Basic Transistor Amplifier Configurations

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Outline

- ✓ Phasor Notation
- ✓ Bipolar Junction Transistor (BJT) Amplifiers
  - Basic Transistor Amplifier Configurations
  - Common-Emitter (CE) Amplifiers
  - Common-Collector (CC) or Emitter-Follower Amplifier
  - Common-Base (CB) Amplifier
  - Multi-stage Amplifiers
    - Cascade Configuration
    - Darlington Pair Configuration

Phasor Notation

Euler's identity

- A lowercase letter with an uppercase subscript, such as i_B and v_{BE}, indicates a *total instantaneous value*. An uppercase letter with an uppercase subscript, such as I_B and V_{BE}, indicates a *dc quantity*.
- A lowercase letter with a lowercase subscript, such as i_b and v_{be}, indicates an *instantaneous value* of a time-varying signal. Finally, an uppercase letter with a lowercase subscript, such as I_b and V_{be}, indicates a *phasor quantity*. For instance, consider a sinusoidal voltage superimposed on a dc voltage as

$$v_{BE} = V_{BE} + v_{be} = V_{BE} + V_M \cos(\omega t + \Phi_m)$$

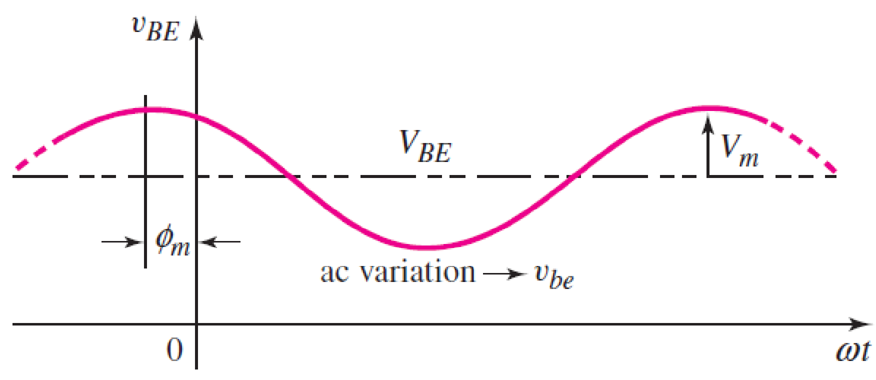
We can write the sinusoidal voltage as,

$$v_{be} = V_M \cos(\omega t + \Phi_m) = V_M \mathrm{Re}\left\{e^{j(\omega t + \Phi_m)}\right\} = \mathrm{Re}\left\{V_M e^{j\Phi_m} e^{j\omega t}\right\}$$

Therefore, the complex number can be,

$$V_{be} = V_M e^{j\Phi_m}$$

which represents amplitude and phase angle of sinusoidal voltage.



Basic Bipolar Junction Transistor (BJT)

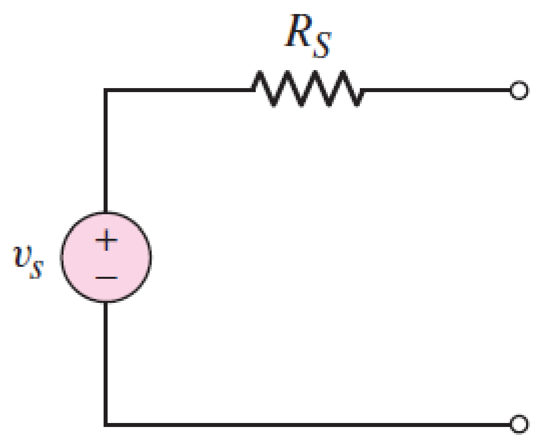
- ✓ Three basic single transistor amplifier configurations can be formed, depending on which of *three transistor terminals is used as signal ground*.

  1. Common-Emitter (CE), 2. Common-Collector (CC) – Emitter follower,

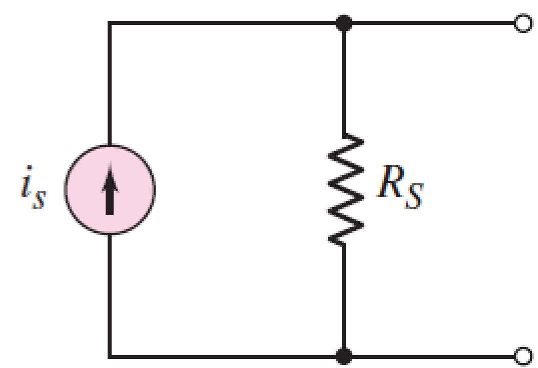
  3. Common-Base (CB)

- ✓ Particular application of these configurations depends on whether the input signal is a voltage/current and whether the output signal is voltage/current.

- ✓ Input signal source modeled as either *Thevenin/Norton equivalent circuit*.



Thevenin equivalent circuit
(output of a microphone)



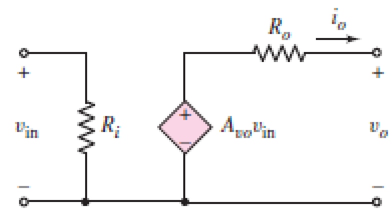
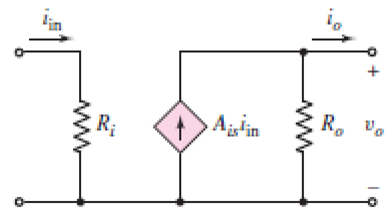
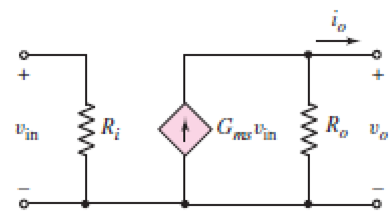
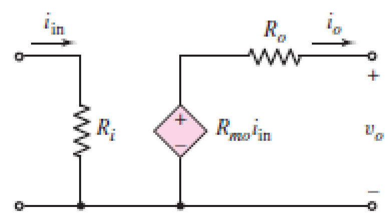
Norton equivalent circuit
(output of a photodiode)

Basic Transistor Amplifier Configurations

✓ Although one configuration may be preferable for a given application, any one of the four can be used to model a given amplifier.

Each of the 3 basic transistor amplifiers can be modeled as a two-port network in one of the four configurations

Four equivalent two-port networks

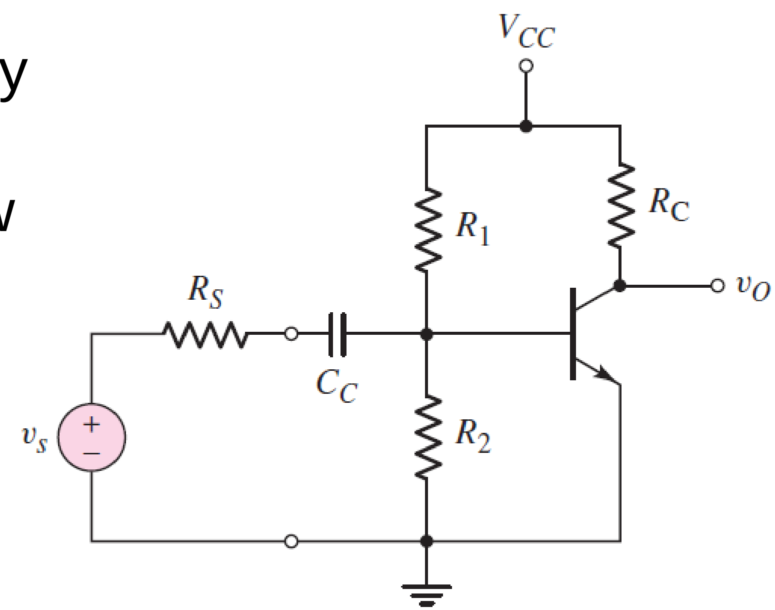
Type	Equivalent circuit	Gain property
Voltage amplifier		Output voltage proportional to input voltage
Current amplifier		Output current proportional to input current
Transconductance amplifier		Output current proportional to input voltage
Transresistance amplifier		Output voltage proportional to input current

Common-Emitter (CE) Amplifier

- ✓ Note that the *emitter is at ground potential* – hence called common-emitter.
- ✓ Signal from the signal source is coupled into the base of the transistor through the coupling capacitor C_C, which provides *dc isolation* between the amplifier and the signal source.
- ✓ The *DC transistor biasing* is established by R_1 and R_2, and is not disturbed when the signal source is capacitively coupled to the amplifier.

Assume that the signal frequency is 1) sufficiently high that any *coupling capacitance* acts as a perfect short circuit, and 2) is also sufficiently low that the *transistor capacitances* are neglected.

Neglect any capacitance effects within the transistor.



