(1) Review of The **BJT**

(**B**ipolar **J**unction **T**ransistor)

Reference: Wikipedia, Neamen (Chapter 5 and Chapter 6)

1

Learning Outcome

Able to:

Å Describe the general **current-voltage characteristics** for both npn and pnp bipolar transistors.

Å Define the four **modes of operation** of a bipolar transistor.

Å Describe the **small-signal hybrid-π** equivalent circuit of a bipolar transistor and determine the values of the small-signal **hybrid-π parameters**.

Å Understand the importance of a **multistage amplifier**.

2

1.0) Transistor

1.0.1) Introduction

ÅIn electronics, a **transistor** is a **semi-conductor device** commonly used to **amplify or switch electronic signals**.

ÅA transistor is made of a solid piece of a semiconductor material, with **at least three terminals for connection to an external circuit**. A voltage or current applied to one pair of the transistor's terminals changes the current flowing through another pair of terminals.

ÅThe transistor is the **fundamental building block of modern electronic devices**, and is used in radio, telephone, computer and other electronic systems. Some transistors are packaged individually but **most are found in integrated circuits**.

From: Wikipedia

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1.0) Transistor (Cont)

1.0.2) Importance

ÅThe transistor is considered by many to be **the greatest invention of the 20th-century**, or as one of the greatest. It is the key active component in practically all modern electronics.

ÅAlthough several companies each produce over a billion individually-packaged (known as *discrete*) transistors every year, the **vast majority of transistors produced are in Integrated Circuits** (often shortened to **IC**, *microchips* or simply *chips*) along with diodes, resistors, capacitors and other electronic components to produce complete electronic circuits.

From: Wikipedia

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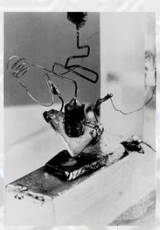
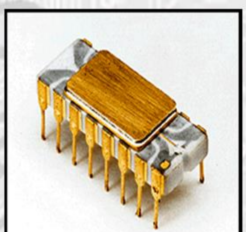
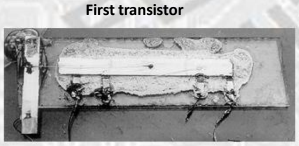
1.0) Transistor (Cont)



First transistor



The Intel4004, it was supposed to be the brains of a calculator. Instead, it turned into a general-purpose micro-processor as powerful as ENIAC.



Integrated circuit

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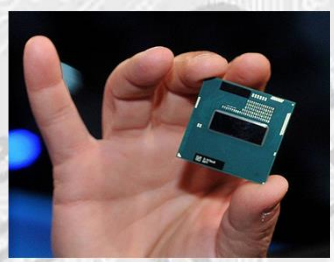
1.0) Transistor (Cont)



Intel reinvents personal computing with Ultrabooks: **Ivy Bridge** is built on a **22 nm (nanometer) process** and has **1.48 billion** 3D tri-gate **transistors**

From: The STAR, 15 September 2011

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1.0) Transistor (Cont)

1.0.2) Importance (Cont)

Å A **logic gate** consists of about **twenty transistors** whereas an advanced **micro-processor**, as of **2006**, can use as many as **1.7 billion transistors** (MOSFETs). ñAbout 60 million transistors were built in 2002 ... for [every] man, woman, and child on Earth.ò

ÅThe transistor's low cost, flexibility and reliability have made it a **ubiquitous device**.

ÅTransistorized mechatronic circuits have replaced electromechanical devices in controlling appliances and machinery.

From: Wikipedia

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1.0) Transistor (Cont)

1.0.3) Applications

Å The **bipolar junction transistor (BJT)** was the first transistor invented, and through the 1970s, was the most commonly used transistor. Even after **MOSFET**s became available, the BJT remained the transistor of choice for many analog circuits such as simple amplifiers because of **their greater linearity and ease of manufacture**.
Å Desirable properties of **MOSFET**s, such as their utility in **low-power devices**, usually in CMOS configuration, allowed them to capture nearly all market share for **digital circuits**; more recently MOSFETs have captured most analog and power applications as well, including modern clocked analog circuits, voltage regulators, amplifiers, power transmitters, motor drivers, etc.

From: Wikipedia

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1.0) Transistor (Cont)

1.0.4) Categories

Transistors are **categorized by**:

[1] **Semiconductor material**: germanium, silicon, gallium arsenide, silicon carbide, etc.
[2] **Structure**: BJT, JFET, IGFET (MOSFET), IGBT, "other types".
[3] **Polarity**: NPN, PNP (BJTs); N-channel, P-channel (FETs).
[4] Maximum **power rating**: low, medium, and high.

From: Wikipedia

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1.0) Transistor (Cont)

1.0.4) Categories (Cont)

Transistors are **categorized by**:

[5] Maximum **operating frequency**: low, medium, high, radio frequency (RF), microwave
[6] **Application**: switch, general purpose, audio, high voltage, super-beta, matched pair.
[7] Physical **packaging**: through hole metal, through hole plastic, surface mount, ball grid array, power modules.
[8] **Amplification factor** (transistor beta).

From: Wikipedia

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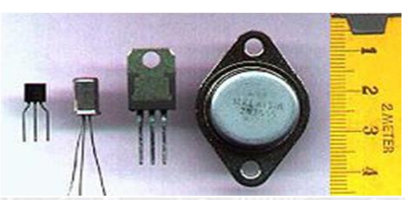
1.0) Transistor (Cont)

1.0.4) Categories (Cont)

Thus, a particular transistor may be described as: *silicon, surface mount, BJT, NPN, low power, high frequency switch*.



From: Wikipedia

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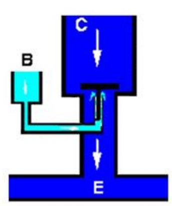
1.0) Transistor (Cont)

1.0.5) How a transistor functions?

An illustration of BJT transistor using water rather than electricity to illustrate the way it functions:



The illustration [taken from http://www.satcure-focus.com/tutor/page4.htm] shows pipe work with three openings of **B** (**B**ase), **C** (**C**ollector), and **E** (**E**mitter).

