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MOS Reference Current Source Insensitive to Temperature Variation

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OUTLINE

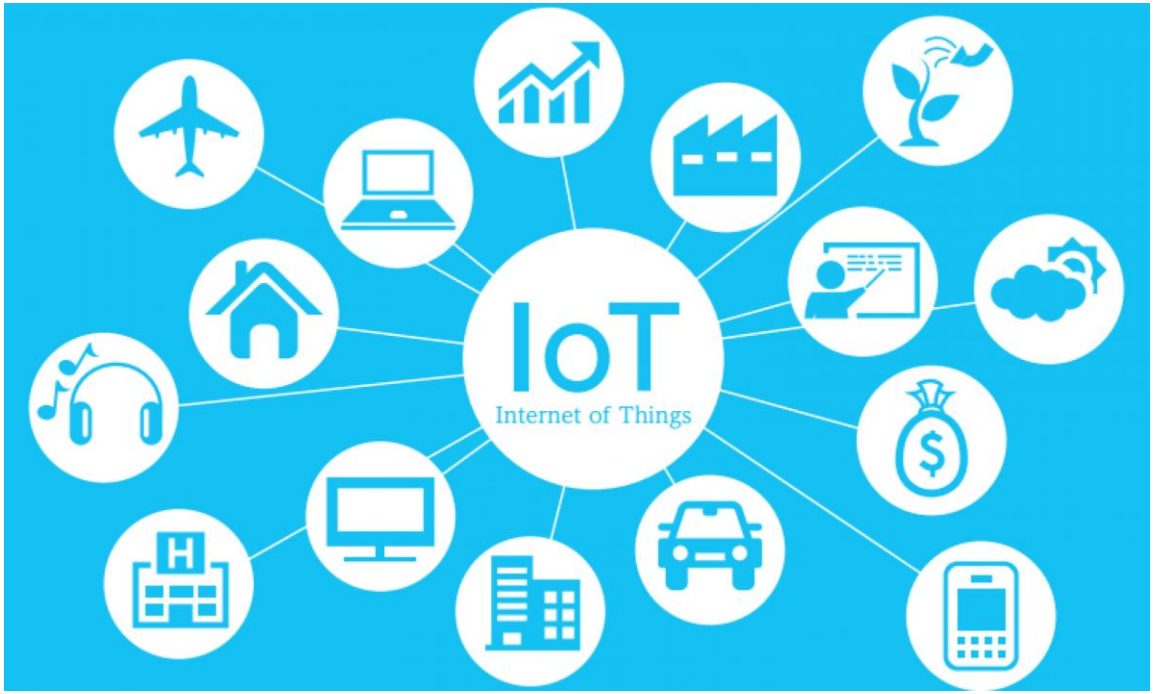
- Research background
- Reference Current Source
- Temperature Characteristics of MOS FET
- Propose MOS reference Current Source
- Simulation result
- Conclusion

Research Background

IoT(Internet of Things)

Increasing electronic equipment

Reliability is important



Research Background: Reliability

Reliability problem in electronic circuits

Factors that lose reliability

- Process
- Voltage
- Temperature

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Reliability problem in electronic circuits

Factors that lose reliability

- Process
- Voltage
- Temperature

Reference current source

Importance of Temperature Characteristics

Under blazing sun

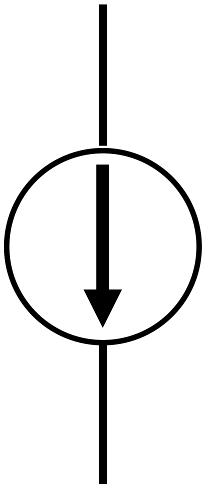
Below freezing point

Under any temperature environment

→ Guarantee desirable performance operation

What is Reference Current Source?

Provide constant current to circuits

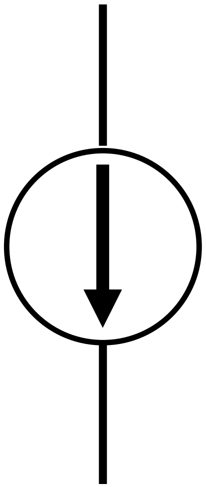


One is necessary in an analog IC

Reference current source ⟹ Polaris

What is Reference Current Source?