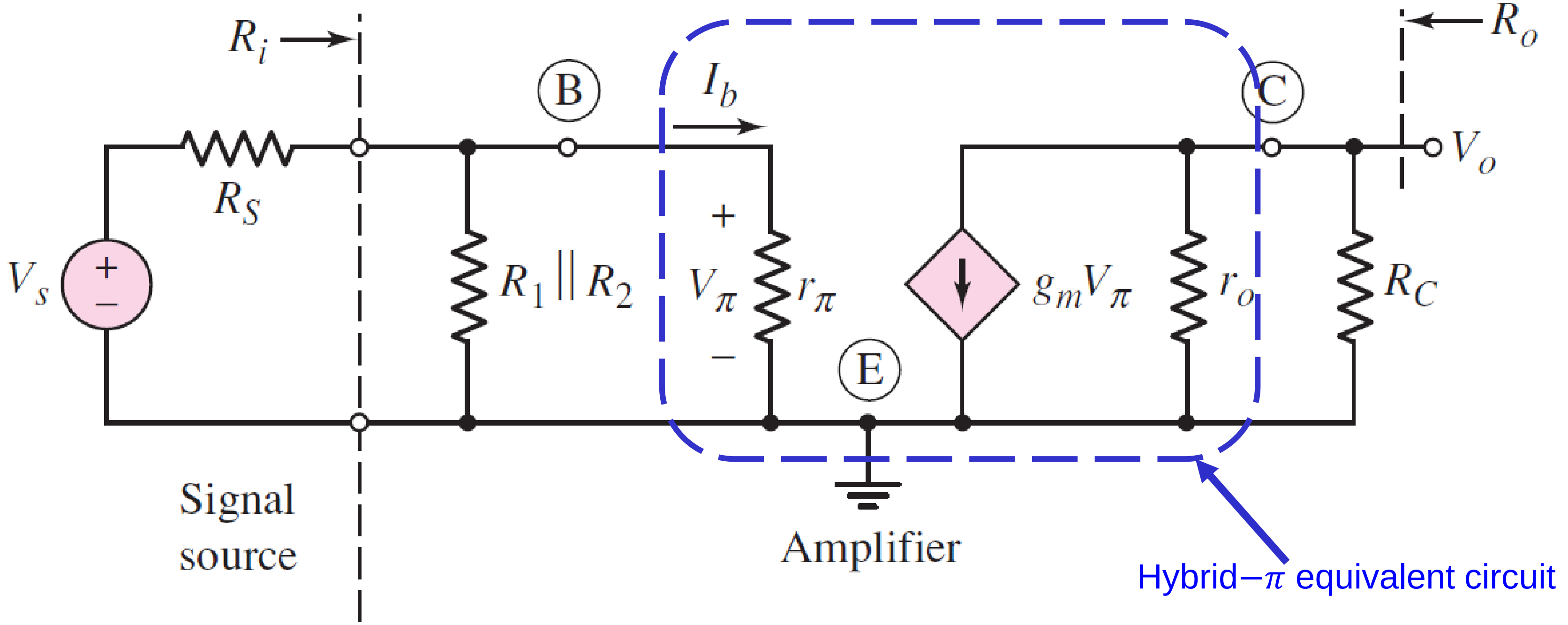
Basic CE circuit with coupling capacitor

Common-Emitter – Small-signal Circuit

The output voltage can be written as, $V_o = -g_m V_\pi (r_o || R_C)$

The control voltage V_π is found to be, $V_\pi = \frac{R_1||R_2||r_\pi}{R_1||R_2||r_\pi + R_S} \times V_s$

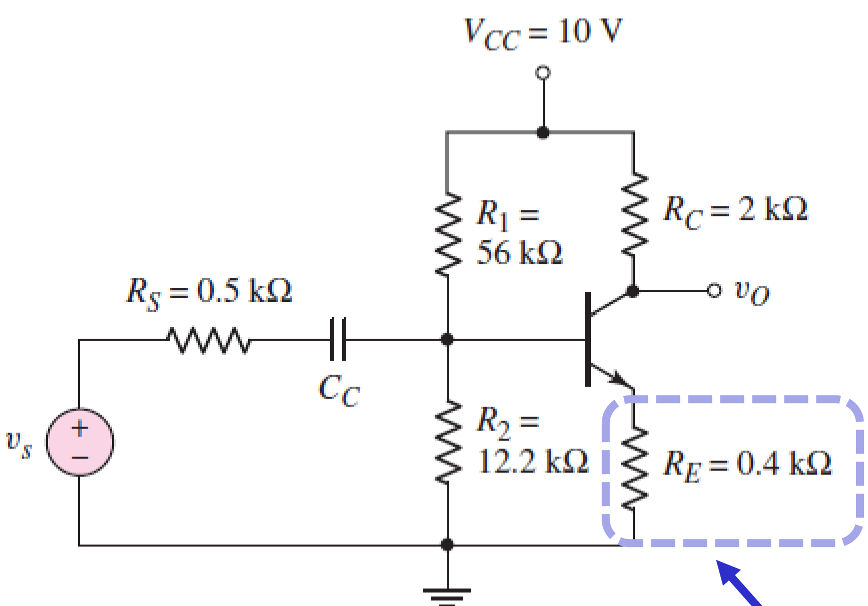
Thus, the small-signal voltage gain is, $A_v = \frac{V_o}{V_s} = -g_m (r_o || R_C) \frac{R_1||R_2||r_\pi}{R_1||R_2||r_\pi + R_S}$



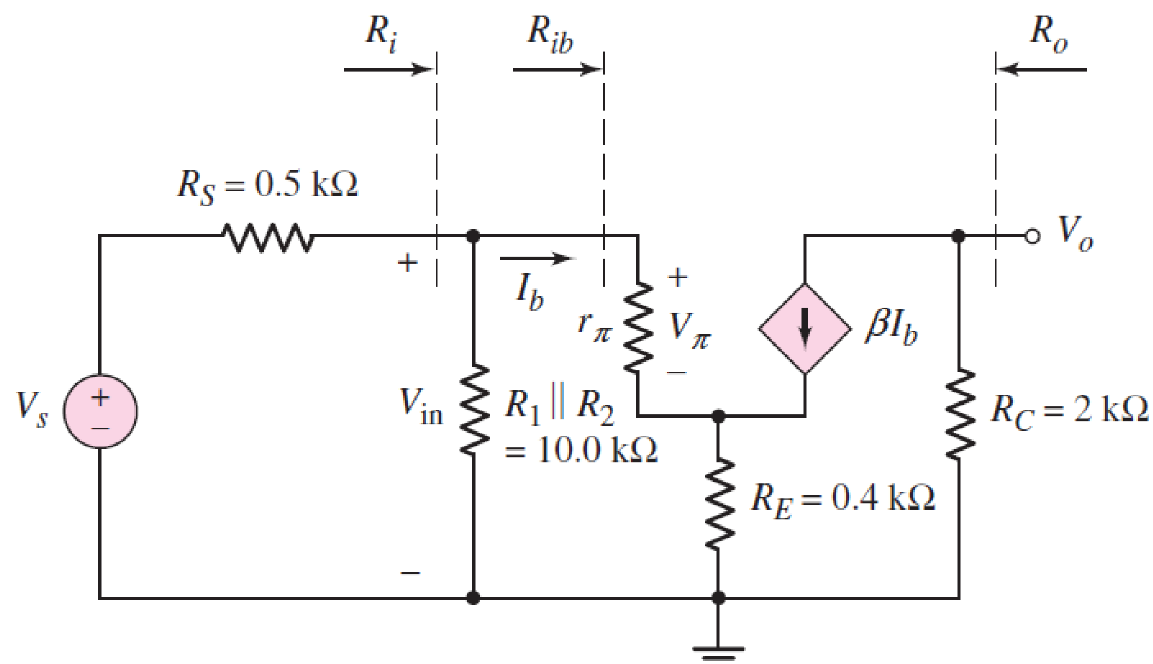
Small-signal equivalent circuit assuming coupling capacitor is a short circuit

Common-Emitter with Emitter Resistor

- ✓ The earlier CE circuit is not very practical – voltage across R_2 provides the base-emitter voltage to bias the transistor in the forward-active region.
- ✓ A slight variation in the resistor value or in the transistor characteristics may cause the transistor to be biased in cutoff or saturation.
- ✓ *Although the emitter is not at ground potential, it is still called as CE circuit*.



Emitter resistor



Small-signal equivalent circuit

Common-Emitter with Emitter Resistor

Note that current gain β is used in the equivalent circuit & assume that Early voltage is infinite so the transistor output resistance (r_o) can be neglected.

Input resistance R_{ib}: It is the input resistance looking into the base

Use KVL for the loop, $V_{in} = I_b r_\pi + (I_b + \beta I_b)R_E \ \rightarrow \ R_{ib} = \frac{V_{in}}{I_b} = r_\pi + (1+\beta)R_E$

Voltage gain A_v:

The output voltage is, $V_o = -(\beta I_b)\ R_C$

The input resistance to the amplifier, $R_i = R_1||R_2||R_{ib}$

Moreover, $V_{in} = \left(\frac{R_i}{R_i+R_S}\right)V_s$

Therefore, $A_v = \frac{V_o}{V_s} = \frac{-(\beta I_b)\ R_C}{V_s} = -\beta R_C\left(\frac{V_{in}}{R_{ib}}\right)\left(\frac{1}{V_s}\right) = \frac{-\beta R_C}{r_\pi+(1+\beta)R_E}\left(\frac{R_i}{R_i+R_S}\right)$

If $R_i \gg R_S$ & $(1+\beta)R_E \gg r_\pi \ \rightarrow A_v \cong \frac{-\beta R_C}{(1+\beta)R_E} \cong \frac{-R_C}{R_E}$