From **http://www.reuk.co.uk/What-is-a-Transistor.htm**

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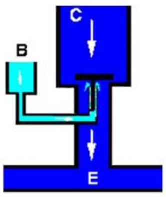
1.0) Transistor (Cont)

1.0.5) How a transistor functions? (Cont)

An illustration of BJT transistor using water rather than electricity to illustrate the way it functions:



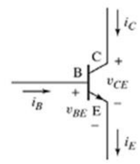
The reservoir of water at **C** is the *supply voltage* which is prevented from getting through to **E** by a plunger. If water is poured into **B**, it pushes up the plunger letting water to flow from **C** to **E**.

From **http://www.reuk.co.uk/What-is-a-Transistor.htm**

1.0) Transistor (Cont)

1.0.5) How a transistor functions? (Cont)

If even more water is poured into **B**, the plunger moves higher, and the flow of water from **C** to **E** increases.



Therefore, for a BJT transistor for example, a small input current of electricity to the Base leads to a large flow of electricity (or current) from the Collector to the Emitter.

From **http://www.reuk.co.uk/What-is-a-Transistor.htm**

Puzzle 1:

How to make **10** from **9** sticks?

Puzzle 2:

How to make **5** from **10** sticks?

Conclusion!

Know the ñ**secret**ò then you can solve the problem!

Puzzle 3:

How to make **4 inside** number **5**?

Conclusion!

Know the ñ**secret**ò then you can solve the problem!

1.1) BJT Characteristics and Properties

1.1.1) Circuit Symbols and Conventions

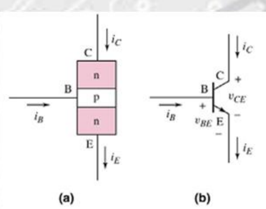


Fig 5.8: npn bipolar transistor
(a) block diagrams
and (b) circuit symbols.

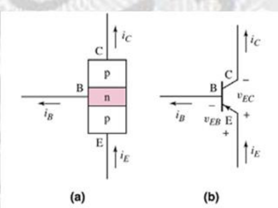


Fig 5.9: pnp bipolar transistor
(a) block diagrams
and (b) circuit symbols.

Full [more detail] picture helps us identify somebody correctly!

➔ Correct symbol helps us identify which type of transistor correctly!

Fast Forward…

Past Question

Question 1 [16 marks]

(a) A basic **two-transistor BJT current source** consists of two **npn-type BJT transistors** and a resistor, R_1, to establish its **reference current**, I_{REF}. The reference current is established when the circuit is connected to positive and negative power source, V^+ and V^-.

(i) Let the second transistor, Q_2, be the output transistor. **Draw and label** the circuit and its components **clearly**.

[3 marks]

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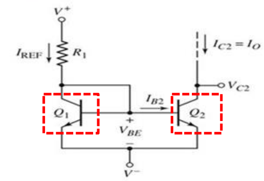
Fast Forward… (Cont)

Past Question (Cont) – Model Answer

Q1(a)(i)

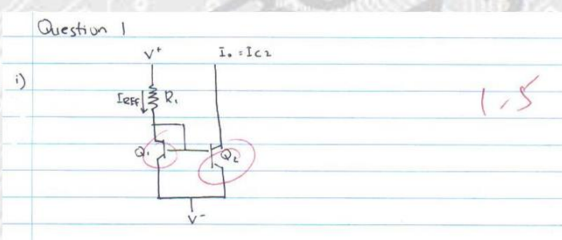


Transistors	[1]
I_{REF}	[0.5]
R_1	[0.5]
I_O	[0.5]
Connection	[0.5]
Total	**[3 marks]**

20

Fast Forward… (Cont)

Past Question (Cont) – Not ALL correct answer



➔ ➔ **Draw transistor with correct symbol!** 🡐 🡐

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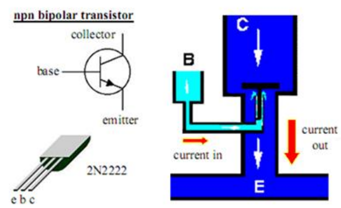
1.1) BJT Characteristics and Properties (Cont)

1.1.2) Basic Principle of Operation

"The voltage between two terminals (B-E) controls the current through the third terminal (C)"



➔ **Transistor = a Voltage-controlled Resistor.**

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1.1) BJT Characteristics and Properties (Cont)

1.1.3) Modes of Operation

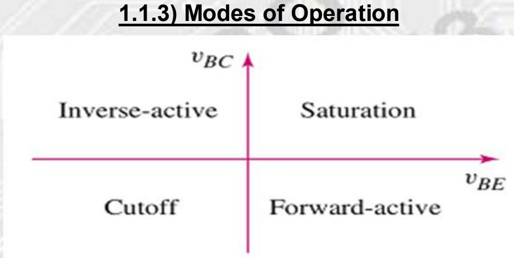

Fig 5.25: Bias conditions for the 4 modes of operations of an npn transistor.

➔ **Forward-active region is usually used for amplifier circuit.**

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1.1) BJT Characteristics and Properties (Cont)

1.1.3) Modes of Operation (Cont)

1) The transistor is biased in **Inverse-active mode** if B-E junction is **reverse biased (v_{BE} < 0)** and B-C junction is **forward biased (v_{BC} > 0)**.
2) Transistor is in the **Saturation** if both junctions are forward biased.
3) Transistor is in the **Cutoff** if both junctions are zero or reverse biased.
4) The transistor is biased in the **Forward-active mode** if **B-E junction is forward biased (v_{BE} > 0)** and **B-C junction is reverse biased (v_{BC} < 0)**.

