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Self-biasing Reference Current Source with Two Nagata Current Mirrors Insensitive to Temperature and Supply Voltage

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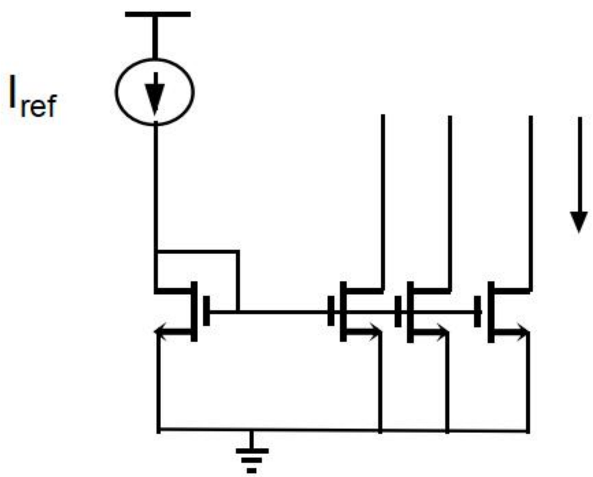
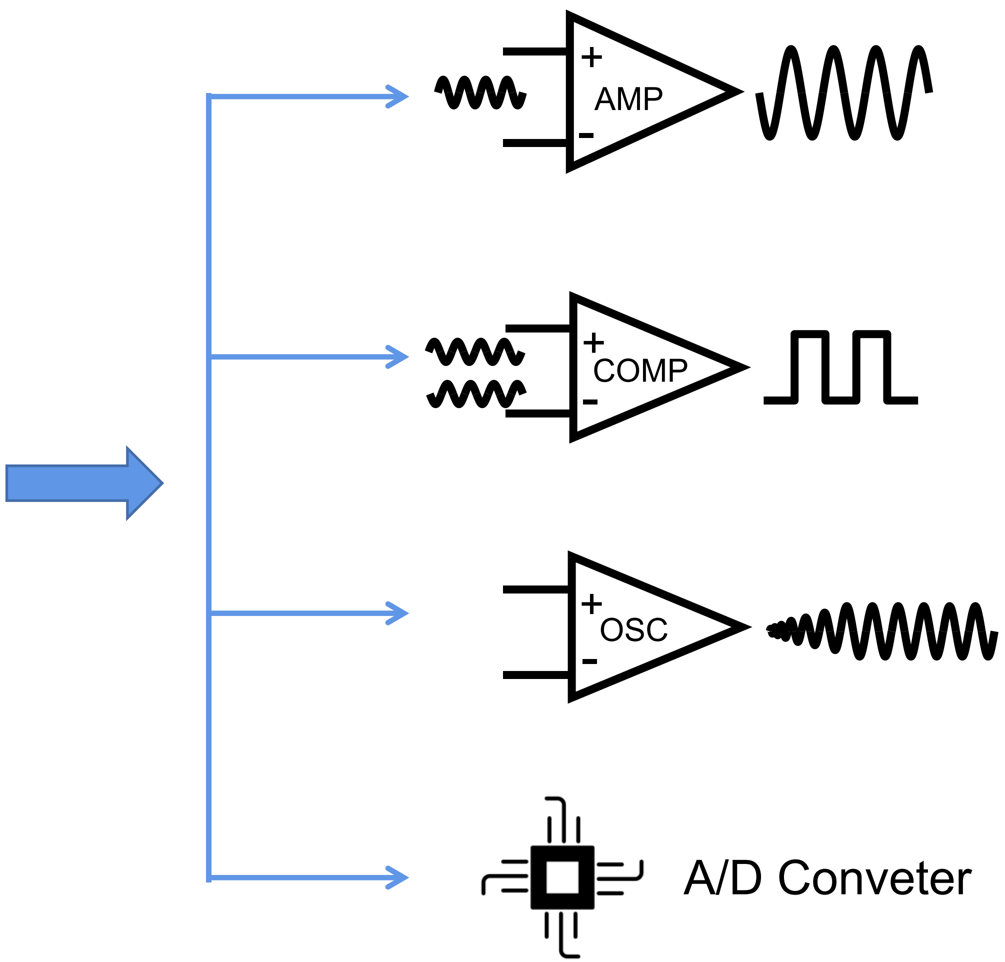
Research Background

Reference current

→ Important in analog circuit

Especially PVT insensitive current





Research Objective

Development of reference current source insensitive to temperature and supply voltage with simple CMOS circuit.

Bandgap reference circuit

Complicated
Large chip area

Nagata current source

Simple
Insensitive to supply voltage

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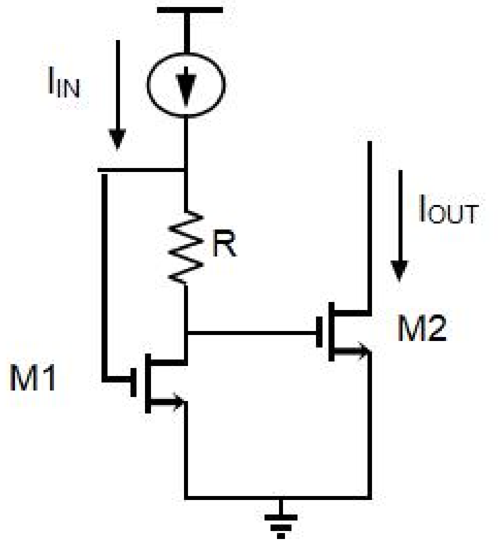
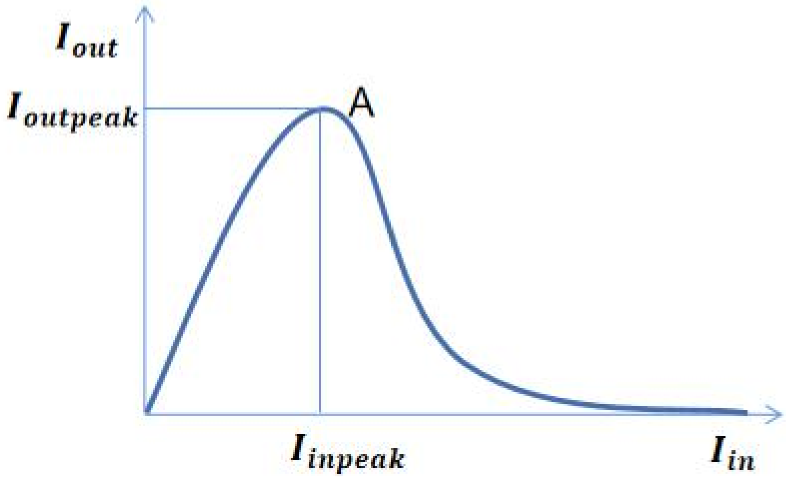
Nagata Current Mirror