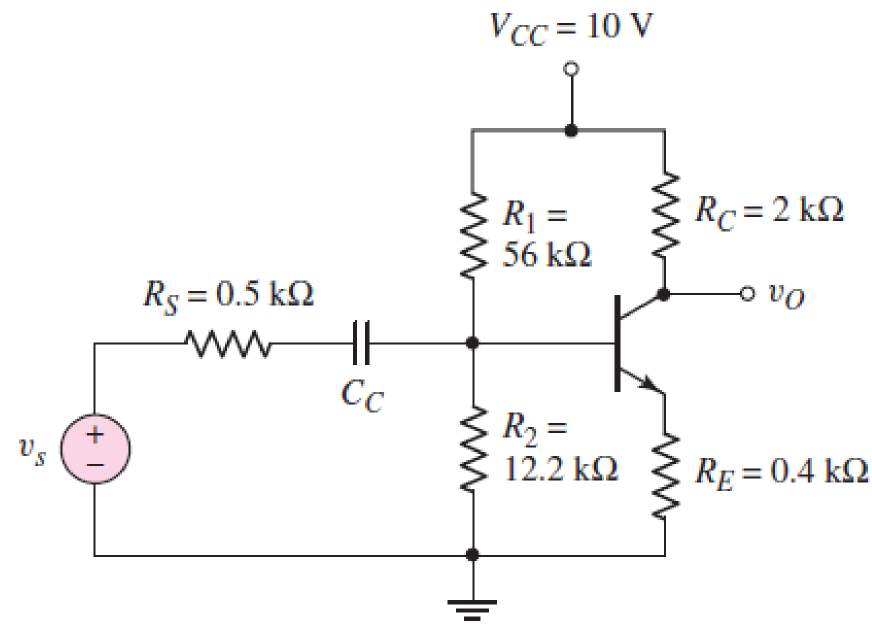
Common-Emitter with Emitter Resistor

Exercise–1: Consider the following transistor parameters for the circuit shown below: $\beta = 100, V_{BE(on)} = 0.7\ V$, and $V_A = \infty$. Determine the small-signal voltage gain and input resistance of CE circuit with an emitter resistor.

Solution

DC Solution: From dc analysis, we can get

$I_{CQ} = 2.16\ mA$ and $V_{CEQ} = 4.81\ V$.



AC Solution

The small-signal hybrid−π parameters are,

$$r_\pi = \frac{V_T \beta}{I_{CQ}} = \frac{0.026 \times 100}{2.16} = 1.20\ k\boldsymbol{\Omega}$$

$$g_m = \frac{I_{CQ}}{V_T} = \frac{2.16}{0.026} = 83.1\ mA/V \text{ and } r_o = \frac{V_A}{I_{CQ}} = \infty$$

Common-Emitter with Emitter Resistor

The input resistance looking in to the base can be obtained as

$$R_{ib} = r_\pi + (1+\beta)R_E = 1.20 + (101)(0.4) = 41.6\ k\boldsymbol{\Omega}$$

The input resistance to the amplifier is

$$R_i = R_1||R_2||R_{ib} = 10||41.6 = 8.06\ k\boldsymbol{\Omega}$$

Therefore, the voltage gain is,

$$A_v = \frac{-\beta R_C}{r_\pi + (1+\beta)R_E}\left(\frac{R_i}{R_i + R_S}\right) = \frac{-(100)(2)}{1.20 + (101)(0.4)}\left(\frac{8.06}{8.06 + 0.5}\right) = -4.53$$

If we use the approximation, $A_v \cong \frac{-R_C}{R_E} = \frac{-2}{0.4} = -5.0$

Common-Emitter with Emitter Resistor

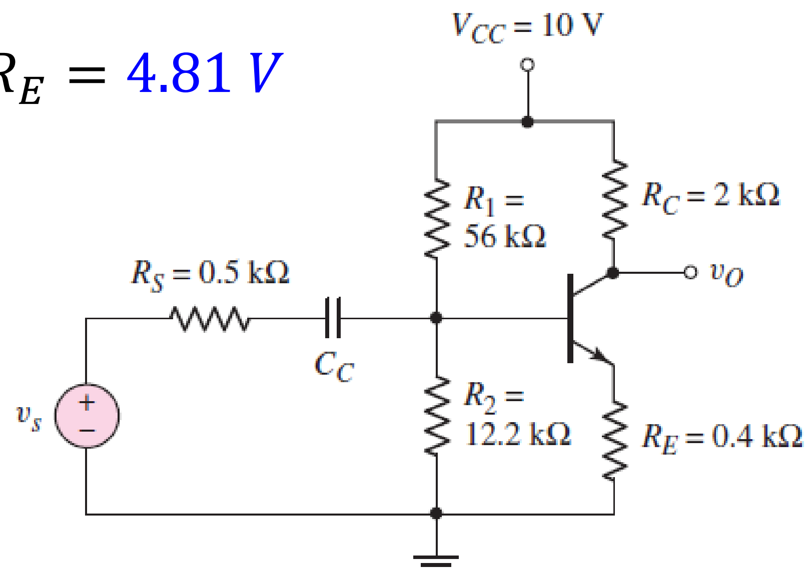
DC Solution: The circuit is most easily analyzed by forming a Thevenin equivalent circuit for the base circuit. Coupling capacitor acts as open circuit to dc. The equivalent Thevenin voltage is, $V_{TH} = V_{CC}[R_2/(R_1 + R_2)] = 1.79\, V$.

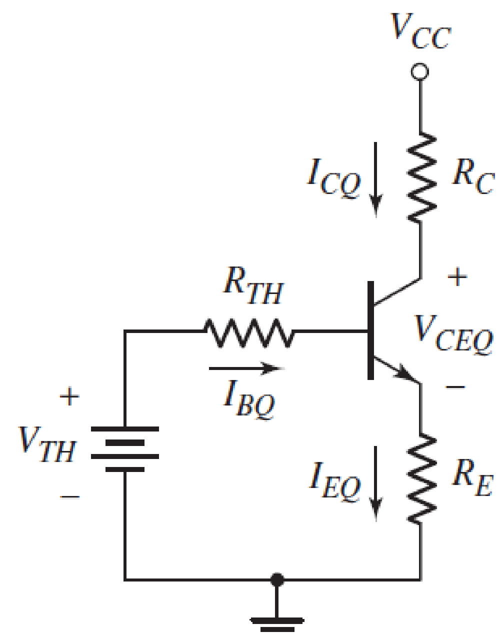
The equivalent Thevenin resistance, $R_{TH} = R_1 || R_2 = 10\ k\boldsymbol{\Omega}$

KVL around B-E loop, $I_{BQ} = \frac{V_{TH} - V_{BE(on)}}{R_{TH} + (1+\beta)R_E} = 21.6\,\mu A$ & $I_{CQ} = \beta I_{BQ} = 2.16\, mA$

$I_{EQ} = (1+\beta)I_{BQ} = 2.18\, mA$

$V_{CEQ} = V_{CC} - I_{CQ}R_C - I_{EQ}R_E = 4.81\ V$

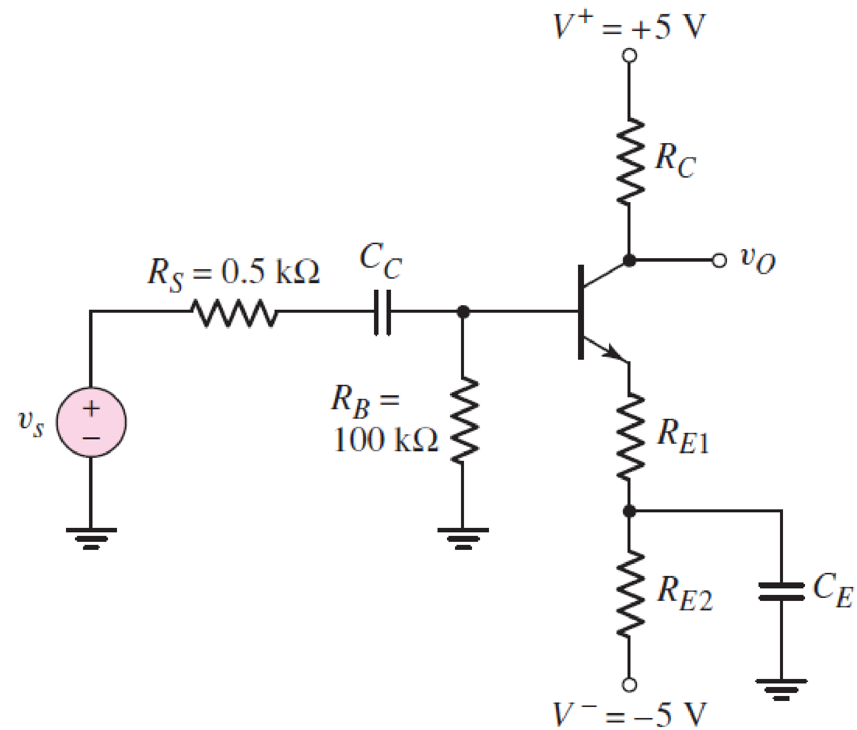




CE Circuit with Emitter Bypass Capacitor

- ✓ Sometimes it is necessary to have a large emitter resistor for the purpose of dc design, but it degrades the small-signal voltage gain severely.
- ✓ Emitter bypass capacitor can be used to effectively short out a portion or all of the emitter resistance as seen by the ac signals.