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1.1) BJT Characteristics and Properties (Cont)

1.1.4) Current-voltage Relationships in the Forward-active Region

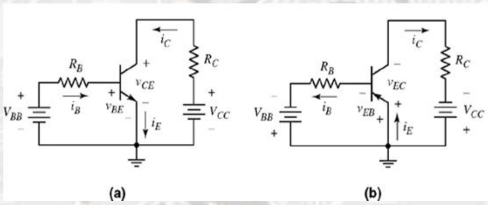

Figure 5.10: **Common-emitter** circuits:
(a) with an **npn** transistor,
and (b) with a **pnp** transistor.

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1.1) BJT Characteristics and Properties (Cont)

Table 5.1: Summary of the bipolar current-voltage relationships in the forward active region

For npn	For pnp
$i_C = I_S e^{v_{BE}/V_T}$	$i_C = I_S e^{v_{EB}/V_T}$
$i_E = \frac{i_C}{\alpha} = \frac{I_S}{\alpha} e^{v_{BE}/V_T}$	$i_E = \frac{i_C}{\alpha} = \frac{I_S}{\alpha} e^{v_{EB}/V_T}$
$i_B = \frac{i_C}{\beta} = \frac{I_S}{\beta} e^{v_{BE}/V_T}$	$i_B = \frac{i_C}{\beta} = \frac{I_S}{\beta} e^{v_{EB}/V_T}$

I_s = Saturation current (strongly dependent on device and temperature)
V_T = Thermal voltage
β = Common-emitter current gain
α = Common-base current gain

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1.1) BJT Characteristics and Properties (Cont)

Table 5.1: Summary of the bipolar current-voltage relationships in the forward active region (Cont)

For both transistors

$$\alpha = \left(\frac{\beta}{1+\beta}\right); \beta = \left(\frac{\alpha}{1-\alpha}\right)$$

$$i_C = \beta i_B$$

$$i_C = \alpha i_E = \left(\frac{\beta}{1+\beta}\right) i_E$$

$$i_E = i_B + i_C = (1+\beta) i_B$$

β = Common-emitter current gain
α = Common-base current gain

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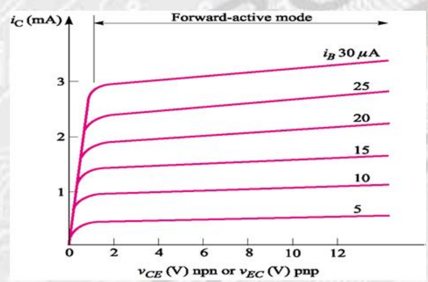
1.1) BJT Characteristics and Properties (Cont)

1.1.5) BJT Operating Curve



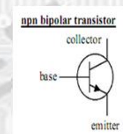


Fig 5.13: Transistor current-voltage characteristics (i_C vs v_{CE}) of the common-emitter circuit

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1.1) BJT Characteristics and Properties (Cont)

1.1.6) Early Effect

For V_{CE} > V_{BE}**(on)**, the output curve has a finite slope due to **base-width modulation** (reduction of effective base width with increasing collector-base reverse bias).

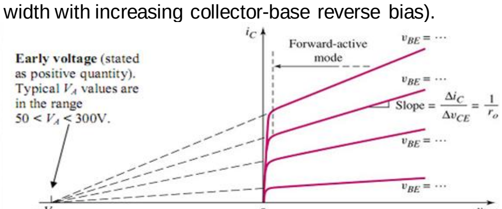

Figure 5.14: Current-voltage characteristics for the common-emitter circuit, showing **Early voltage (V_A)** and finite **output resistance, r_o,** of the transistor.

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1.1) BJT Characteristics and Properties (Cont)

1.1.6) Early Effect (Cont)

This **Early effect** is included in the collector current equation:

$$i_C = I_S e^{v_{BE}/V_T} \Rightarrow i_C = I_S e^{v_{BE}/V_T}\left(1+\frac{v_{CE}}{V_A}\right) \quad (5.16)$$

Output resistance, $$r_o = \left[\frac{\partial i_C}{\partial v_{CE}}\Big|_{v_{BE}=const}\right]^{-1} \cong \frac{V_A}{I_C} \quad (5.17)$$

where I_C = quiescent collector current when v_{BE} is constant and v_{CE} is small compared to V_A.

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1.2) DC Analysis Of Bipolar Transistor Circuits

➔ DC biasing of **linear amplifiers** is required to obtain **forward-active mode** of operation

Step 1	Assume transistor is biased in the forward-active mode, i.e. $V_{BE} = V_{BE}$ (on), $I_B > 0$ and $I_C = \beta I_B$.
Step 2	Analyze the ñlinearò circuit with this assumption. ❑ Perform KVL on B-E (or E-B) loop to find current I_B. ❑ Calculate I_C and I_E from I_B. ❑ Perform KVL on C-E (or E-C) loop to find voltage V_{CE}.

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1.2) DC Analysis Of Bipolar Transistor Circuits (Cont)

➔ DC biasing of **linear amplifiers** is required to obtain **forward-active mode** of operation

Step 3	Evaluate the resulting state of the transistor. If initial assumed parameters and $V_{CE} > V_{CE}$ (sat) are true, then the initial assumption is correct. However, ❑ if $I_B < 0$, then the transistor is probably cut off, and ❑ if $V_{CE} < 0$, the transistor is likely to be biased in saturation.
Step 4	If the initial assumption is proven incorrect, then a new assumption must be made and the new ñlinearò circuit must be analyzed. **Step 3** must then be repeated.