Provide constant current to circuits

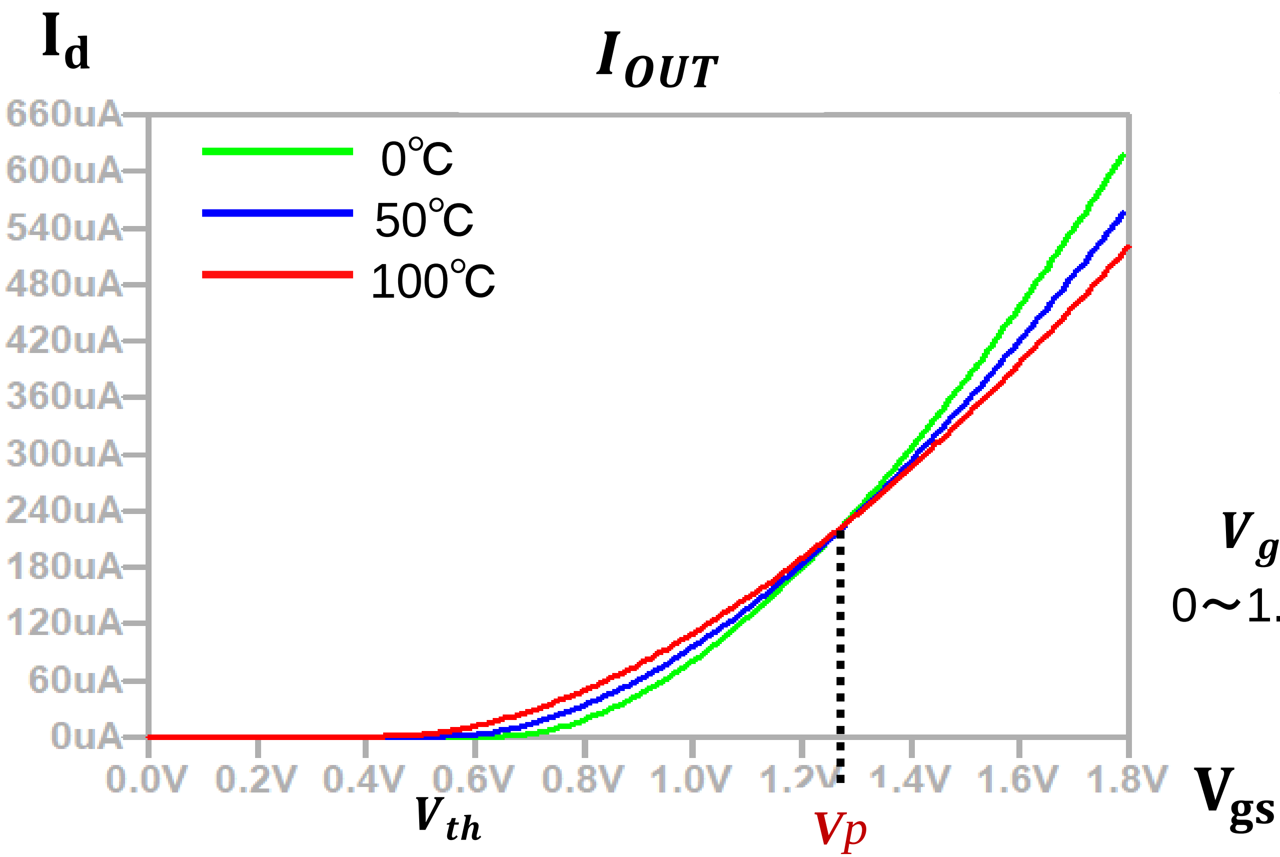


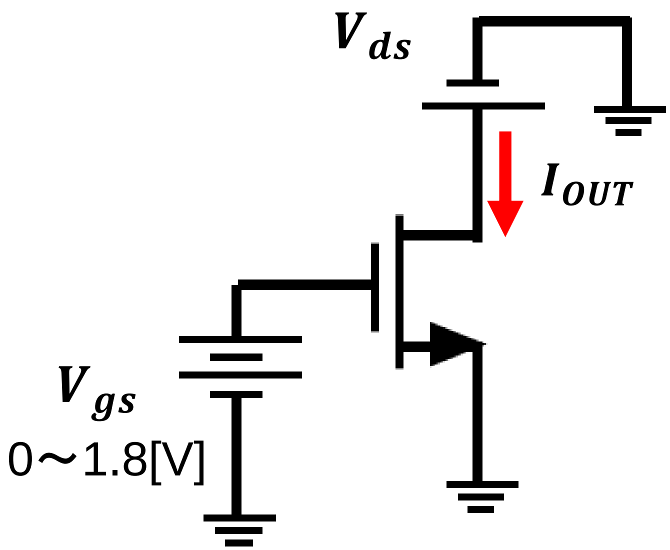
One is necessary in an analog IC

This time

Robust against temperature variation

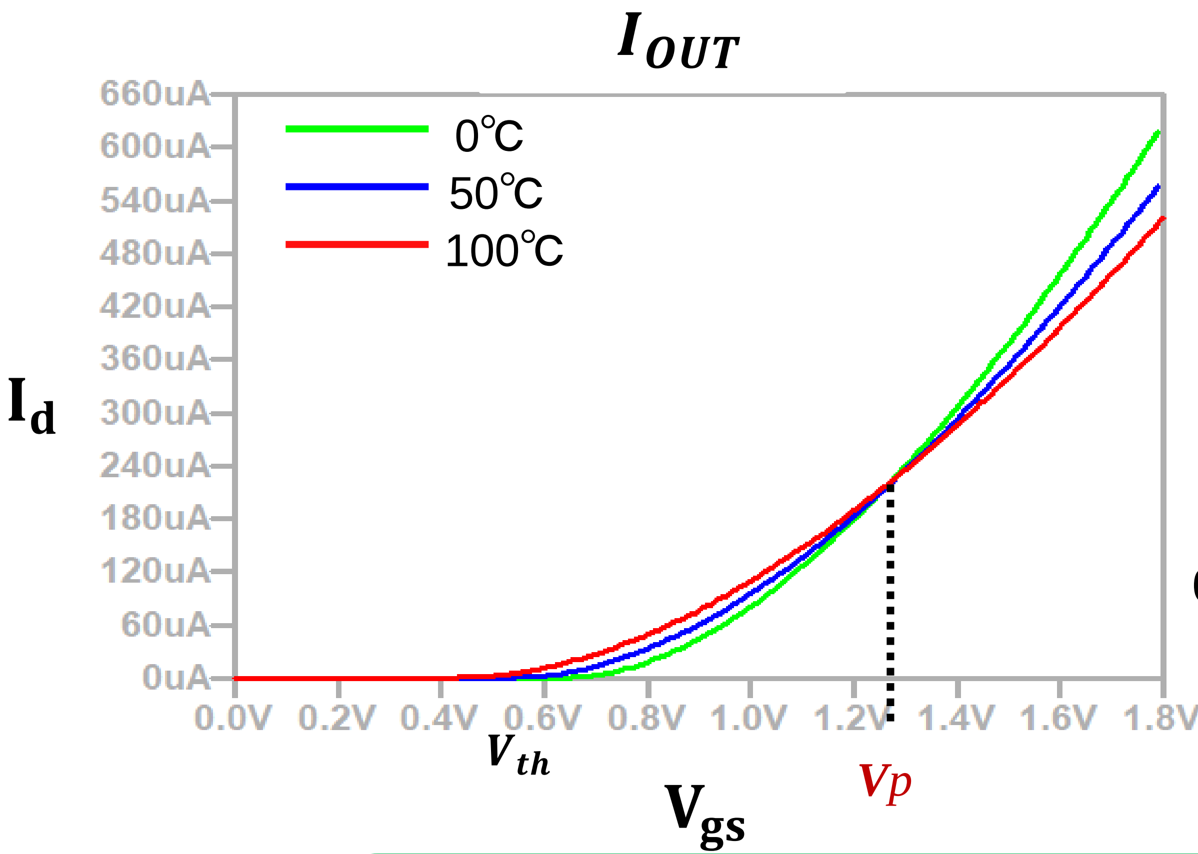
Temperature Characteristics of MOSFET



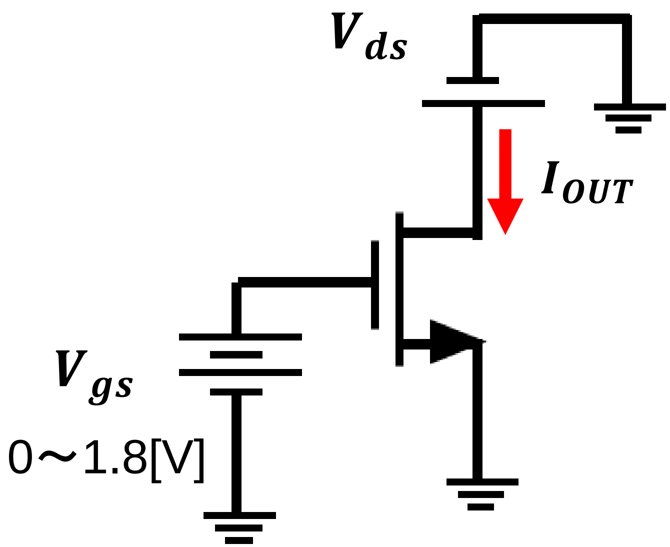


Temperature characteristics of $I_d - V_{gs}$ of MOS

Characteristic Change due to Temperature Rise



Simulation circuit



Temperature rise

Vth ➡ Lower

Vgs < Vp : drain current ➡ Larger

Vgs > Vp : drain current ➡ Smaller

Current Equation of MOSFET

- Linear region

$$I_d = \frac{W}{L}\mu C_{OX}\left[(V_{GS} - V_{th})V_{DS} - \frac{1}{2}{V_{DS}}^2\right]$$

- Saturation region

$$I_d = \frac{W}{2L}\mu C_{OX}(V_{GS} - V_{th})^2(1 - \lambda V_{ds})$$

$\frac{\mathrm{W}}{\mathrm{L}}$: Aspect ratio
$C_{O\,X}$: Gate oxide capacitance per unit area
V_{th}: Threshold
μ: Mobility

Causes of Temperature Characteristics

$$I_d = \frac{W}{L}\mu C_{OX}\left[(V_{GS} - V_{th})V_{DS} - \frac{1}{2}{V_{DS}}^2\right] \quad \cdots\cdots\cdots \quad (1)$$

$$I_d = \frac{W}{2L}\mu C_{OX}(V_{GS} - V_{th})^2(1 - \lambda V_{ds}) \quad \cdots\cdots\cdots \quad (2)$$

μ : Mobility

$$\mu = \mu_0 (T/T_0)^{-1.5} \quad \cdots\cdots (3)$$

↓

Temperature : Rises

↓

current(: I_d) : Decrease

V_{th} : Threshold

$$V_{th} = \frac{\sqrt{2eN_A\varepsilon_{Si}(2\varphi_B)}}{C_{OX}} + 2\varphi_B + V_{FB} \quad \cdots (4)$$

$$\varphi_B = \frac{k_B T}{e}\ln\left(\frac{N_A}{n_i}\right), \quad n_i = N exp\left(-\frac{\varepsilon_g}{2k_B T}\right) \quad \cdots (5)$$