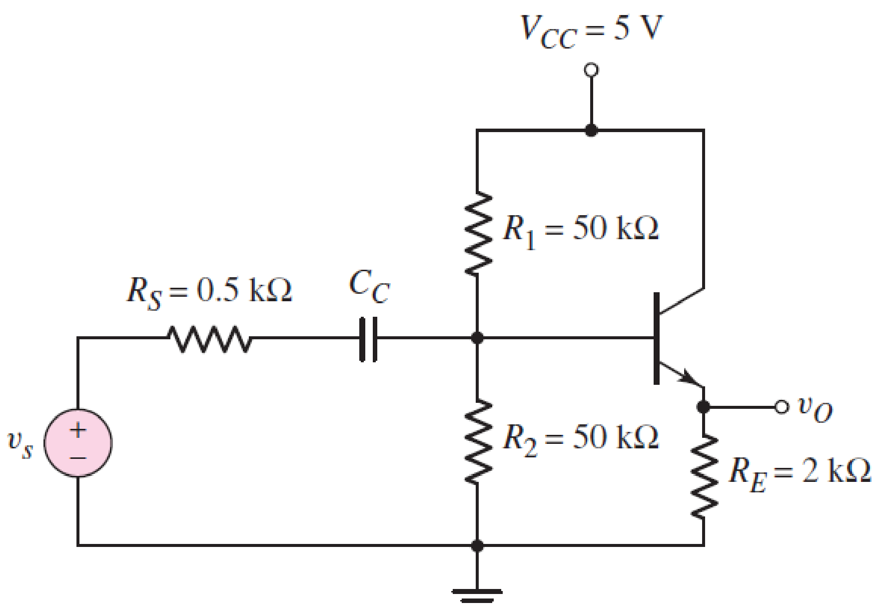
Consider the circuit biased with *both positive and negative voltages*. Both emitter resistors R_{E1} & R_{E2} are factors in the dc design of the circuit, but R_{E1} is part of the ac equivalent circuit, since C_E provides a short circuit to ground for the ac signals.

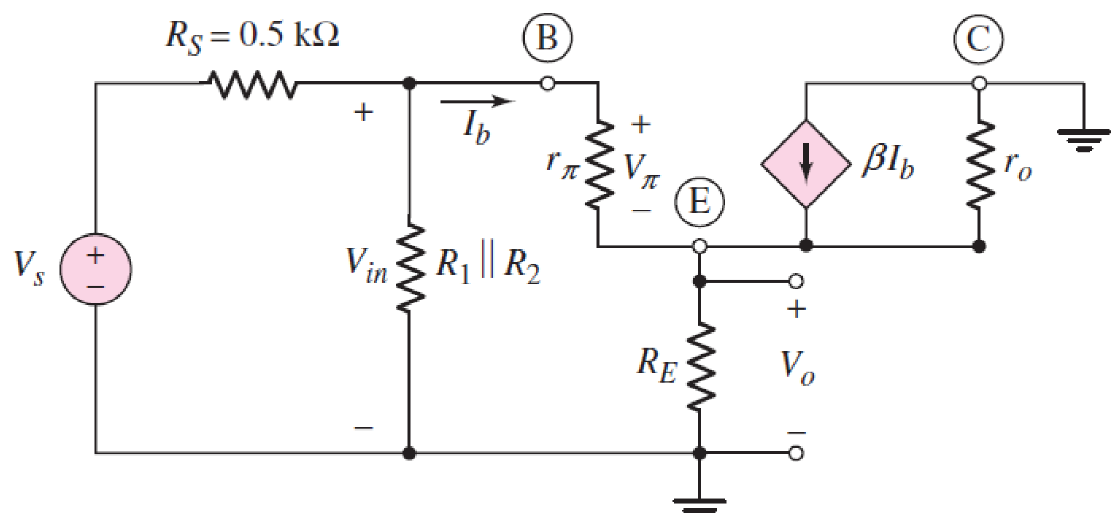


In summary, the *ac* gain stability is due to only R_{E1} & most of *dc* stability is due to R_{E2}.

Common-Collector (CC) Amplifier

- ✓ The output signal is taken off of the emitter with respect to ground and the collector is connected directly to V_{CC}. Since V_{CC} is at signal ground in the ac equivalent circuit (*see*) – named as common-collector (*Emitter follower*).
- ✓ Equivalent circuit – assume the coupling capacitor C_C acts as a short circuit. Collector terminal is at signal ground & the transistor output resistance r_o is in parallel with the dependent current source.





Small-signal equivalent circuit

Common-Collector (CC) Amplifier

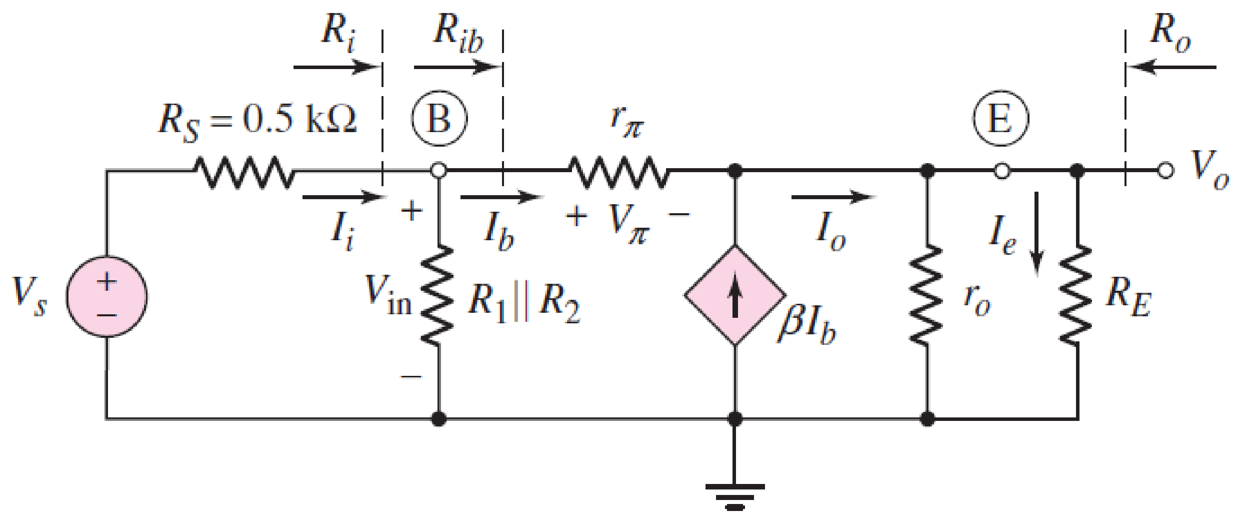
From the equivalent circuit,

$$I_o = (1+\beta)I_b$$

$$V_o = I_b(1+\beta)(r_o||R_E)$$

KVL for base-emitter loop,

$$V_{in} = I_b[r_\pi + (1+\beta)(r_o||R_E)]$$



Small-signal equivalent circuit with all signal grounds connected together

$$R_{ib} = \frac{V_{in}}{I_b} = r_\pi + (1+\beta)(r_o||R_E) \Longrightarrow$$ Input resistance looking into the base

We also write, $V_{in} = \left(\frac{R_i}{R_i+R_S}\right)V_s$; where, $R_i = R_1||R_2||R_{ib}$.

Small-signal voltage gain, $A_v = \frac{V_o}{V_s} = \frac{(1+\beta)(r_o||R_E)}{r_\pi+(1+\beta)(r_o||R_E)}\left(\frac{R_i}{R_i+R_S}\right)$

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Common-Collector (CC) Amplifier

Small-signal current gain, $A_i = \frac{I_e}{I_i}$

Using current divider rule, $I_b = \left(\frac{R_1||R_2}{R_1||R_2 + R_{ib}}\right) I_i$

Since, $g_m V_\pi = \beta I_b$, then, $I_o = (1+\beta) I_b = (1+\beta)\left(\frac{R_1||R_2}{R_1||R_2 + R_{ib}}\right) I_i$

Write the load current in terms of I_o produces, $I_e = \left(\frac{r_o}{r_o + R_E}\right) I_o$

Therefore, small-signal current gain, $A_i = \frac{I_e}{I_i} = (1+\beta)\left(\frac{R_1||R_2}{R_1||R_2 + R_{ib}}\right)\left(\frac{r_o}{r_o + R_E}\right)$

If we assume $R_1||R_2 \gg R_{ib}$ and $r_o \gg R_E$, then $A_i \cong (1+\beta)$

Although small-signal voltage gain of CC amplifier is slightly less than 1, the small-signal current gain is normally greater than 1.

Common-Collector (CC) Amplifier

Small-signal output resistance, R_o

- ✓ Assume that the input signal source is ideal and $R_S = 0$. See below circuit to determine the output resistance looking back into the output terminals.
- ✓ Note that a test voltage V_x is applied to the output terminal that results I_x.