MOS Nagata current mirror

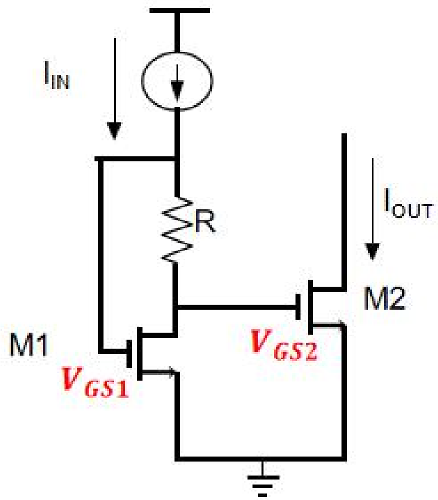


I-O current characteristics

Output current has a peak

$I_{IN} < I_{INpeak}$, I_{OUT} monotonically increasing
$I_{IN} > I_{INpeak}$, monotonically decreasing

Analysis of Nagata Current Mirror



MOS Nagata current mirror

Peak current value $I_{outpeak}$

$$V_{GS1} = V_{GS2} + I_{in}R$$

$$①V_{GS1} = \sqrt{\frac{I_{in}}{K_1}} + V_{th} \quad (K_1 = {}^1/_2\, \mu_n C_{ox} \frac{W_1}{L_1})$$

$$②V_{GS2} = \sqrt{\frac{I_{out}}{K_2}} + V_{th} \quad (K_2 = {}^1/_2\, \mu_n C_{ox} \frac{W_2}{L_2})$$

$$I_{out} = K_2 R^2 \left(\sqrt{\frac{I_{in}}{K_1 R^2}} - I_{in} \right)^2$$

To find the maximal value, differentiate I_{out} with respect to I_{in}

$$\frac{dI_{out}}{dI_{in}} = K_2 R^2 \left(\sqrt{\frac{I_{in}}{K_1 R^2}} - I_{in} \right) \left(\sqrt{\frac{1}{K_1 R^2}} \times \sqrt{\frac{1}{4I_{in}}} - 1 \right)$$

$$I_{inpeak} = \frac{1}{4K_1 R^2} \quad , \quad I_{outpeak} = \frac{1}{16K_1 R^2} \times \frac{K_2}{K_1}$$

Output current → function of R, K_1, K_2

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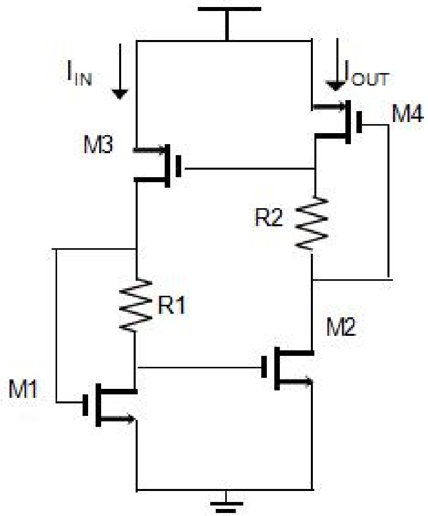
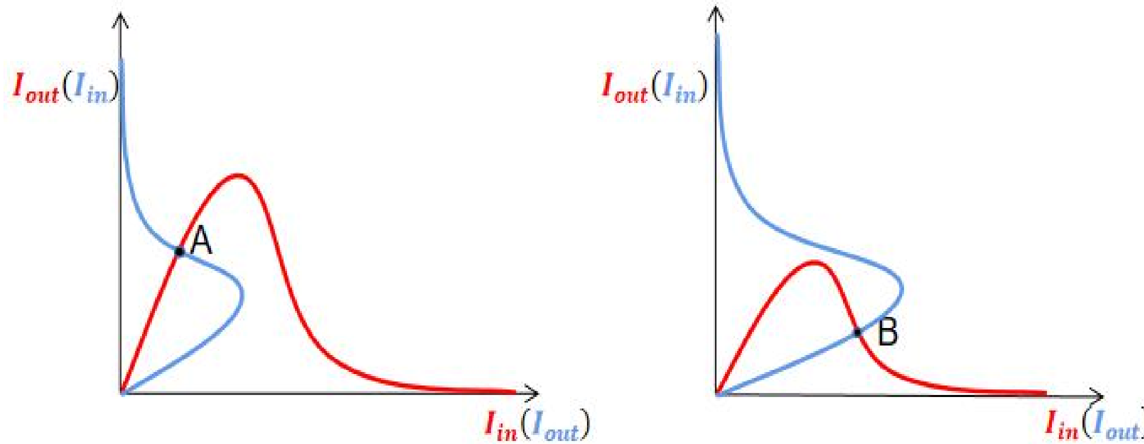
Two Nagata Current Mirrors Configuration



