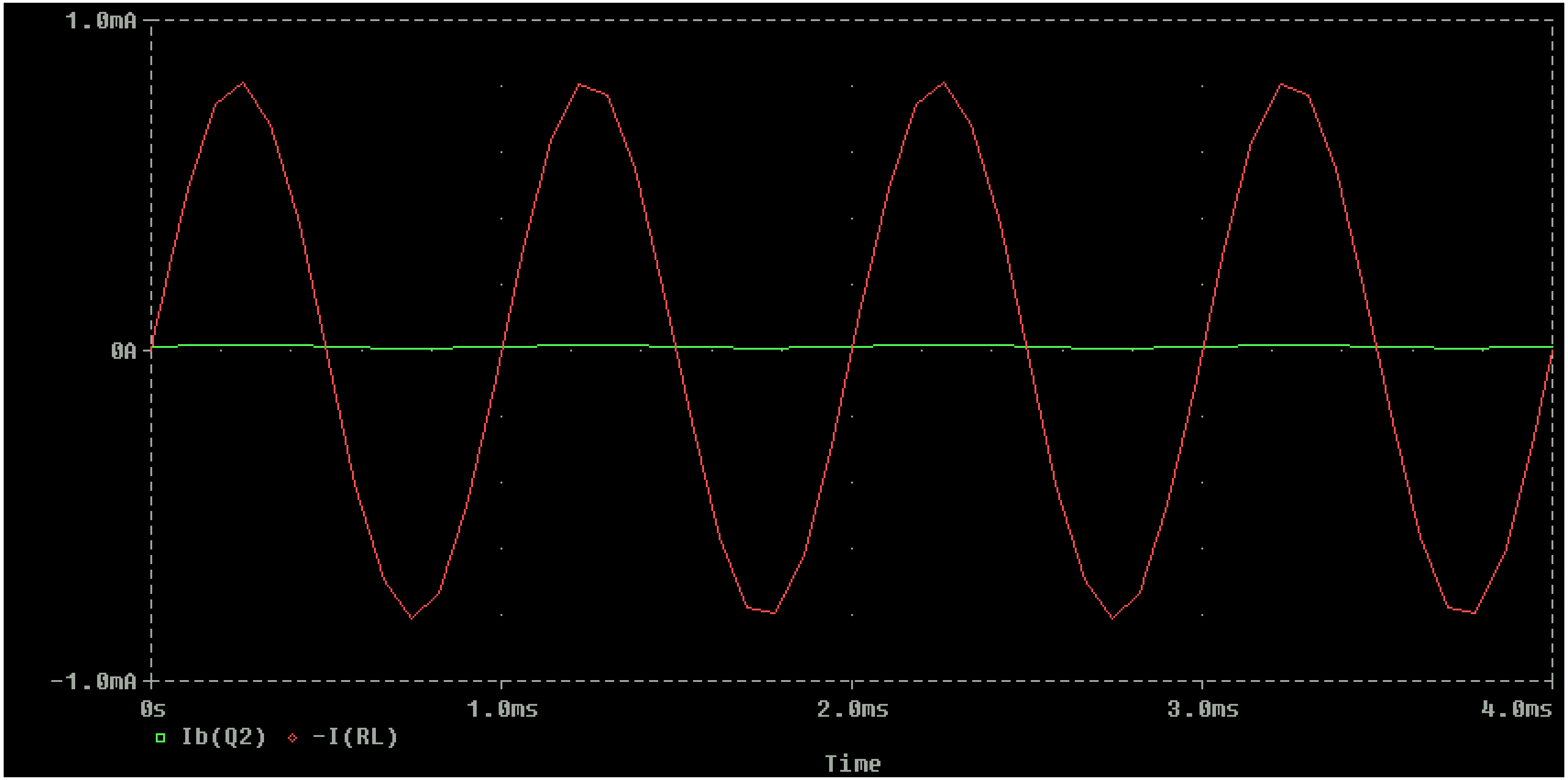
(Prob. 4.96) Current



Input to stage 2 (ib2)