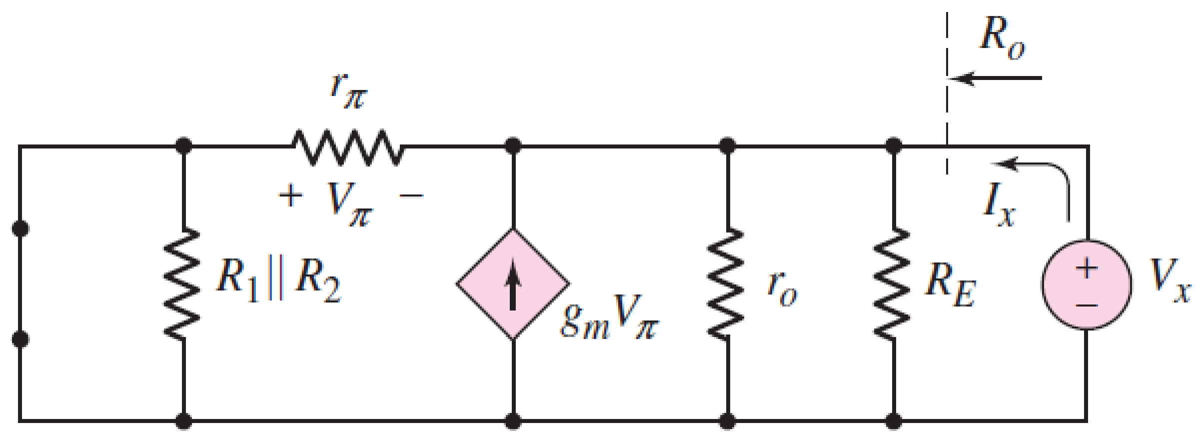
$$R_o = \frac{V_x}{I_x}$$

- ✓ Control voltage V_π is not zero, $V_\pi = -V_x$. Summing currents at output node.

$$I_x + g_m V_\pi = \frac{V_x}{R_E} + \frac{V_x}{r_o} + \frac{V_x}{r_\pi}$$

$$\frac{I_x}{V_x} = \frac{1}{R_o} = g_m + \frac{1}{R_E} + \frac{1}{r_o} + \frac{1}{r_\pi}$$

$$\therefore R_o = \frac{V_x}{I_x} = \frac{1}{g_m} || R_E || r_o || r_\pi$$



Try considering non-zero source resistance R_S.

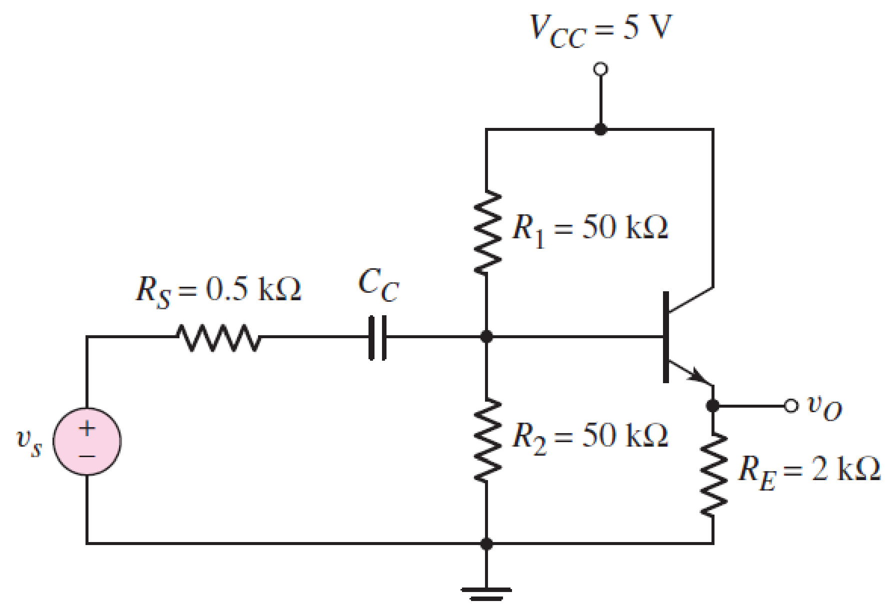
Common-Collector (CC) Amplifier

Exercise–2: Consider the following transistor parameters for the CC circuit shown below: $\beta = 100, V_{BE(on)} = 0.7\ V$, and $V_A = 80\ V$. Determine the small-signal voltage gain, input and output resistances.

Solution

DC Solution: From dc analysis, we can get

$I_{CQ} = 0.793\ mA$ and $V_{CEQ} = 3.4\ V$.



AC Solution

The small-signal hybrid–π parameters are,

$$r_\pi = \frac{V_T\beta}{I_{CQ}} = \frac{0.026\times 100}{0.793} = 3.28\ k\boldsymbol{\Omega}$$

$$g_m = \frac{I_{CQ}}{V_T} = \frac{0.793}{0.026} = 30.5\ mA/V \quad \text{and } r_o = \frac{V_A}{I_{CQ}} = \frac{80}{0.793} = 100\ k\boldsymbol{\Omega}$$

Common-Collector (CC) Amplifier

The input resistance looking into the base can be obtained as

$$R_{ib} = r_\pi + (1+\beta)(r_o||R_E) = 3.28 + (101)(100||2) = 201\ k\boldsymbol{\Omega}$$

The input resistance seen by the signal source R_i is

$$R_i = R_1||R_2||R_{ib} = 50||50||201 = 22.2\ k\boldsymbol{\Omega}$$

Therefore, the voltage gain is,

$$A_v = \frac{(1+\beta)(r_o||R_E)}{r_\pi + (1+\beta)(r_o||R_E)}\left(\frac{R_i}{R_i+R_S}\right) = \frac{(100)(100||2)}{3.28+(101)(100||2)}\left(\frac{22.2}{22.2+0.5}\right) = 0.962$$

The output resistance, $R_o = \frac{1}{g_m}||R_E||r_o||r_\pi = 32\ \boldsymbol{\Omega}$

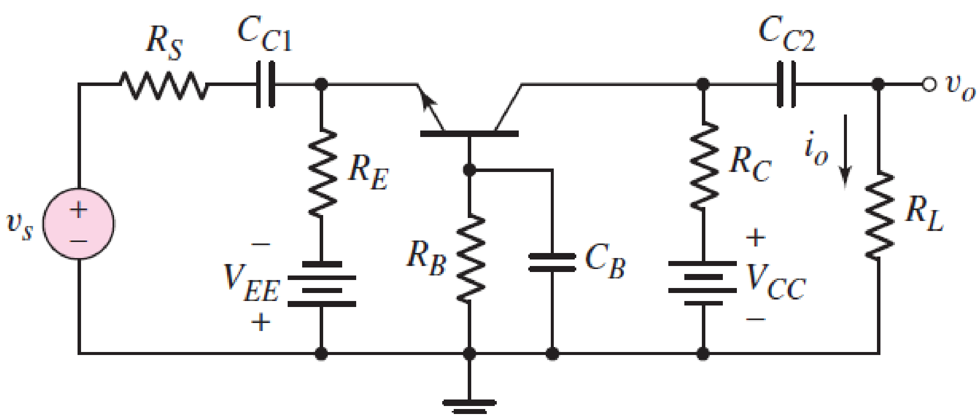
Note that input impedance is large and output impedance is small – also called as *impedance transformer*. The very low output resistance makes CC act almost like an ideal voltage source, so the output is not loaded down when used to drive another load – because of this, it is *often used as the the output stage of multistage amplifier*.

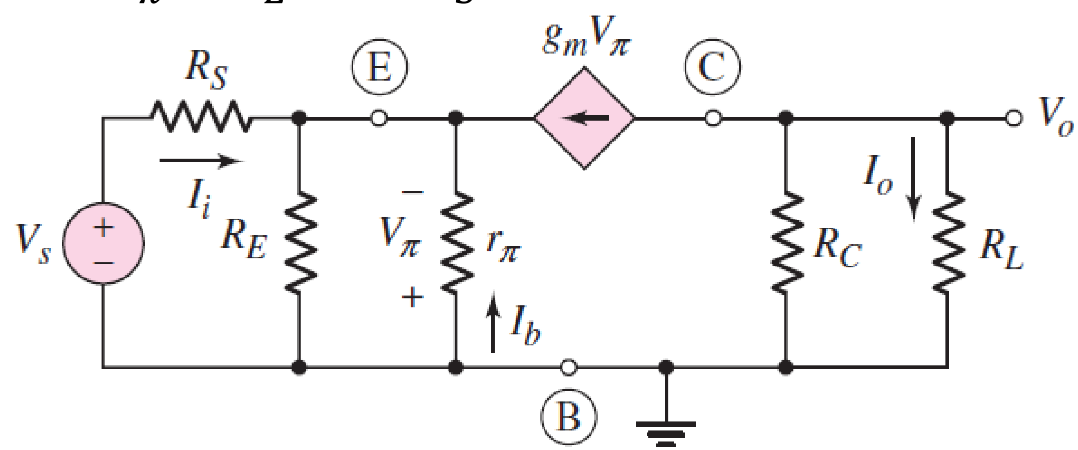
Common-Base (CB) Amplifier

- ✓ Base is at signal ground & input signal is applied to emitter – *Common-Base*
- ✓ Assume the load is connected to the output through coupling capacitor C_{C2}.
- ✓ Assume output resistance r_o to be infinite. The small-signal equivalent circuit of a CB configuration with hybrid$-\pi$ model is complex.

