Week 2, Lectures 3-5, February 22-26, 2001

EECS 105 Microelectronics Devices and Circuits, Spring 2001

Andrew R. Neureuther

Topics: Practice Loop and Node Eqns., Two-Ports, Silicon Physics – Carriers, Process Flow and Layout, Sheet Resistance, Squares

Reading for week: (review of EE 40), HS 8.2.2, 9.1, 2.1-2.4, 2.5.4-2.6, 4.1.1, 4.5.7, 6.2, 7.1.1, 7.7,
Outline: Week 2 Lectures 3-5

L3: More Basic Circuits (HS 8.2.2, 9.1)
   Loop and Node Equations, Two-Ports
L4: Silicon Physics (HS 2.1-2.4, 2.5.4, 4.1.1, 5.4.7, 6.2, 7.1.1, 7.1)
   Carriers, Process Flow and Layout
L5: IC Resistors (HS 2.6)
   Sheet resistance and Number of Squares
Lecture 3, February 22, 2001

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Topics:
Practice Circuit Analysis,
Two-Ports

Reading: (review of EE 40), HS 8.2.2, 9.1
W2 M L3 : More Basic Circuits

- Practice circuit analysis
  - \( R_{IN} \) with \( R_E \)
  - Gain or Rout with \( R_E \)
- Standard Two-ports
- Difficulty of two-ports with output coupled back to input
High Input Impedance Circuit

\[ R_E = 30 \text{k}\Omega \quad R_{IN\,EQ} = R_{IN} + (\beta + 1)R_E = 3.06 \text{M}\Omega \]

23.5 times less current

\[ \Delta V'_{S} \]

\[ V_{OUT} = \left[ \frac{\Delta V'_{S}}{(R_S + R_{SA} + R_{IN\,EQ})} \right](-\beta)R_{LOAD} = 5 \text{mV} \]

\[ \Sigma V_i = 0 \Rightarrow i_{IN} \]

23.5 times smaller gain

Note ground connections

Analog Integrated Circuits

Overview and Circuit Value Added
High Input Impedance Circuit

\[ V_{\text{OUT}} = \frac{\Delta V_S'}{(R_S + R_{SA} + R_{\text{IN EQ}})}(\beta)R_{\text{LOAD}} \]

Result:

How is the circuit analysis done?
Write a Node Equation for $I_E$

\[ \Delta V_S + \Delta Q = I_E R_S \]

Node

\[ I_E = \beta i_{IN} \]

\[ R_{OUT} = \text{infinite} \]
Write a Loop Equation for $I_{IN}$

$$\Delta V_S$$

$\Delta Q$

Loop

$$R_{OUT} = \text{infinite}$$
Find $V_{OUT}/ \Delta V'_S$

$$V_{OUT}/ \Delta V'_S = \left[\frac{1}{R_S + R_{SA} + R_{IN_{EQ}}}\right](-\beta)R_{LOAD}$$
Analysis of Multistages

Node

Node

Loop
Background on Two-Ports

- Designed for cascading components
  - Hi-Fi components
  - IC stages of amplifier circuit
- Based on Matrix Multiplication

\[
\begin{align*}
V_1 &= Z_{11}I_1 + Z_{12}I_2 \\
V_2 &= Z_{21}I_1 + Z_{22}I_2 \\
I_1 &= Y_{11}V_1 + Y_{12}V_2 \\
I_2 &= Y_{21}V_1 + Y_{22}V_2 \\
V_1 &= H_{11}I_1 + H_{12}V_2 \\
I_2 &= H_{21}I_1 + H_{22}V_2
\end{align*}
\]

Impedance (transresistance)  Admittance (transconductance)  Hybrid_1 (current 1-2)
Two-Port Equivalent Circuits

\[ V_1 = Z_{11}I_1 + Z_{12}I_2 \]
\[ V_2 = Z_{21}I_1 + Z_{22}I_2 \]

**Two Thevenin**  
(transresistance)

\[ I_1 = Y_{11}V_1 + Y_{12}V_2 \]
\[ I_2 = Y_{21}V_1 + Y_{22}V_2 \]

**Two Norton**  
(transconductance)

\[ V_1 = H_{11}I_1 + H_{12}V_2 \]
\[ I_2 = H_{21}I_1 + H_{22}V_2 \]
Finding the Two-Port Parameters

\[ V_1 = H_{11} I_1 + H_{12} V_2 \]
\[ I_2 = H_{21} I_1 + H_{22} V_2 \]

\( H_{11} \) is found by taking \( V_1 \) over \( I_1 \) when \( V_2 \) is zero.

\( H_{12} \) is found by taking \( V_1 \) over \( V_2 \) when \( I_1 \) is zero.

**Note:** The conditions to determine each matrix element arise from the terminal variables multiplying the right hand side.
Hybrid Two-Port for a Resistor

\[ V_1 = H_{11} I_1 + H_{12} V_2 \]

\[ I_2 = H_{21} I_1 + H_{22} V_2 \]

\[ V_2 = 0: \]

\[ V_1 = H_{11} I_1 = R_{SA} I_1 \]

\[ H_{11} = R_{SA} \]

\[ I_2 = H_{21} I_1 = -I_1 \]

\[ H_{21} = -1 \]

\[ V_1 = H_{12} V_2 = +1 V_2 \]

\[ H_{12} = +1 \]

\[ I_2 = H_{22} V_2 = 0 V_2 \]

\[ H_{22} = 0 \]

Analog Integrated Circuits

Overview and Circuit Value Added
Find $H_{11}$ with $R_E$ and $R_{OUT}$

\[ V_1 = H_{11} I_1 + H_{12} V_2 \]
\[ I_2 = H_{21} I_1 + H_{22} V_2 \]

\[ V_X = (\beta + 1) \frac{i_{IN}}{1/R_S + 1/R_{OUT}} \]
\[ V_{IN} = i_{IN} R_{IN} + V_X \]
\[ V_2 = 0: \]
\[ R_{OUT} \text{ in } || \text{ with } R_E \]

Node Eq. For $V_X$

\[ i_{IN} - \frac{V_X}{R_S} - \frac{V_X}{R_{OUT}} + \beta i_{IN} = 0 \]

Note: $R_{IN}$ depends on $R_{OUT}$ when the output feeds back to the input.
Find $H_{12}$ with $R_E$ and $R_{OUT}$

Voltage $V_2$ is divided across $R_{OUT}$ and $R_E$

$I_1 = 0$:

$i_{IN} = 0$

$V_1 = V_x$

$V_1 = H_{11}I_1 + H_{12}V_2$

$I_2 = H_{21}I_1 + H_{22}V_2$

$b_{IN}$

Note: The voltage source in the input port is not zero when $R_E$ is not zero.
Multistage Amplifiers

This example from the reading in Chapter 8 this week.
Classification of Two-Port Amplifiers

Voltage Amplifier

Current Amplifier

Transconductance Amplifier

Transresistance Amplifier

Figure 8.2

Analog Integrated Circuits Overview and Circuit Value Added