CHAPTER.3: Transistor at Low Frequencies

- Introduction
- Amplification in the AC domain
- BJT transistor modeling
- The re Transistor Model
- The Hybrid equivalent Model

Introduction

- There are three models commonly used in the small – signal ac analysis of transistor networks:
- The re model
- The hybrid π model
- The hybrid equivalent model

Amplification in the AC domain

The transistor can be employed as an amplifying device, that is, the output ac power is greater than the input ac power. The factor that permits an ac power output greater than the input ac power is the applied DC power. The amplifier is initially biased for the required DC voltages and currents. Then the ac to be amplified is given as input to the amplifier. If the applied ac exceeds the limit set by dc level, clipping of the peak region will result in the output. Thus, proper (faithful) amplification design requires that the dc and ac components be sensitive to each other's requirements and limitations. The superposition theorem is applicable for the analysis and design of the dc and ac components of a BJT network, permitting the separation of the analysis of the dc and ac responses of the system.

BJT Transistor modeling

- The key to transistor small-signal analysis is the use of the equivalent circuits (models). A MODEL IS A COMBINATION OF CIRCUIT ELEMENTS LIKE VOLTAGE OR CURRENT SOURCES, RESISTORS, CAPACITORS etc. that best approximates the behavior of a device under specific operating conditions. Once the model (ac equivalent circuit) is determined, the schematic symbol for the device can be replaced by the equivalent circuit and the basic methods of circuit analysis applied to determine the desired quantities of the network.

- Hybrid equivalent network – employed initially. Drawback – It is defined for a set of operating conditions that might not match the actual operating conditions.

- re model: desirable, but does not include feedback term

- Hybrid π model: model of choice.

AC equivalent of a network

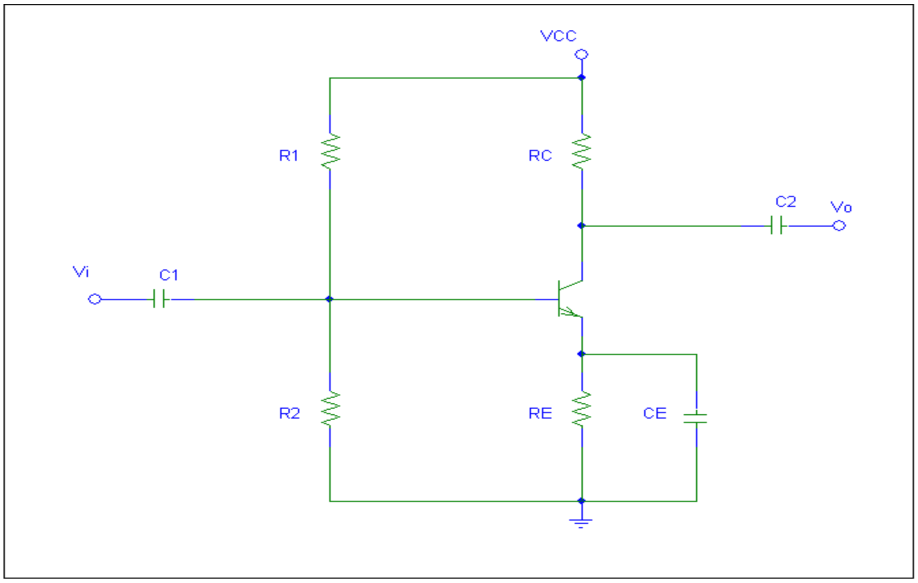
- AC equivalent of a network is obtained by:

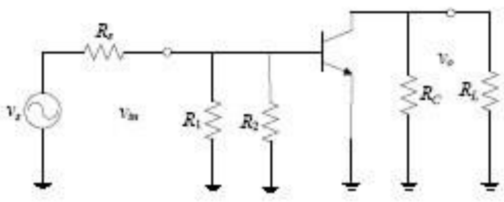
- Setting all dc sources to zero and replacing them by a short – circuit equivalent

- Replacing all capacitors by short – circuit equivalent

- Removing all elements bypassed by the short – circuit equivalents

- Redrawing the network in a more convenient and logical form.





re model

• In re model, the transistor action has been replaced by a single diode between emitter and base terminals and a controlled current source between base and collector terminals.

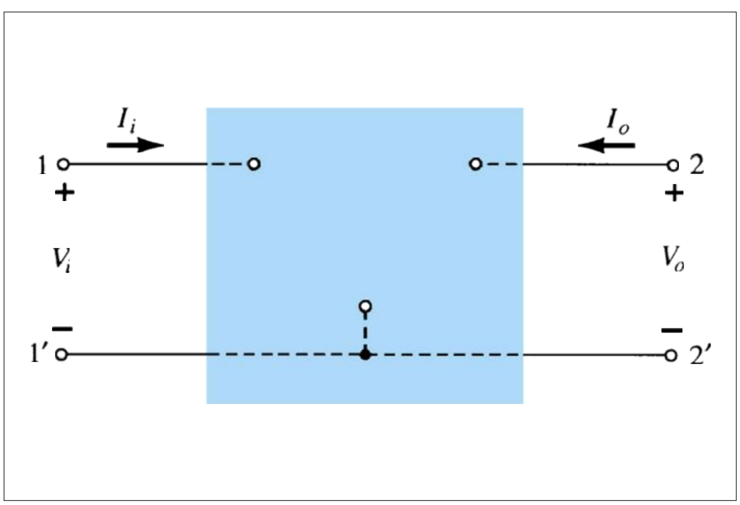
• This is rather a simple equivalent circuit for a device

The Hybrid equivalent model

• For the hybrid equivalent model, the parameters are defined at an operating point.

• The quantities hie, hre,hfe, and hoe are called hybrid parameters and are the components of a small – signal equivalent circuit.

• The description of the hybrid equivalent model will begin with the general two port system.



- The set of equations in which the four variables can be related are:
- $V_i = h_{11}I_i + h_{12}V_o$
- $I_o = h_{21}I_i + h_{22}V_o$
- The four variables h11, h12, h21 and h22 are called hybrid parameters (the mixture

of variables in each equation results in a “ hybrid” set of units of measurement for

the h – parameters.

- Set Vo = 0, solving for h11, h11 = Vi / Ii Ohms
- This is the ratio of input voltage to the input current with the output terminals

shorted. It is called Short circuit input impedance parameter.

- If Ii is set equal to zero by opening the input leads, we get expression for h12:

h12 = Vi / Vo , This is called open circuit reverse voltage ratio.

- Again by setting Vo to zero by shorting the output terminals, we get

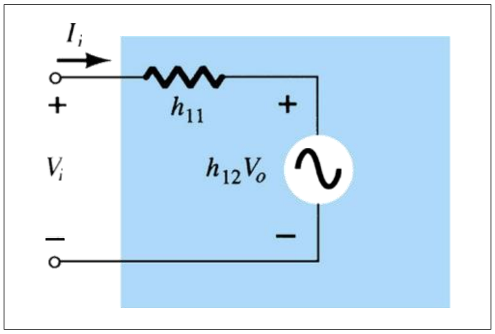
h21 = Io / Ii known as short circuit forward transfer current ratio.

- Again by setting I1 = 0 by opening the input leads, h22 = Io / Vo . This is known as

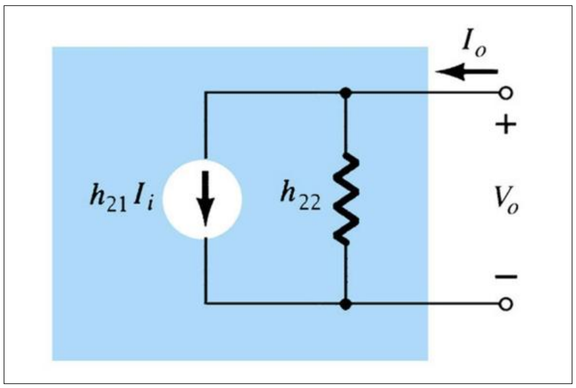
open – circuit output admittance. This is represented as resistor (1/h22)

- h11 = hi = input resistance
- h12 = hr = reverse transfer voltage ratio
- h21 = hf = forward transfer current ratio
- h22 = ho = Output conductance

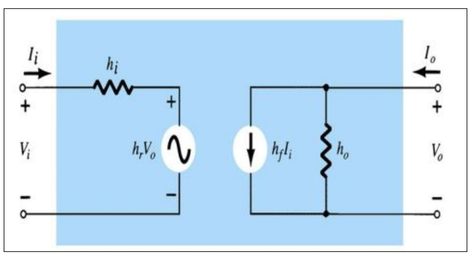
Hybrid Input equivalent circuit



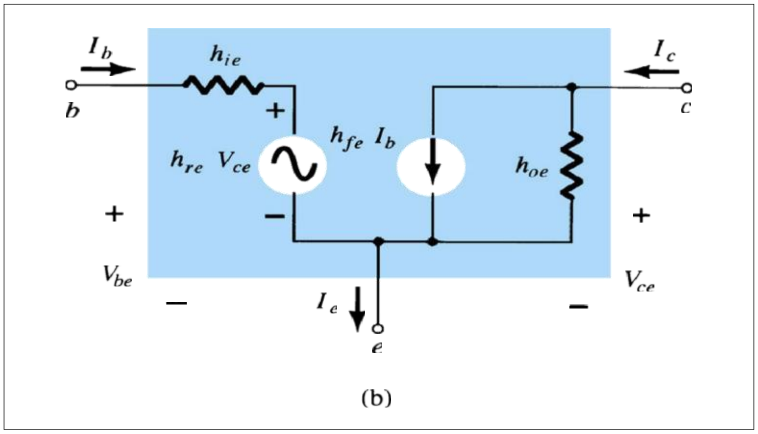
Hybrid output equivalent circuit



Complete hybrid equivalent circuit

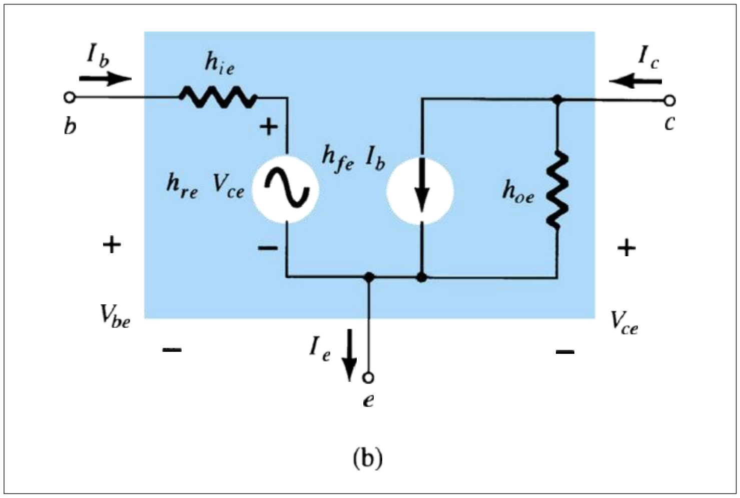


Common Emitter Configuration - hybrid equivalent circuit



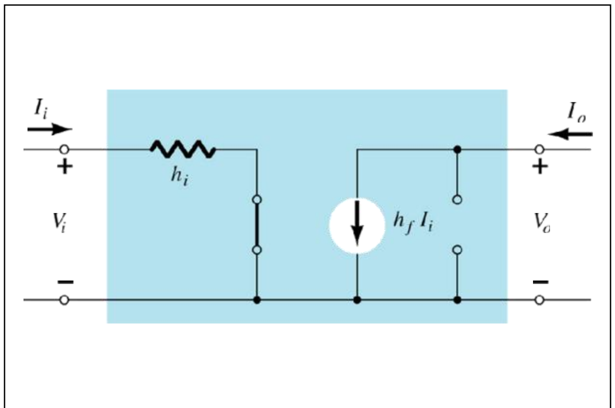
- Essentially, the transistor model is a three terminal two – port system.
- The h – parameters, however, will change with each configuration.
- To distinguish which parameter has been used or which is available, a second subscript has been added to the h – parameter notation.
- For the common – base configuration, the lowercase letter b is added, and for common emitter and common collector configurations, the letters e and c are used respectively.