$$\frac{dV_{th}}{dT} = -1 \sim -3 \ [mV/℃]$$

↓

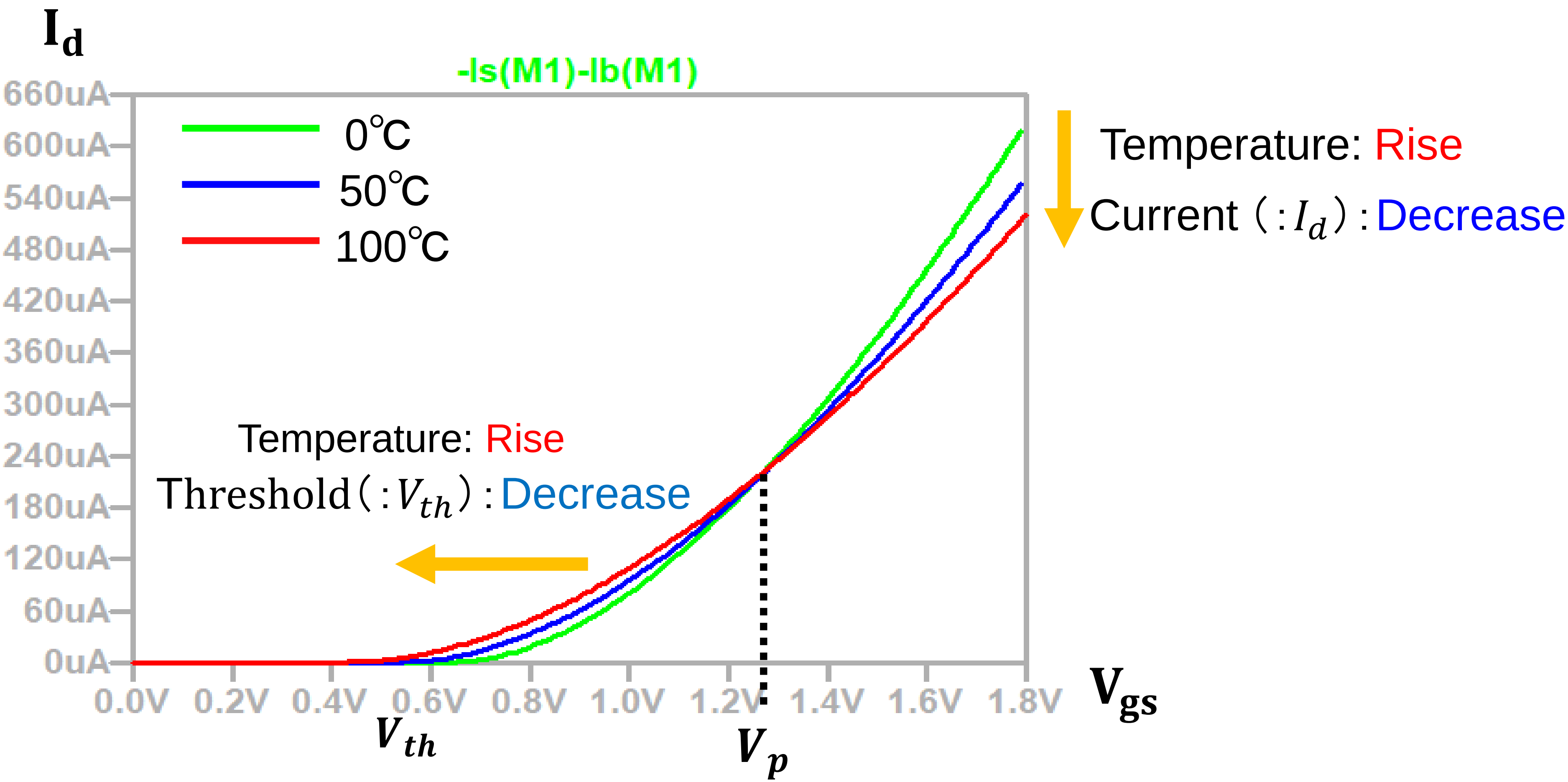
Temperature : Rises

↓

threshold(: V_{th}) : Decrease

φ_B : Built-in potential
n_i : Intrinsic carrier density of NMOSFET

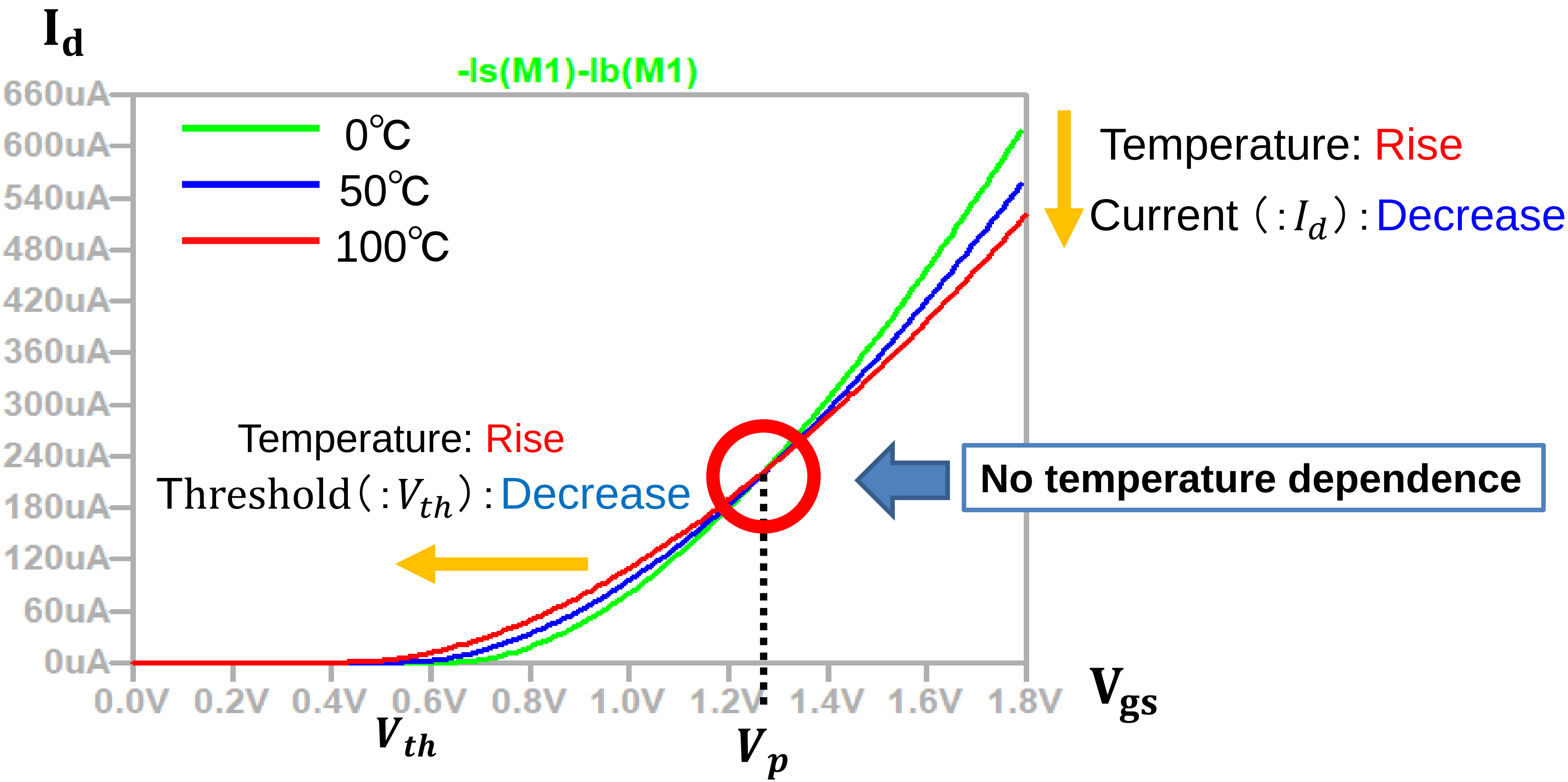
Simulation Confirmation Using SPICE



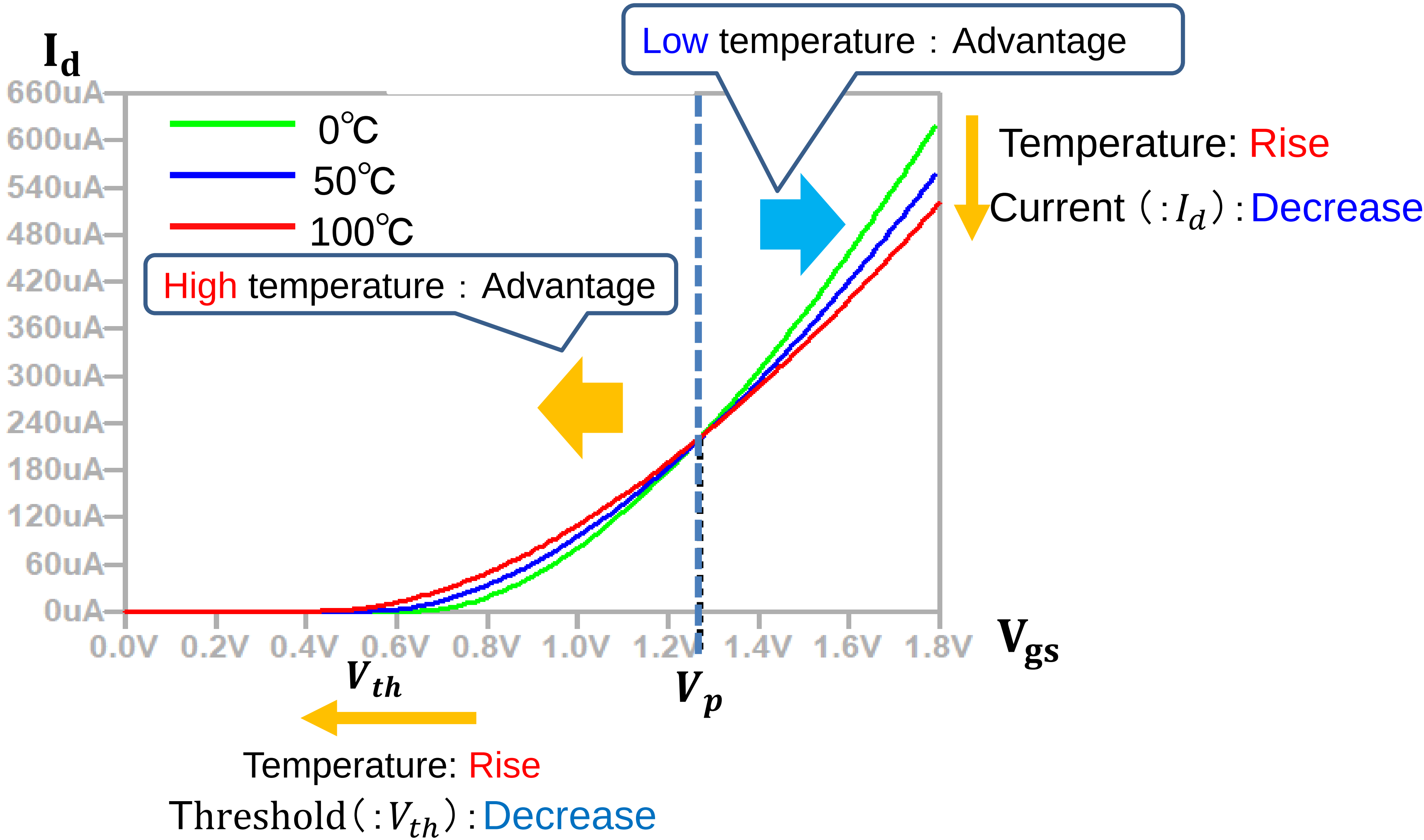
$$I_d = \frac{W}{L}\mu C_{OX}\left[(V_{GS} - V_{th})V_{DS} - \frac{1}{2}{V_{DS}}^2\right] \quad \cdots\cdots \quad (1)$$

$$I_d = \frac{W}{2L}\mu C_{OX}(V_{GS} - V_{th})^2(1+\lambda V_{ds}) \quad \cdots\cdots \quad (2)$$