Small-signal output voltage, $V_o = -(g_m V_\pi)(R_C||R_L)$

KCL at the emitter node gives, $g_m V_\pi + \frac{V_\pi}{r_\pi} + \frac{V_\pi}{R_E} + \frac{V_S-(-V_\pi)}{R_S} = 0$





Small-signal equivalent circuit

Common-Base (CB) Amplifier

Since $\beta = g_m r_\pi$, the above equation is $V_\pi \left(\frac{1+\beta}{r_\pi} + \frac{1}{R_E} + \frac{1}{R_S}\right) = -\frac{V_s}{R_S}$

Then, $V_\pi = -\frac{V_s}{R_S}\left[\left(\frac{r_\pi}{1+\beta}\right)||R_E||R_S\right]$

Substitute the control voltage V_π in the output voltage equation, which results

Small-signal voltage gain, $A_v = \frac{V_o}{V_s} = g_m\left(\frac{R_C||R_L}{R_S}\right)\left[\left(\frac{r_\pi}{1+\beta}\right)||R_E||R_S\right]$

If $R_S \rightarrow 0$, the voltage gain becomes,

$$A_v = g_m(R_C||R_L)$$

For CB circuit, the small-signal voltage gain is usually greater than 1.

Common-Base (CB) Amplifier

Small-signal current gain, $A_i = \frac{I_o}{I_i}$

Write KCL at the emitter node, we get, $I_i + \frac{V_\pi}{r_\pi} + g_m V_\pi + \frac{V_\pi}{R_E} = 0$

Solving for V_π gives, $V_\pi = -I_i \left[\left(\frac{r_\pi}{1+\beta} \right) || R_E \right]$

The load current, $I_o = -(g_m V_\pi) \left(\frac{R_C}{R_C + R_L} \right)$

Therefore, the small-signal current gain can be written as

$$A_i = \frac{I_o}{I_i} = g_m \left(\frac{R_C}{R_C + R_L} \right) \left[\left(\frac{r_\pi}{1+\beta} \right) || R_E \right]$$

$$A_i = \frac{I_o}{I_i} = \frac{g_m r_\pi}{1+\beta} = \frac{\beta}{1+\beta} \quad \text{if } R_E \to \infty \ \& \ R_L \to 0$$

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Small-signal current gain is slightly less than 1.

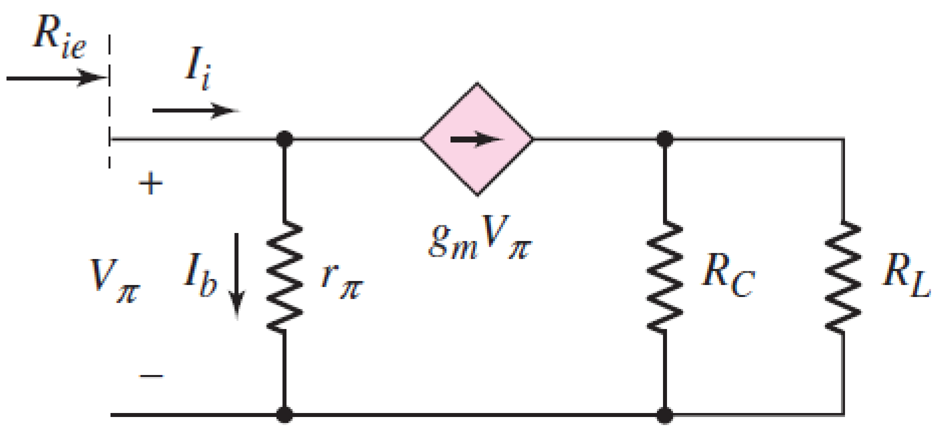
Common-Base (CB) Amplifier

Note: For convenience only, the *polarity of the control voltage is reversed*, which reverses the direction of the dependent current source.

Small-signal input resistance, $R_{ie} = \frac{V_\pi}{I_i}$ → Input resistance looking into emitter

Write KCL at the input, we get, $I_i = I_b + g_m V_\pi = \frac{V_\pi}{r_\pi} + g_m V_\pi = V_\pi \left(\frac{1+\beta}{r_\pi}\right)$

Therefore, $R_{ie} = \frac{V_\pi}{I_i} = \frac{r_\pi}{1+\beta} \equiv r_e$ → resistance looking into the emitter, with base grounded, usually quite small – desirable when input signal is current source.



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Common-Base (CB) Amplifier

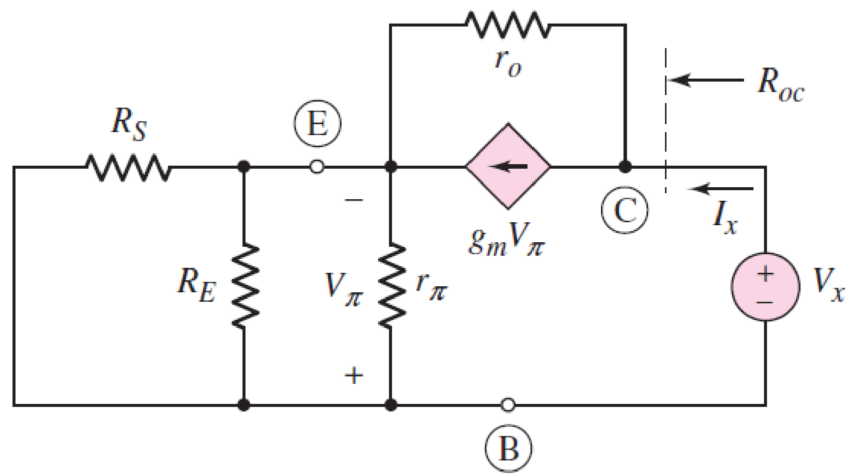
Small-signal output resistance, $R_{oc} = \frac{V_x}{I_x}$ → Output resistance looking back into collector terminal – small-signal resistance r_o included & v_s has set equal to 0.

Write KCL at output node, $I_x = g_m V_\pi + \frac{V_x - (-V_\pi)}{r_o}$

Write KCL at emitter node, $\frac{V_\pi}{R_{eq}} + g_m V_\pi + \frac{V_x - (-V_\pi)}{r_o} = 0$, where $R_{eq} = R_S || R_E || r_\pi$

Therefore, the output resistance, $R_{oc} = \frac{V_x}{I_x} = r_o\left(1 + g_m R_{eq}\right) + R_{eq}$

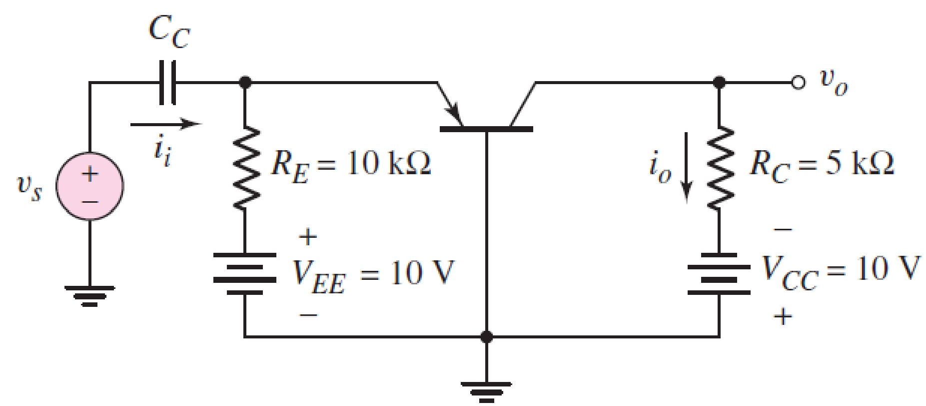
If $R_S = 0, R_{eq} = 0 \rightarrow R_{oc} = r_o$



Common-Base (CB) Amplifier

<u>Exercise</u>–<u>3</u>: Consider the following transistor parameters for the CB circuit shown below: $\beta = 100, V_{BE(on)} = 0.7\ V$, and $r_o = \infty$. Determine the quiescent values of I_{CQ} & V_{CEQ}, the small-signal current gain, and voltage gain.

Solution



DC Solution: From dc analysis, we can get

$I_{CQ} = 0.921\ mA$ and $V_{CEQ} = 6.1\ V$.

AC Solution

The small-signal hybrid–π parameters are,

$$r_\pi = \frac{V_T \beta}{I_{CQ}} = \frac{0.026 \times 100}{0.921} = 2.82\ k\mathbf{\Omega}$$

$$g_m = \frac{I_{CQ}}{V_T} = \frac{0.921}{0.026} = 35.42\ mA/V \quad \text{and } r_o = \infty$$

Calculate $A_i = \frac{i_o}{i_i} = 0.987$,
$A_v = \frac{v_o}{v_s} = 177$ by yourself.

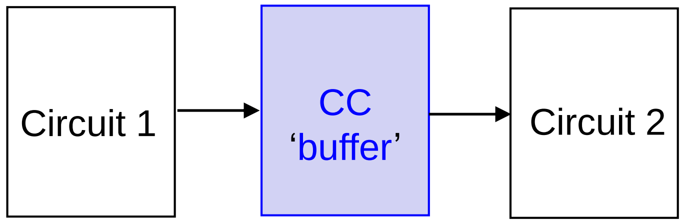
Comparison of Three Amplifiers

Characteristics of the three BJT amplifier configurations

Configuration	Voltage gain	Current gain	Input resistance	Output resistance
Common emitter	$A_v > 1$	$A_i > 1$	Moderate	Moderate to high
Emitter follower	$A_v \cong 1$	$A_i > 1$	High	Low
Common base	$A_v > 1$	$A_i \cong 1$	Low	Moderate to high

CC circuit has very high input resistance, low output resistance, and $A_v \cong 1$.

✓ It is often used to isolate two circuits from each other, so circuit 2 does not draw current from circuit 1 – useful as *buffer*.