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1.2) DC Analysis Of Bipolar Transistor Circuits (Cont)

Example 5.3: DC Analysis of Common-emitter Circuit

Calculate the base (I_B), collector (I_C), and emitter (I_E) currents and the C-E voltage (V_{CE}) for a common-emitter circuit. (Note: V_{BE} (on) = 0.7V and β = 200)

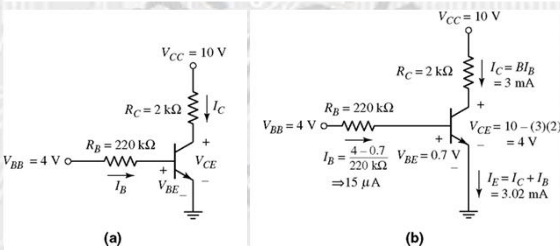

Figure 5.20: Circuit for Example 5.3

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1.3) Transistor As Amplifier

1.3.1) Voltage Transfer Characteristics

Å Output voltage versus input voltage
Å Used to visualise the operation of a circuit or the state of a transistor

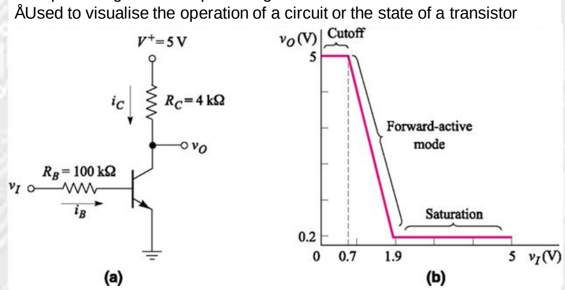

Figure 5.48: (a) A bipolar inverter used as an amplifier; (b) the inverter voltage transfer characteristics

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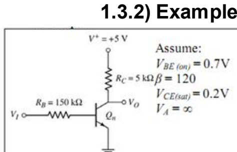
1.3) Transistor As Amplifier (Cont)

1.3.2) Example of DC Analysis of BJT



Assume: $V_{BE(on)} = 0.7V$, $\beta = 120$, $V_{CE(sat)} = 0.2V$, $V_A = \infty$

○ $V_i \le 0.7V$, Q_n = cut off: ⇨ $I_B = I_C = 0$, $V_o = V^+ = 5V$

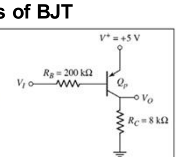
○ $V_i > 0.7V$, Q_n = turned on (forward-active):

$$I_B = \frac{V_i - 0.7}{R_B},\ I_C = \beta I_B = \frac{\beta(V_i - 0.7)}{R_B}$$

and

$$V_o = V^+ - I_C R_C = 5 - \frac{\beta(V_i - 0.7)R_C}{R_B}$$

This eq. is valid for $0.2 \le V_o < 5V$.



Assume: $V_{EB(on)} = 0.7V$, $\beta = 80$, $V_{EC(sat)} = 0.2V$, $V_A = \infty$

○ $4.3 \le V_i \le 5V$, Q_p = cut off: ⇨ $I_B = I_C = 0$, $V_o = 0V$

○ $V_i < 4.3V$, Q_p = turned on (forward-active):

$$I_B = \frac{(5 - 0.7) - V_i}{R_B},\ I_C = \beta I_B = \beta\left[\frac{(5 - 0.7) - V_i}{R_B}\right]$$

and

$$V_o = I_C R_C = \beta R_C\left[\frac{(5 - 0.7) - V_i}{R_B}\right]$$

This eq. is valid for $0 \le V_o < 4.8V$.

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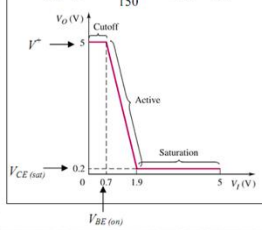
1.3) Transistor As Amplifier (Cont)

1.3.2) Example of DC Analysis of BJT (Cont)

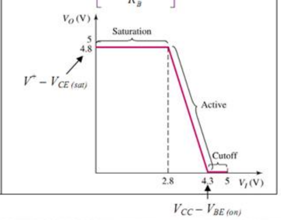
○ When V_o = 0.2V, Q_n goes into saturation and V_i is found from:

$$0.2 = 5 - \frac{120(V_i - 0.7)5}{150} \Rightarrow V_i = 1.9V$$



○ When V_o = 4.8V, Q_p goes into saturation and V_i is found from:

$$4.8 = (80)(8)\left[\frac{(5 - 0.7) - V_i}{R_B}\right] \Rightarrow V_i = 2.8V$$



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1.4) AC Analysis Of Bipolar Transistor Circuits

ÅA BJT linear **amplifier** magnifies an ac input signal and produces an output signal that is larger in magnitude and directly proportional to the input. Therefore, ac analysis of transistor circuits is required.

Å**Superposition theory** applies, i.e. perform dc and ac analysis separately.

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1.4) AC Analysis Of Bipolar Transistor Circuits (Cont)

Step 1	Analyze the circuit with only dc sources present. This will give the dc or quiescent solution. The transistor must be biased in the **forward-active region** in order to produce a linear amplifier.
Step 2	Replace each element in the circuit with its small-signal model. **The small-signal hybrid-π model** applies for the transistor. **To draw the small-signal model of the amplifier circuit:** ❑ **Start with the three terminals of the transistor.** ❑ **Then sketch the hybrid-π equivalent circuit between these terminals.** ❑ **Connect the small-signal model of the remaining circuit elements to the transistor terminals.**
Step 3	**Analyze the small-signal equivalent circuit, setting the dc source components equal to zero, to produce the response of the circuit to time-varying input signals only.**

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1.4) AC Analysis Of Bipolar Transistor Circuits (Cont)

1.4.1) Small-signal Hybrid-π Equivalent Circuit of npn BJT

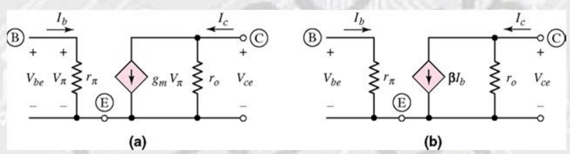

Figure 6.13: Expanded small-signal model of the **npn BJT**, including the **Early effect** when the circuit contains the **(a) voltage controlled** current source (transconductance) and **(b) current controlled** current source (current gain parameters)

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1.4) AC Analysis Of Bipolar Transistor Circuits (Cont)

1.4.2) Small-signal Hybrid-π Equivalent Circuit of pnp BJT

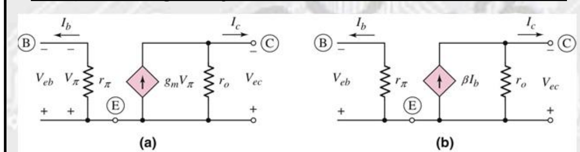

Figure 6.15: Expanded small-signal model of the **pnp BJT**, including the **Early effect** when the circuit contains the **(a) voltage controlled** current source (transconductance) and **(b) current controlled** current source (current gain parameters)

Note: The small-signal model of the **pnp BJT** is the same as in **Fig 6.13** but with all ac **voltage polarities and current directions reversed**.