Input current

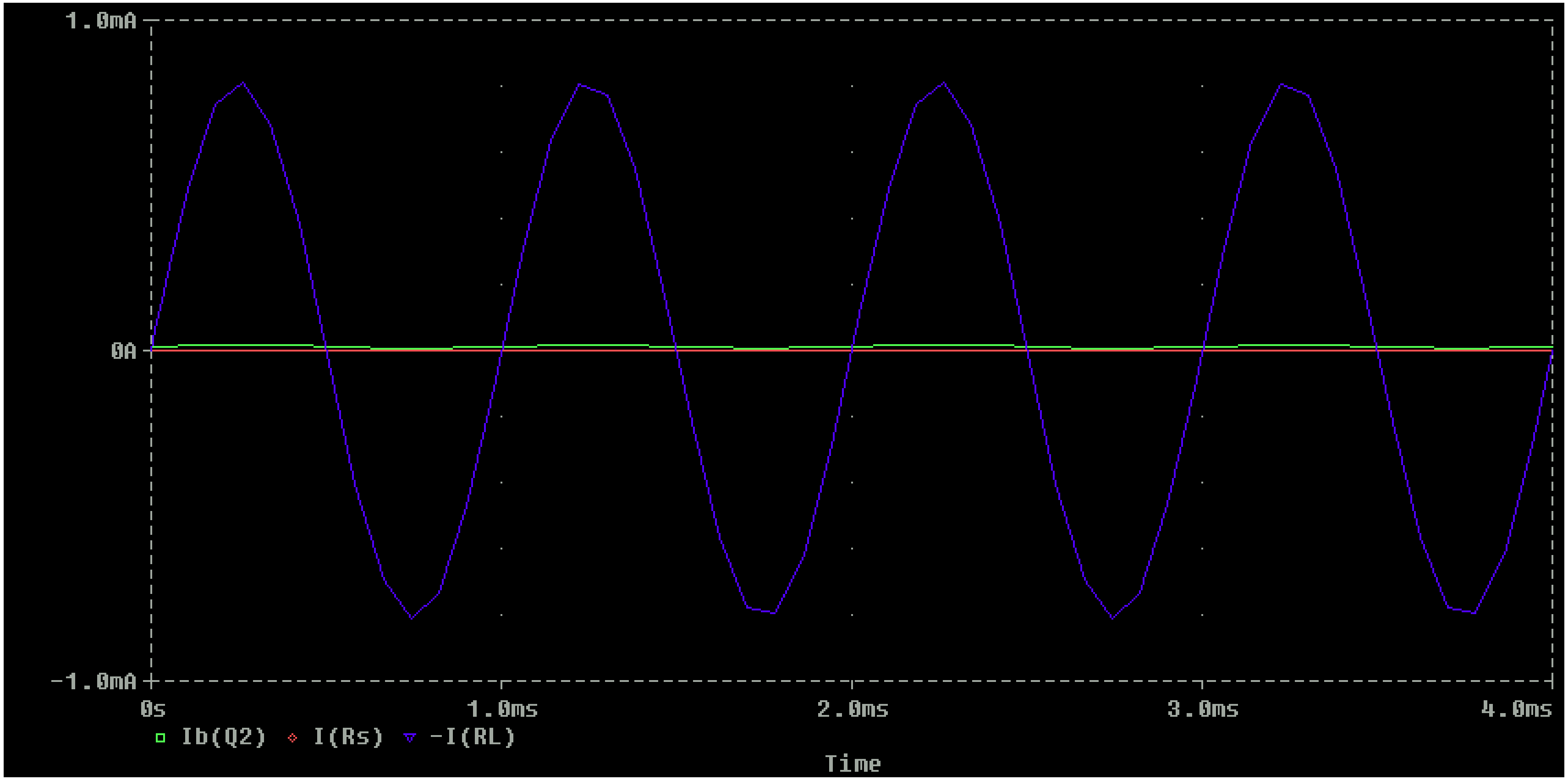
(Prob. 4.96) Current



Input to
stage 2 (ib2)

output
current

(Prob. 4.96) Current



Input to stage 2 (ib2)

