CHAPTER 5

BIST MODELING

SMALL SIGNAL RESPONSE

Re-Model

hybrid equivalent

\[ P_e < P_{in} \]

\[ \text{efficiency } N = \frac{P_{o\,ac}}{P_{L\,dc}} \]

where

\[ P_{dc} = \text{DC Power in} \]

\[ P_{o\,ac} = \text{ac power to the load} \]

use superposition \( ac + dc \)

\[ i \quad i_{ac} \quad \quad I_{dc} \]

MODEL—COMBINATION OF CIRCUIT ELEMENTS THAT BEST APPROXIMATES ACTUAL BEHAVIOR OF A SEMICONDUCTOR DEVICE UNDER SPECIFIC CONDITIONS
Figure 7.3 TRANSISTOR CIRCUIT UNDER EXAMINATION IN THIS Introductory Discussion.

Figure 7.4 THE NETWORK OF FIG. 7.3 FOLLOWING REMOVAL OF THE DC SUPPLY AND INSERTION OF THE SHORT-CIRCUIT EQUIVALENT FOR THE CAPACITORS.
Figure 7.5 Circuit of Fig. 7.4 redrawn for small-signal AC analysis.
**INPUT IMPEDANCE, \( Z_i \)**

\[
Z_i = \frac{V_i}{I_i}
\]

\( Z_i \) of a BJT is purely resistive - few ohms \( \leq Z_i \leq \) few Ms.

**DC BIASING CONDITIONS CAN APPROXIMATE \( Z_i \)**

For \( f \leq 100 \text{KHz (Typ)} \)

\[
\begin{align*}
I_i & \rightarrow \\
V_i & \Rightarrow V_i \\
Z_i & \\
\end{align*}
\]

\[
I_i = \frac{V_s - V_i}{R_{\text{sense}}}
\]

\[
Z_i = \frac{V_i}{I_i}
\]

**EX**

\[
\begin{align*}
V_i & \rightarrow \\
I_i & \Rightarrow \\
600 \Omega & R_{\text{sense}} \\
10 \text{mV} & Z_i = 1.2 \text{K}\Omega \\
\text{Amp} & \\
\end{align*}
\]

Using voltage divider rule:

\[
V_i = V_i \frac{Z_i}{Z_i + R_{\text{sense}}}
\]

\[
V_i = 1.2 \text{K}\Omega \frac{10 \text{mV}}{1.2 \text{K}\Omega + 600 \Omega} = 6.67 \text{mV}
\]
Output Impedance \( Z_0 \)

Output impedance - IMPEDANCE @ THE OUTPUT
LOOKING INTO THE SYSTEM WITH APPLIED INPUT SIGNAL SET TO ZERO

\[ R_{\text{source}} \rightarrow \text{TWO-PORT SYSTEM} \rightarrow + \xrightarrow{I_0} V_o \xrightarrow{Z_0} V \]

For \( f \leq 100 \text{kHz} \), \( Z_0 \) purely resistive in nature
few \( \text{\ohms} \leq Z_0 \leq \text{\ohms} \text{\max} \) (or greater)

\[ R_0 = Z_0 \]
\[ I_{\text{R0}} \]
\[ I_L \]

For \( R_0 \gg R_L \)
\( I_L \gg I_{\text{R0}} \)

For significant current gain

\( Z_0 \) frequently \( \gg R_L \) i.e., \( Z_0 \) replaced with 'open circuit'

Ex - \( Z_0 = ? \)

\[ R_{\text{sense}} = 20 \text{\kilo\ohms} \]
\[ + \xrightarrow{I_0} V_o = 680 \text{mV} \]
\[ V = 1V \]

\[ I_0 = \frac{V - V_o}{Z_0} = 16 \text{mA} \]

\[ Z_0 = \frac{V_o}{I_0} = 42.5 \text{\kilo\ohms} \]
Voltage Gain, $A_V$

\[ A_V = \frac{V_o}{V_i} \]

No load voltage gain
\[ A_{\text{VNL}} > A_V \]

Using VDR, \[ \frac{V_i}{V_s} = \frac{Z_i}{Z_i + R_{\text{source}}} \]

\[ A_{\text{VNL}} = \frac{V_o}{V_s} = \frac{V_o}{V_i} \cdot \frac{V_i}{V_s} = \frac{Z_i}{Z_i + R_{\text{source}}} \]

Single-stage loaded amplifier

less than 1 \leq A_{\text{VNL}} \leq \text{Few hundred}
**CURRENT GAIN A_i**

\[ A_i = \frac{I_o}{I_i} \]

\[ \approx 1 < A_i < 100 \]

**Loaded Condition**

\[ I_L = \frac{V_i}{Z_i} \]

\[ I_o = -\frac{V_o}{R_L} \]

\[ A_i = \frac{I_o}{I_i} = -\frac{V_o/R_L}{V_i/Z_i} = -\frac{V_o}{V_i} \frac{Z_i}{R_L} \]

\[ A_i = AV \frac{Z_i}{R_L} \]

**Phase**

Input & Output for BJT Amp.