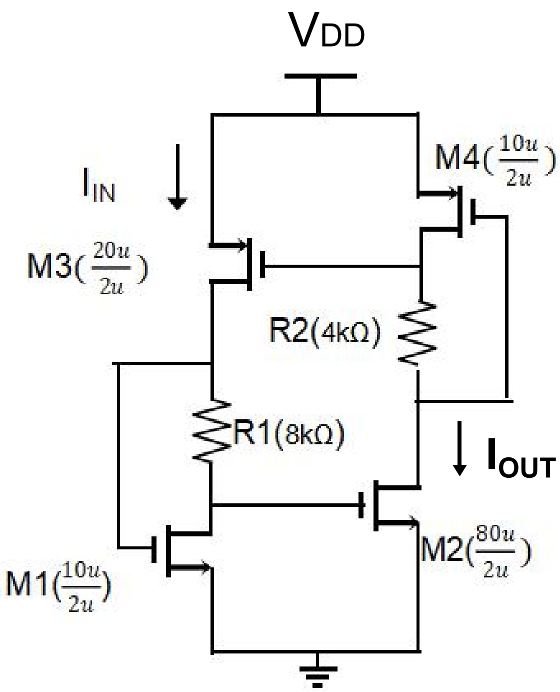


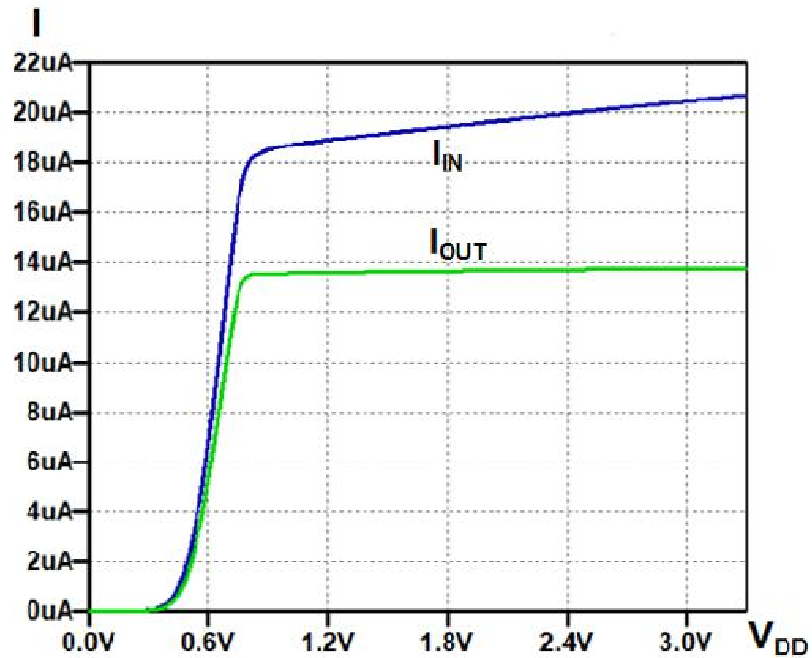
I-O current characteristics of
upper current mirror and lower current mirror

Two different monotonic properties → Negative feedback state

Adjusting the value of R1,K1,K2 and R2,K3,K4 → Stable output current

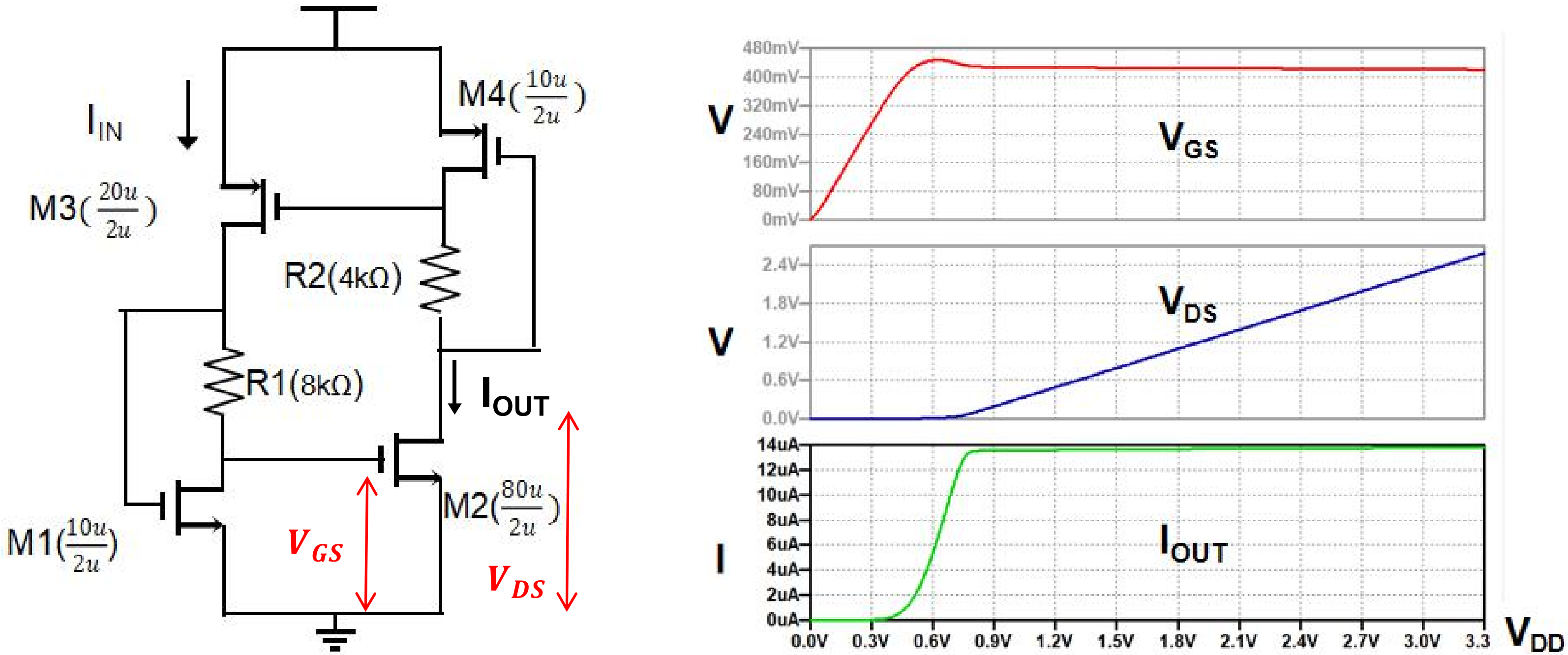
Simulation Result of Supply Voltage Variation





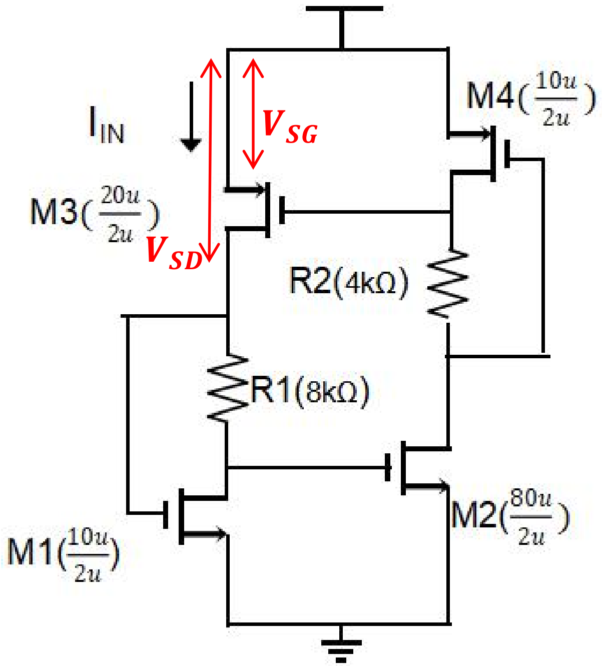
Output current → Insensitive to supply voltage