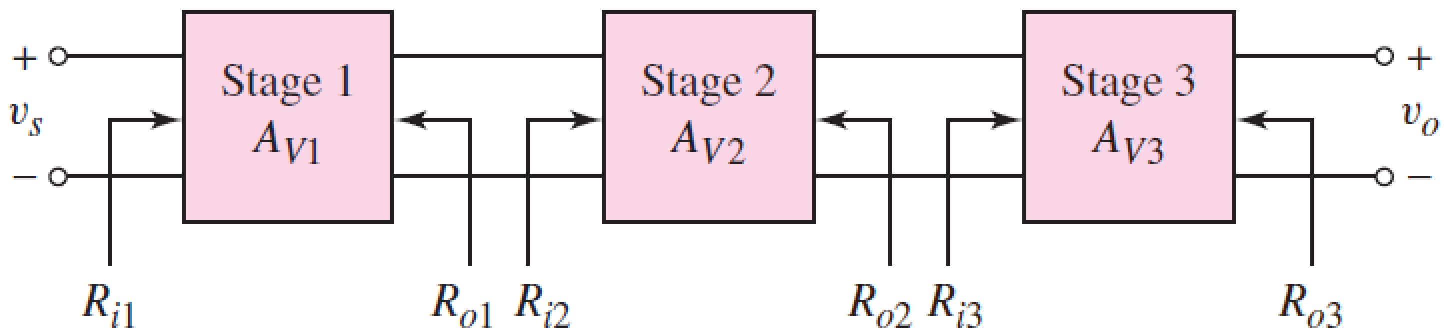
High input impedance means it draws very little current from circuit 1 & is also able to drive circuit 2 easily from its low output impedance & high current gain. A voltage gain of nearly unity means the signal from circuit 1 is passed onto circuit 2 unchanged.

Multistage Amplifiers

In most applications, *single transistor* amplifier *will not be able to meet* the combined specifications of a given amplification factor, input resistance, and output resistance. For example, the required voltage gain may exceed in a single transistor circuit.

- ✓ Transistor amplifier circuits can be connected in *series, or cascaded*, either to increase the overall small-signal voltage gain or to provide an overall voltage gain greater than 1, with a very low output resistance.

- ✓ The overall voltage or current gain, in general, is not simply the product of the individual amplification factors – for instance, the *gain of stage 1 is a function of the input resistance of stage 2*.

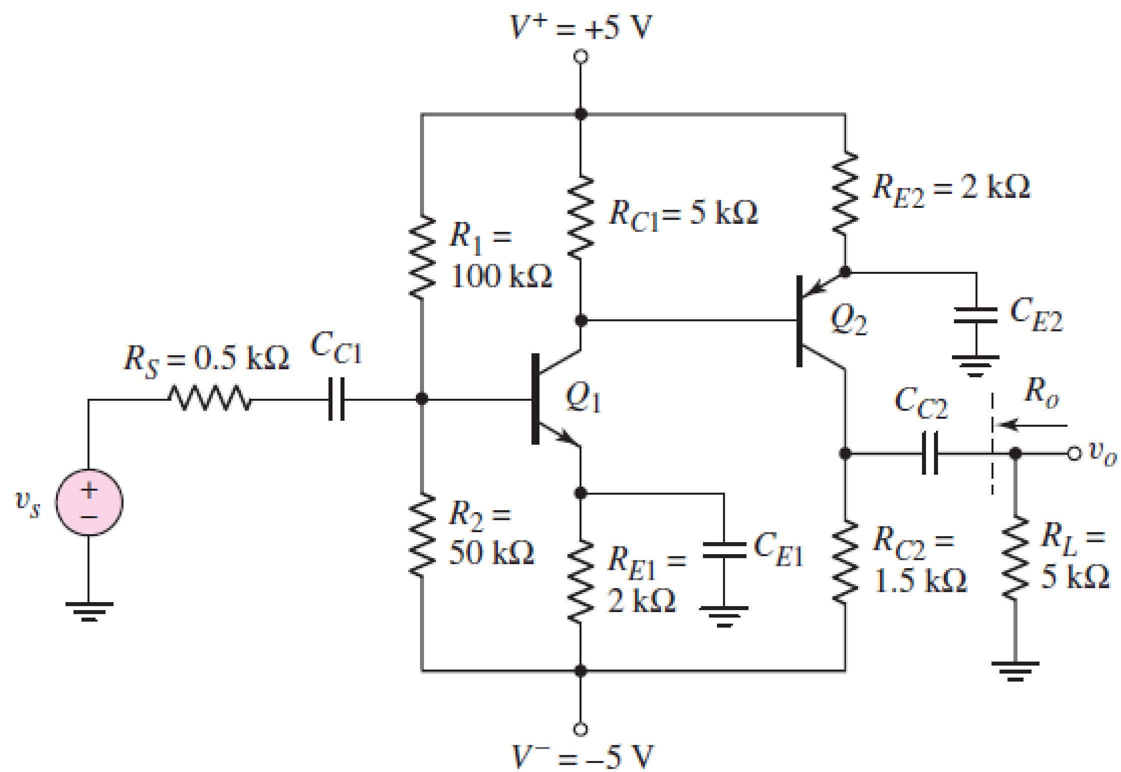


A generalized three-stage amplifier.

Multistage Amplifiers – Two CE circuits

Example of multistage amplifier – See the circuit with a cascade configuration of two common-emitter circuits. Note that one is npn transistor & the other is pnp transistor.

Small-signal equivalent circuit can be obtained by assuming all capacitors act as short circuits and each transistor output resistance (r_o) is infinite.



A two-stage CE amplifier.

Multistage Amplifiers – Two CE circuits

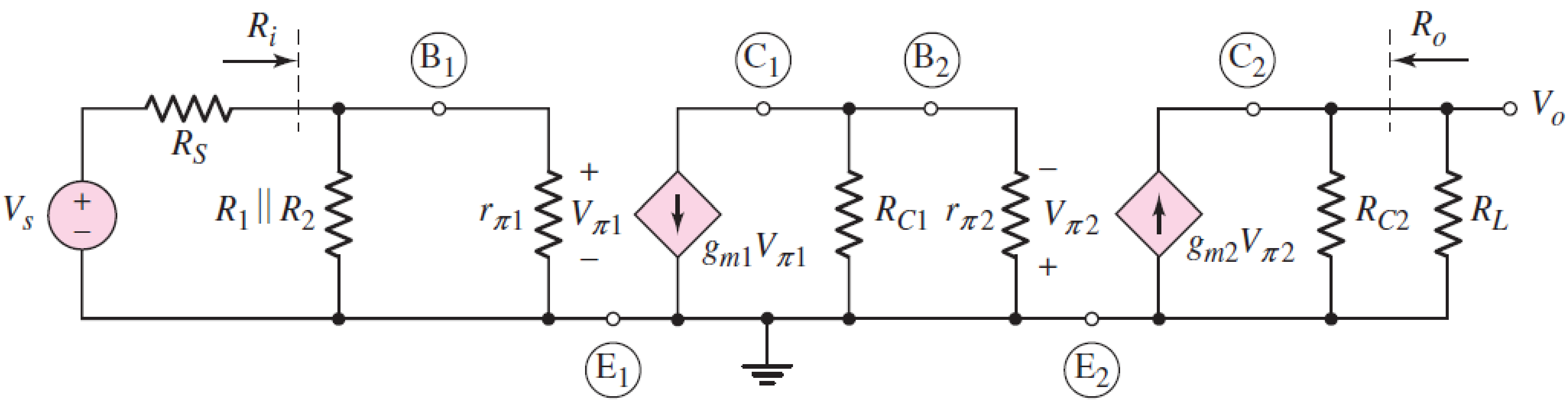
Try!

The small-signal voltage gain, $A_v = \frac{V_o}{V_s} = g_{m1} g_{m2} (R_{C1}||r_{\pi2})(R_{C2}||R_L)\left(\frac{R_i}{R_i + R_S}\right)$

The input resistance, $R_i = R_1||R_2||r_{\pi1}$ is identical to that of single-stage CE circuit.

The output resistance, $R_o = R_{C2}$ is also same as the single-stage CE circuit.