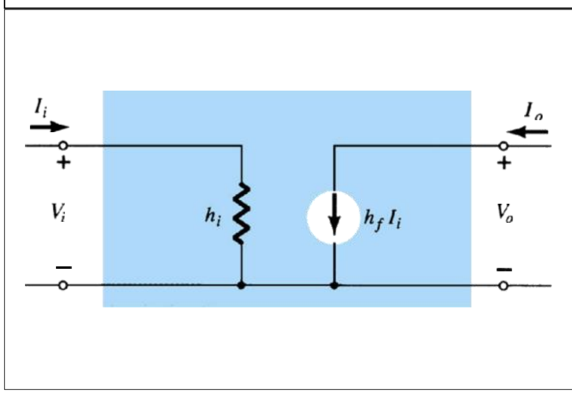
Common Base configuration - hybrid equivalent circuit



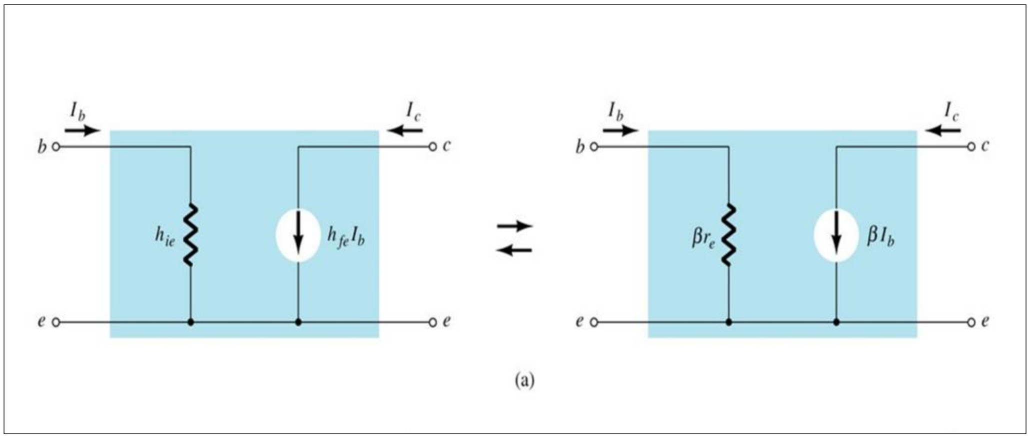
Configuration	Ii	Io	Vi	Vo
Common emitter	Ib	Ic	Vbe	Vce
Common base	Ie	Ic	Veb	Vcb
Common Collector	Ib	Ie	Vbe	Vec

- Normally hr is a relatively small quantity, its removal is approximated by hr ≅ 0 and hrVo = 0, resulting in a short – circuit equivalent.
- The resistance determined by 1/ho is often large enough to be ignored in comparison to a parallel load, permitting its replacement by an open – circuit equivalent.





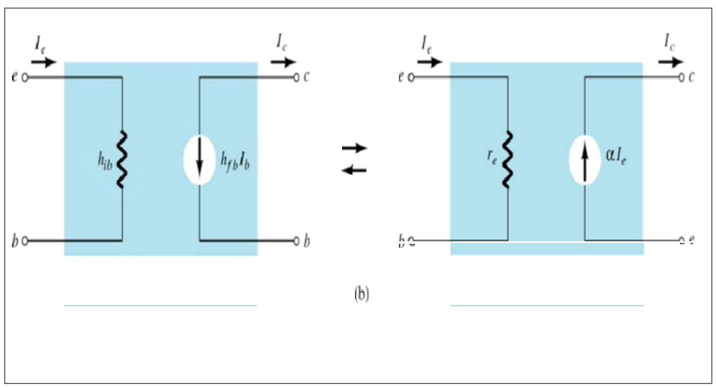
h-Parameter Model v/s. re Model



hie = βre

hfe = βac

Common Base: re v/s. h-Parameter Model



Common-Base configurations - h-Parameters

hib= re

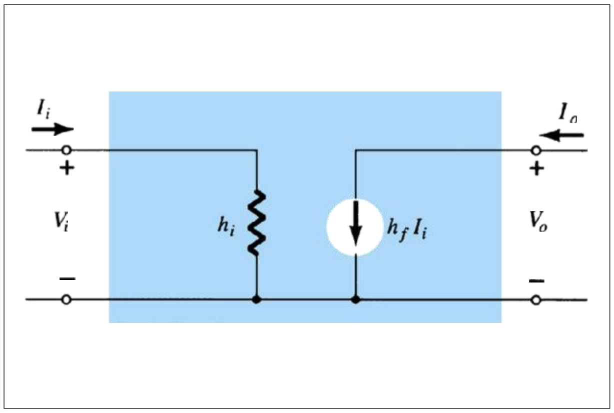
hfb= - α = -1

Problem

- Given IE = 3.2mA, hfe = 150, hoe = 25µS and hob = 0.5 µS . Determine

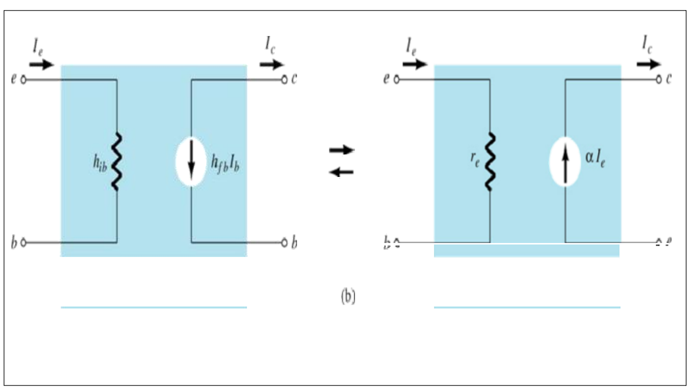
– The common – emitter hybrid equivalent

– The common – base re model



Solution:

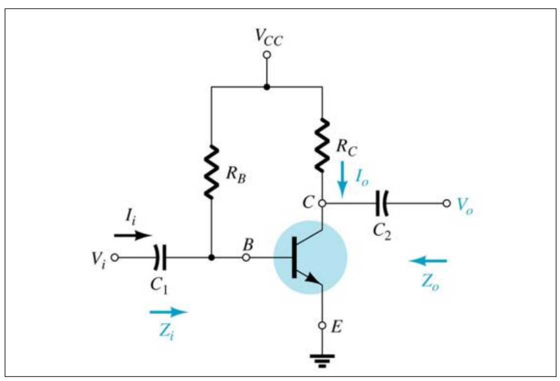
- We know that, hie = βre and re = 26mV/IE = 26mV/3.2mA = 8.125Ω
- βre = (150)(8.125) = 1218.75kΩ
- ro = 1 /hoe = 1/25µS = 40kΩ



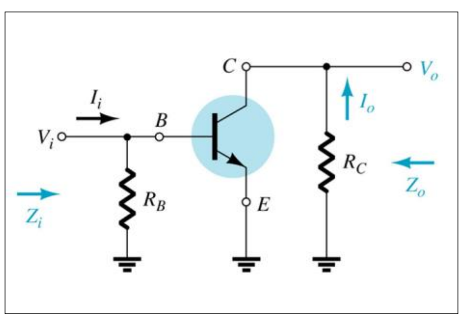
- re = 8.125Ω
- ro = 1/ hob = 1/0.5µS = 2M Ω
- α ≅ 1

- Small signal ac analysis includes determining the expressions for the following parameters in terms of Zi, Zo and AV in terms of
  - β
  - re
  - ro and
  - RB, RC
- Also, finding the phase relation between input and output
- The values of β, ro are found in datasheet
- The value of re must be determined in dc condition as re = 26mV / IE

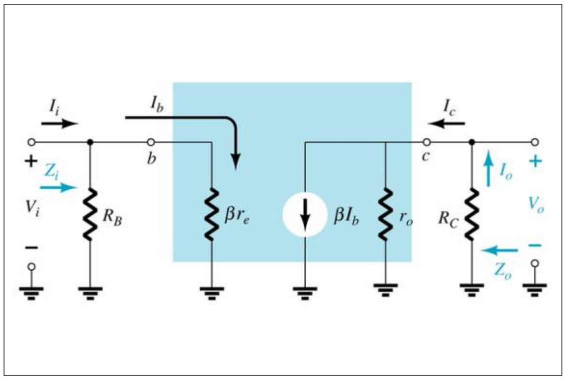
Common Emitter - Fixed bias configuration



Removing DC effects of VCC and Capacitors



re model



Small signal analysis – fixed bias

- From the above re model,

Zi = [RB II βre] ohms

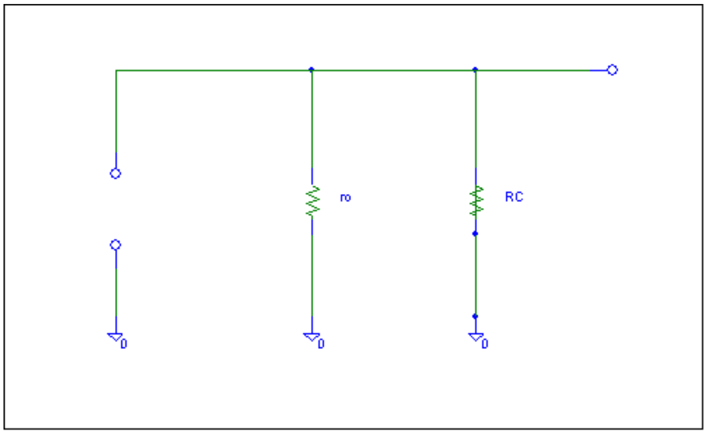
If RB > 10 βre, then,

$$[RB\ II\ \beta re] \cong \beta re$$

Then, Zi ≅ βre

- Zo is the output impedance when Vi =0. When Vi =0, ib =0, resulting in open circuit

equivalence for the current source.