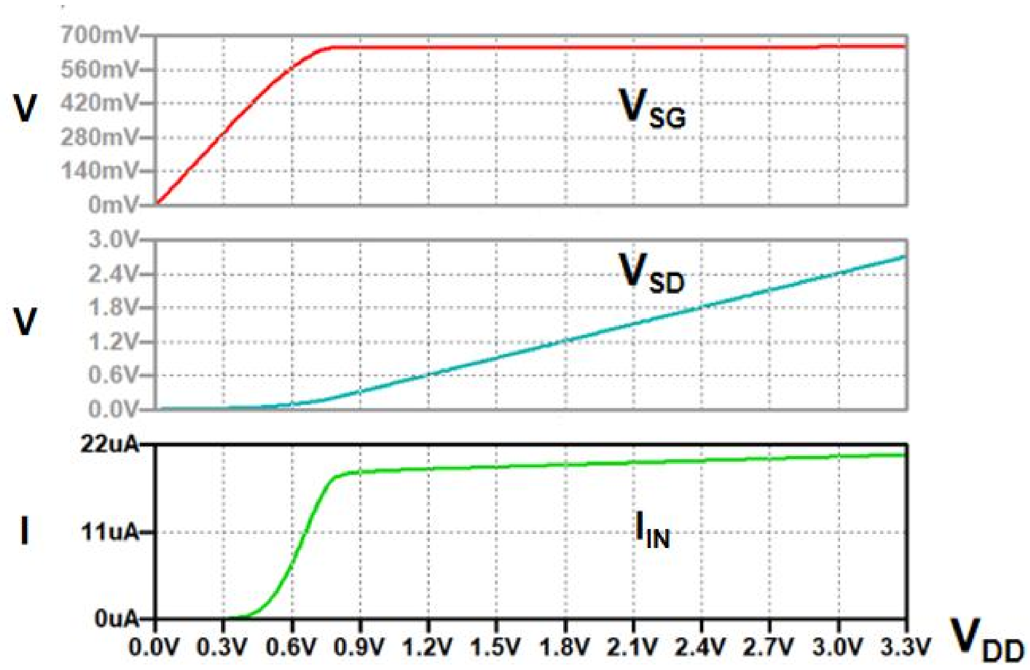
The Source-Gate,Source-Drain Voltage of M2



Because the lower current mirror in monotonic decreasing state
The V_{GS} slightly decreases , makes the current of M2 almostly insensitive to voltage

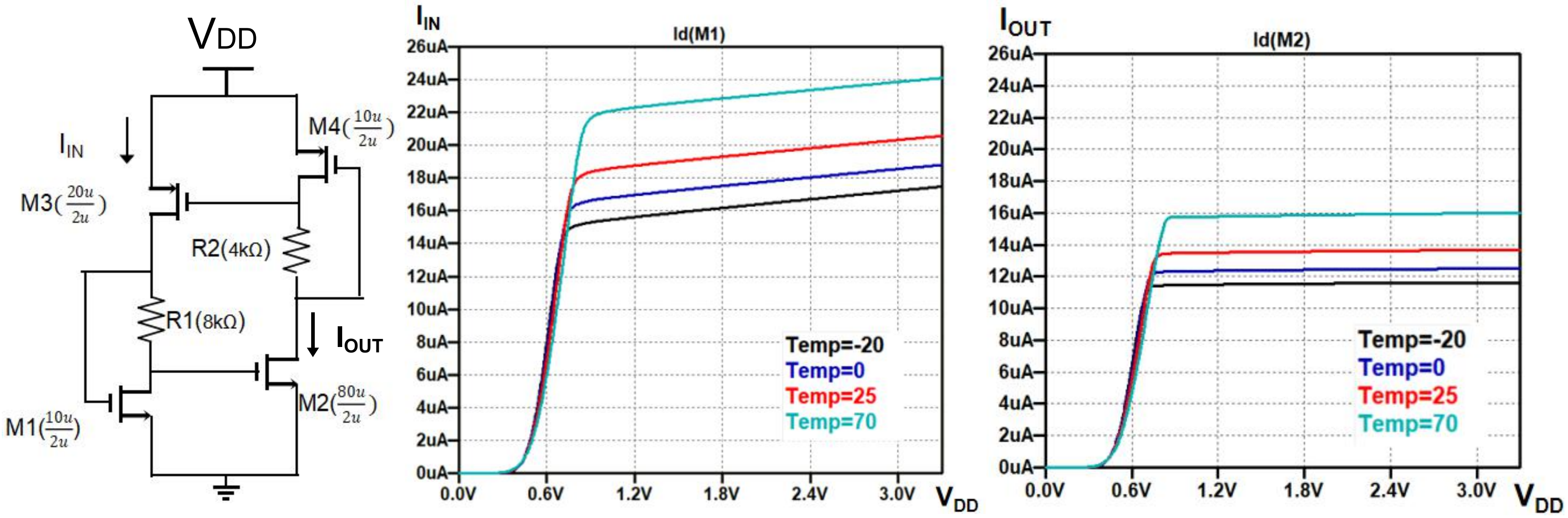
The Source-Gate,Source-Drain Voltage of M3





The current of M3 increases slightly as a result of channel length modulation effect