Input current

output current

(Prob. 4.96) Power and current gain

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

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

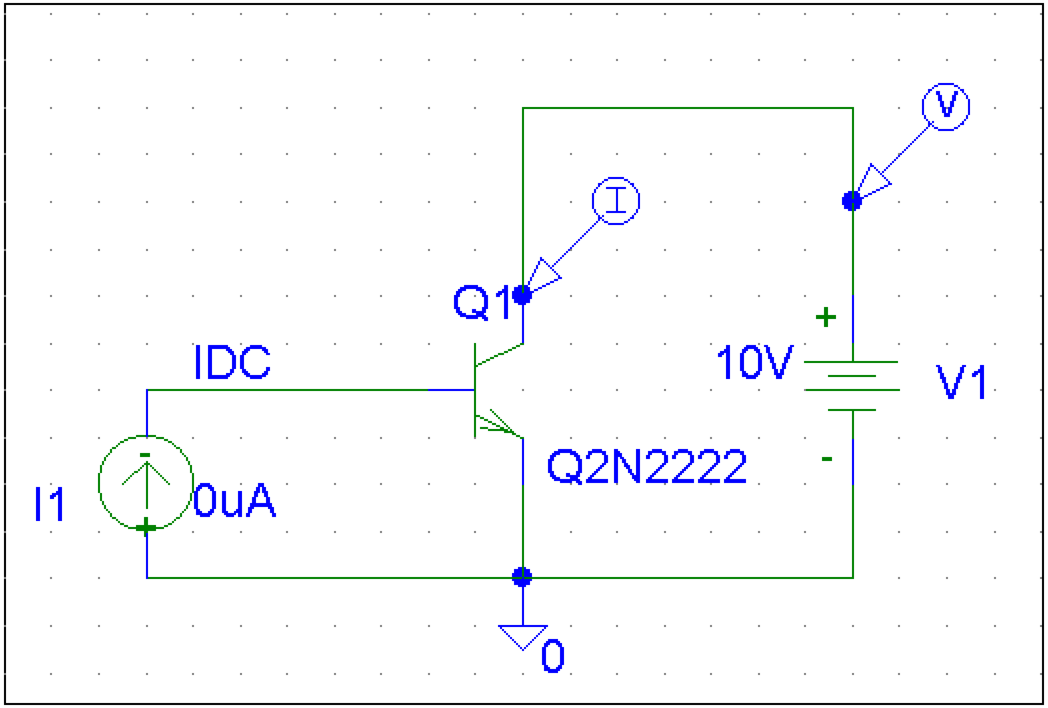
current gain = 0.81mA/ 2.0μA = 405

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

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

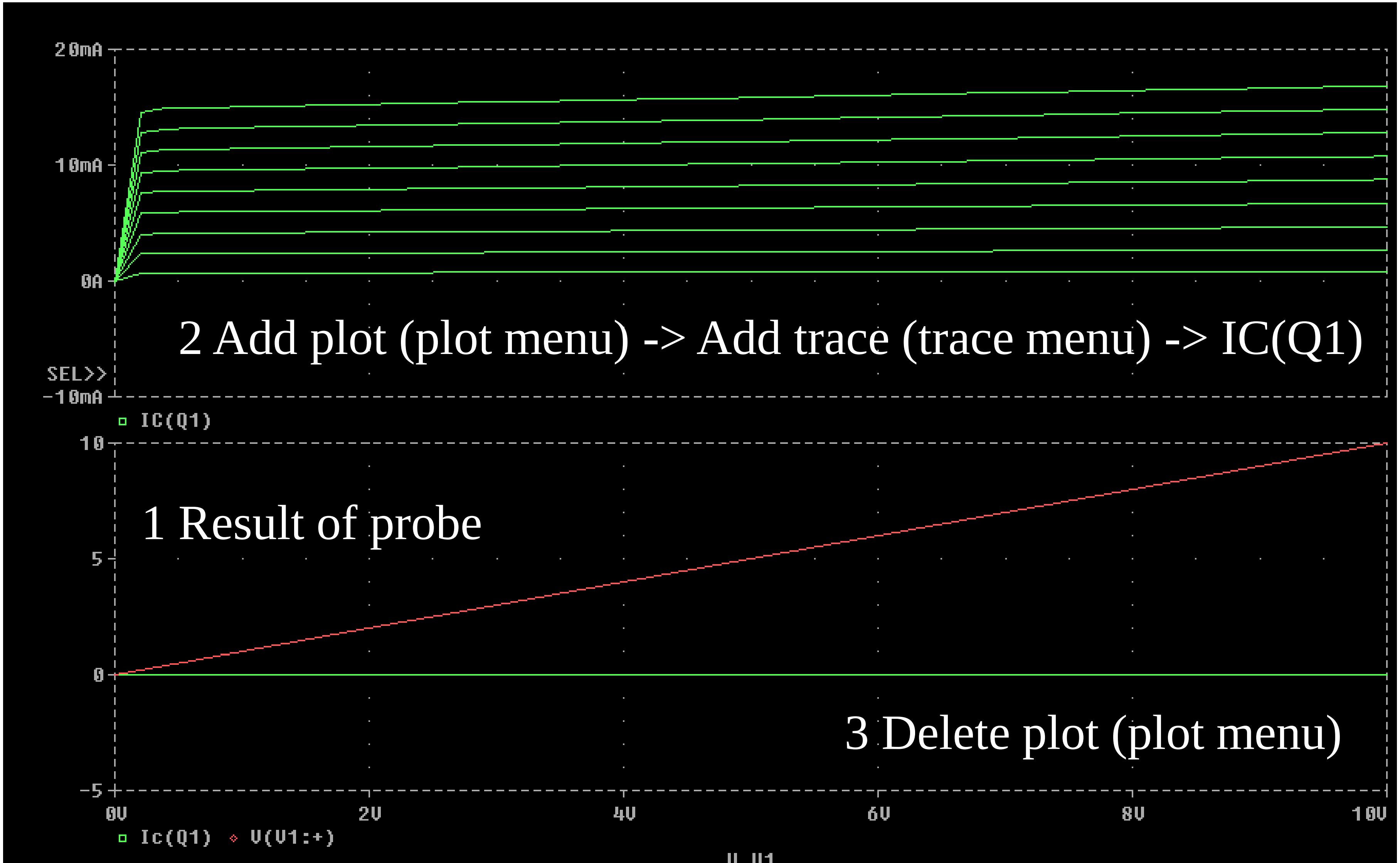