- Zo = [RCII ro] ohms
- AV

– Vo = - βIb(RC || ro)

- From the re model, Ib = Vi / β re
- thus,

– Vo = - β (Vi / β re) (RC || ro)

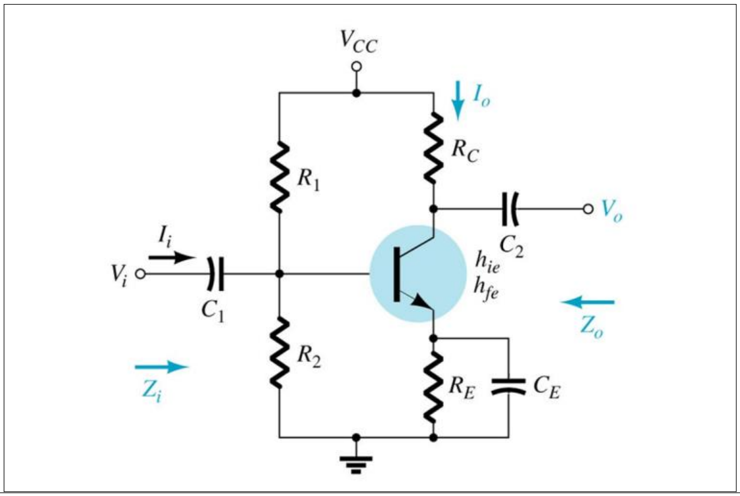
– AV = Vo / Vi = - (RC || ro) / re

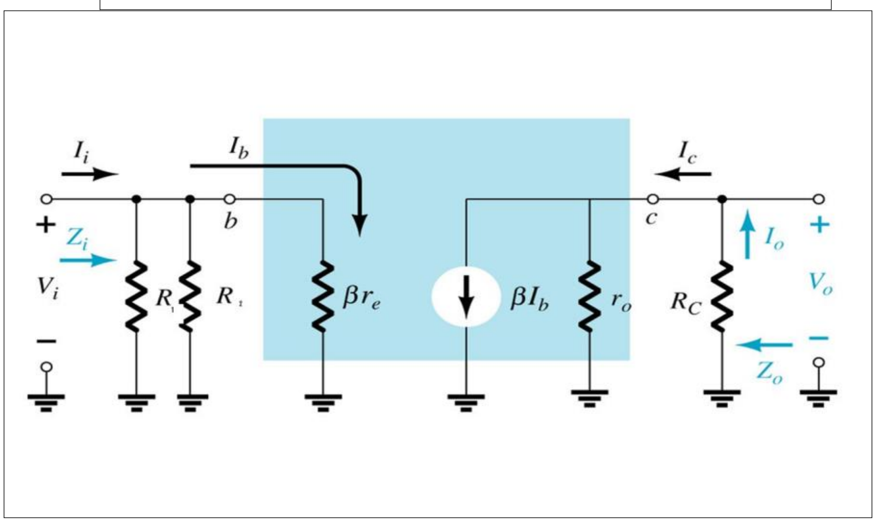
- If ro >10RC,

– AV = - (RC / re)

- The negative sign in the gain expression indicates that there exists 180o phase shift between the input and output.

Common Emitter - Voltage-Divider Configuration





- The re model is very similar to the fixed bias circuit except for RB is R1II R2 in the case of voltage divider bias.

- Expression for AV remains the same.

Zi = R1 II R2 II β re

Zo = RC

- From the re model, Ib = Vi / β re

- thus,

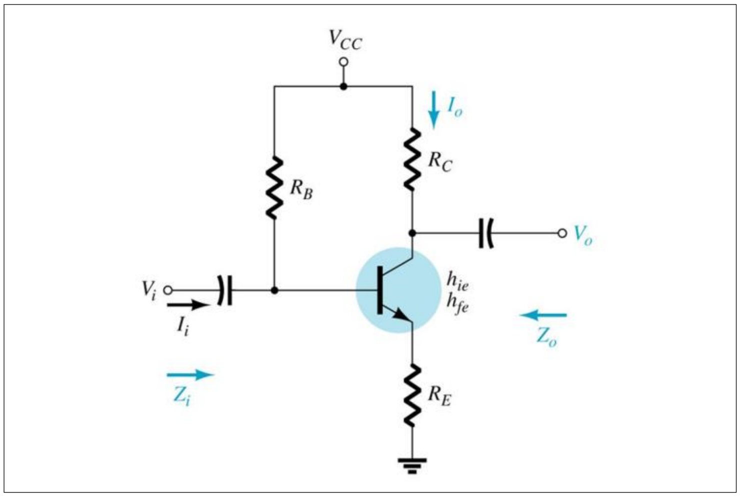
  Vo = - β (Vi / β re) (RC || ro)

- AV = Vo / Vi = - (RC || ro) / re

  If ro >10RC,

AV = - (RC / re)

Common Emitter - Unbypassed Emitter-Bias Configuration



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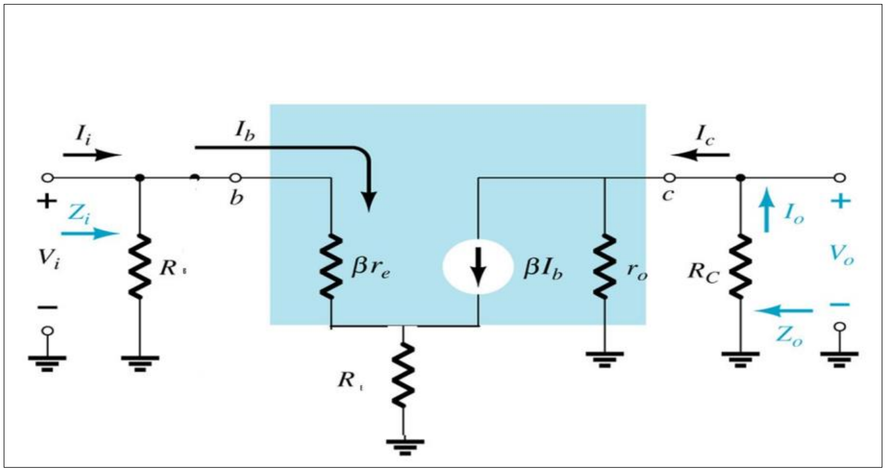


- Applying KVL to the input side:

$V_i = I_b \beta r_e + I_e R_E$

$V_i = I_b \beta r_e + (\beta + 1) I_b R_E$

Input impedance looking into the network to the right of RB is

$Z_b = V_i / I_b = \beta r_e + (\beta + 1) R_E$

Since $\beta >> 1$, $(\beta + 1) = \beta$

Thus,

$Z_b = V_i / I_b = \beta (r_e + R_E)$

- Since RE is often much greater than re, $Z_b = \beta R_E$,

$Z_i = R_B || Z_b$

•Zo is determined by setting Vi to zero, Ib = 0 and β Ib can be replaced by open circuit equivalent. The result is,

- $Z_o = R_C$

•AV : We know that, $V_o = - I_o R_C$

$= - \beta I_b R_C$

$= - \beta (V_i/Z_b) R_C$

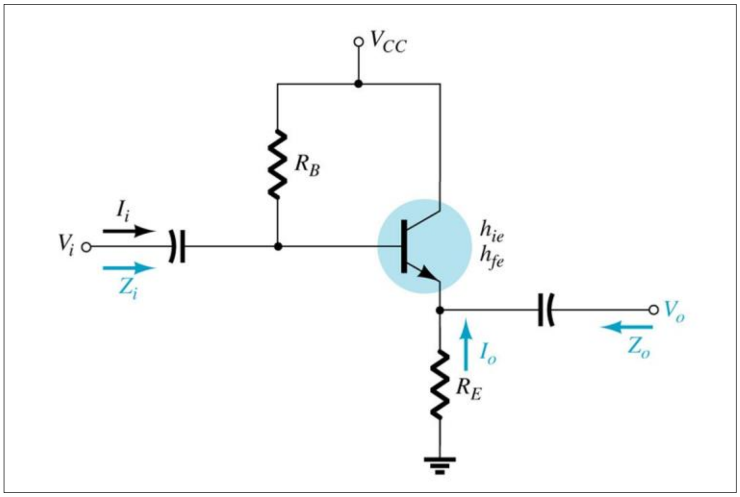
$A_V = V_o / V_i = - \beta (R_C/Z_b)$

Substituting, $Z_b = \beta (r_e + R_E)$

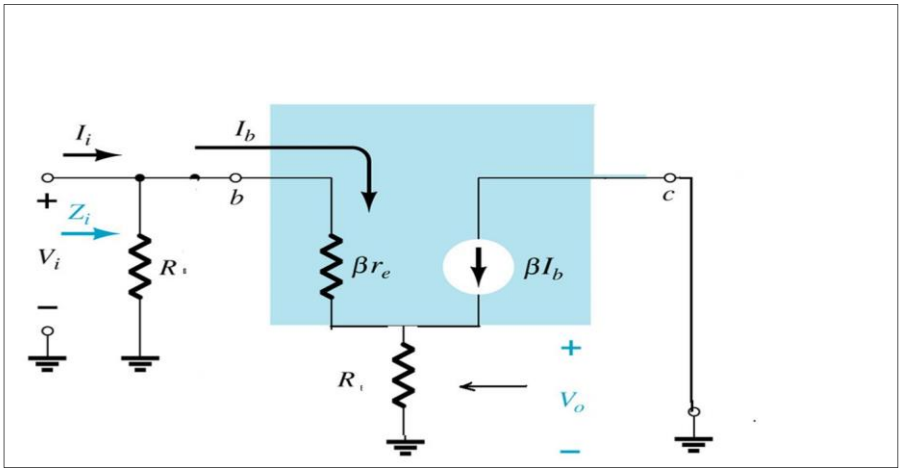
$A_V = V_o / V_i = - \beta [R_C / (r_e + R_E)]$ $R_E >> r_e$, $A_V = V_o / V_i = - \beta [R_C / R_E]$

- Phase relation: The negative sign in the gain equation reveals a 180o phase shift between input and output.

Emitter – follower



r_e model



- Zi = RB || Zb
- Zb = βre+ (β +1)RE
- Zb = β(re+ RE)
- Since RE is often much greater than re, Zb = βRE

- To find Zo, it is required to find output equivalent circuit of the emitter follower at its input terminal.

- This can be done by writing the equation for the current Ib.

$Ib = Vi / Zb$

$Ie = (\beta + 1)Ib$

$= (\beta + 1) (Vi / Zb)$

- We know that, $Zb = \beta re + (\beta + 1)RE$ substituting this in the equation for Ie we get,

$Ie = (\beta + 1) (Vi / Zb)$

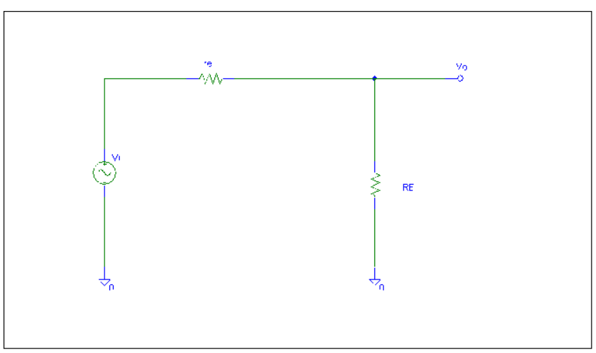
$= (\beta + 1) (Vi / \beta re + (\beta + 1)RE)$

$Ie = Vi / [\beta re / (\beta + 1)] + RE$

- Since $(\beta + 1) = \beta$,

$Ie = Vi / [re + RE]$

- Using the equation $Ie = Vi / [re + RE]$, we can write the output equivalent circuit as,

- 

- As per the equivalent circuit,

$Zo = RE \| re$

- Since RE is typically much greater than re, $Zo \cong re$

- AV – Voltage gain:

- Using voltage divider rule for the equivalent circuit, Vo = Vi RE / (RE+ re)

AV = Vo / Vi = [RE / (RE+ re)]

