IC implementations

- So far, we talked mostly about discrete circuits...
- In IC:
  - Very rare use of capacitors, inductors practically never (only in some RF circuits)
  - you typically do not have resistors > several K Ohm,
  - the larger resistance, the more expensive it is,
  - a resistor is much more expensive than a bunch of transistors!

\[
\begin{align*}
9V & \quad 10k\Omega & \quad 9V \\
100k\Omega & \quad 270k\Omega \\
3.3V & \\
\end{align*}
\]
Opamps

- Previously we looked at the **block-level** internal structure of an operational amplifier.
- We are now starting to look at the transistor level implementations of these blocks.
- What sort of amplifier circuits would you propose for the blocks below based on what you’ve seen so far?

![Diagram of Opamp Blocks](image)

- $G_m$ (Differential Input Trans-conductance Amplifier)
- $-\mu$ (Voltage Amplifier)
- $+1$ (Unity-Gain Buffer)

$C$ (compensation capacitor)

$v_{id}$

$+1$

$2$

$1$

$v_o$
Opamps

- We macromodeled these blocks in the following way:

\[ v_1 + \frac{1}{C} \]

\[ R_{o1} \]

\[ G_m v_{id} \]

\[ v_{i2} \]

\[ -\mu v_{i2} \]

\[ R_{i2} \]

\[ v_o \]

- What do the R’s represent?
IC implementations

• There is one more thing you have when you design IC:

Device Matching

For example:

- electrical parameters of device 0.1 %
- temperature of operation of many devices can be almost the same.

• This would be to some extent possible, but veeeeeeeeeeeeeery expensive in discrete design
Basic Differential Amplifier

- Emitter voltage becomes whatever value is necessary so that forward active transistor currents sum to current source value, I
Basic Differential Amplifier

- You can express input signal in more convenient terms:

common mode signal:

differential mode signal:

then:
Basic Differential Amplifier

- Differential output rejects **common mode** inputs
Differential Amplifier: Qualitative View (1)

- Think about seesaw...

\[ \text{VCC} \quad R_C \quad \text{VCC} \]

\[ v_{\text{CM}} \quad v_{\text{C}1} \quad v_{\text{C}2} \]

\[ -v_{\text{D}} /2 \quad v_{\text{E}} \quad i_{E1} \quad v_{\text{D}} /2 \]

\[ v_{\text{B}1} \quad v_{\text{E}} \quad v_{\text{B}2} \]

- Is \( v_{\text{E}} \) constant for a given value of \( v_{\text{CM}} \) and varying \( v_{\text{D}} \)?
Differential Amplifier: Qualitative View (2)

- Is $v_E$ constant for a given value of $v_{CM}$ and varying $v_D$?
Mismatch of elements

- Differential output rejects common mode inputs, but what if T1 and T2 are not identical or “$R_c$ in not identical to $R_c$”?
What if we have only single ended output?

- Using transistors as loads we can do some tricks not to lose gain for asymmetric output - you will see this later.
ECL

- Basic component of an *emitter-coupled logic* (ECL) gate

![ECL Circuit Diagram](image-url)
Switch Example

- **VCC**: 10V
- **RC1**: 10E3 Ω
- **IC1**: 967.584 µA
- **RC2**: 10E3 Ω
- **IC2**: 19.775 pA
- **Vin**: 1000.000 mV
- **VO1**: 324.164 mV
- **VO2**: 10.000 V
- **Vref**: 1E-3 A
- **Vee**: -10V

**Symbols**:
- **+** positive terminal
- **-** negative terminal
dc Characteristic

The graph shows the dc characteristic of a device, with voltage $V$ on the vertical axis and input voltage $V_{in}$ on the horizontal axis. The characteristic curve is non-linear, indicating a threshold behavior where the output voltage $V$ changes abruptly at a certain value of $V_{in}$. The graph includes two curves, VO2 (solid square) and VO1 (open circle), indicating different modes or states of the device.
Small Signal Differential Amplifier

- For analog applications we use the differential amplifier in a small signal sense.
PNP Differential Amplifier

- Works the same way, but VEE is more positive than VCC
Small Signal Differential Amplifier

• Assume that the common mode signal has been used for biasing and the input is a small signal differential input.

What is the added resistor modeling?
Small Signal Model of Diff Amp

- Establish small signal model the same way as we did for other amplifiers
- Fabricated very carefully for perfect matching of parameters
Calculate Gain

\[ v_{o1} = -\frac{v_d}{2} \]

\[ g_m v_{\pi 1} R_C \]

\[ v_{o2} = v_{\text{diff}} - v_{o1} \]

\[ g_m v_{\pi 2} R_C \]

\[ \frac{v_{o2}}{v_{\text{diff}}} = \frac{g_m v_{\pi 2} R_C}{-\frac{v_d}{2} - g_m v_{\pi 1} R_C} \]

\[ \frac{v_{o2}}{v_{\text{diff}}} = \frac{g_m v_{\pi 2} R_C}{-\frac{v_d}{2} - g_m v_{\pi 1} R_C} \]
Calculate Gain

- What is the impact of \( r_o \)?
Differential Input Resistance

- The differential input resistance is huge

\[ R_{id} \]
Differential Input Resistance

\[ R_{id} \]

\[ V_{o1} \quad + \quad \text{v}_{\text{diff}} \quad - \quad V_{o2} \]

\[ g_m v_\pi 1 \quad R_C \quad g_m v_\pi 2 \quad R_C \]

\[ r_\pi \]
Common Mode Gain

- Just consider the common component of the input signal
- By symmetry arguments we only have to look at half of the ckt
Common Mode Gain

• “Looks” like a common emitter amplifier with an emitter resistor
Common Mode Gain

The diagram shows a circuit with a common mode input voltage $v_{cm}$ and parameters $r_\pi$, $g_m v_{\pi 1}$, $R_C$, and $2R$. The output voltage is $v_{o1}$. The circuit illustrates the concept of common mode gain in electronic circuits.
Common Mode Rejection Ratio

\[ CMRR = \left| \frac{A_d}{A_{cm}} \right| \]

- If output is taken differentially, then the CMRR is apparently infinite

- But for a single sided output response is has a finite value
Common Mode Rejection Ratio

- More importantly, due to mismatch in parameters even the differential output CMRR is not infinite
- Assume one side has a variation in $R_C$
Common Mode and Differential Gain

- Process is controlled as tightly as possible to minimize $A_{cm}$

$$v_o = A_d(v_1 - v_2) + A_{cm}\left(\frac{v_1 + v_2}{2}\right)$$

- Mismatch in transistors Q1 and Q2 creates a dc offset voltage
Common Mode Characteristics

- Differential inputs (like opamps) have a common mode input resistance too -- see derivation in the book
- Also, there is an input bias current to both inputs

- When the transistors are not perfectly matched there will be a slight offset in these values