power gain = 656μW/2μW = 329

BJT Output Characteristics

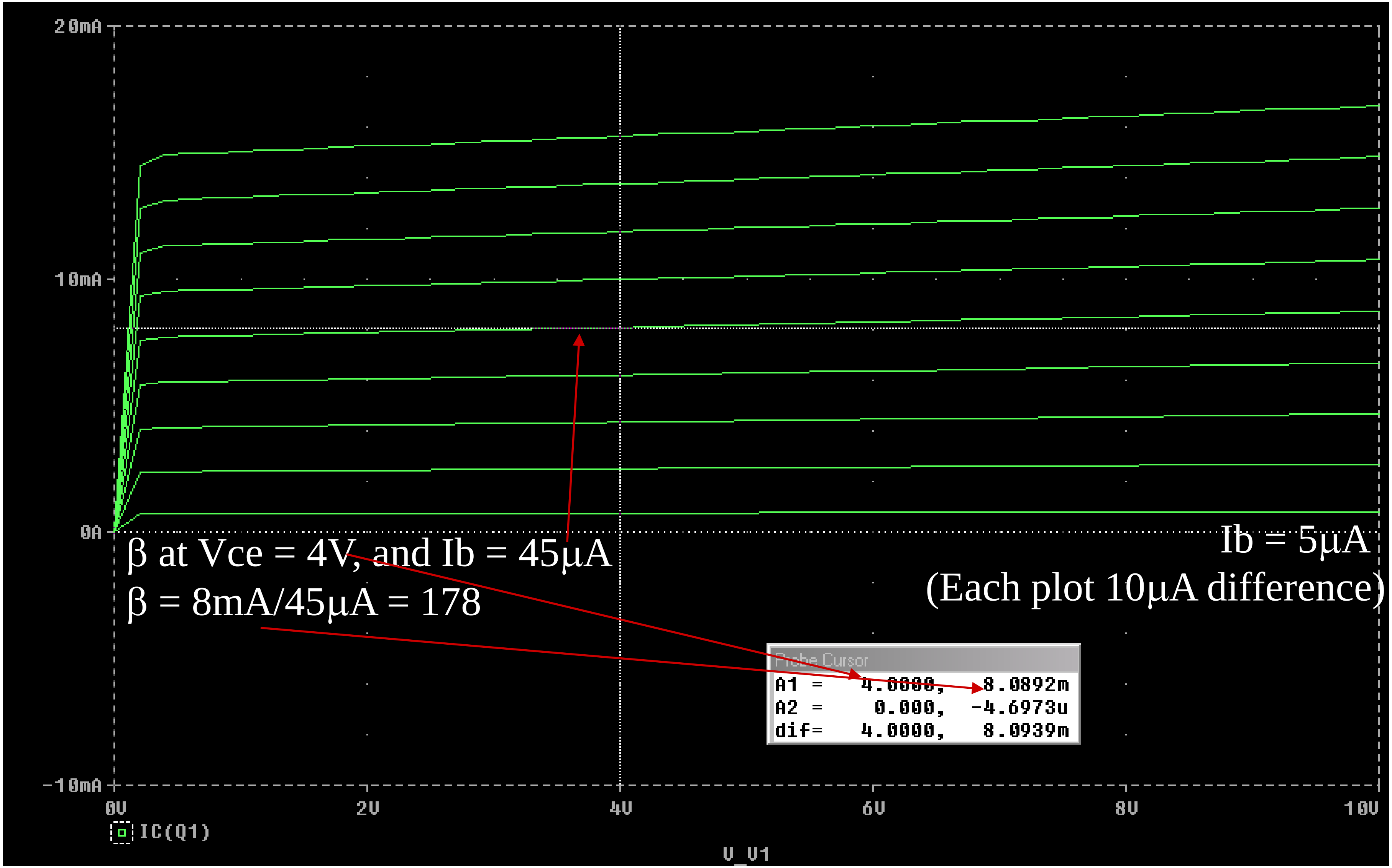


•Plot Ic vs. Vce for multiple values of Vce and Ib
•From Analysis menu use DC Sweep
•Use Nested sweep in DC Sweep section

Probe: BJT Output Characteristics



BJT Output Characteristics: current gain



BJT Output Characteristics: transistor output resistance

Ib = 5µA

(Each plot 10µA difference)