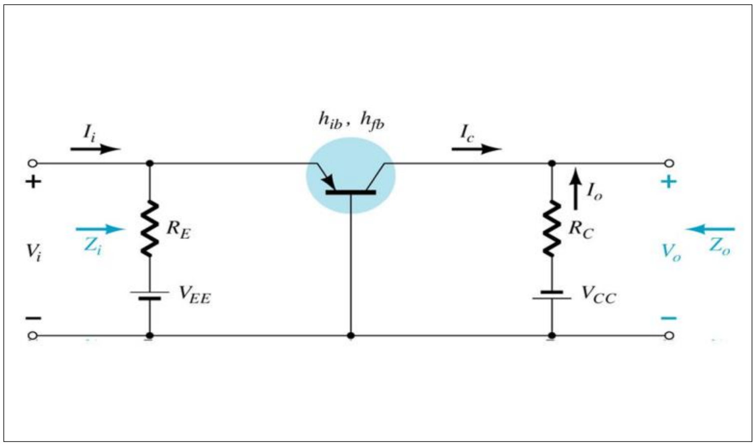
- Since (RE+ re) ≅ RE,

AV ≅ [RE / (RE] ≅ 1

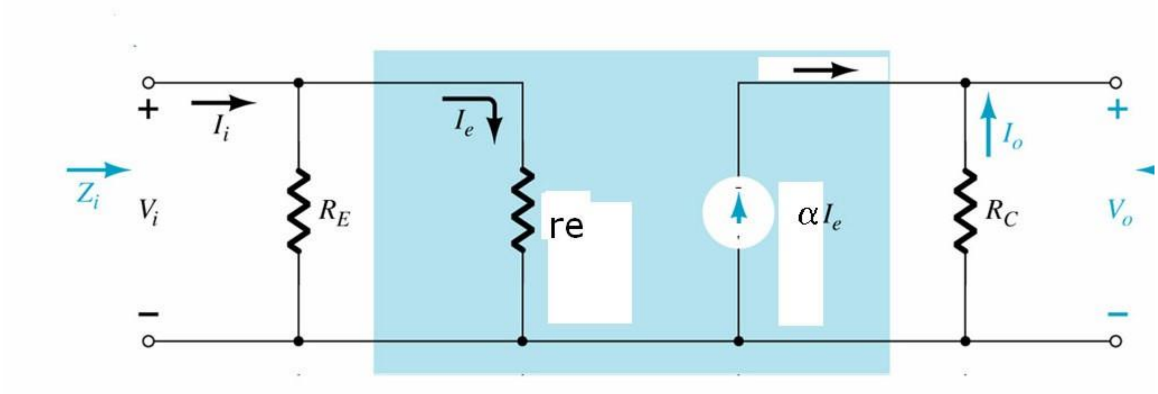
- Phase relationship

As seen in the gain equation, output and input are in phase.

Common base configuration



re model



Small signal analysis

- Input Impedance: $Z_i = R_E \| r_e$

- Output Impedance: $Z_o = R_C$

- To find, Output voltage, $V_o = - I_o R_C$

$V_o = - (-I_C) R_C = \alpha I_e R_C$

o Ie = Vi / re, substituting this in the above equation, $V_o = \alpha (V_i / r_e) R_C$

$V_o = \alpha (V_i / r_e) R_C$

Voltage Gain: AV:

$A_V = V_o / V_i = \alpha (R_C / r_e)$

$\alpha \cong 1$; $A_V = (R_C / r_e)$

Current gain

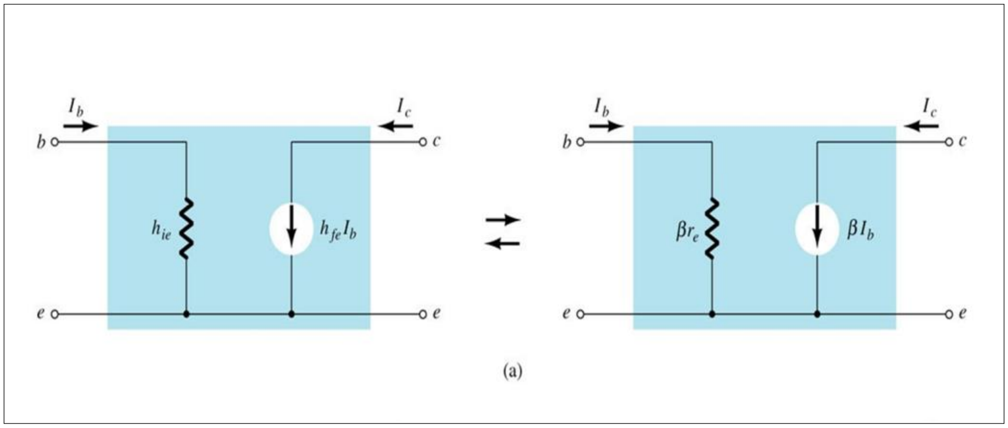
$A_i = I_o / I_i$

$I_o = - \alpha I_e = - \alpha I_i$

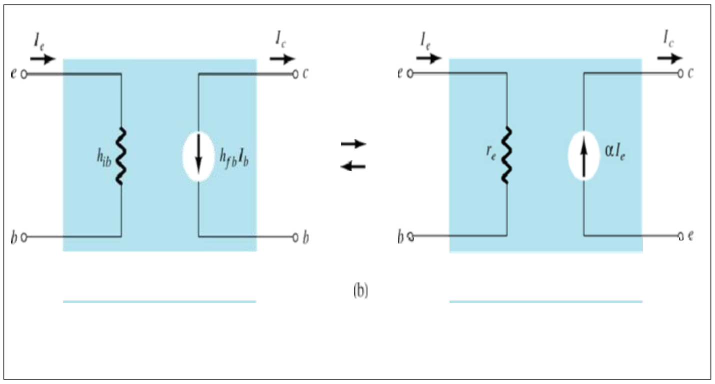
$I_o / I_i = - \alpha \cong -1$

Phase relation: Output and input are in phase.

h-Parameter Model vs. re Model



- CB re vs. h-Parameter Model



Common-Base h-Parameters

$$h_{ib} = r_e$$

$$h_{fb} = -\alpha \cong -1$$

- Small signal ac analysis includes determining the expressions for the following parameters in terms of Zi, Zo and AV in terms of

– β

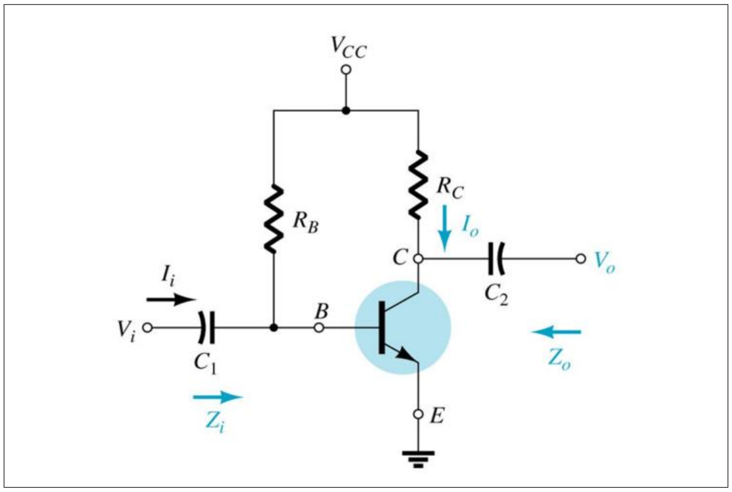
– re

– ro and

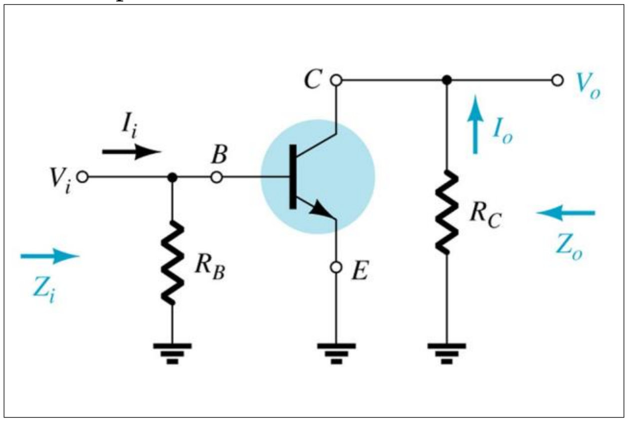
– RB, RC

- Also, finding the phase relation between input and output
- The values of β, ro are found in datasheet
- The value of re must be determined in dc condition as re = 26mV / IE

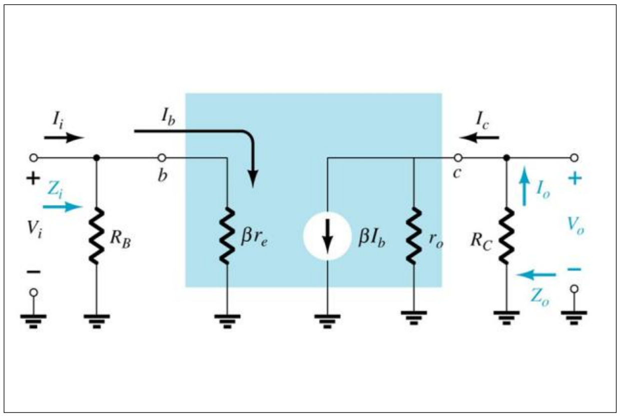
Common Emitter Fixed bias configuration

- 

Removing DC effects of VCC and Capacitors



re model



Small signal analysis – fixed bias

Input impedance Zi:

From the above re model, is,

Zi = [RB II βre] ohms

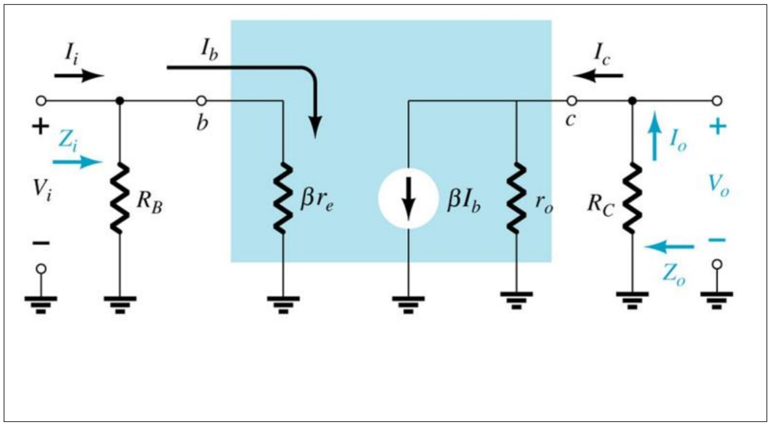
If RB > 10 βre, then,

[RB II βre] ≅ βre

Then, Zi ≅ βre

Ouput impedance Zoi:

Zo is the output impedance when Vi = 0. When Vi = 0, ib = 0, resulting in open circuit equivalence for the current source.