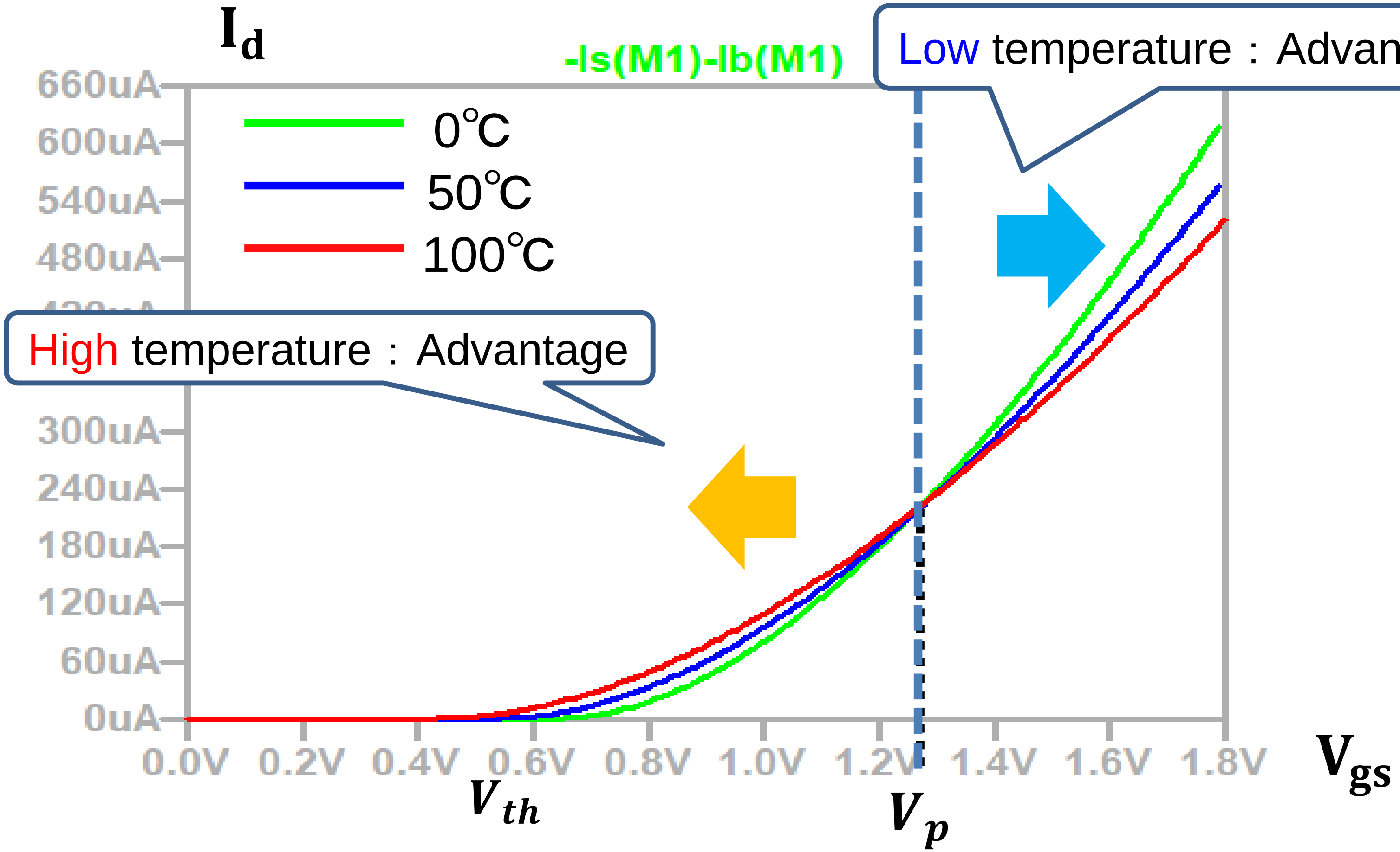
Simulation Confirmation Using SPICE



Changes in Temperature Characteristics



Concept of Proposed Circuit

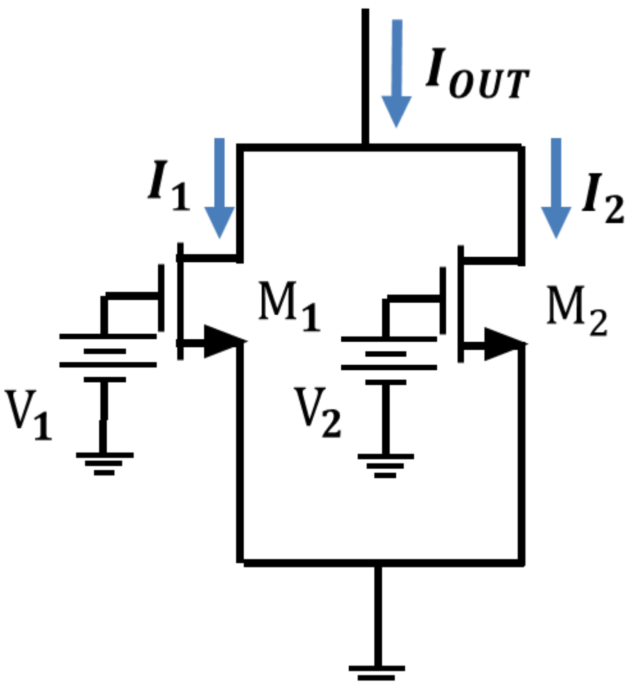


Constant current source without temperature fluctuation

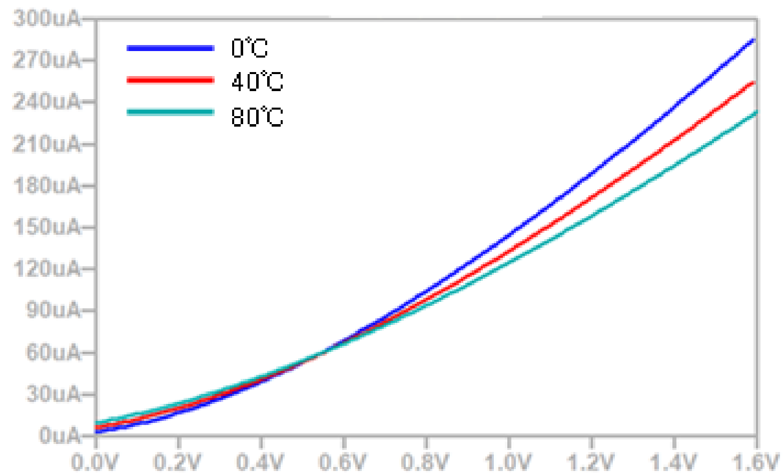
Use superiority changes at high and low temperatures

Proposed Circuit Concept

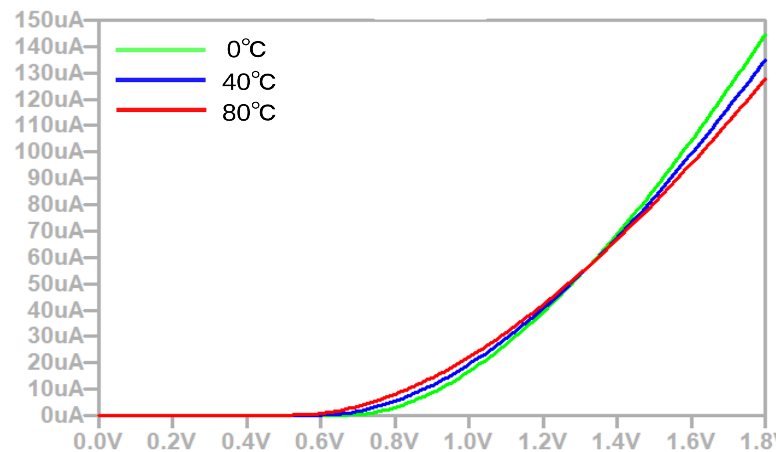
Circuit concept
Give different bias voltages



$V_1 > V_2$



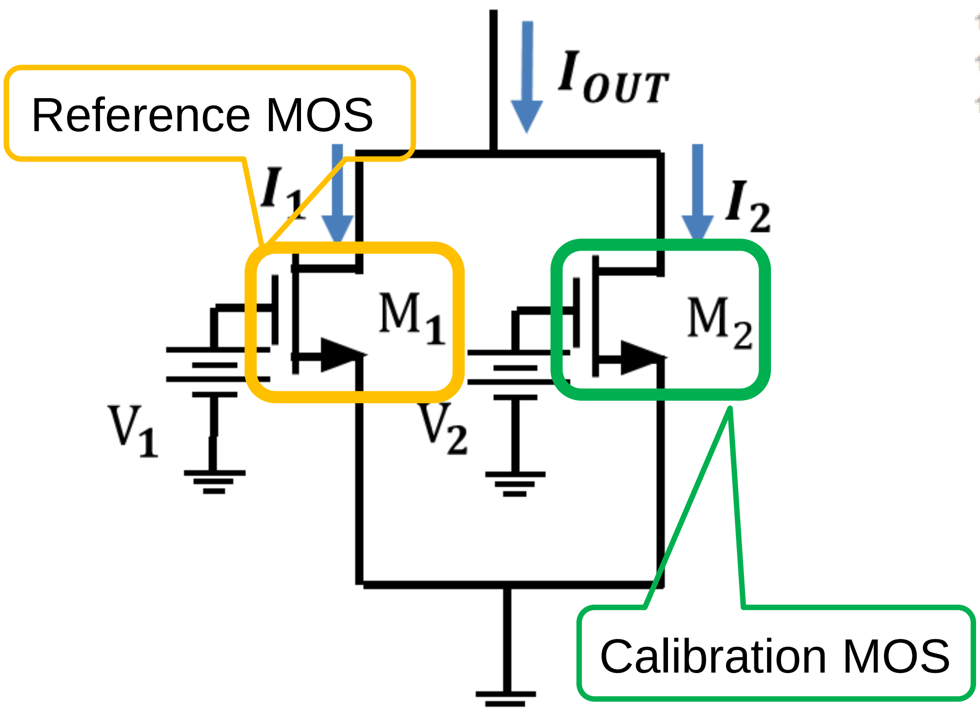
$\mathbf{I_D - V_{GS}}$ **characteristics of** $\mathbf{M_1}$



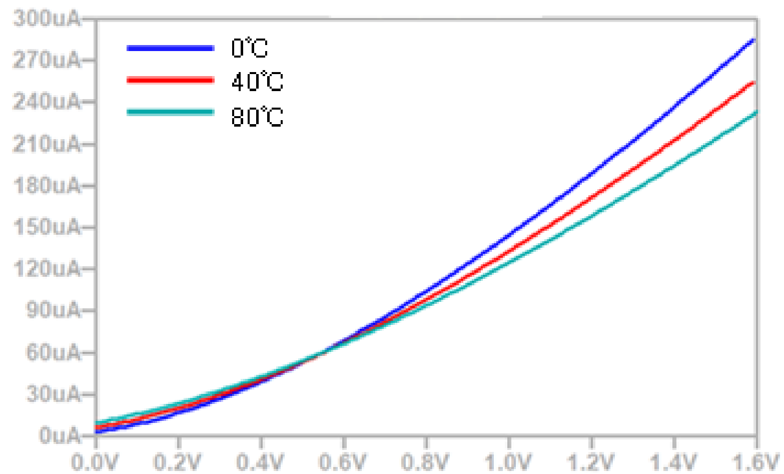
$\mathbf{I_D - V_{GS}}$ **characteristics of** M_2

Concept Circuit Definition

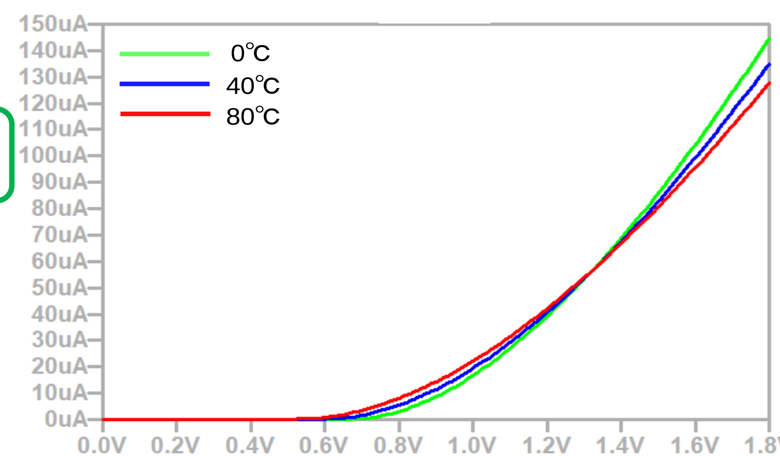
Circuit concept



$V_1 > V_2$



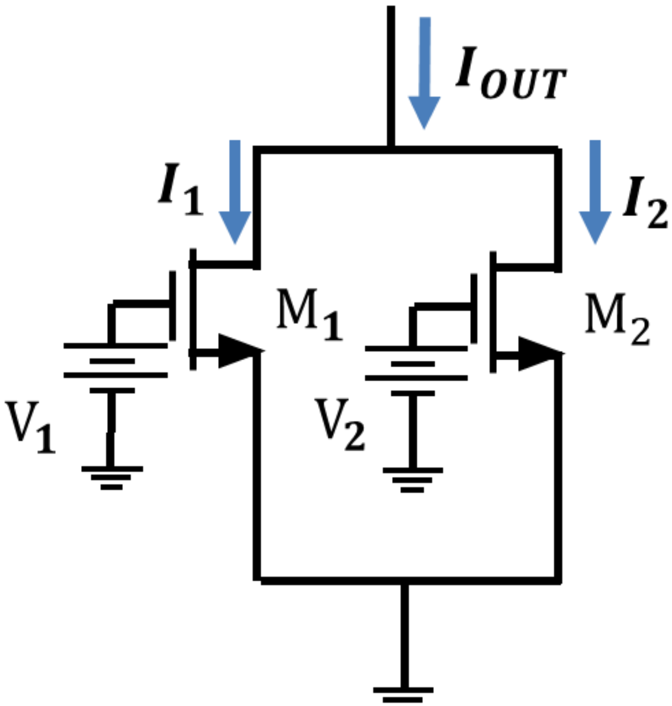
$\mathbf{I_D - V_{GS}}$ **characteristics of** $\mathbf{M_1}$



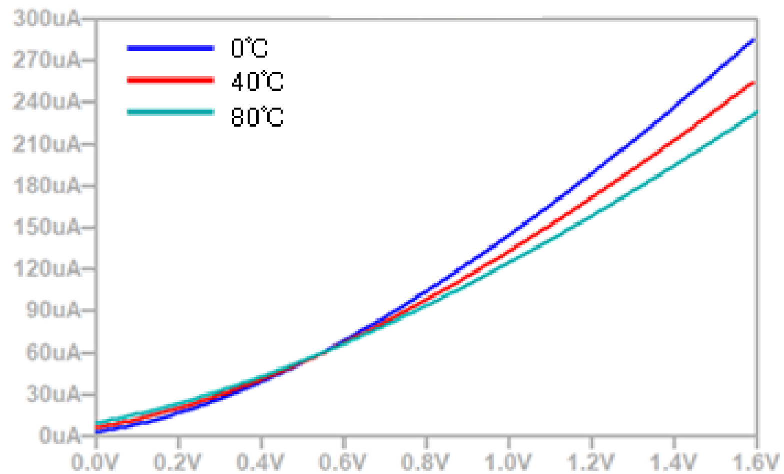
$\mathbf{I_D - V_{GS}}$ **characteristics of** M_2