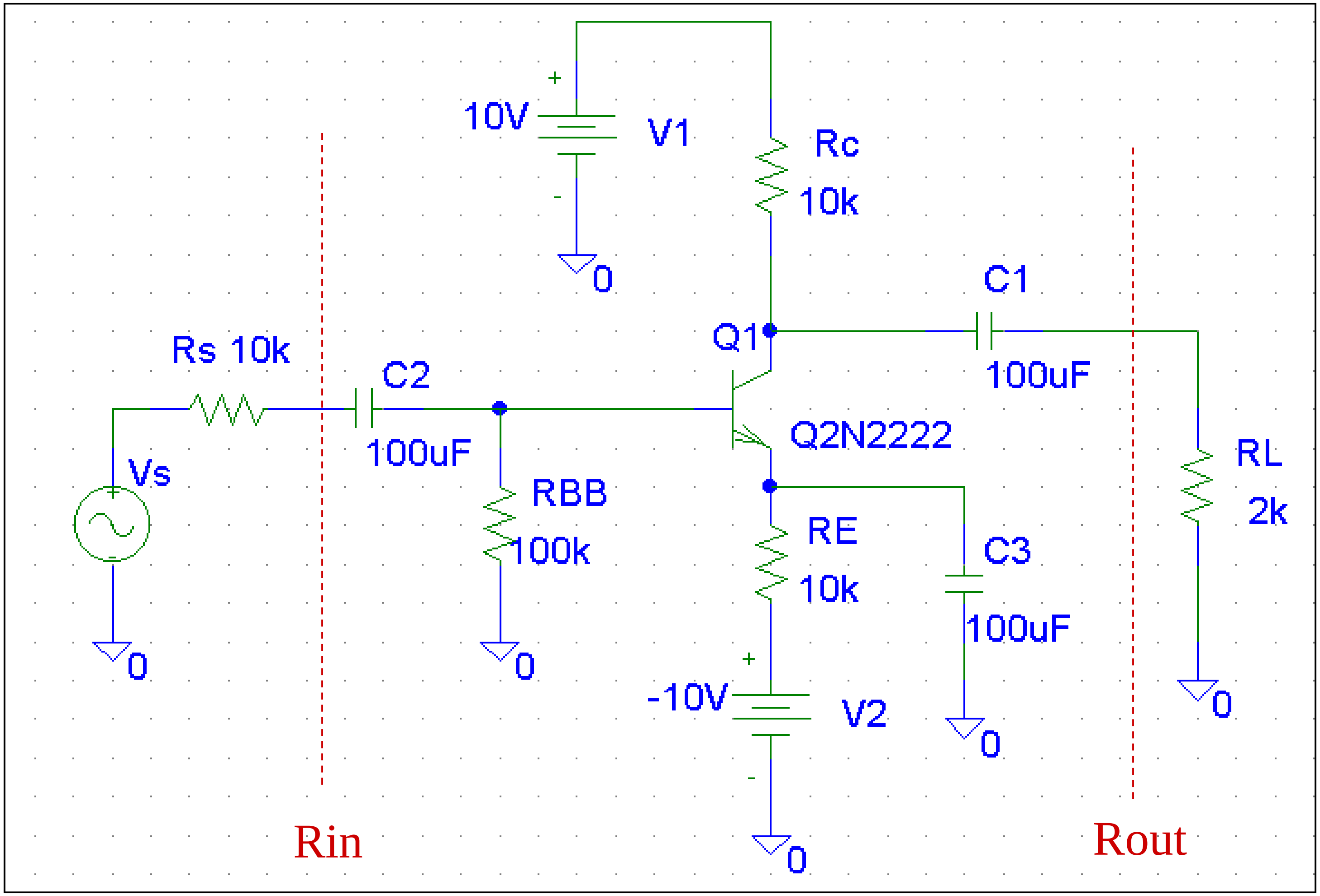
Ro = 1/slope

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

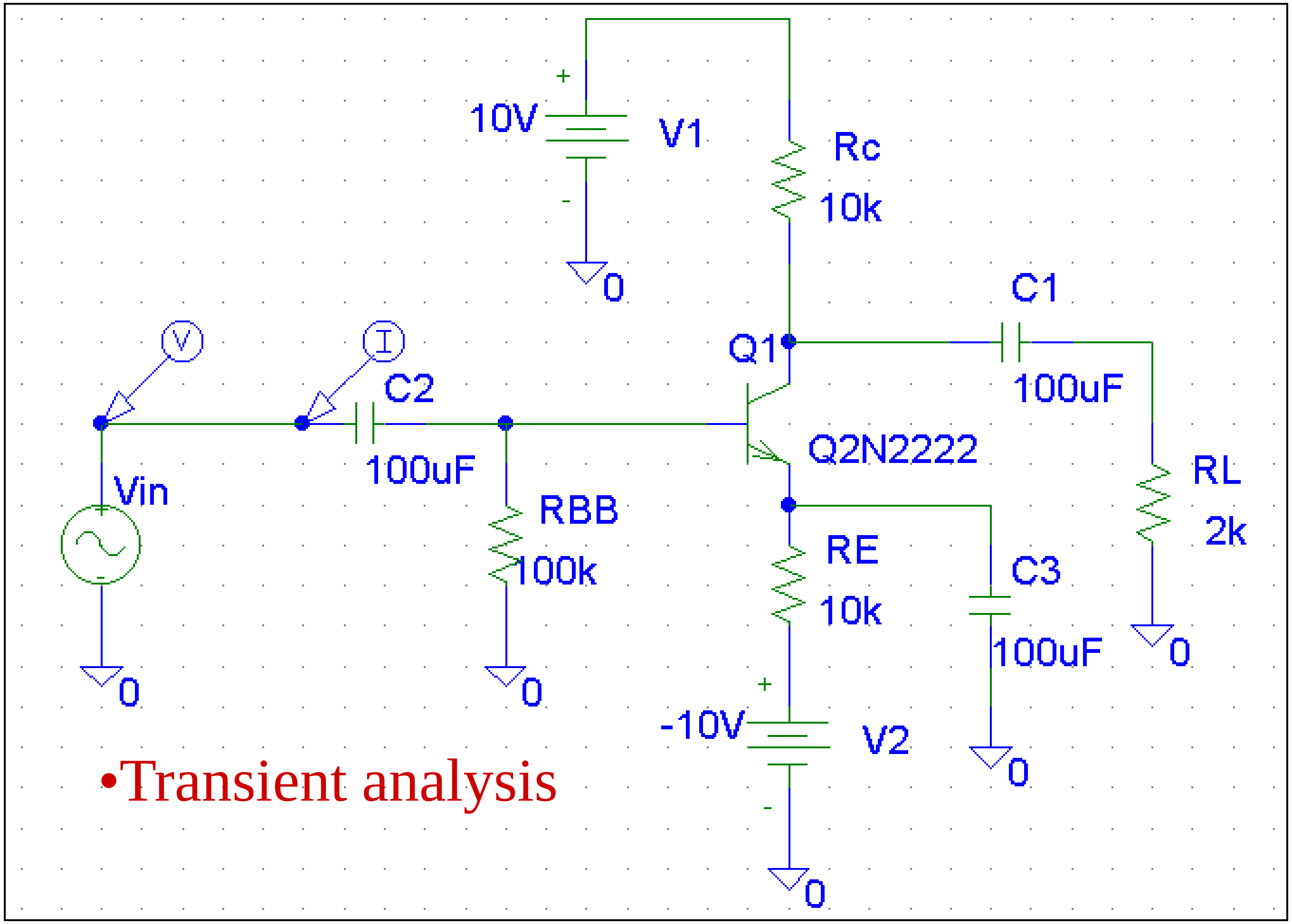
- Replace source, Vs and Rs with Vin, measure
  Rin = Vin/Iin