Zo = [RCII ro] ohms

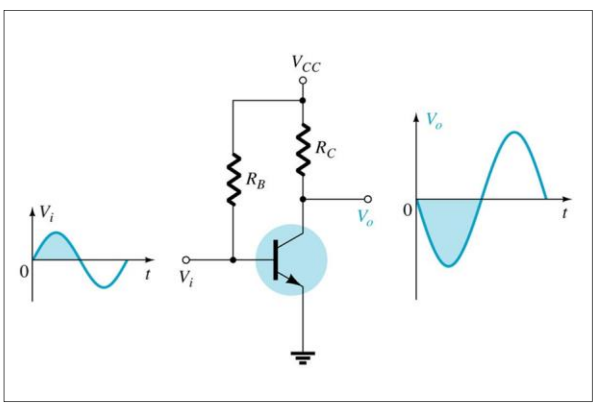
Voltage Gain Av:

Vo = - βIb(RC || ro) From the re model,   Ib = Vi / β re

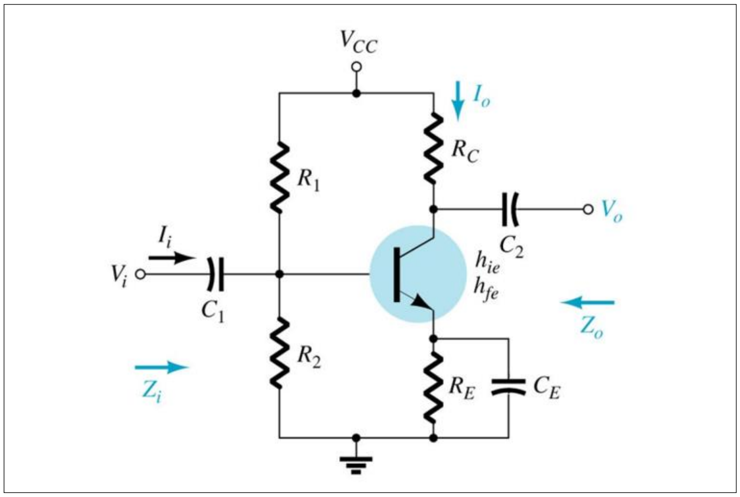
thus,   Vo = - β (Vi / β re) (RC || ro) AV = Vo / Vi = - (RC || ro) / re

If ro >10RC,   AV = - (RC / re) Phase Shift:

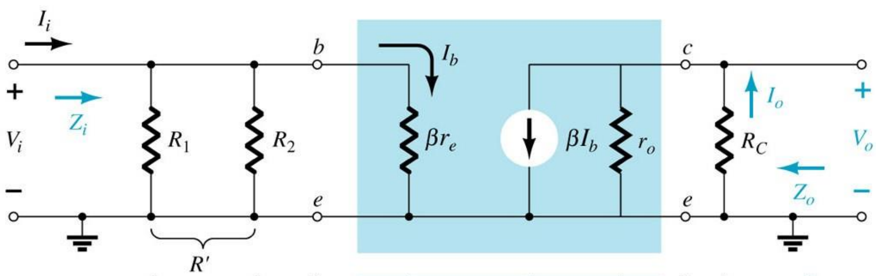
The negative sign in the gain expression indicates that there exists 180o phase shift between the input and output.



Common Emitter - Voltage-Divider Configuration



Equivalent Circuit:



The re model is very similar to the fixed bias circuit except for RB is R1II R 2 in the case of voltage divider bias.

Expression for AV remains the same. Zi = R1 II R2 II β re

Zo = RC

:

Voltage Gain, AV:

From the re model,

$I_b = V_i / \beta r_e$

$V_o = - I_o (R_C \| r_o)$,

$I_o = \beta I_b$

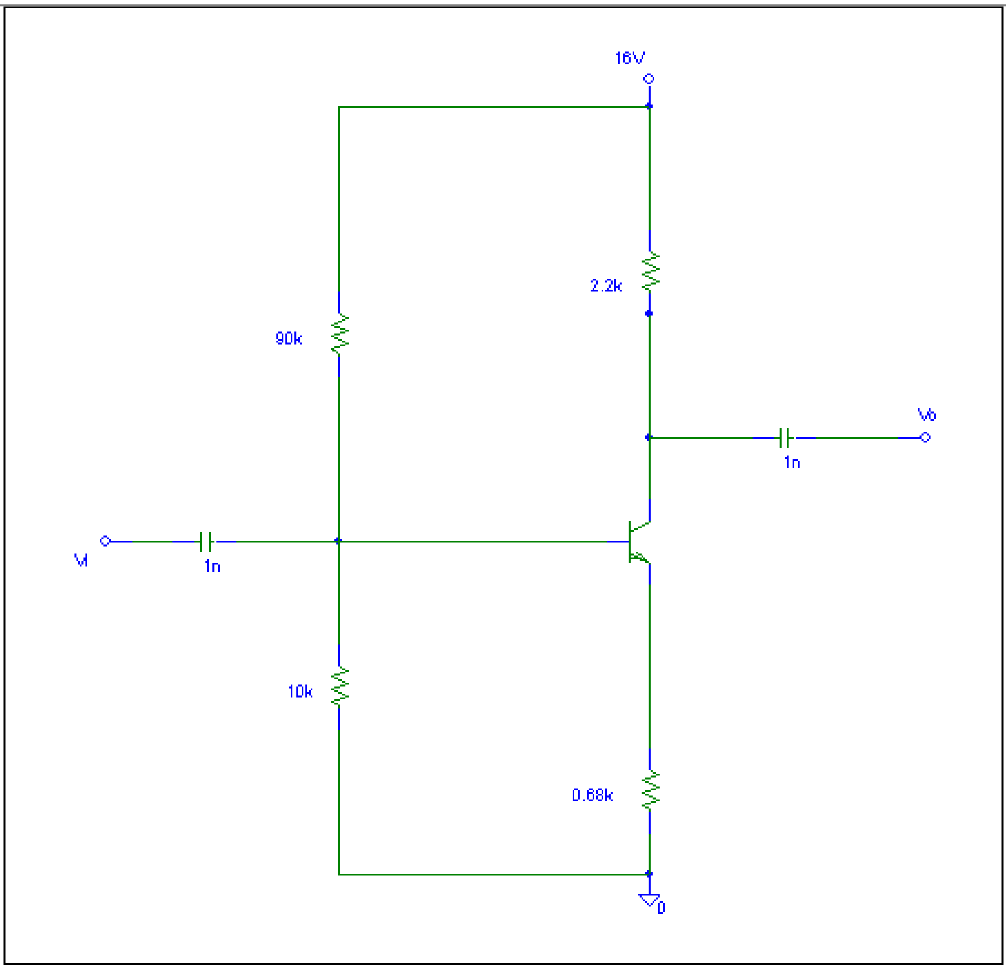
thus, $V_o = - \beta (V_i / \beta r_e) (R_C \| r_o)$ $A_V = V_o / V_i = - (R_C \| r_o) / r_e$

If $r_o > 10R_C$, $A_V = - (R_C / r_e)$

Problem:

Given: $\beta = 210$, $r_o = 50k\Omega$.

Determine: re, Zi, Zo, AV. For the network given:



To perform DC analysis, we need to find out whether to choose exact analysis or approximate analysis.

This is done by checking whether $\beta RE > 10R2$, if so, approximate analysis can be chosen. Here, $\beta RE = (210)(0.68k) = 142.8k\Omega$.

$10R2 = (10)(10k) = 100k$. Thus, $\beta RE > 10R2$.

Therefore using approximate analysis,

$VB = VccR2 / (R1+R2)$

$= (16)(10k) / (90k+10k) = 1.6V$ $VE = VB – 0.7 = 1.6 – 0.7 = 0.9V$

$IE = VE / RE = 1.324mA$

$re = 26mV / 1.324mA = 19.64\Omega$

Effect of ro can be neglected if ro ≥ 10(RC). In the given circuit, 10RC is 22k, ro is 50K.

Thus effect of ro can be neglected.

Zi = (R1||R2||βRE)

= [90k||10k||(210)(0.68k)] = 8.47kΩ

Zo = RC = 2.2 kΩ

AV = - RC / RE = - 3.24

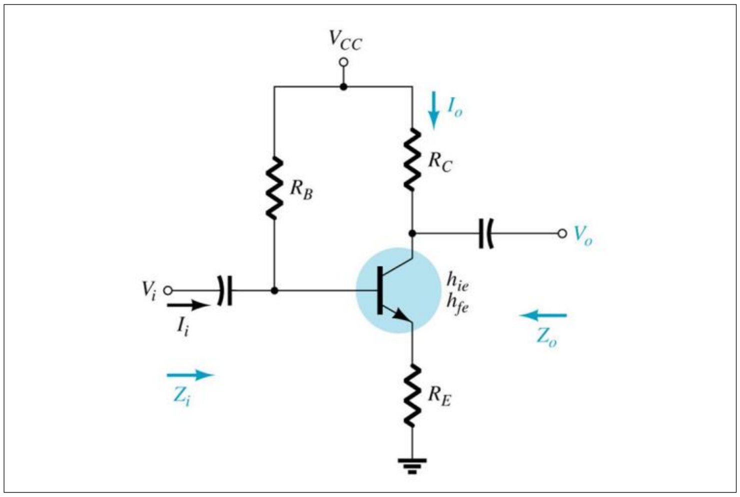
If the same circuit is with emitter resistor bypassed, Then value of re remains same.

Zi = (R1||R2||βre) = 2.83 kΩ

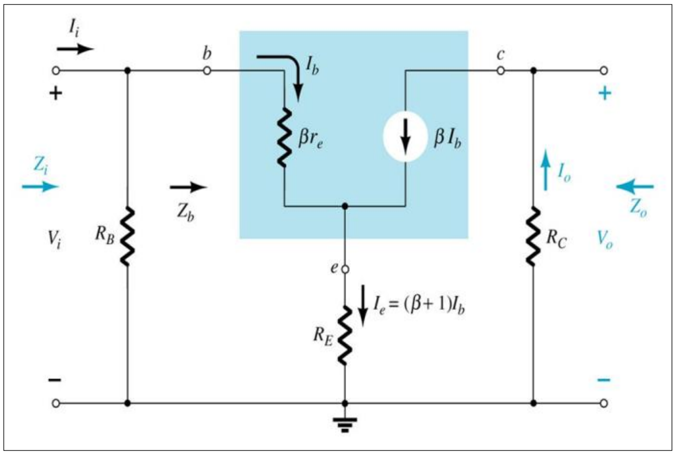
Zo = RC = 2.2 kΩ

AV = - RC / re = - 112.02

Common Emitter Un bypassed Emitter - Fixed Bias Configuration



Equivalent Circuit:



Applying KVL to the input side:

Vi = Ibβre + IeRE

Vi = Ibβre +(β +1) IbRE

Input impedance looking into the network to the right of RB is

Zb = Vi / Ib = βre+ (β +1)RE

Since β>>1,   (β +1) = β

Thus,   Zb = Vi / Ib = β (re+RE)

Since RE is often much greater than re, Zb = βRE, Zi = RB||Zb

Zo is determined by setting Vi to zero, Ib = 0 and βIb can be replaced by open circuit equivalent.