Current of Each MOSFET in Proposed Circuit

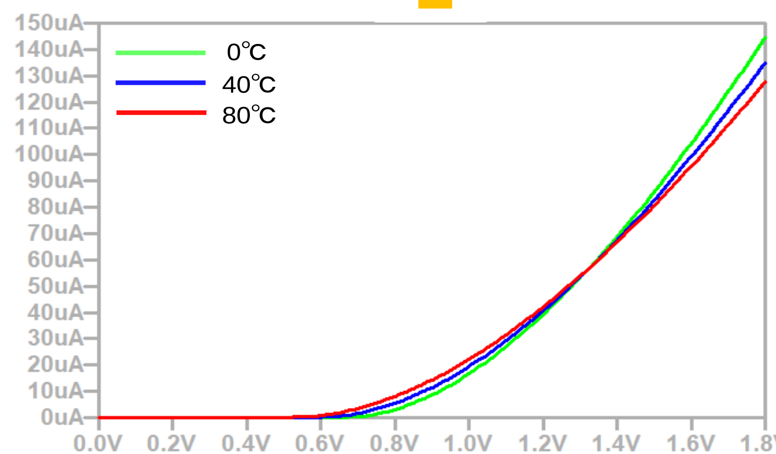
Circuit concept



$V_1 > V_2$



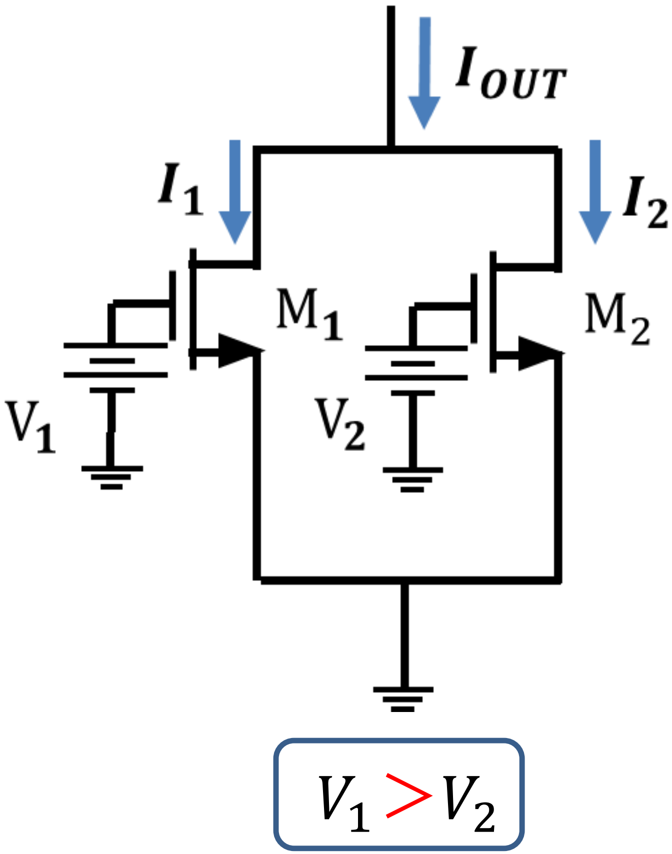
$I_D - V_{GS}$ characteristics of M_1

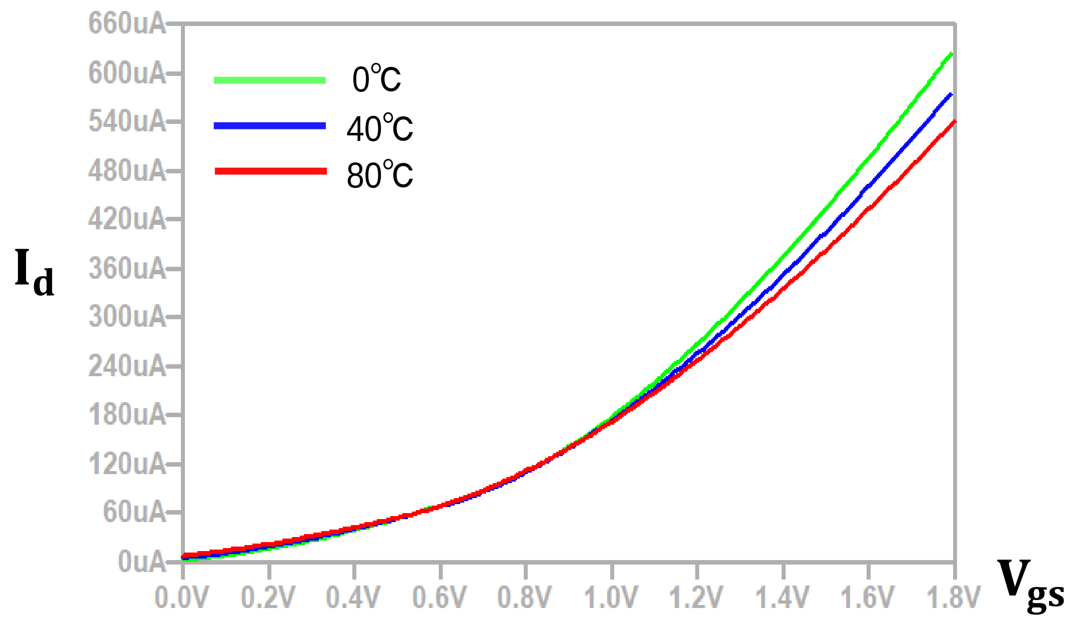


$I_D - V_{GS}$ characteristics of M_2

Output Current in Proposed Circuit

Circuit concept

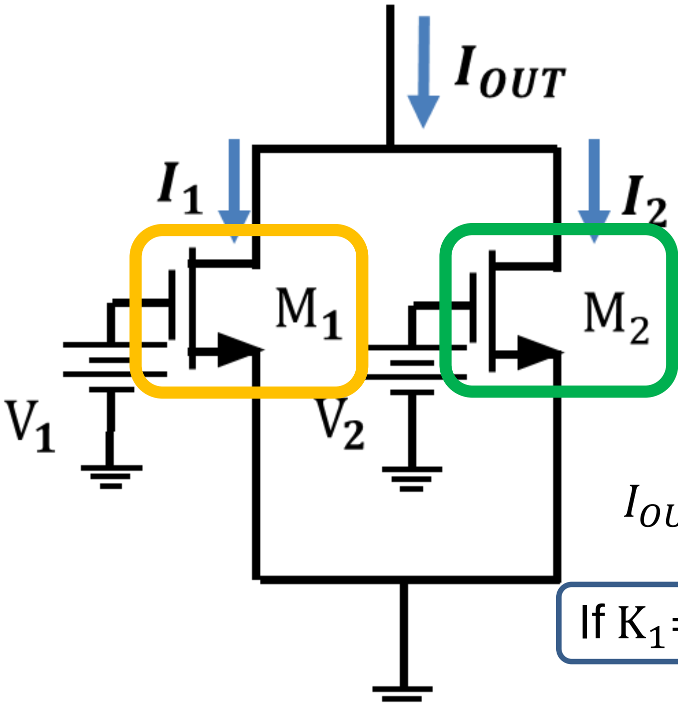




$I_D - V_{GS}$ characteristics of I_{OUT}

Output Current Formula

Propose circuit



$$I_1 = K_1(V_1 - V_{th})^2(1+\lambda V_{ds}) \cdots (5)$$

$$I_2 = K_2(V_2 - V_{th})^2(1+\lambda V_{ds}) \cdots (6)$$

It is defined as $V_1 = V_2 + V_P$ when designing

If $K_1 = K_2$

$$I_1 = K(V_{GS} + V_2 + V_P)^2(1+\lambda V_{ds}) \cdots (7)$$

$$I_{OUT} = K_1\{(V_2 + V_P - V_{th})^2 + (V_2 - V_{th})^2\}(1+\lambda V_{ds}) \cdots (8)$$

If $K_1 \neq K_2$

$$I_{OUT} = \{K_1(V_2 + V_P - V_{th})^2 + K_2(V_2 - V_{th})^2\}(1+\lambda V_{ds}) \cdots (9)$$