Usually in phase or 180° out of phase (ignoring reactive elements)
Re Transistor Model

Comprised of Diode & Controlled Current Source

BJT Amplifier is a Current- Controlled Device.

Common Base Configuration Fig 7.16

Using a PNP Transistor, a model replaces the Transistor - approximates the behaviour at an operating region.

A Diode-Equivalent Model replaces the 'BE' Junction

Emitter $\rightarrow$ Base

A Current- Controlled Current Source replaces B-C JUNCTION

$B \rightarrow$ $O_C$

$I_C = \alpha I_E$

For the range of values of $V_{CE}$
Figure 7.16 (a) Common-base BJT transistor; (b) $r_e$ model for the configuration of Fig. 7.16a.

Figure 7.17 Common-base $r_e$ equivalent circuit.
The ac resistance of a diode is

\[ V_{ac} = \frac{2.6 \text{ mV}}{I_e} = R_e \]

\( R_e \) used because the DC level of \( I_e \) determines \( V_{ac} \).

Figure 7.16 (b) can be rewritten as Figure 7.17.

**Input Impedance** (Common Base)

\[ Z_i = R_e \]

\( \Rightarrow \)

\[ V_o \]

\( 50 > Z_i > \) few ohms

**Output Impedance** \( Z_o \)

Setting the signal to 0, \( I_e = 0 \), \( I_c = 0 \), open circuit

\[ Z_o \approx \infty \Omega \]

Graphically

\[ \Delta V_{cb} \]

\[ \Delta I_c \]

\( Z_o \) (measure)

Typically 1-2 mA
Common Base

Input Impedance $Z_i$ Small
Output Impedance $Z_o$ High

$\alpha I_e R_L \quad V_{cb} = V_0 \quad V_0 = -I_o R_L$

$= +I_c R_L \quad V_0 = +\alpha I_e R_L$

$V_i = I_e R_e$

$A_V = \frac{V_o}{V_i} = \frac{\alpha I_e R_L}{I_e R_e}$

$A_i = \frac{I_o}{I_i} = \frac{-\alpha I_e}{I_e} = \alpha \Rightarrow -1 = A_i$

NPN

Common Base
Common Emitter Configuration

Fig 7.21

\[ I_e \approx \beta I_B \quad \text{`be' junction} \]

`be' junction is DIODE

\[
\begin{bmatrix}
I_c = \beta I_B \\
I_e = (\beta+1) I_B
\end{bmatrix}
\]

\[ Z_i = \frac{V_i}{I_i} = \frac{V_{be}}{I_b} \]

\[ V_{be} = I_e r_e \approx \beta I_b r_e \]

by subst

\[ Z_i = \beta r_e \quad \text{CE} \]

6-7 kΩ range

\[ Z_0 = \Gamma_0 \]

Ignored in \( \Gamma_e \) model
Figure 7.21 (A) COMMON-EMITTER BJT TRANSISTOR;
(B) APPROXIMATE MODEL FOR THE CONFIGURATION
OF FIG. 7.21A.

Figure 7.22 DETERMINING $Z_i$ USING THE APPROXIMATE MODEL.

Figure 7.27 $r_e$ MODEL FOR THE COMMON-EMITTER TRANSISTOR
CONFIGURATION.
**Voltage Gain Common Emitter**

\[ V_i = I_b (\beta r_e) \]

\[ V_o = -I_o R_L = -\beta I_b R_L = V_o \]

\[ A_v = \frac{V_o}{V_i} = \frac{-I_o \beta R_L}{I_b \beta r_e} = \frac{-R_L}{r_e} = A_v \]

For \( r_o = \infty \)

**Current Gain**

\[ A_i = \frac{I_o}{I_i} = \frac{\beta I_b}{I_b} = \beta = A_i \]

For \( r_o = \infty \)

**Common Collector**

Use common emitter model
EXAMPLE OF COMMON Emitter (IE model)

\[ GIVEN \]
\[ \beta = 120 \]
\[ I_E = 3.2 \text{ mA} \]
\[ r_o = \infty \Omega \]

1. \[ Z_i = \frac{V_i}{I_i} \]
\[ r_e = \frac{V_e}{I_e} = \frac{26 \text{ mV}}{3.2 \text{ mA}} = 8.125 \Omega \]
\[ Z_i = \beta r_e = 120(8.125 \Omega) = 975 \Omega \]

2. \[ A_v \text{ for } R_L = 2 \text{ k}\Omega \]
3. \[ \frac{V_o}{V_i} = -\frac{\beta I_E R_L}{I_E r_e} = -\frac{R_L}{r_e} = -\frac{2 \text{ k}\Omega}{8.125 \Omega} = -246.15 \]

4. \[ A_i \text{ with } 2 \text{ k}\Omega \text{ load} \]
\[ A_i = \frac{I_o}{I_i} = \beta = 120 \]