The result is,   Zo = RC

We know that, Vo = - IoRC

= - βIbRC

= - β(Vi/Zb)RC

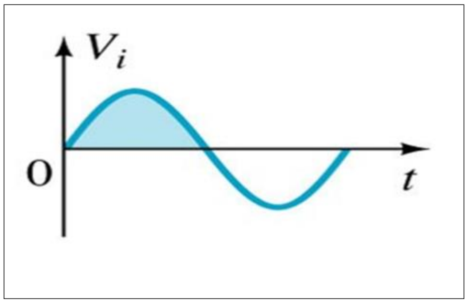
AV = Vo / Vi = - β(RC/Zb)

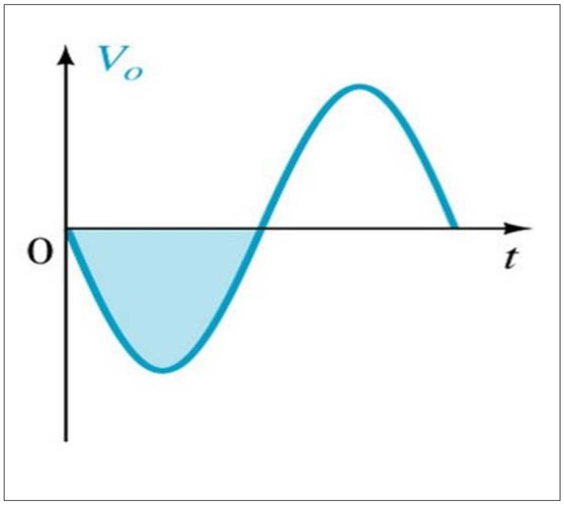
Substituting Zb = β(re + RE)

AV = Vo / Vi = - β[RC /(re + RE)]

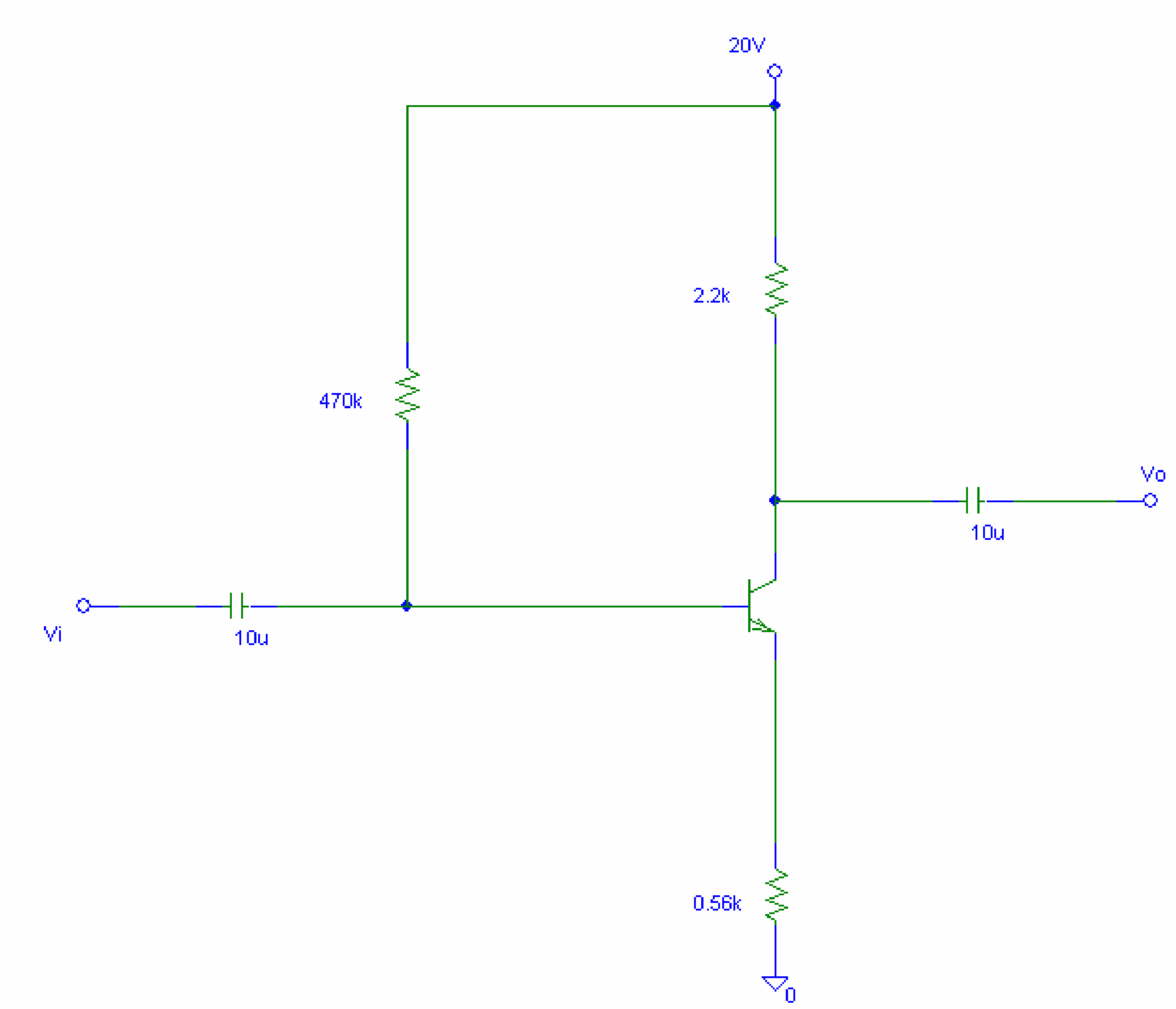
RE >>re, AV = Vo / Vi = - β[RC /RE]

Phase relation: The negative sign in the gain equation reveals a 180o phase shift between input and output.





Problem:



Given: $\beta = 120$, ro = 40kΩ.

Determine: re, Zi, Zo, AV.

To find re, it is required to perform DC analysis and find IE as re = 26mV / IE

To find IE, it is required to find IB.

We know that,

$IB = (VCC – VBE) / [RB + (\beta+1)RE]$

$IB = (20 – 0.7) / [470k + (120+1)0.56k] = 35.89\mu A$

$IE = (\beta+1)IB = 4.34mA$

$re = 26mV / IE = 5.99\Omega$

Effect of ro can be neglected, if $ro \geq 10(RC + RE)$

$10(RC + RE) = 10(2.2 k\Omega + 0.56k)$

$= 27.6 k\Omega$

and given that ro is 40 kΩ, thus effect of ro can be ignored.

$Z i = RB|| [\beta (re + RE)]$

$= 470k || [120 (5.99 + 560)] = 59.34\Omega$

$Zo = RC = 2.2 k\Omega$

$AV = - \beta RC / [\beta (re + RE)]$

$= - 3.89$

Analyzing the above circuit with Emitter resistor bypassed i.e., Common Emitter

$IB = (VCC – VBE) / [RB + (\beta+1)RE]$

$IB = (20 – 0.7) / [470k + (120+1)0.56k]$

$= 35.89\mu A$

$IE = (\beta+1)IB = 4.34mA$

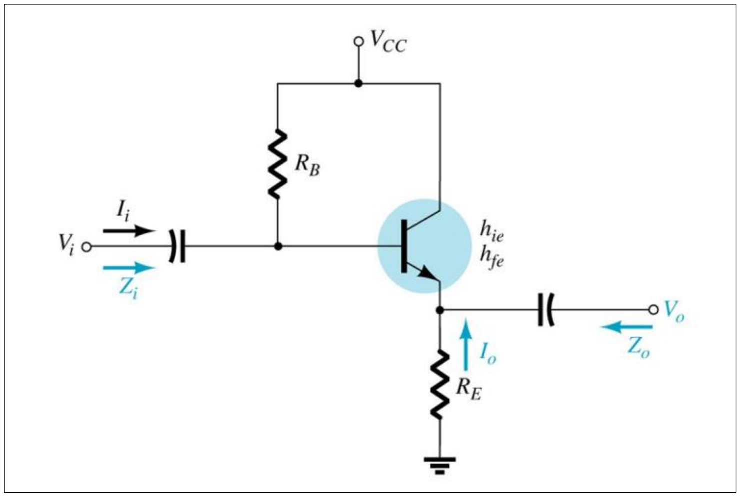
$re = 26mV / IE = 5.99\Omega$

$Zi = RB|| [\beta re] = 717.70\Omega$

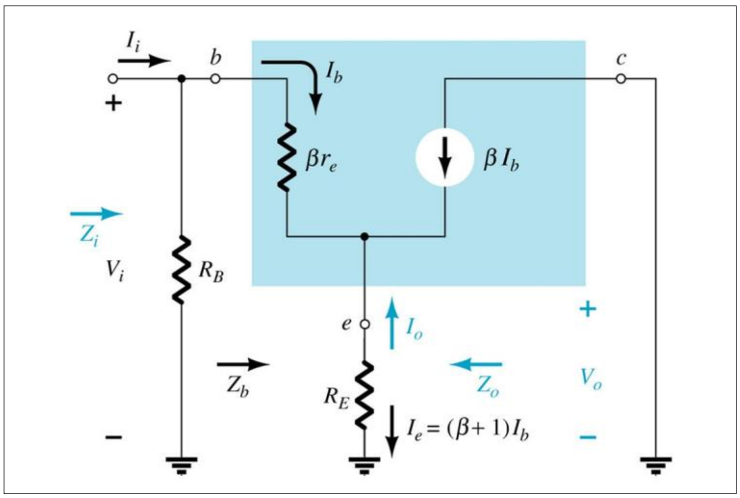
$Zo = RC = 2.2\ k\Omega$

$AV = - RC / re = - 367.28$ (a significant increase)

Emitter – follower



re model



$Zi = RB || Zb$

$Zb = \beta re+ (\beta +1)RE$

$Zb = \beta(re+ RE)$

Since RE is often much greater than re, $Zb = \beta RE$

To find Zo, it is required to find output equivalent circuit of the emitter follower at its input terminal.

This can be done by writing the equation for the current Ib.

$Ib = Vi / Zb$

$Ie = (\beta + 1) Ib$

$= (\beta + 1) (Vi / Zb)$

We know that, $Zb = \beta re + (\beta + 1) RE$

substituting this in the equation for Ie we get,

$Ie = (\beta + 1) (Vi / Zb)$

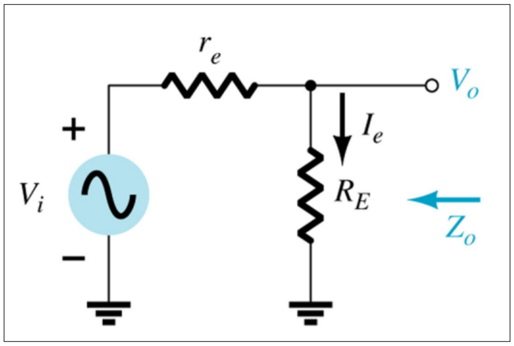
$= (\beta + 1) (Vi / \beta re + (\beta + 1) RE)$

dividing by $(\beta + 1)$, we get, Since $(\beta + 1) = \beta$,

$Ie = Vi / [\beta re / (\beta + 1)] + RE$

$Ie = Vi / [re + RE]$

Using the equation $Ie = Vi / [re + RE]$, we can write the output equivalent circuit as,



As per the equivalent circuit,

$$Zo = RE||re$$

Since RE is typically much greater than re, Zo ≅ re

AV – Voltage gain:

Using voltage divider rule for the equivalent circuit, Vo = Vi RE / (RE+ re)

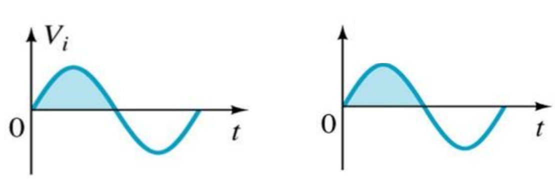
AV = Vo / Vi = [RE / (RE+ re)]