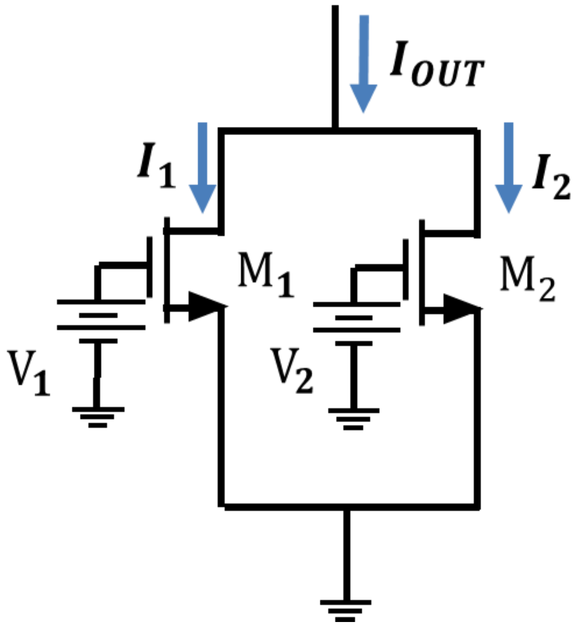
$V_1 > V_2$

$$(n = 1,2,3, \ldots\ldots)$$

$$(K = \frac{W}{2L}\mu C_{OX})$$

Approach to Concept Circuit

Propose circuit

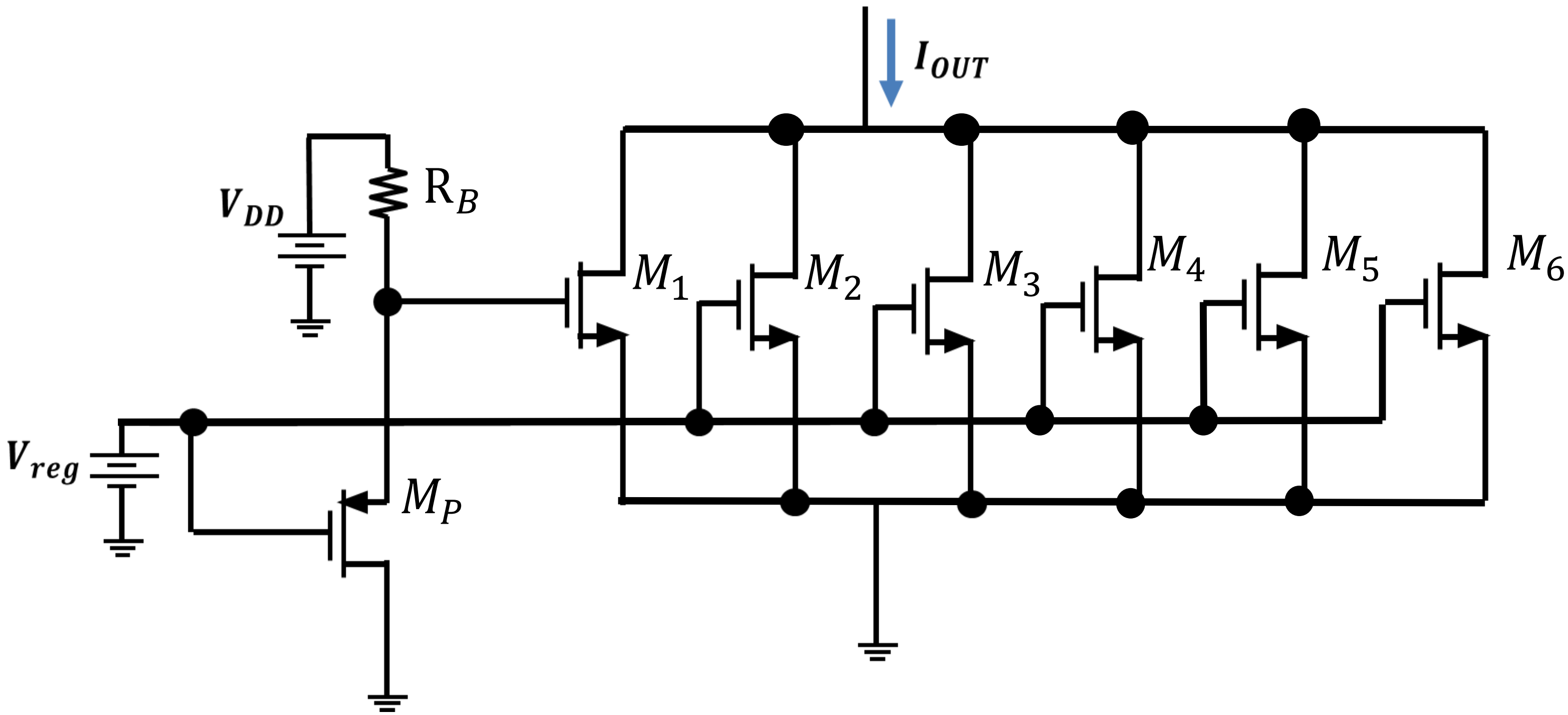


$V_1 > V_2$

How to apply bias voltage to MOS gate?