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

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

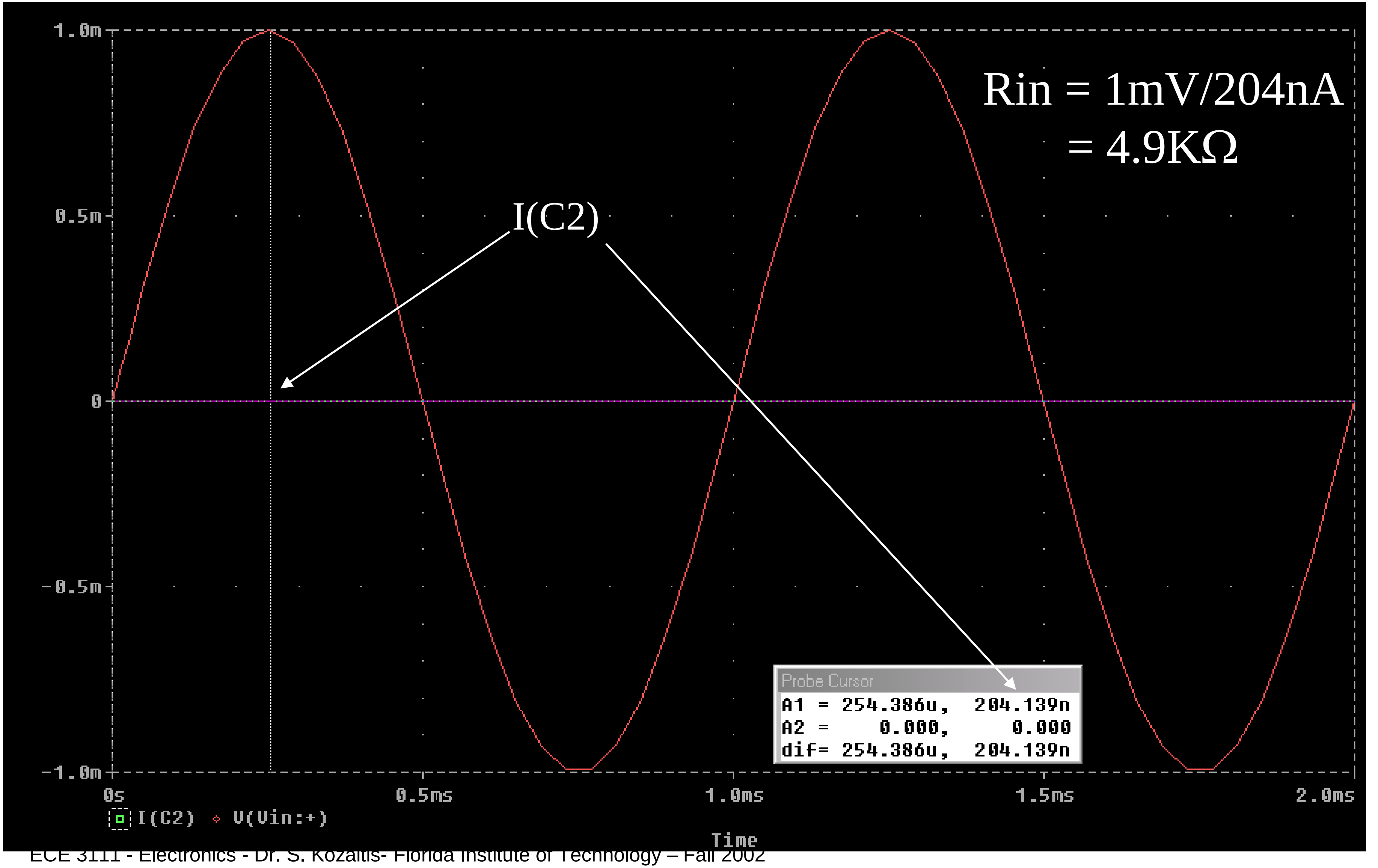
- Vin should have a small value so operating point does not change
  $V_{in} \cong 1mV$