Since (RE+ re) ≅ RE,

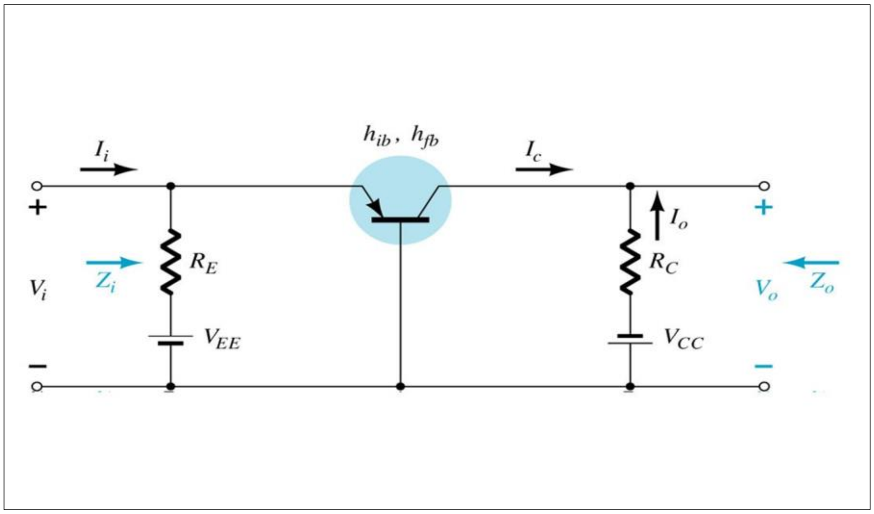
$$AV \cong [RE / (RE] \cong 1$$

Phase relationship

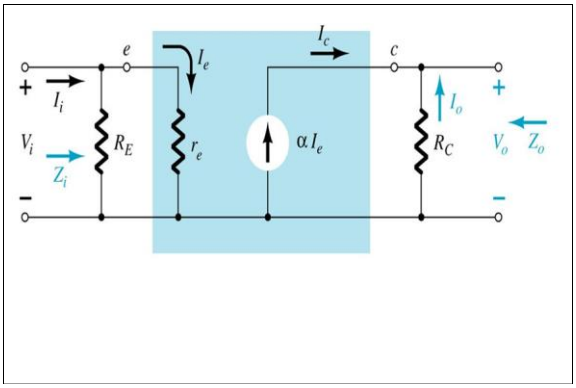
As seen in the gain equation, output and input are in phase.



Common base configuration



re model



Small signal analysis

Zi = RE||re

Zo = RC

To find Vo = - IoRC

Vo = - (-IC)RC = αIeRC

Substituting this in the above equation, Ie = Vi / re, Vo = α (Vi / re) RC

Vo = α (Vi / re) RC

AV = Vo / Vi = α (RC/ re)

α ≅ 1; AV = (RC/ re)

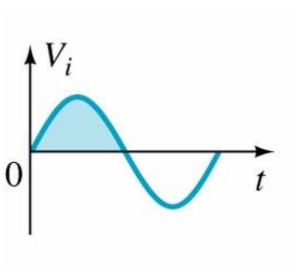
Current gain Ai :

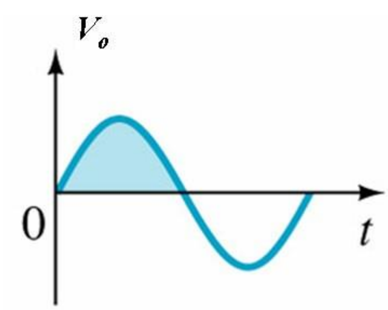
Ai = Io / Ii

Io = - α Ie = - α Ii

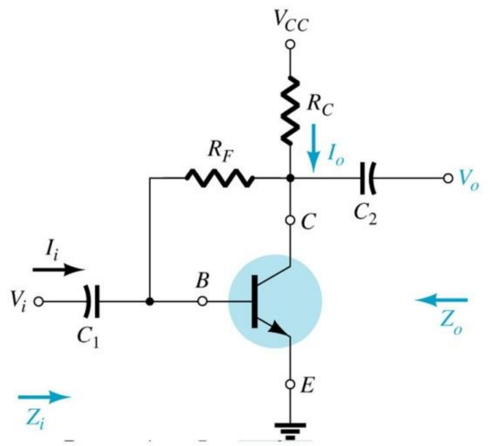
Io / Ii = - α ≅ -1

Phase relation: Output and input are in phase.

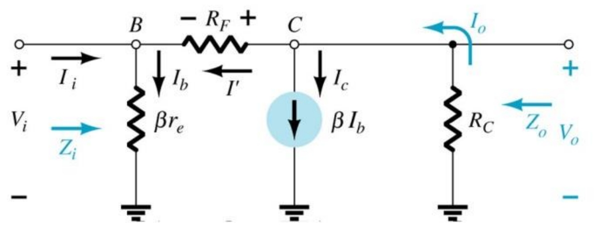




Common Emitter - Collector Feedback Configuration



re Model



Input Impedance: Zi

Zi = Vi / Ii, Ii = Ib – I′,

thus it is required to find expression for I′ in terms of known resistors.

I′ = (Vo – Vi)/ RF (1)

Vo = - IoRC

Io = βIb + I′ Normally, I′ << βIb thus, Io = βIb ,

Vo = - IoRC

Vo = - βIb RC,

Replacing Ib by $V_i / \beta r_e$

Thus,

Substituting (2) in (1):

$Vo = - \beta (Vi\ RC) / \beta re$

$= - (Vi\ RC) / re$ (2)

$I' = (Vo – Vi)/ RF$

$= (Vo / RF) - (Vi/ RF)$

$= - [(Vi\ RC) / RF\ re] - (Vi/ RF)$

$I' = - Vi/RF[(RC / re)+1]$

We know that, $Vi = Ib\beta re$,

$Ib = Ii + I'$

and, $I' = - Vi/RF[(RC / re) +1]$

Thus, $Vi = (Ii + I') \beta re = Ii \beta re + I' \beta re$

$= Ii \beta re - (Vi \beta re)(1/RF)[(RC / re)+1]$

Taking Vi terms on left side:

$Vi + (Vi \beta re)(1/RF)[(RC / re)+1] = Ii \beta re$

$Vi[1 + (\beta re)(1/RF)[(RC / re) +1] = Ii \beta re$

$Vi / Ii = \beta re / [1 + (\beta re)(1/RF)[(RC / re) +1]$

But, $[(RC / re)+1] \cong RC / re$

(because $RC >> re$)

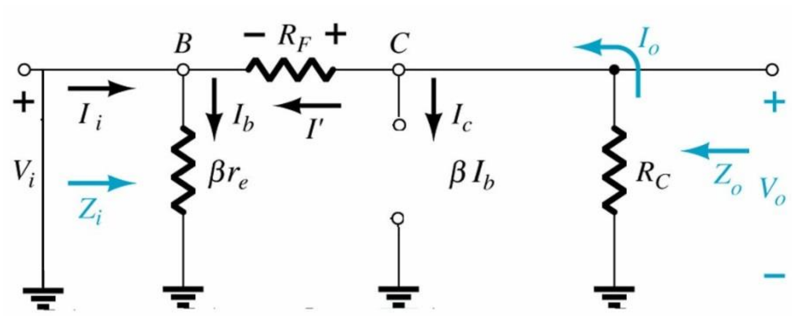
Thus, $Zi = Vi / Ii$

$= \beta re / [1 + (\beta re)(1/RF)[(RC / re)]$

$= \beta re \ / [1 + (\beta)(RC/RF)]$

Thus, $Zi = re \ / [(1/\beta) + (RC/RF)]$

To find Output Impedance Zo:



Zo = RC || RF (Note that ib = 0, thus no effect of βre on Zo)

Voltage Gain AV:

Vo = - IoRC

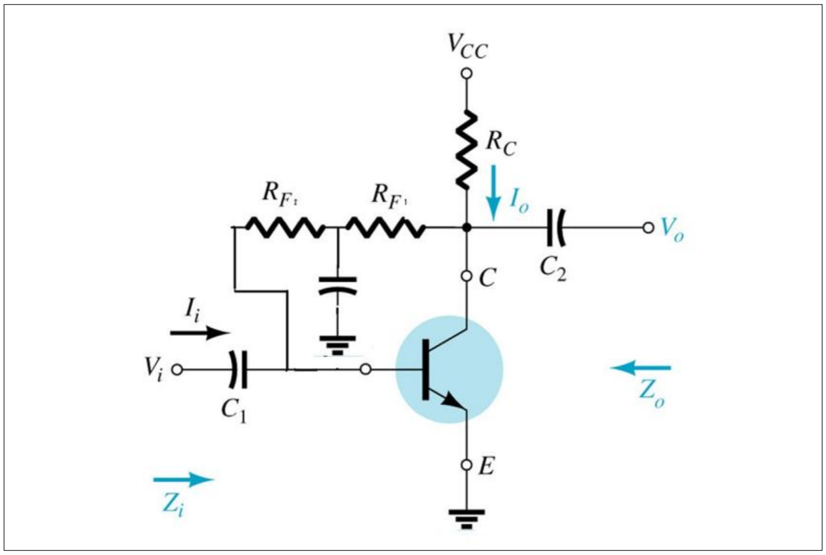
= - βIbRC (neglecting the value of I′)

= - β(Vi/ βre)RC

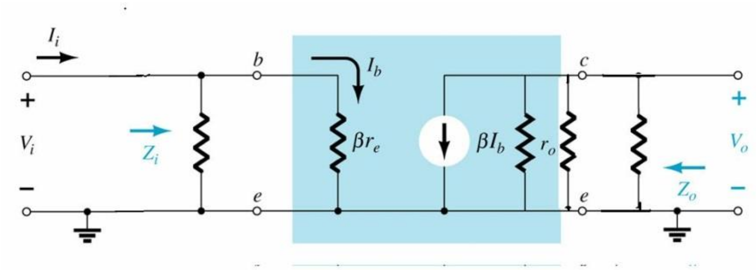
AV = Vo / Vi = - (RC/re)

Phase relation: - sign in AV indicates phase shift of 180° between input and output.

Collector DC feedback configuration



re model



Zi = RF1 ||βre

Zo = RC||RF2||ro, for ro≥10RC, Zo = RC||RF2

To find Voltage Gain AV :

Vo = - βIb(RF2||RC||ro), Ib = Vi / βre

Vo = - β (Vi / βre)(RF2||RC||ro)

Vo / Vi = - (RF2||RC||ro) / re,

for ro≥10RC,

AV = Vo / Vi = - (RF2||RC) / re

Determining the current gain

For each transistor configuration, the current gain can be determined directly from the voltage gain, the defined load, and the input impedance.

We know that, current gain (Ai) = Io / Ii

$Io = (Vo / RL)$ and $Ii = Vi / Zi$

Thus, $Ai = - (Vo /RL) / (Vi / Zi)$

$= - (Vo\ Zi / Vi\ RL)$ $Ai = - AV\ Zi / RL$

Example:

For a voltage divider network, we have found that, $Zi = \beta re$

$AV = - RC / re$ and $RL = RC$

Thus, $Ai = - AV\ Zi / RL$

$= - (- RC / re)(\beta re) / RC$

$Ai = \beta$

For a Common Base amplifier, $Zi = re$, $AV = RC / re$, $RL = RC$

$Ai = - AV\ Zi / RL$

$= - (RC / re)(re) / RC$

$= - 1$

Effect of RL and RS:

Voltage gain of an amplifier without considering load resistance (RL) and source resistance (RS) is AVNL.