Simulation Result of Temperature Variation



Input and output currents both increase with temperature increases

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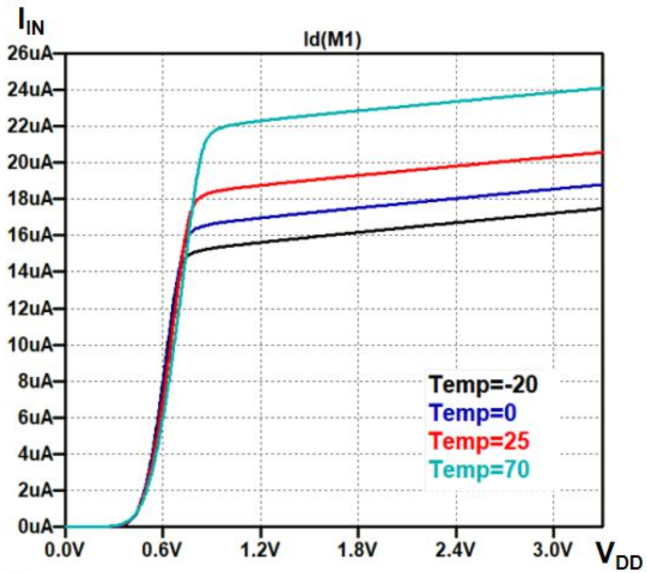
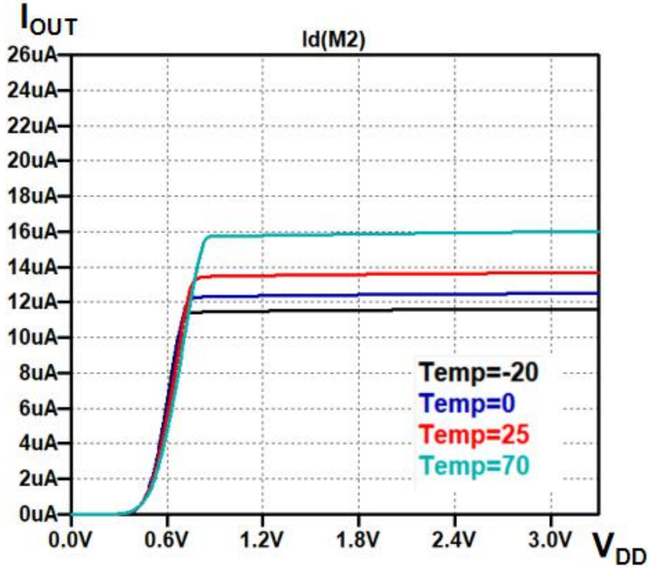
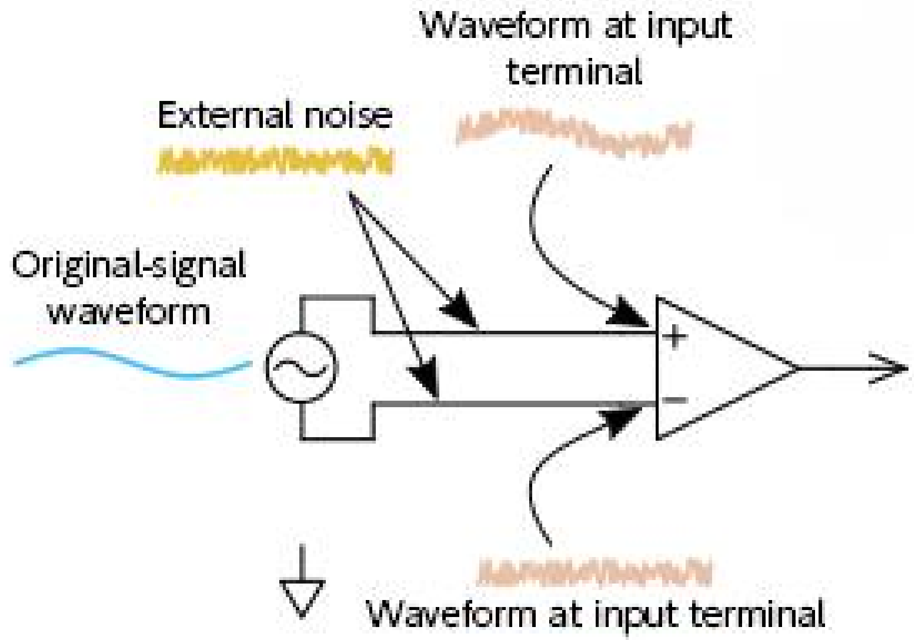
Two Nagata Current Sources with Subtraction Circuit