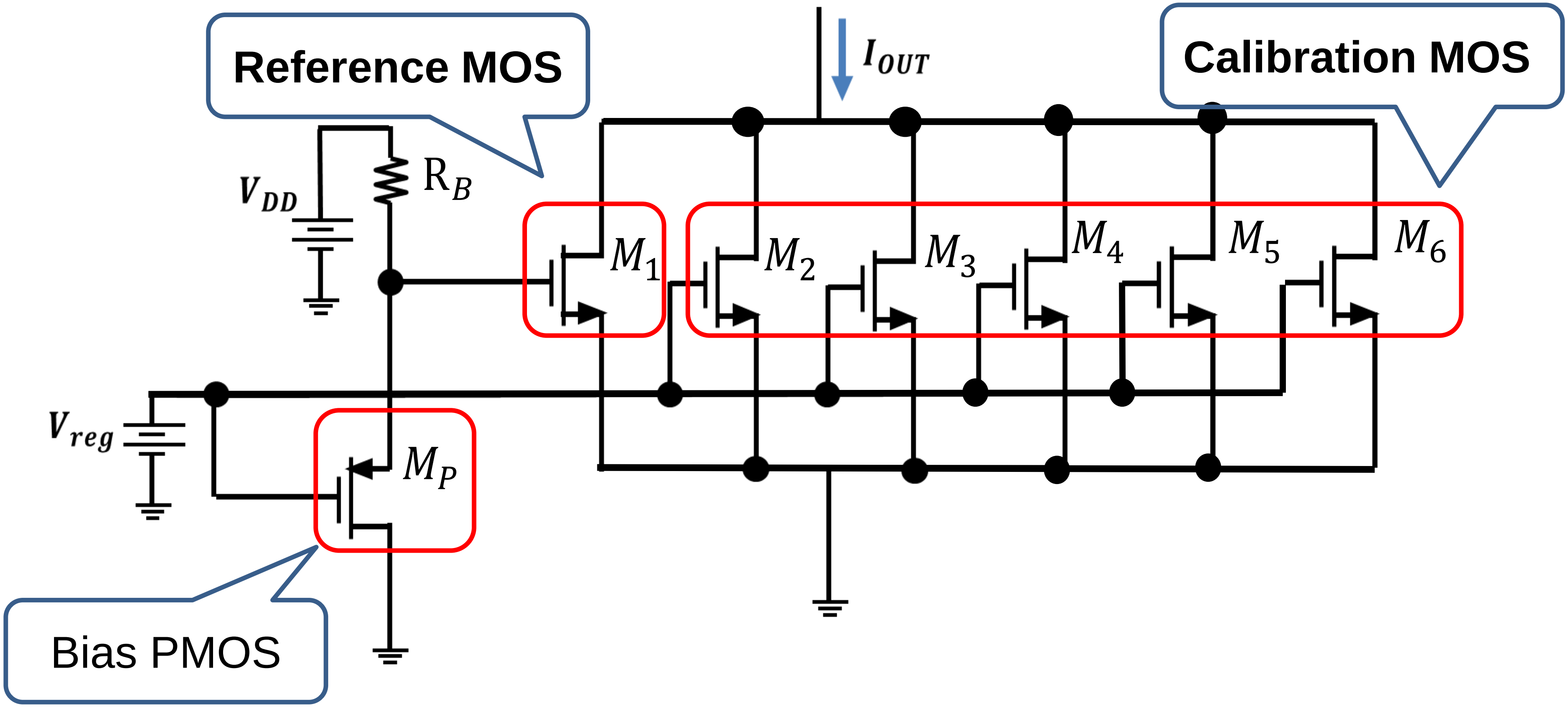
Proposed Circuit：1

Propose circuit：bias voltage by PMOS



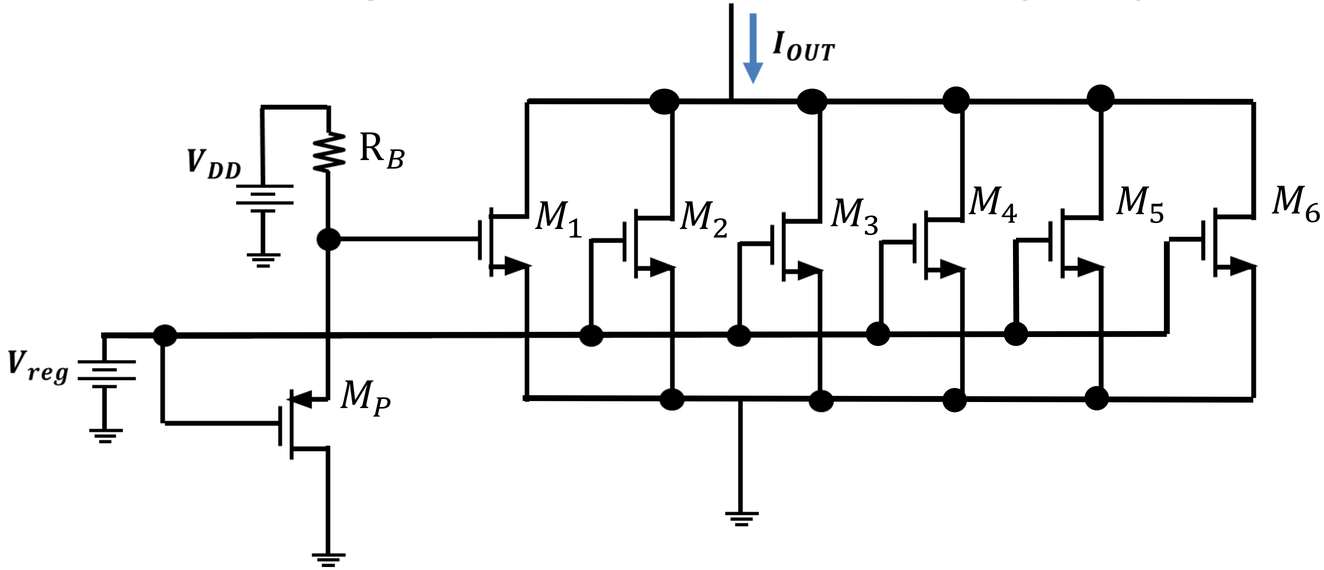
Circuit Content

Propose circuit：bias voltage by PMOS



Simulation Conditions

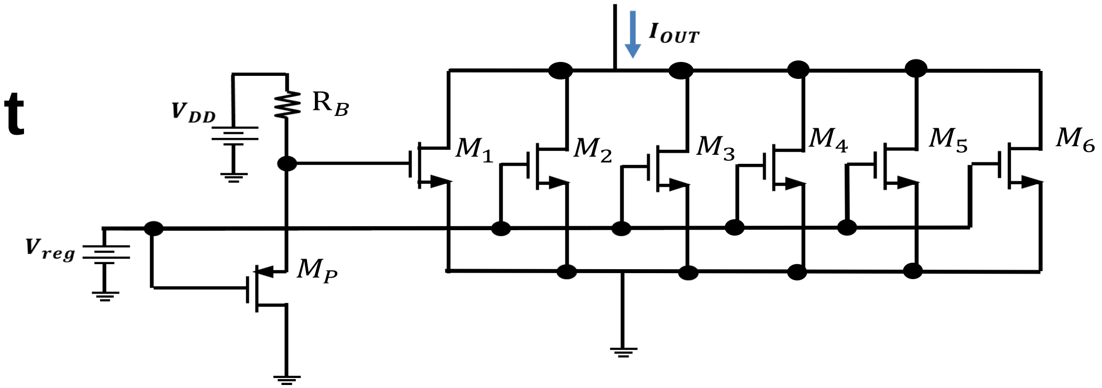
Propose circuit：bias voltage by PMOS

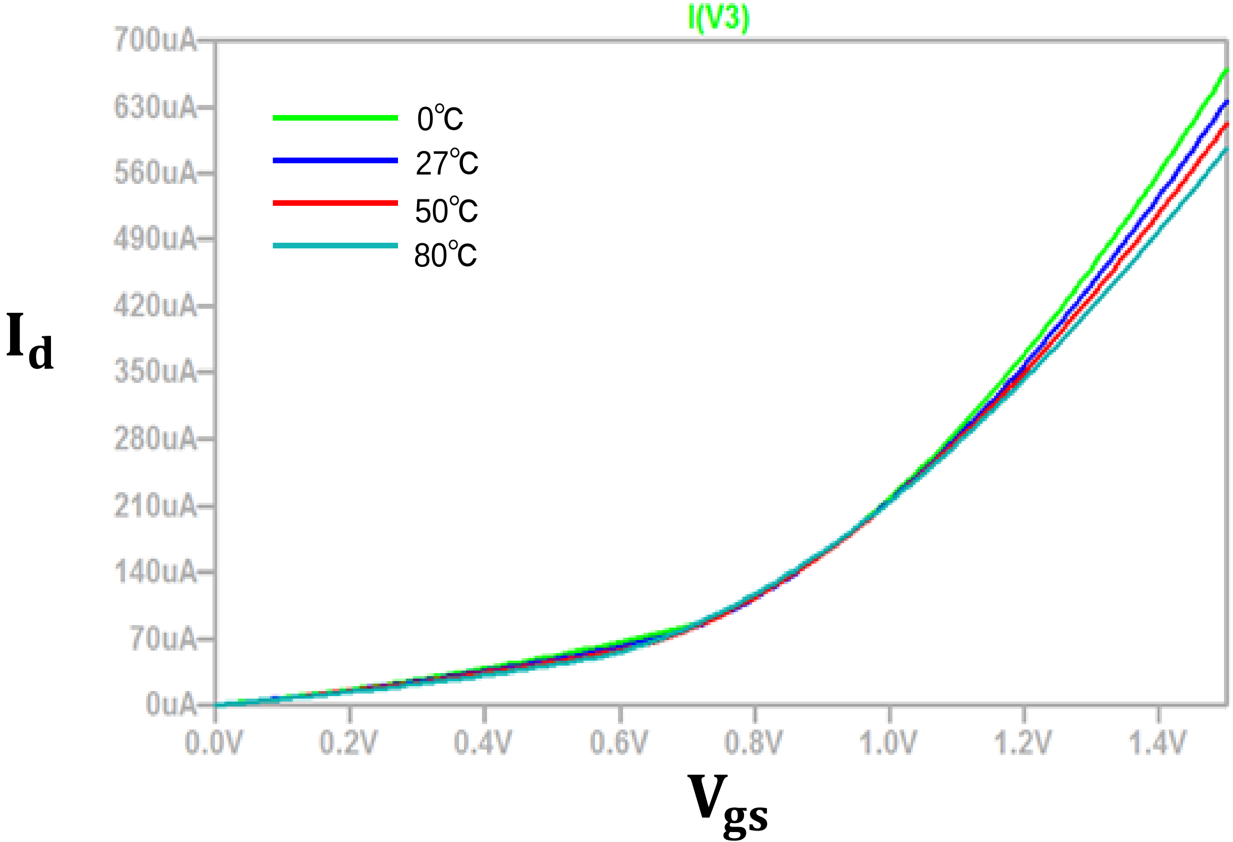


Parameter	Value
$M_1 \sim M_6$	W＝5[um],L=2[um]
M_P	W＝5[um],L=2[um]
R_B	100 [kΩ]
V_{DD}	3 [V]
V_{reg}	0～1.5 [V]
temperature	0, 27, 50, 80 [℃]

Simulation Result

Propose circuit

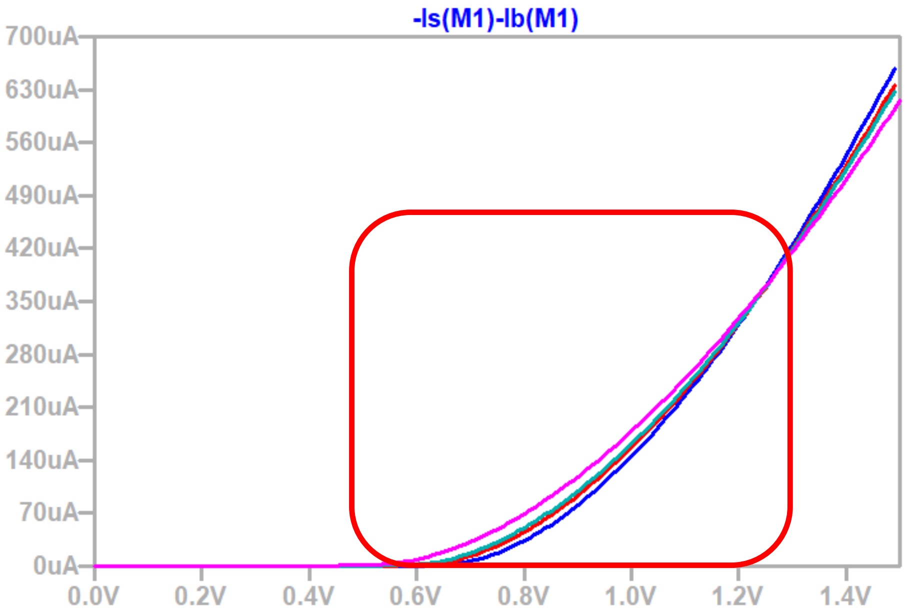




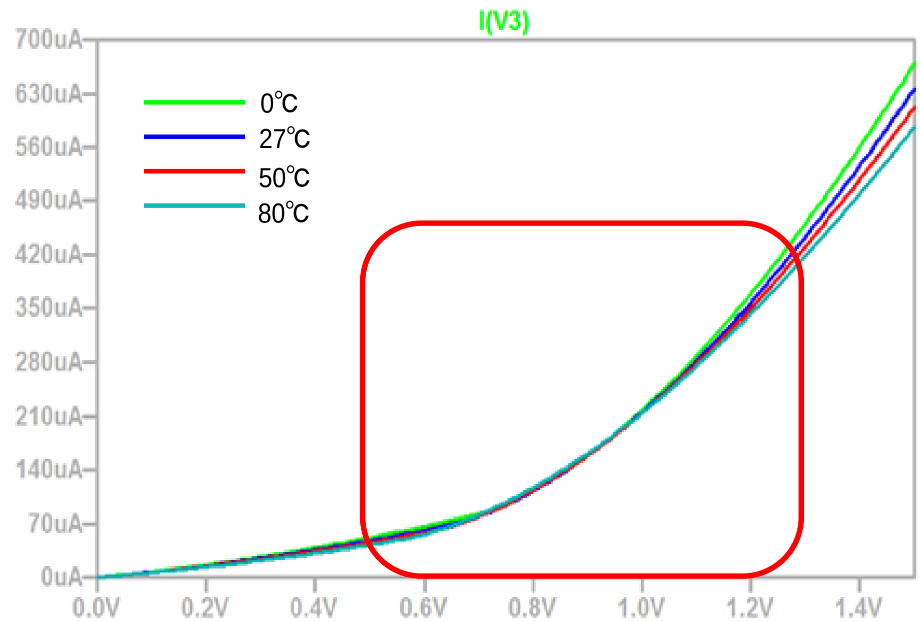
Comparison of Simulation Results

Adjust the aspect ratio

Before calibration



After calibration



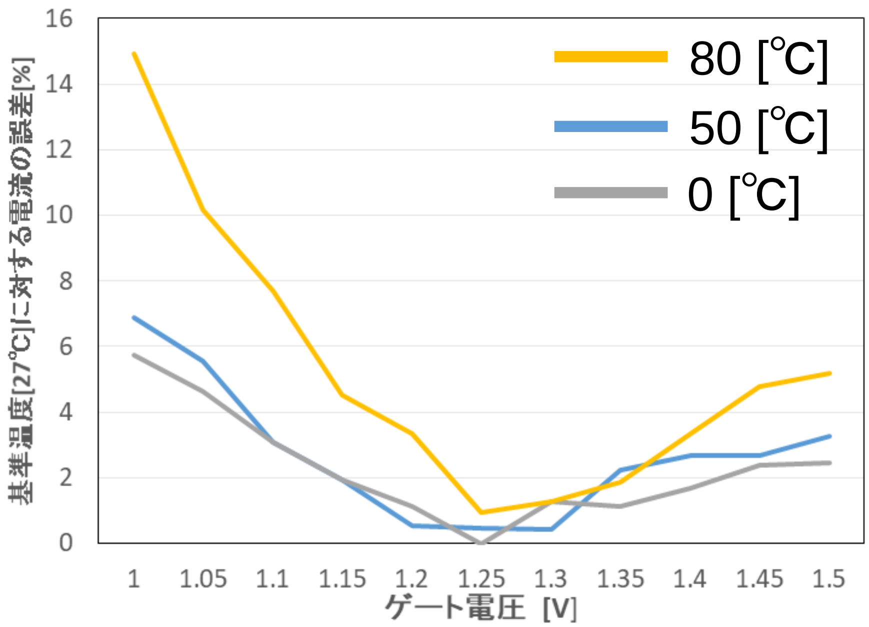
Extensive temperature characteristic calibration

Comparison of Variations

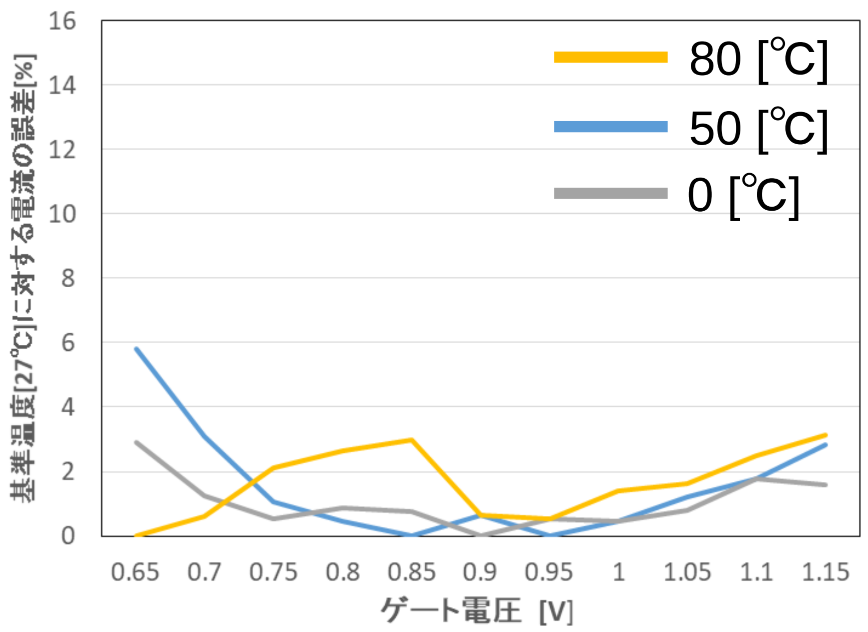
Evaluation formula

Based on 27 ℃ $$\frac{I_{OUT(27℃)} - I_{OUT(\text{comparison temperature})}}{I_{OUT(27℃)}} * 100[\%] \quad \cdots (10)$$