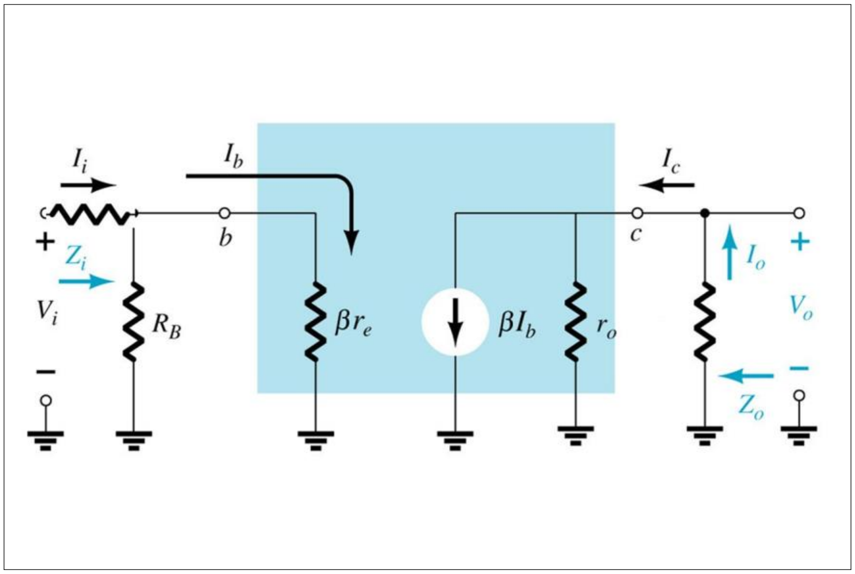
Voltage gain considering load resistance (RL) is $AV < AVNL$

Voltage gain considering RL and RS is AVS, where AVS<AVNL< AV

For a particular design, the larger the level of RL, the greater is the level of ac gain.

Also, for a particular amplifier, the smaller the internal resistance of the signal source, the greater is the overall gain.

Fixed bias with RS and RL:



AV = - (RC||RL) / re

Z i = RB|| βre

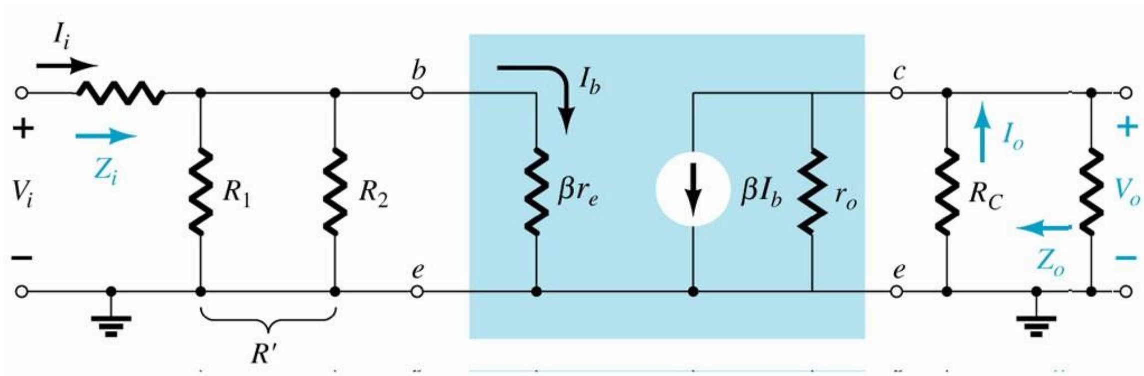
Zo = RC||ro

To find the gain AVS, (Zi and RS are in series and applying voltage divider rule) Vi = VSZi / (Zi+RS)

Vi / VS = Zi / (Zi+RS)

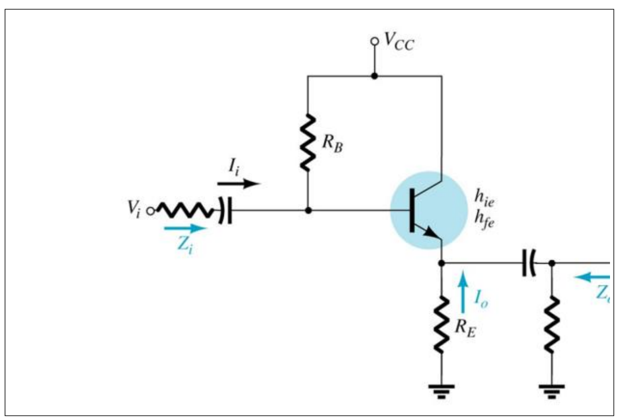
AVS = Vo / VS = (Vo/Vi) (Vi/VS) AVS = AV [Zi / (Zi+RS)]

Voltage divider with RS and RL

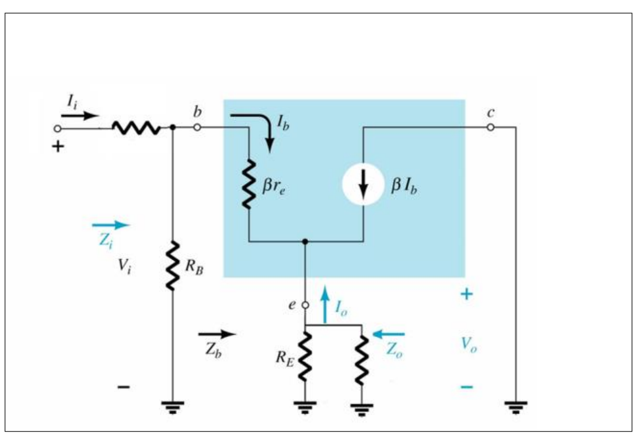


Voltage gain: AV = - [RC||RL] / re Input Impedance: Zi = R1||R2||β re Output Impedance: Zo = RC||RL||ro

Emitter follower with RS and RL



re model:



Voltage Gain: AV = (RE||RL) / [RE||RL+re] Input Impedance: Zi = RB || Zb

Input Impedance seen at Base: Zb = β(RE||RL)

Output Impedance Zo = re

Two – port systems approach

This is an alternative approach to the analysis of an amplifier.

This is important where the designer works with packaged with packaged products rather than individual elements.

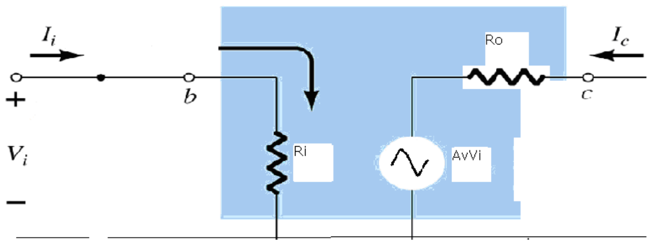
An amplifier may be housed in a package along with the values of gain, input and output impedances.

But those values are no load values and by using these values, it is required to find out the gain and various impedances under loaded conditions.

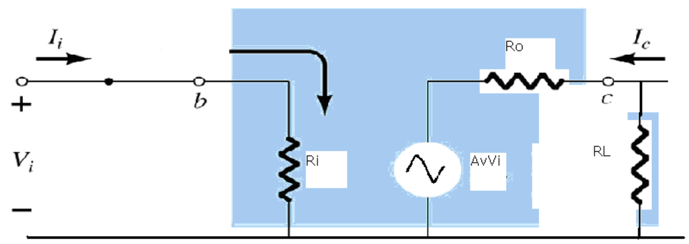
This analysis assumes the output port of the amplifier to be seen as a voltage source. The value of this output voltage is obtained by Thevinising the output port of the amplifier.

$E_{th} = A_{VNL}V_i$

Model of two port system



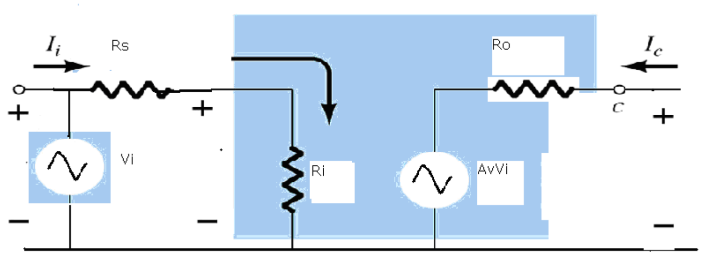
Applying the load to the two port system



Applying voltage divider in the above system: Vo = AVNLViRL / [RL+Ro]

Including the effects of source resistance RS

Applying voltage divider at the input side, we get:



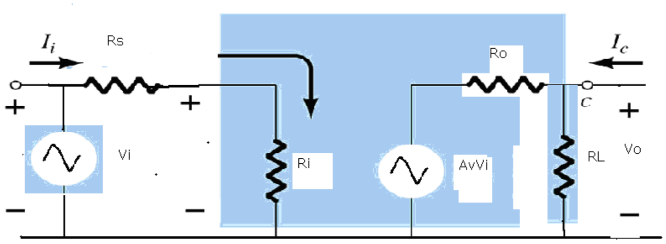
Vi = VSRi /[RS+Ri] Vo = AVNLVi

Vi = VSRi /[RS+Ri]

Vo = AVNL VSRi /[RS+Ri]

Vo/ VS = AVS = AVNLRi /[RS+Ri]

Two port system with RS and RL



We know that, at the input side

Vi = VSRi /[RS+Ri]

Vi / VS = Ri /[RS+Ri]

At the output side,

Vo = AVNLViRL / [RL+Ro] Vo / Vi = AVNLRL / [RL+Ro]

Thus, considering both RS and RL: AV = Vo / Vs

= [Vo / Vi] [Vi / Vs]

AV = (AVNLRL / [RL+Ro]) (Ri / [RS+Ri])

Example:

Given an amplifier with the following details:

RS = 0.2 kΩ, AVNL = - 480, Zi = 4 kΩ, Zo = 2 kΩ

Determine:

AV with RL =1.2kΩ

AV and Ai with RL= 5.6 kΩ, AVS with RL = 1.2

Solution:

AV = AVNLRL / (RL + Ro)

= (- 480)1.2k / (1.2k+2k)

= - 180

With RL = 5.6k, AV = - 353.76

This shows that, larger the value of load resistor, the better is the gain.

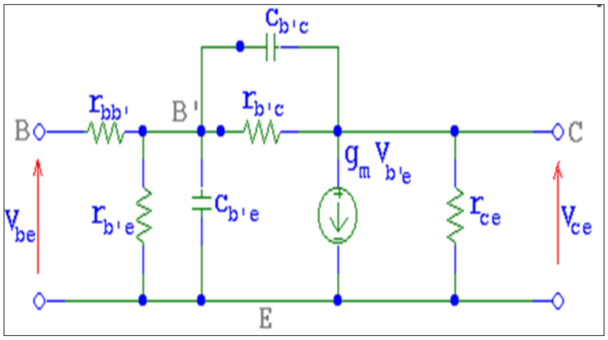
AVS = [Ri /(Ri+RS)] [RL / (RL+Ro)] AVNL

= - 171.36

Ai = - AVZi/RL, here AV is the voltage gain when RL = 5.6k. Ai = - AVZi/RL

= - (-353.76)(4k/5.6k) = 252.6

Hybrid π model



This is more accurate model for high frequency effects. The capacitors that appear are stray parasitic capacitors between the various junctions of the device. These capacitances come into picture only at high frequencies.

- Cbc or Cu is usually few pico farads to few tens of pico farads.
- rbb includes the base contact, base bulk and base spreading resistances.
- rbe (rπ), rbc, rce are the resistances between the indicated terminals.

- r_{be} (r_π) is simply βr_e introduced for the CE r_e model.
- r_{bc} is a large resistance that provides feedback between the output and the input.
- $r_\pi = \beta r_e$
- $g_m = 1/r_e$
- $r_o = 1/h_{oe}$
- $h_{re} = r_\pi / (r_\pi + r_{bc})$