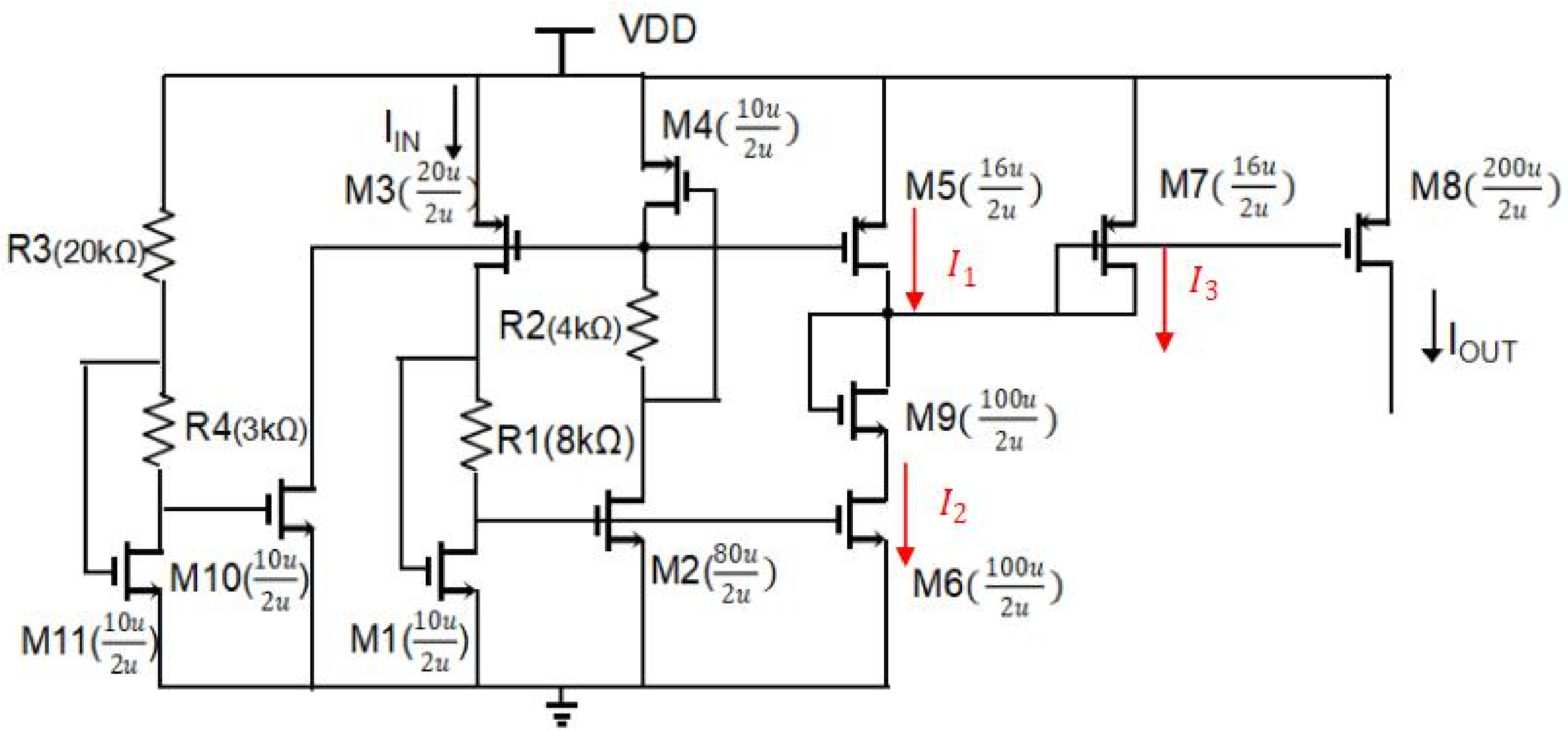






Use subtraction circuit
to cancel temperature dependence

Simulation Circuit of Whole Circuit

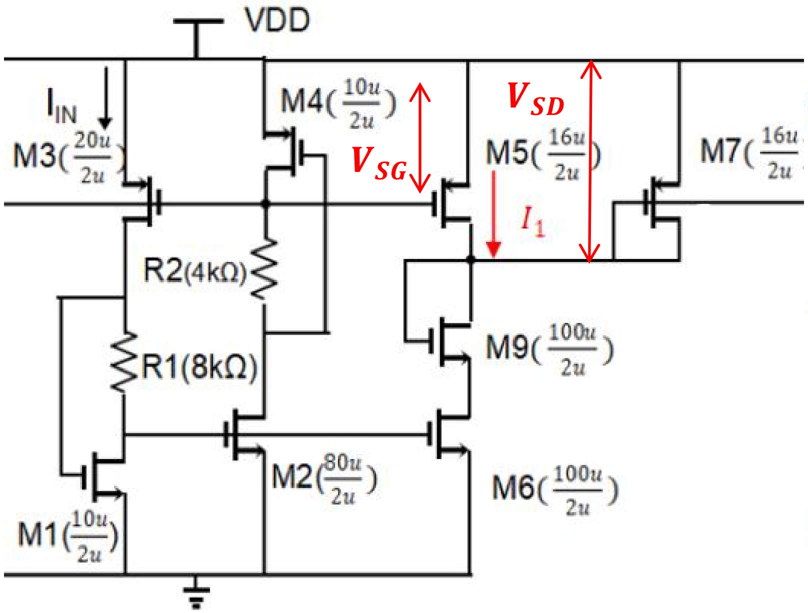


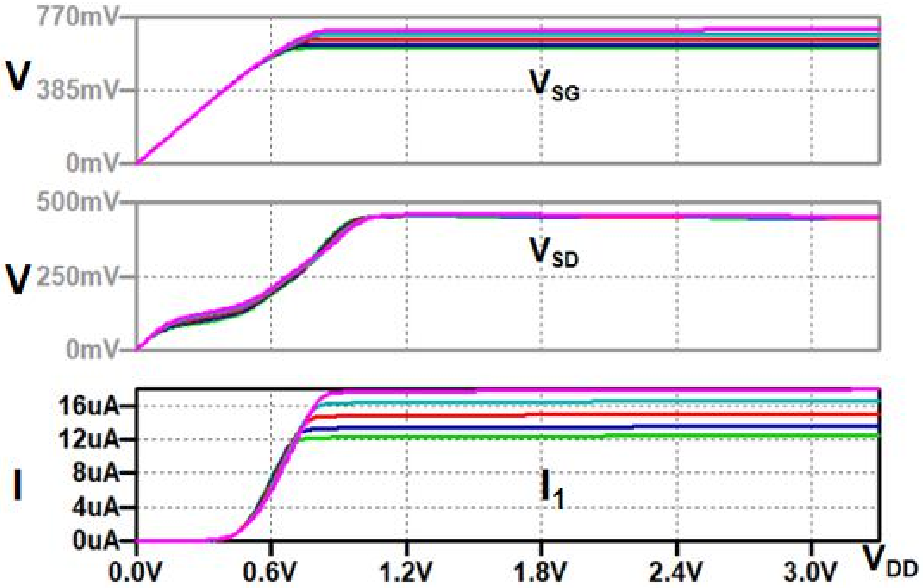
$I_{OUT} = I_3$

$\quad\quad = I_2 - I_1$

Subtraction between two currents (I_1 , I_2)

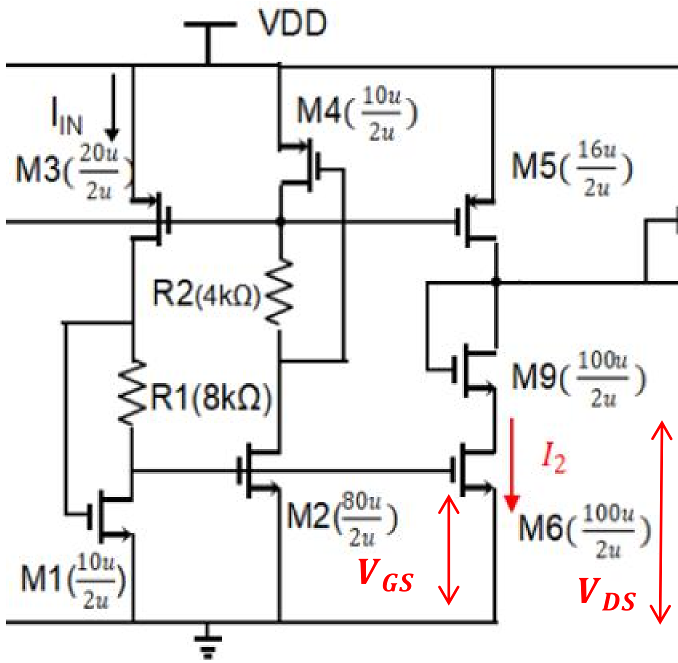
The Source-Gate,Source-Drain Voltage of M5