Rin Measurement



• Transient analysis

Probe results



Output Resistance Measurement Using SPICE

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

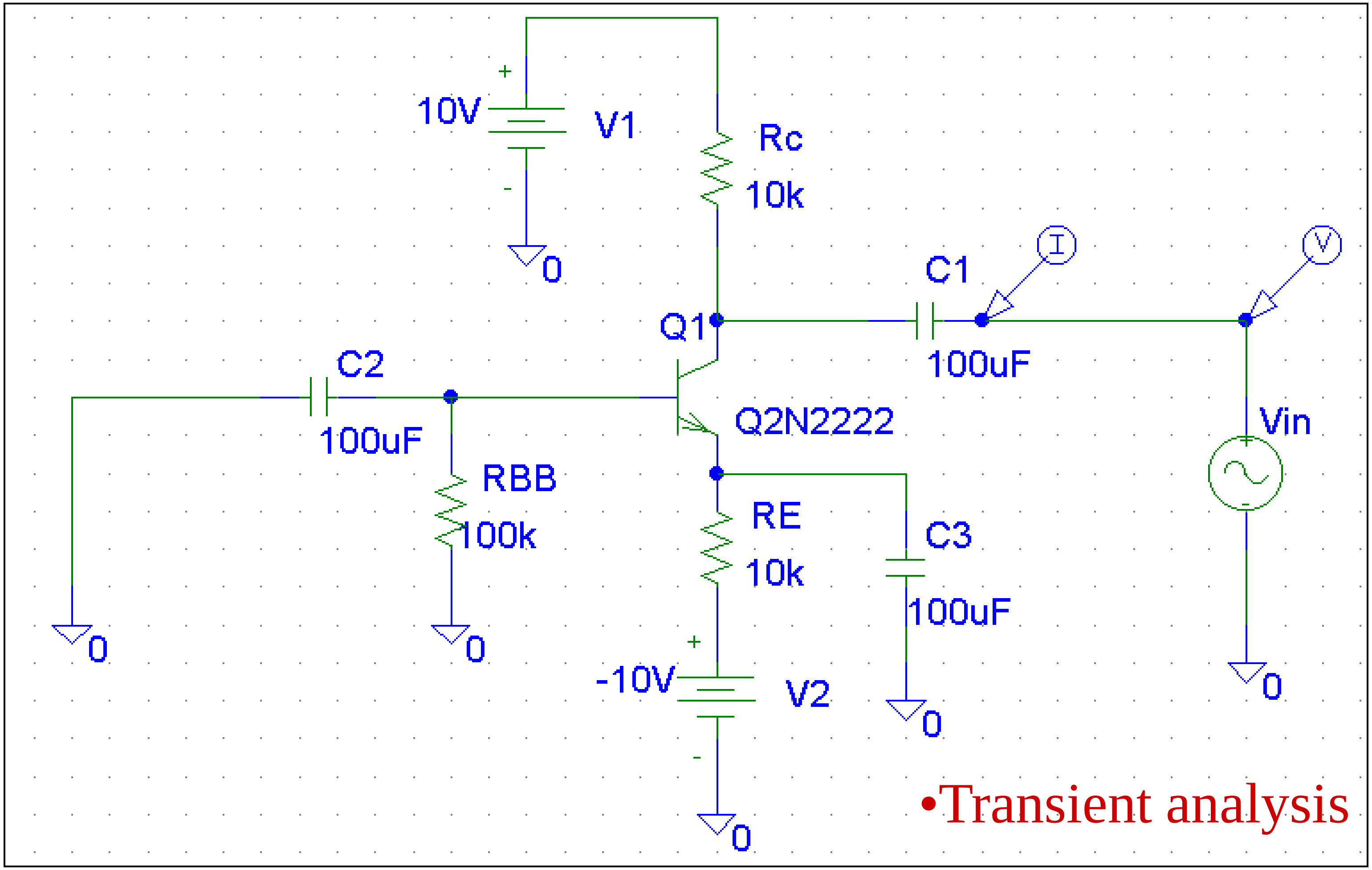
- Set Vs = 0

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

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

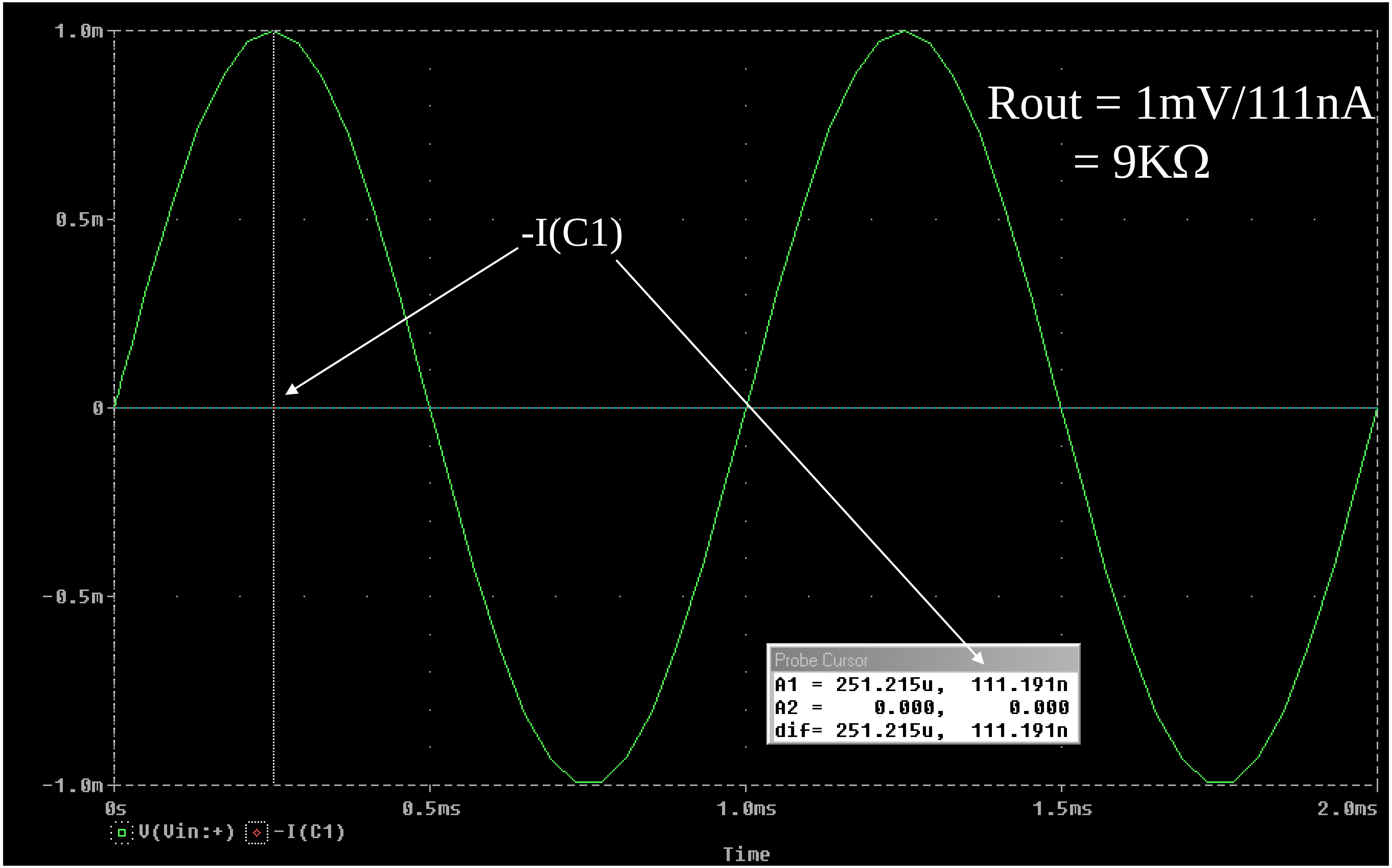
- Vin should have a small value so operating point does not change $V_{in} \cong 1mV$