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1.4) AC Analysis Of Bipolar Transistor Circuits (Cont)

1.4.3) Small-signal Hybrid-π Equivalent Circuit of BJT (Cont)

Å AC common-emitter current gain:	$\beta = \left[\frac{\partial i_C}{\partial i_B}\Big|_{Q-pt}\right] = g_m r_\pi$
ÅTransconductance:	$g_m = \left[\frac{\partial i_C}{\partial v_{BE}}\Big|_{Q-pt}\right] = \frac{I_{CQ}}{V_T}$
ÅDiffusion resistance:	$r_\pi = \left[\frac{\partial i_B}{\partial v_{BE}}\Big|_{Q-pt}\right]^{-1} = \frac{\beta V_T}{I_{CQ}}$
ÅSmall-signal transistor output resistance:	$r_o = \left[\frac{\partial i_C}{\partial v_{CE}}\Big|_{Q-pt}\right]^{-1} = \frac{V_A}{I_{CQ}}$

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1.4) AC Analysis Of Bipolar Transistor Circuits (Cont)

YOU NEED TO MEMORIZE THESE FORMULA

ÅAC common-emitter current gain: $\beta = g_m r_\pi$

ÅTransconductance: $g_m = \frac{I_{CQ}}{V_T}$

ÅDiffusion resistance: $r_\pi = \frac{\beta V_T}{I_{CQ}}$

ÅSmall-signal output resistance: $r_o = \frac{V_A}{I_{CQ}}$

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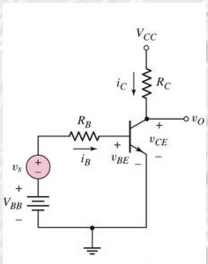
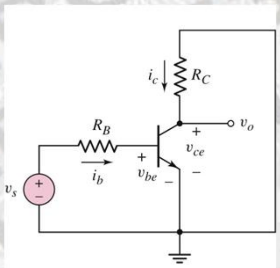
1.4) AC Analysis Of Bipolar Transistor Circuits (Cont)

1.4.4) Common-Emitter (C-E) with Time-Varying Input



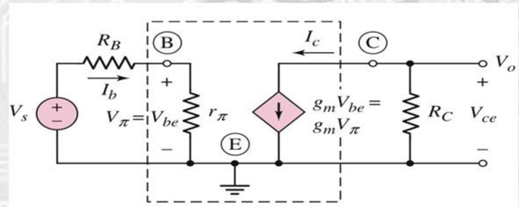
An npn C-E circuit



AC Equivalent Circuit for npn C-E circuit

1.4) AC Analysis Of Bipolar Transistor Circuits (Cont)

1.4.4) Common-Emitter (C-E) with Time-Varying Input (Cont)



Small-signal Equivalent Circuit for npn C-E circuit. Assume $V_A = \infty$, therefore $r_o = \infty$ also.

➔ Voltage Gain, $A_v = -(g_m R_C)(\frac{r_\pi}{r_\pi + R_B})$

1.5) Basic Single Stage BJT Amplifiers

1.5.1) Basic Common-Emitter (C-E) Amplifier Circuit

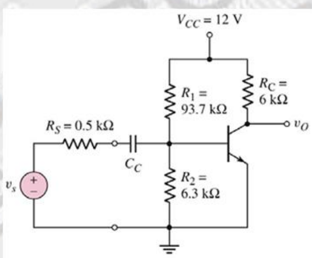
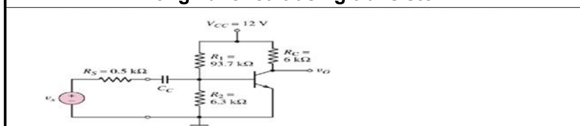


Figure 6.26: A C-E circuit with a voltage-divider biasing circuit and a coupling capacitor.

VERY IMPORTANT TO KNOW!

Steps of getting small-signal equivalent circuit from the original circuit using transistor

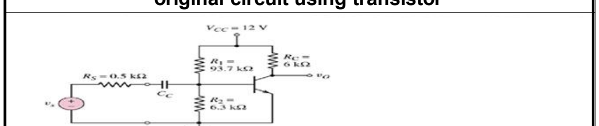


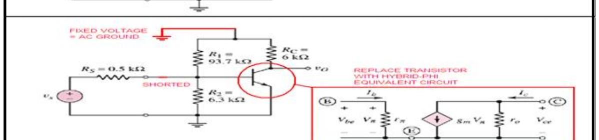
Step 1: From the original circuit:
- **Replace a fixed-voltage with a signal ground (AC GND)**
- **Replace a capacitor with a short circuit**
- **Replace an inductor with an open circuit**

Step 2: Replace a transistor with its small-signal equivalent circuit (for EEEB273 we will use hybrid-π equivalent circuit)

VERY IMPORTANT TO KNOW!

Steps of getting small-signal equivalent circuit from the original circuit using transistor

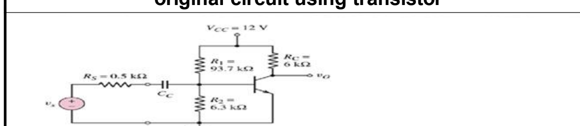


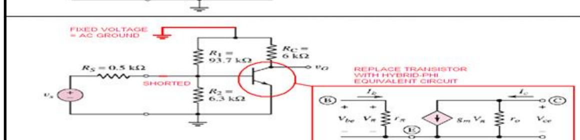


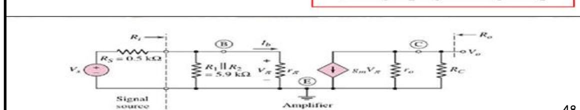
Step 3: Rearrange and reduce (or simplify) the circuit for further analysis.