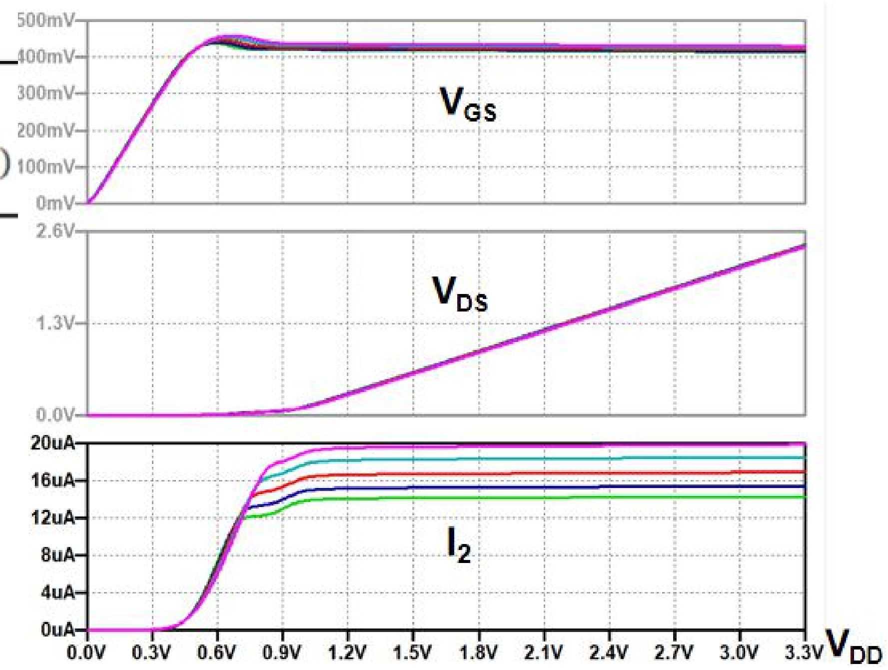




In the subtraction, the V_{SD} of M5 becomes constant
Compared with I_{IN} , the current I_1 is insensitive to supply voltage

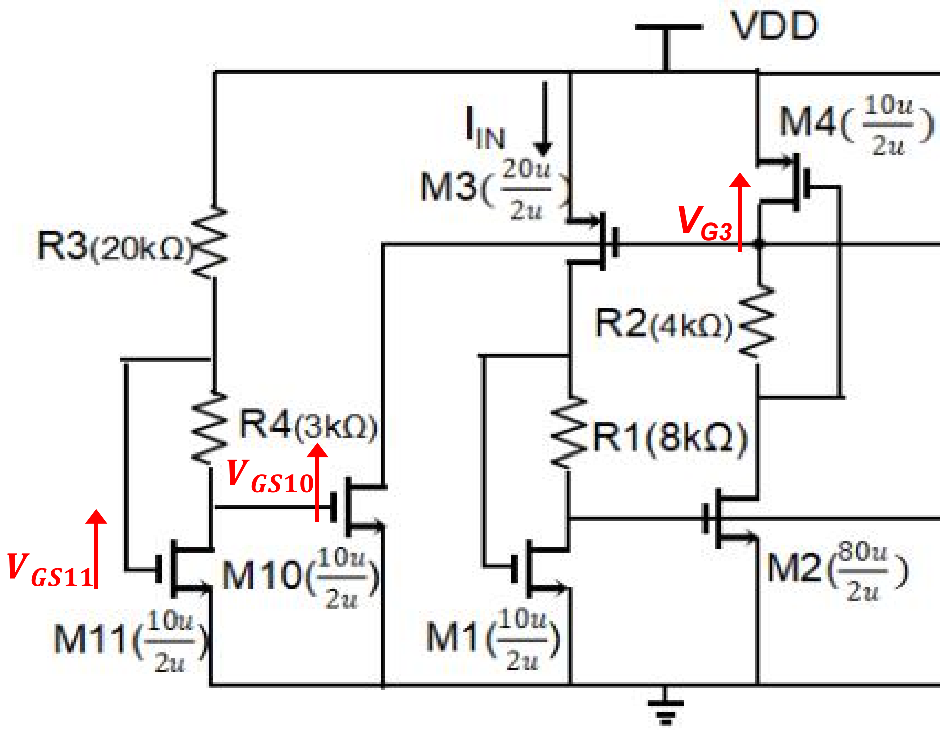
The Source-Gate,Source-Drain Voltage of M6





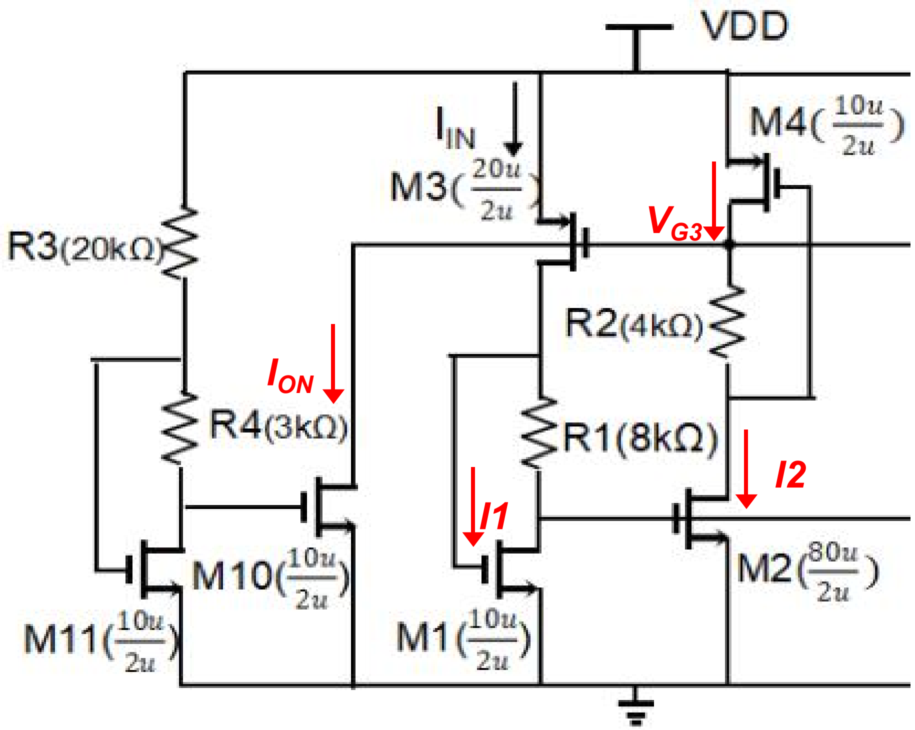
The V_{GS} slightly decreases , makes the current of I_2 almostly insensitive to voltage

