CMOS Analog Addition/Subtraction

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Addition

Why adder?

- Neural network
- Continuous time signal processing application
- Low power / small size
Addition / Subtraction Using Op-Amp

\[ V_{out} = -R_f \left( \frac{V_1}{R_1} + \frac{V_2}{R_2} \right) \]

\[ V_{out} = \frac{R_2}{R_1} \left( V_1 - V_2 \right) \]
Addition / Subtraction Using Op-Amp

\[ V_{out} = \frac{R2}{R1} (V3 - V1) + \frac{R2}{R3} (V4 - V2) \]
Other OP-Amp Applications

- differentiator / integrator
- active filters
- I / V converter
- positive / negative voltage reference
- voltage supply
- wave form generator
- oscillator
- and more...and more...and more...
Addition

- Design #1

\[ V_{1/2} + V_S \]
\[ -V_{1/2} + V_S \]
\[ V_{2/2} + V_S \]
\[ -V_{2/2} + V_S \]

\[ I_1 = \frac{K_1W}{2L} (\frac{V_1}{2} + V_S - V_x - V_{tn})^2 \]
\[ I_2 = \frac{K_1W}{2L} (\frac{V_2}{2} + V_S - V_x - V_{tn})^2 \]
\[ I_3 = \frac{K_1W}{2L} (\frac{-V_1}{2} + V_S - V_y - V_{tn})^2 \]
\[ I_4 = \frac{K_1W}{2L} (\frac{-V_2}{2} + V_S - V_y - V_{tn})^2 \]
Addition

- Design #1

\[ I_1 + I_2 = I_3 + I_4 \quad \Rightarrow \quad V_x - V_y = \frac{V_1 + V_2}{2} \]

Two conditions

\[ V_1(V_2) > 2(-V_S + V_{in} + V_x(V_y)) \quad : \text{turn on} \]

\[ \frac{V_1(V_2)}{2} < V_{dd} - V_S + V_{in} \quad : \text{saturation} \]
Addition

- Design #2
Addition

- Design #2

\[ I_{in} = K(V_a - P) \quad \text{and} \quad I_{out} = K'(0 - V_d) \quad \Rightarrow \quad P = V_a + V_d \]
Addition

- **Design #3**

(Similar to Design #1)
Subtraction

- Design #1 (from adder Design #2)
Subtraction

- Design #1

\[ I_{in} = K(V_a - P) \quad \text{and} \quad I_{out} = K'(V_c - 0) \]

\[ P = V_a - V_c \]
Reference


Simulation

\[ V_{\text{out}} = \frac{R_2}{R_1} (V_3 - V_1) + \frac{R_2}{R_3} (V_4 - V_2) \]

2-stage diff amp

R1 = R2 = R3 = 100 kΩ

Addition: V1 = V2 = 0 V

Subtraction: V4 = V2 = 0 V
Simulation

(1.50460 V)  (2.25000 V)
Simulation

(1.00000 V)    (0.50000 V)    (0.00000 V)
Simulation

M1~M4: 1.98µ/0.48µ
M5, M6: 26.64µ/0.48µ