[Set the independent source $V_s = 0$, which means $V_{\pi1} = 0 \rightarrow g_{m1}V_{\pi1} = 0$, which gives $V_{\pi2} = 0 \rightarrow g_{m2}V_{\pi2} = 0$]

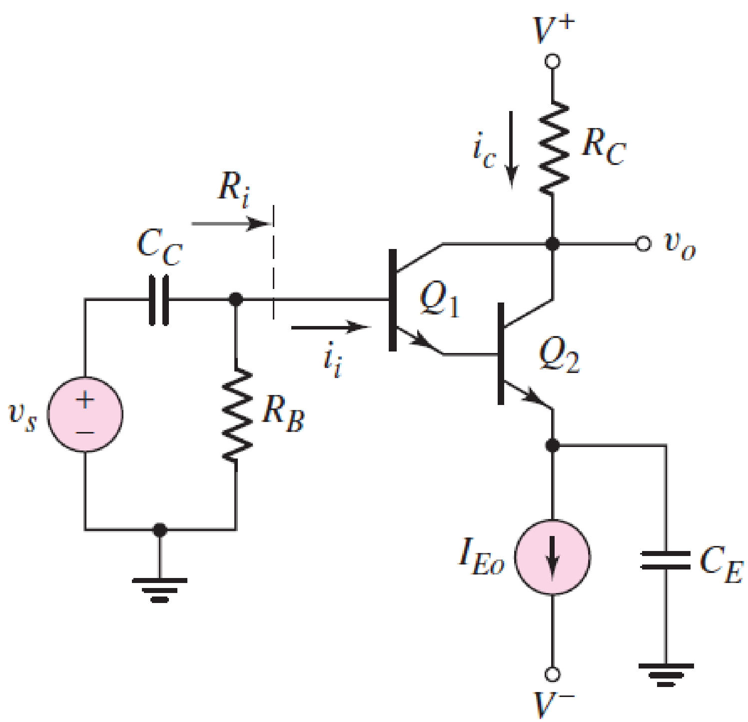


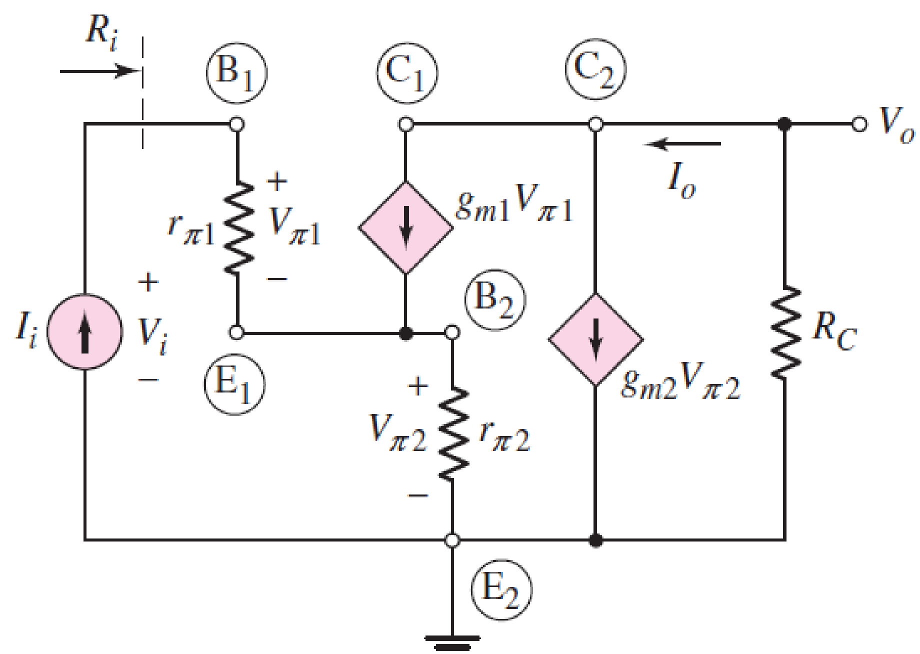
Small-signal equivalent circuit of two-stage amplifier.

Multistage Amplifiers – Darlington Pair

In some applications, it is desirable to have a bipolar transistor with a much larger current gain than can normally be obtained – *Darlington pair* is suitable.

The small-signal equivalent circuit can be obtained by *assuming input signal to be a current source*.

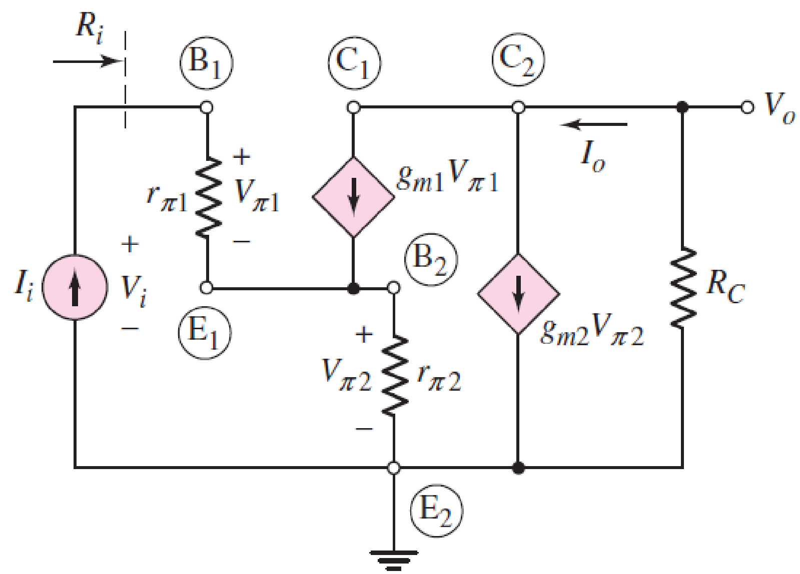




Small-signal equivalent circuit of Darlington pair configuration.

Multistage Amplifiers – Darlington Pair

Small-signal current gain



We can write, $V_{\pi 1} = I_i r_{\pi 1}$

Therefore, $g_{m1}V_{\pi 1} = g_{m1}r_{\pi 1}I_i = \beta_1 I_i$

Then, $V_{\pi 2} = (I_i + \beta_1 I_i)r_{\pi 2}$

The output current can be written as,

$$I_o = g_{m1}V_{\pi 1} + g_{m2}V_{\pi 2} = \beta_1 I_i + \underbrace{g_{m2}(I_i + \beta_1 I_i)r_{\pi 2}}_{} = \beta_1 I_i + \beta_2(1 + \beta_1)I_i$$

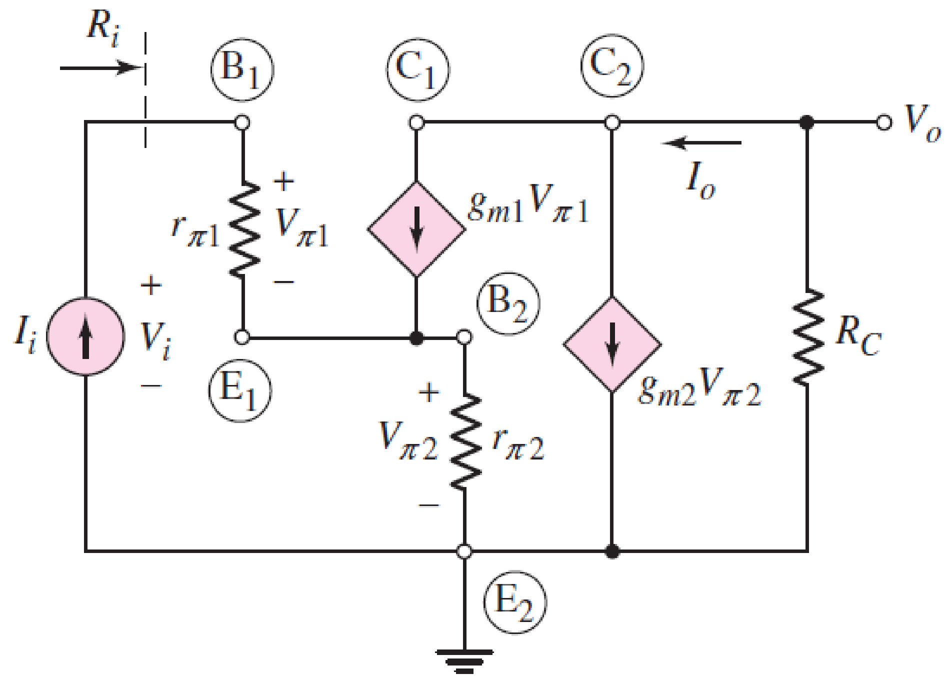
$$\boxed{g_{m2}r_{\pi 2} = \beta_2}$$

The overall current gain, $A_i = \frac{I_o}{I_i} = \beta_1 + \beta_2(1 + \beta_1) \cong \beta_1\beta_2$

It can be observed that the overall small-signal current gain of the Darlington pair is approximated as *product of individual current gains*.

Multistage Amplifiers – Darlington Pair

Input resistance



$V_i = V_{\pi 1} + V_{\pi 2} = I_i r_{\pi 1} + (I_i + \beta_1 I_i) r_{\pi 2}$

Therefore, $R_i = \frac{V_i}{I_i} = r_{\pi 1} + (1 + \beta_1) r_{\pi 2}$

We can write, $r_{\pi 1} = \frac{\beta_1 V_T}{I_{CQ1}}$ and $I_{CQ1} \cong \frac{I_{CQ2}}{\beta_2}$

Therefore, $r_{\pi 1} = \beta_1 \left(\frac{\beta_2 V_T}{I_{CQ2}} \right) = \beta_1 r_{\pi 2}$

The input resistance is then approximated as, $R_i \cong 2\beta_1 r_{\pi 2}$

Note that overall gain of Darlington pair is large. At the same time, input resistance tends to be large, because of β multiplication.

Summary:-

- ✓ Three basic single transistor amplifier configurations can be formed, depending on which of *three transistor terminals is used as signal ground*.

  1. Common-Emitter (CE), 2. Common-Collector (CC) – Emitter follower,

  3. Common-Base (CB)

- ✓ Although the emitter is not at ground potential, it is still called as CE circuit.

- ✓ Note that input impedance is large and output impedance is small – CC circuit is also called as *impedance transformer*.

- ✓ *CC circuit* has very high input resistance, low output resistance, and $A_v \cong 1$ – useful as *buffer*.

- ✓ In some applications, it is desirable to have a bipolar transistor with a much larger current gain than can normally be obtained – *Darlington pair* is suitable.

See you in the next class

The End