Startup Circuit Operation



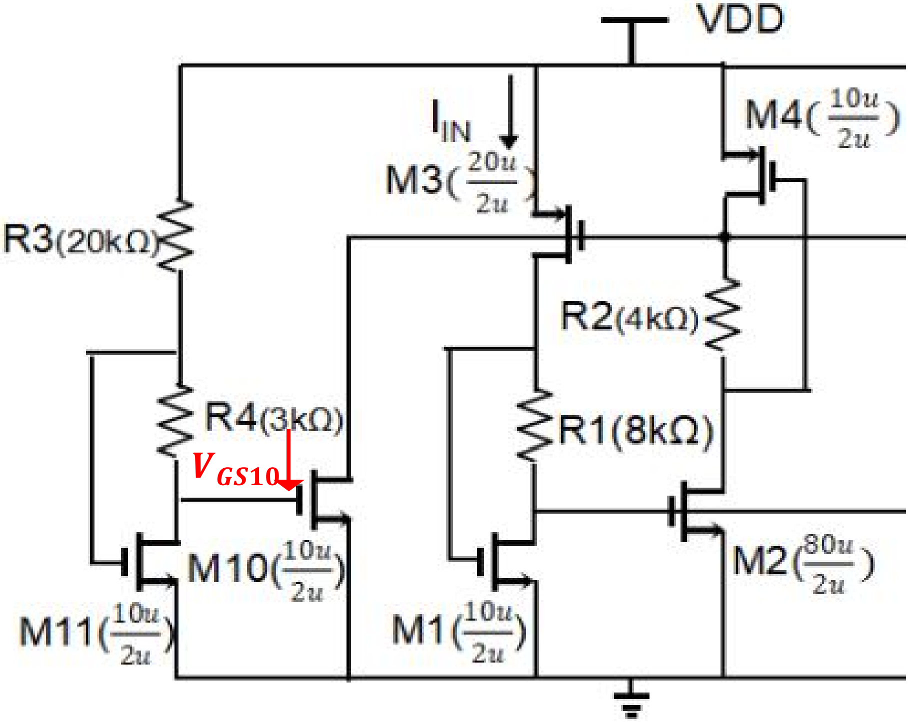
- VDD↑ V_{GS10} ,V_{GS11} ,V_{G3}↑
- M10, M11 turn on

Startup Circuit Operation



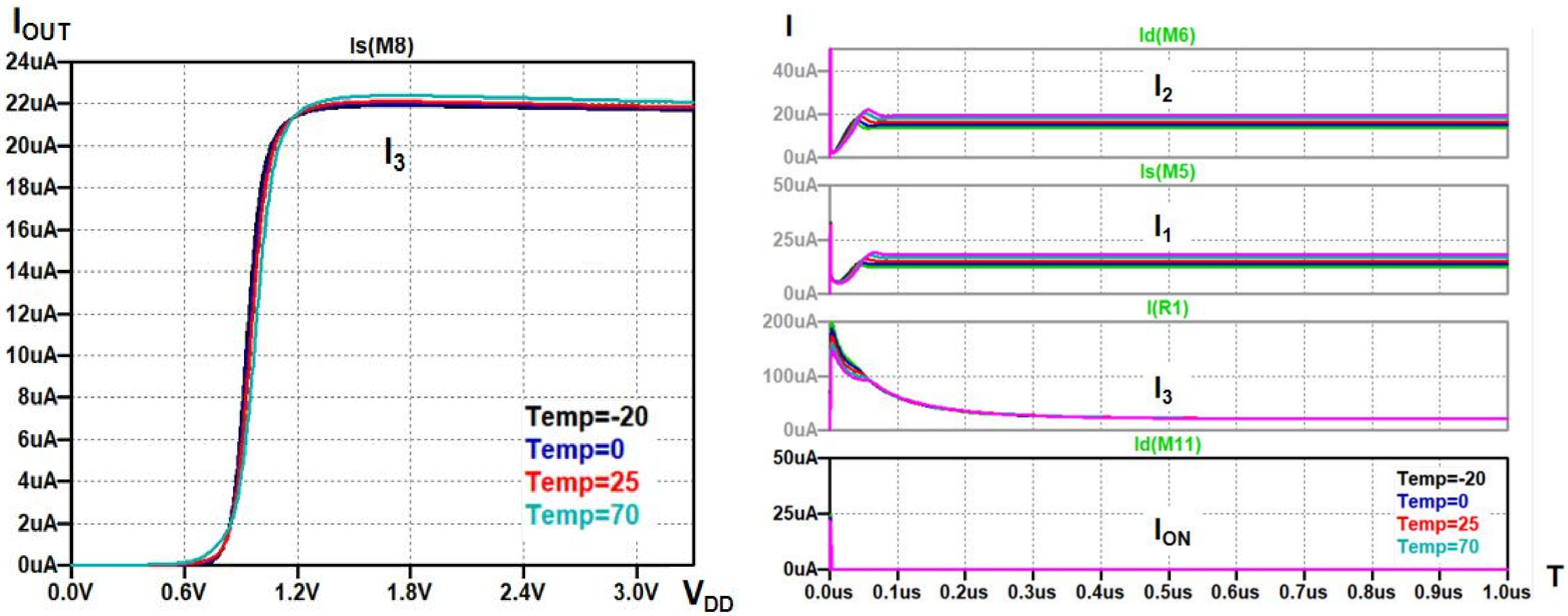
- V_{G3}↓ , M3 turns on
- M1, M2, M4 turn on

Startup Circuit Operation



- VDD↑ M11 in linear region, M10 turns off

Simulation Result of Temperature Variation



Difference current (I_3) between two currents (I_1 , I_2) flows through M7

Insensitive to temperature

It also works well with start-up circuit

Contents

Summary

1. Nagata Current Mirror
   a) I-O current characteristics of Nagata current mirror
   b) Peak value of output current and corresponding input current

2. Two Nagata Current Mirrors Configuration
   a) Simple circuit structure
   b) Output current insensitive to supply voltage

3. Two Nagata Current Sources with Subtraction Circuit
   a) Subtraction circuit
   b) Output current insensitive to temperature
   c) Working well with startup circuit

Acknowledgements

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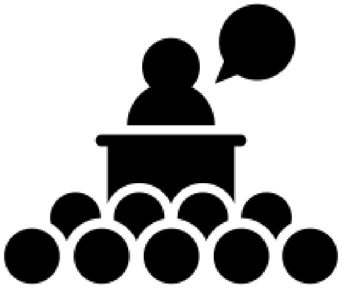

Thank you for your listening