VERY IMPORTANT TO KNOW!

Steps of getting small-signal equivalent circuit from the original circuit using transistor







1.5) Basic Single Stage BJT Amplifiers (Cont)

1.5.1) Basic Common-Emitter (C-E) Amplifier Circuit (Cont)

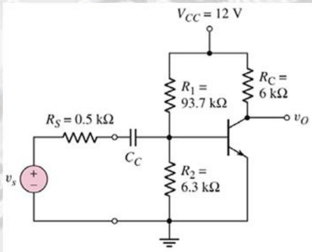


Figure 6.26: A C-E circuit with a voltage-divider biasing circuit and a coupling capacitor.

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1.5) Basic Single Stage BJT Amplifiers (Cont)

1.5.1) Basic Common-Emitter (C-E) Amplifier Circuit (Cont)

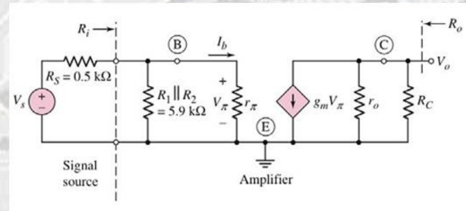

Figure 6.27: The C-E **small-signal equivalent circuit**, assuming the coupling capacitor is a short circuit.

50

1.5) Basic Single Stage BJT Amplifiers (Cont)

1.5.2) Common-Emitter (C-E) Amplifier with Emitter Resistor

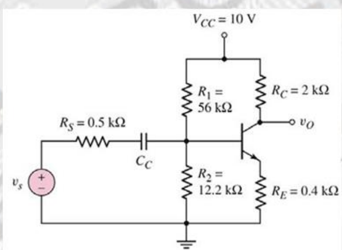

Figure 6.28: A C-E circuit with an emitter resistor, a voltage-divider biasing circuit and a coupling capacitor.

51

1.5) Basic Single Stage BJT Amplifiers (Cont)

1.5.2) C-E Amplifier with Emitter Resistor (Cont)

Assume: $V_A = \infty$. Therefore $r_o = \infty$ (an open circuit).

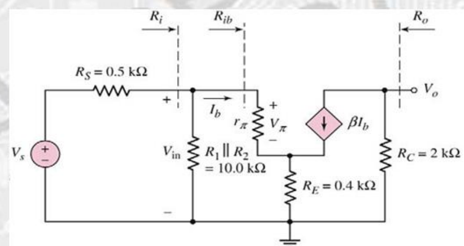

Figure 6.29: The small-signal equivalent circuit with an emitter resistor.

52

1.5) Basic Single Stage BJT Amplifiers (Cont)

1.5.2) C-E Amplifier with Emitter Resistor (Cont)

Assume: V_A = Ð. Therefore r_o = Ð (an open circuit).

$$V_{in} = I_b r_\pi + (I_b + \beta I_b) R_E$$

$$R_{ib} = \frac{V_{in}}{I_b} = r_\pi + (1+\beta) R_E$$

➔In the C-E configuration that includes an emitter resistance R_E, the small-signal input resistance looking into the base of the transistor (R_{ib}) is r_π plus the emitter resistance R_E multiplied by the factor (**$1 + \beta$**). This effect is called the **Resistance Reflection Rule**.

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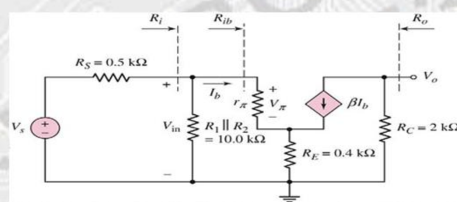
1.5) Basic Single Stage BJT Amplifiers (Cont)

1.5.2) C-E Amplifier with Emitter Resistor (Cont)



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

$$R_i = R_1 \| R_2 \| R_{ib}$$

$$A_v = \frac{-\beta R_C}{r_\pi + (1+\beta) R_E} \left(\frac{R_i}{R_i + R_S} \right)$$

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1.5) Basic Single Stage BJT Amplifiers (Cont)

1.5.3) Common-Collector (C-C) Amplifier a.k.a Emitter Follower

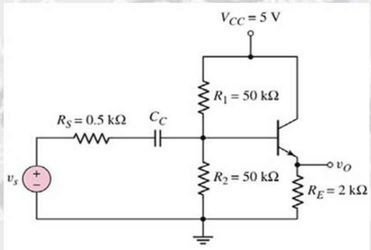


Figure 6.49: An Emitter Follower circuit.

Emitter Follower is a very important circuit for Output Stage!

55

1.5) Basic Single Stage BJT Amplifiers (Cont)

1.5.3) Common-Collector (C-C) Amplifier a.k.a Emitter Follower (Cont)

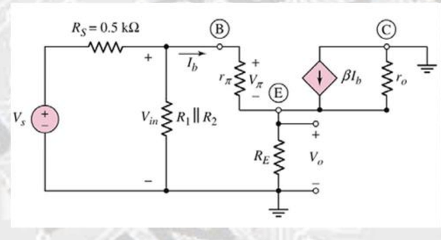


Figure 6.50: Small-signal equivalent circuit of the Emitter Follower.