Rout Measurement



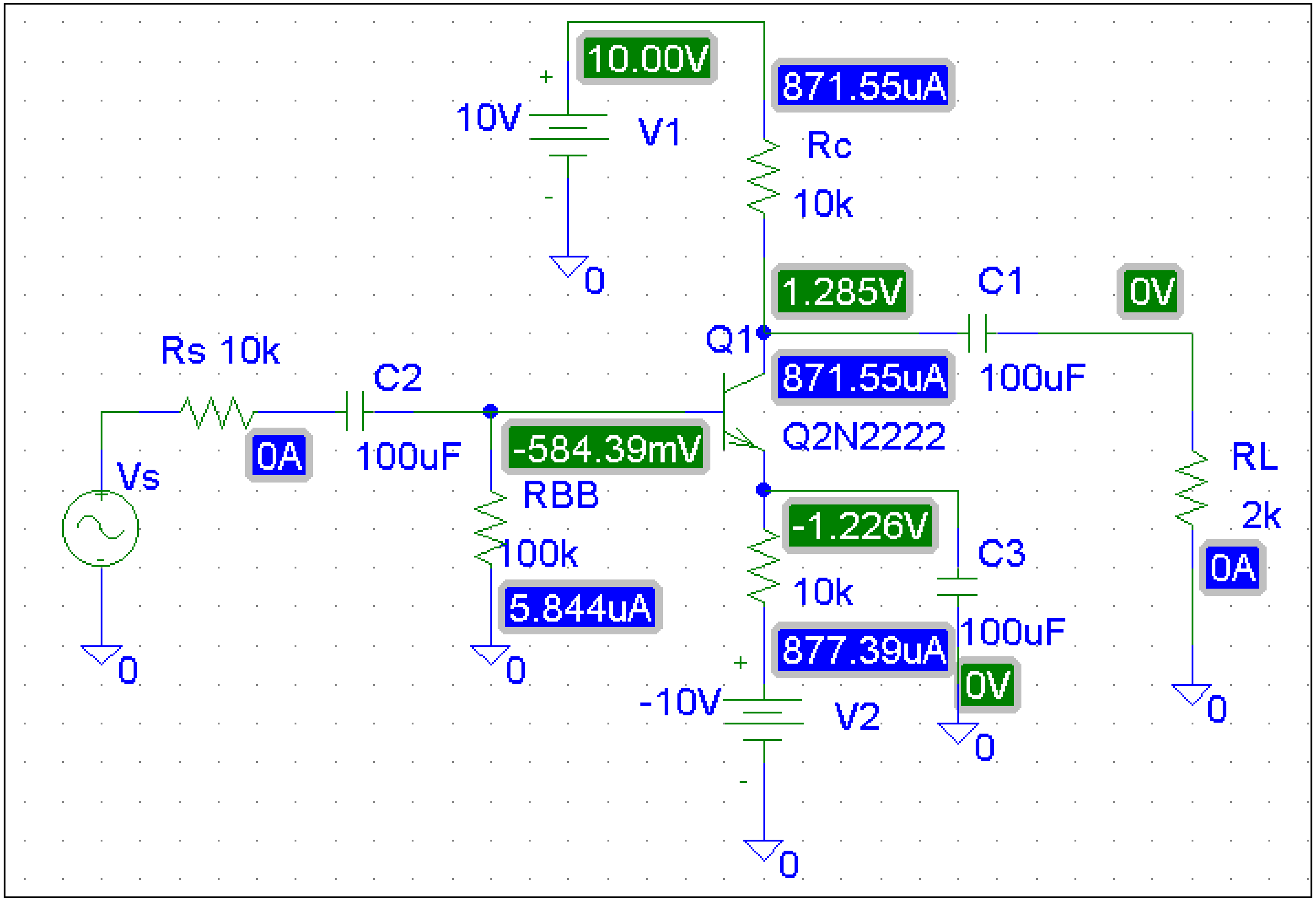
- Transient analysis

Probe results



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

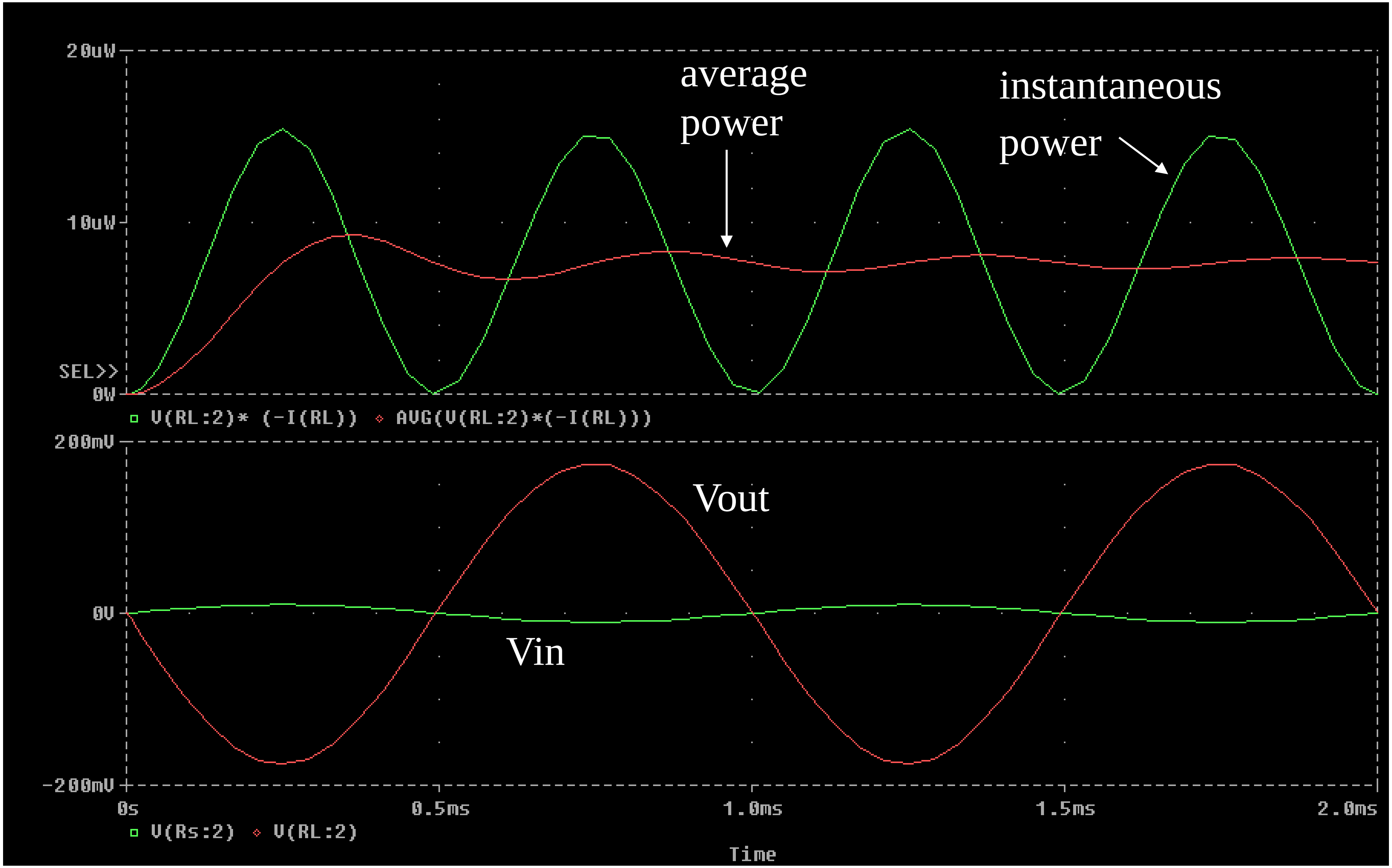
DC Power measurements



Power delivered by ± 10 sources:

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

ac Power Measurements of Load



Reference

- *[www.electronics.teipir.gr/personalpages/.../1/...../ECE3111BJTTransistors.]*