56

1.5) Basic Single Stage BJT Amplifiers (Cont)

1.5.3) Common-Collector (C-C) Amplifier a.k.a Emitter Follower (Cont)

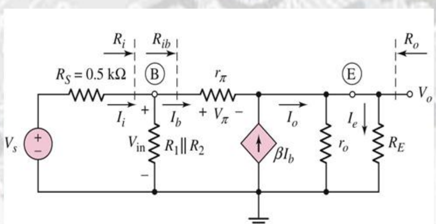


Figure 6.51: All signal grounds connected together.

$$A_v = \frac{(1+\beta)(r_o \| R_E)}{r_\pi + (1+\beta)(r_o \| R_E)}\left(\frac{R_i}{R_i + R_S}\right)$$

57

1.5) Basic Single Stage BJT Amplifiers (Cont)

1.5.4) Common-Base (C-B) Amplifier

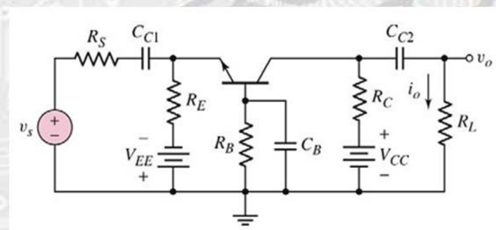


Figure 6.59: Basic Common-Base circuit.

58

1.5) Basic Single Stage BJT Amplifiers (Cont)

1.5.4) Common-Base (C-B) Amplifier (Cont)

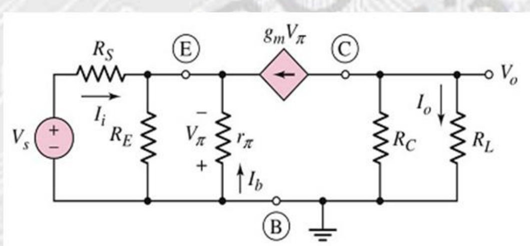


Figure 6.60(b): Small-signal equivalent circuit of the Common-Base circuit.

59

1.5) Basic Single Stage BJT Amplifiers (Cont)

1.5.5) Characteristics of the three BJT Amplifier configurations

Configuration	Voltage gain, *Av*	Current gain, *Ai*	Input Resistance, *Ri*	Output Resistance, *Ro*	Application
Common-Emitter (C-E)	High, *Av* > 1	High, *Ai* > 1	Moderate	Moderate to high	Power amplifier
Common-Collector (C-C)	**Unity, *Av* ≈ 1**	High, *Ai* > 1	High	**Low**	Voltage buffer
Common-Base (C-B)	High, *Av* > 1	Unity, *Ai* å 1	Low	Moderate to high	Current buffer

Table 6.4

60

1.6) Introduction to a multistage amplifier

ÅIn most applications, a single-transistor amplifier (single stage) 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 that which can be obtained in a single stage circuit.

ÅTransistor amplifier circuits can be connected in series, or **cascaded**, as shown in **Figure 6.65**. This may be done, **for example**, to increase the overall small-signal voltage gain or to **provide an overall voltage gain (*Av*) greater than 1, with a very low output resistance (*Ro*)**.

61

1.6) Introduction to a multistage amplifier (Cont)

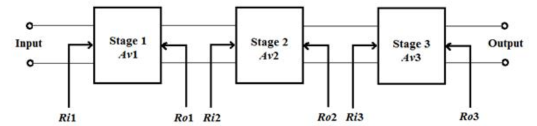
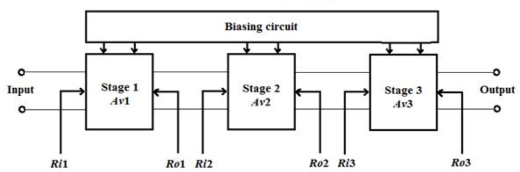


Figure 6.65: A generalized three-stage amplifier

ÅThe overall voltage or current gain, in general, is simply the product of the individual amplification factors. The gain of **Stage 1** is a function of the input resistance of **Stage 2**, etc. Thus, **loading effect** may have to be taken into account in gain calculations.

62

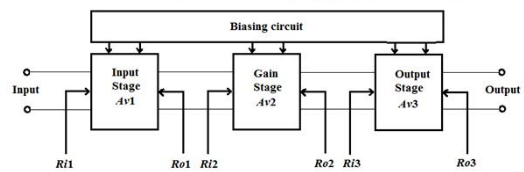
1.6) Introduction to a multistage amplifier (Cont)



ÅUsually every stage in the multistage amplifier needs to be biased correctly, as shown in the figure above. In an integrated circuit (**IC**) design, for example in an **op-amp 741 IC**, the biasing is implemented using **constant current source**.

63

1.6) Introduction to a multistage amplifier (Cont)



ÅTo be more specific, every stage is given a specific name to reflect its function, such as Stage 1 is called **Input Stage**, Stage 2 becomes **Gain Stage**, and Stage 3 is named as **Output Stage**.

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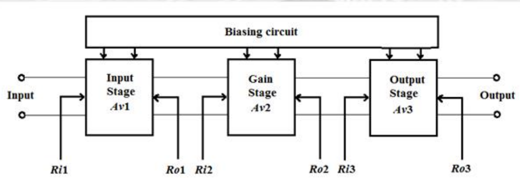
1.7) Useful Equations for Resistance Calculations

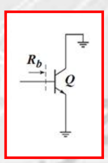


ÅCalculation of **loading effect** (to determine ***Ri*** and ***Ro***) of the next stage to the gain for the previous stage may require implementation of **Resistance Reflection Rule** for the transistor used in the circuit. Equivalent resistance value depends on how it is seen from a particular transistorÕs terminal.

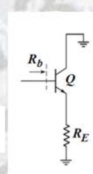
65

1.7) Useful Equations for Resistance Calculations (Cont)

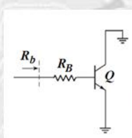
1.7.1) Finding equivalent resistance seen from Base, R_b



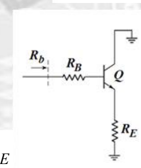
$$R_b = r_\pi$$



$$R_b = r_\pi + (1+\beta)R_E$$



$$R_b = R_B + r_\pi$$

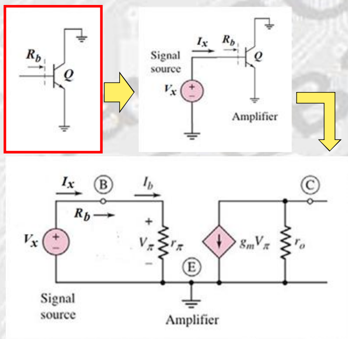


$$R_b = R_B + r_\pi + (1+\beta)R_E$$

66

Example of using Resistance Reflection Rule

Finding equivalent resistance seen from Base, R_b



Define: $R_b = \frac{V_x}{I_x}$

From circuit:

$V_x - V_\pi = 0$

$V_x - I_x r_\pi = 0$

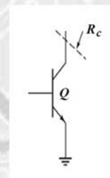
$\frac{V_x}{I_x} = r_\pi$

Thus, $R_b = r_\pi$

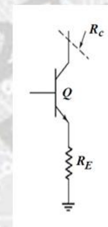
67

1.7) Useful Equations for Resistance Calculations (Cont)

1.7.2) Finding equivalent resistance seen from Collector, R_c



$R_c = r_o$

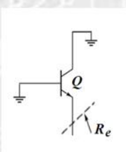


$R_c = r_o\left[1 + g_m\left(r_\pi \| R_E\right)\right]$

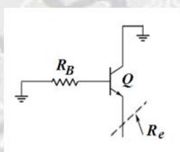
68

1.7) Useful Equations for Resistance Calculations (Cont)

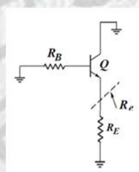
1.7.3) Finding equivalent resistance seen from Emitter, R_e



$R_e = \frac{r_\pi}{(1+\beta)}$



$R_e = \frac{r_\pi + R_B}{(1+\beta)}$

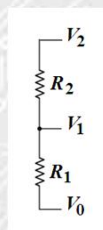


$R_e = R_E \| \frac{r_\pi + R_B}{(1+\beta)}$

69

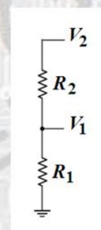
1.7) Useful Equations for Resistance Calculations (Cont)

1.7.4) Voltage Divider (or Potentiometer)



$\frac{V_1 - V_0}{R_1} = \frac{V_2 - V_0}{R_1 + R_2}$

$V_1 = \frac{R_1}{R_1 + R_2}(V_2 - V_0) + V_0$



$V_1 = \frac{R_1}{R_1 + R_2}(V_2 - 0) + 0 = \frac{R_1}{R_1 + R_2} V_2$

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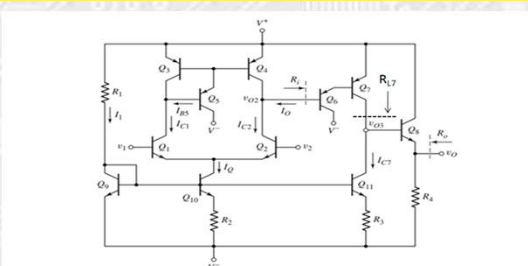
Past Question: A multistage amplifier!



(ii) Assuming that for all transistors: r_o = 500 kΩ, g_m = 5 mA/V, r_π = 3 kΩ, R_3 = 250 Ω, and R_4 =10 kΩ. For Q_7, the Early voltage V_A is assumed to be infinite. **Calculate the small signal input impedance** at the collector of Q_7, i.e. R_{L7} as indicated in the **Figure 3b**. [5 marks]

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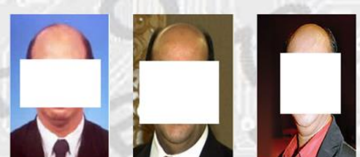
Introducing → LAMIRA

Learn

Analyze

Memorize

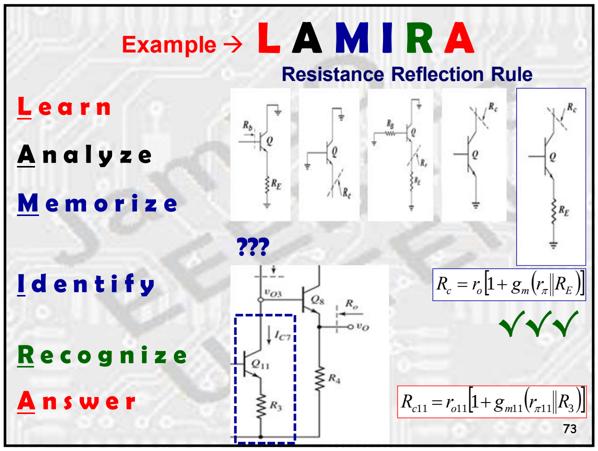


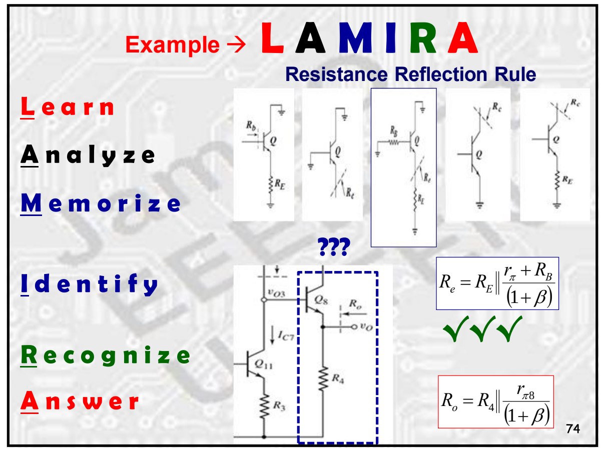
Identify

Recognize

Answer

72


Example → LAMIRA
Resistance Reflection Rule
Learn
Analyze
Memorize
???
Identify
Recognize
Answer
$R_c = r_o\left[1 + g_m\left(r_\pi \| R_E\right)\right]$
$R_{c11} = r_{o11}\left[1 + g_{m11}\left(r_{\pi 11} \| R_3\right)\right]$
73


Example → LAMIRA
Resistance Reflection Rule
Learn
Analyze
Memorize
???
Identify
Recognize
Answer
$R_e = R_E \| \frac{r_\pi + R_B}{(1+\beta)}$
$R_o = R_4 \| \frac{r_{\pi 8}}{(1+\beta)}$
74