Before calibration



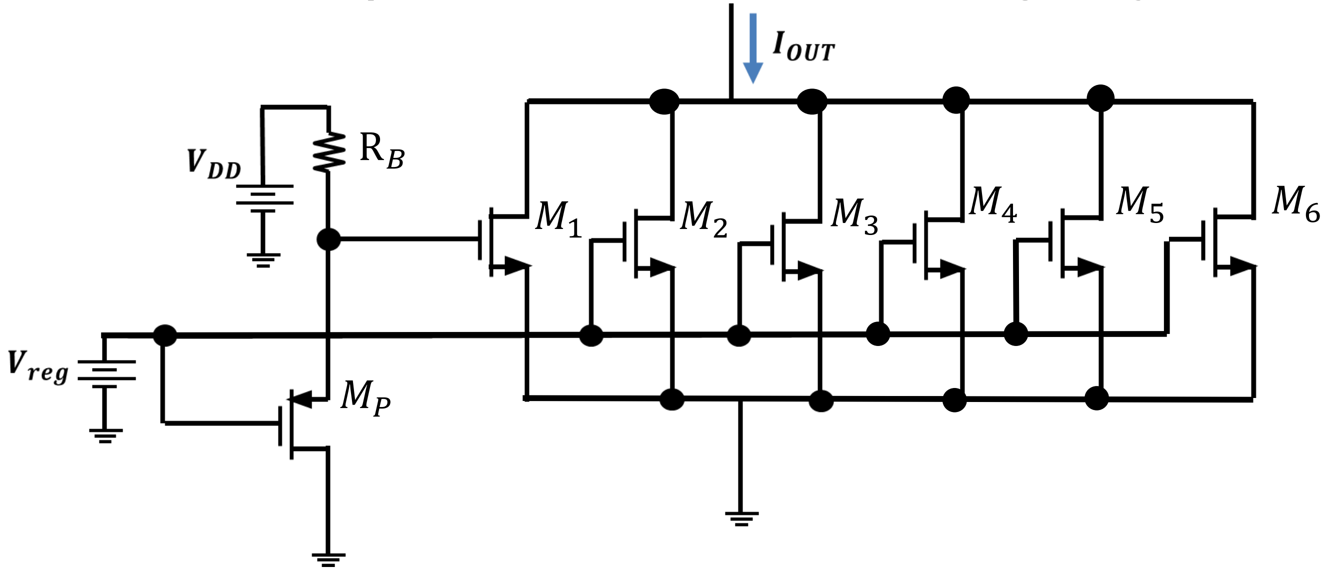
After calibration



Suppress temperature variation under wide range of gate voltage

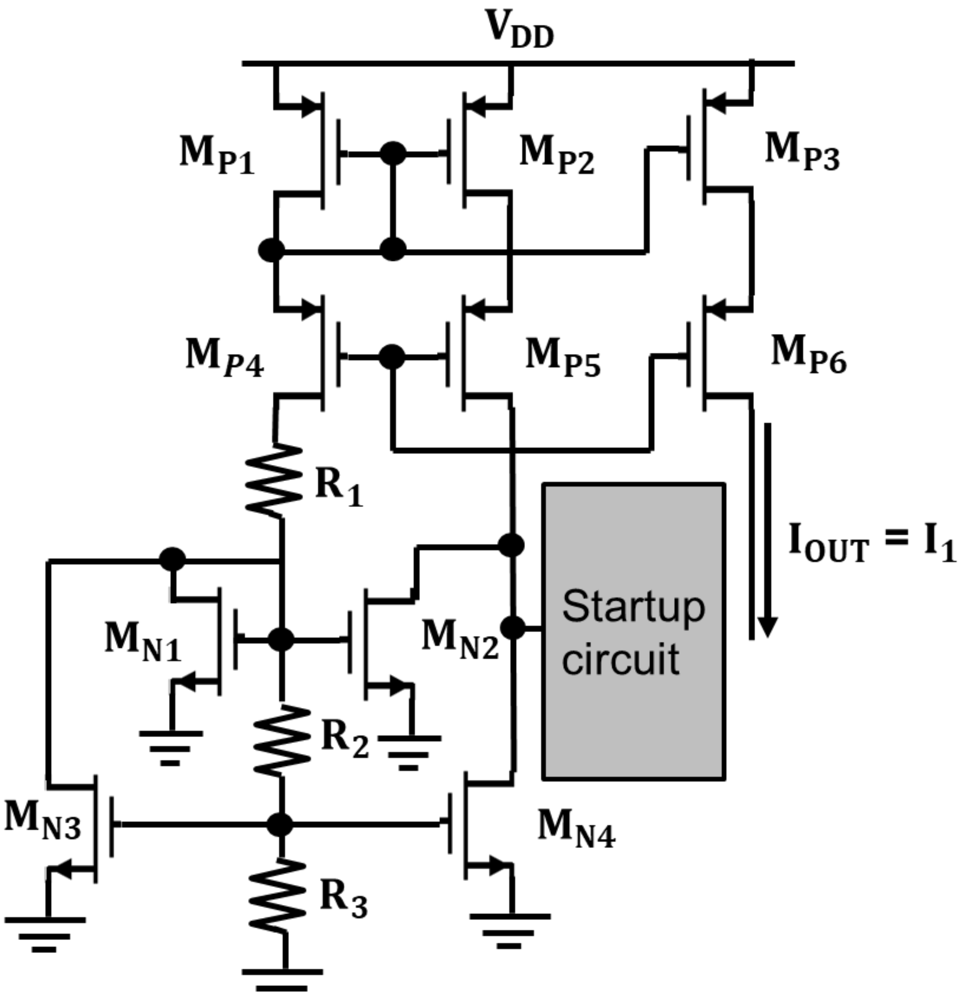
Simulation Conditions

Propose circuit：bias voltage by PMOS



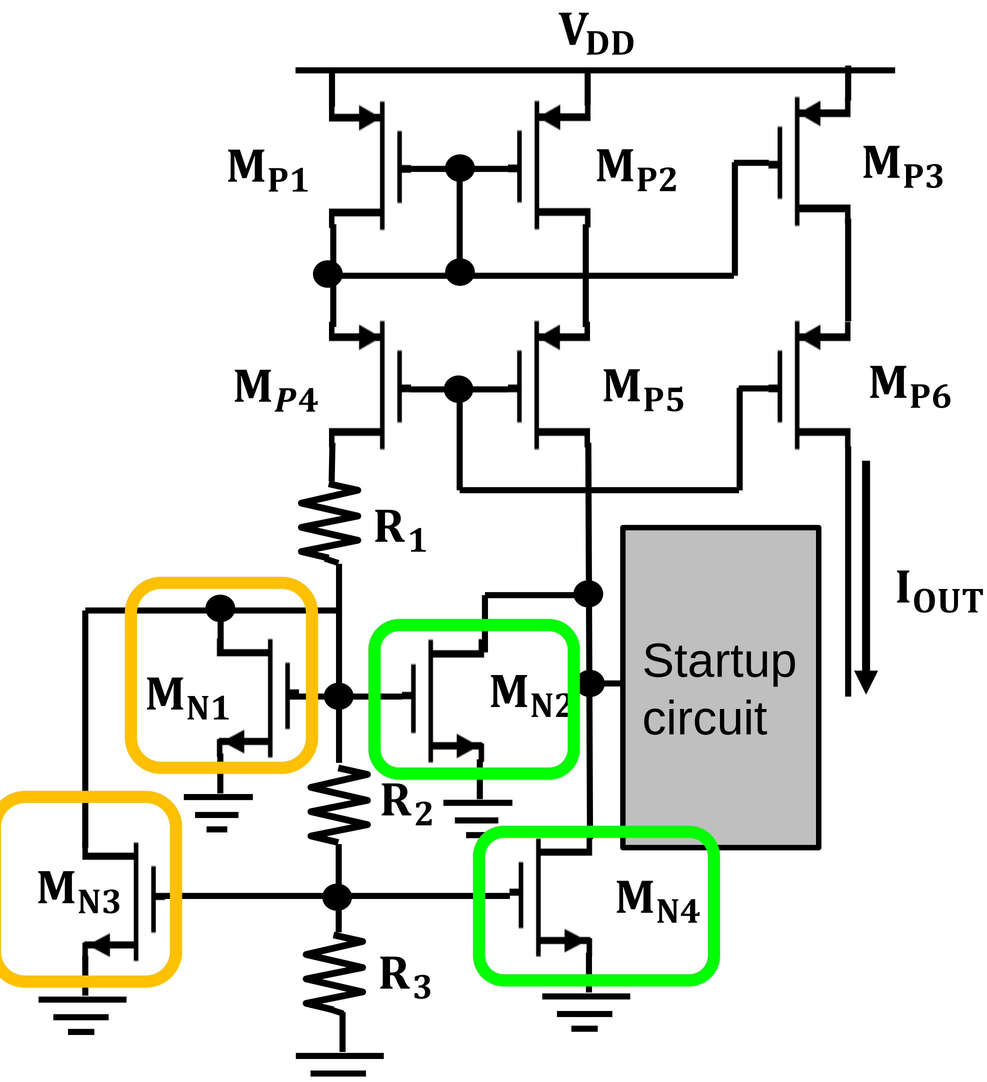
Parameter	Value
$M_1 \sim M_6$	W＝5[um],L=2[um]
M_P	W＝5[um],L=2[um]
R_B	100 [kΩ]
V_{DD}	3 [V]
V_{reg}	0～1.5 [V]
temperature	0, 27, 50, 80 [℃]

Proposed Circuit : 2



Parameter	Value
M_{P1}～M_{P6}	W＝40[um],L=2[um]
M_{N1}	W＝2[um],L=2[um]
M_{N2},M_{N3}	W＝40[um],L=2[um]
M_{N4}	W＝300[um],L=2[um]
R_1	4000[Ω]
R_2	2800[Ω]
R_3	2300[Ω]
V_{DD}	5 [V]

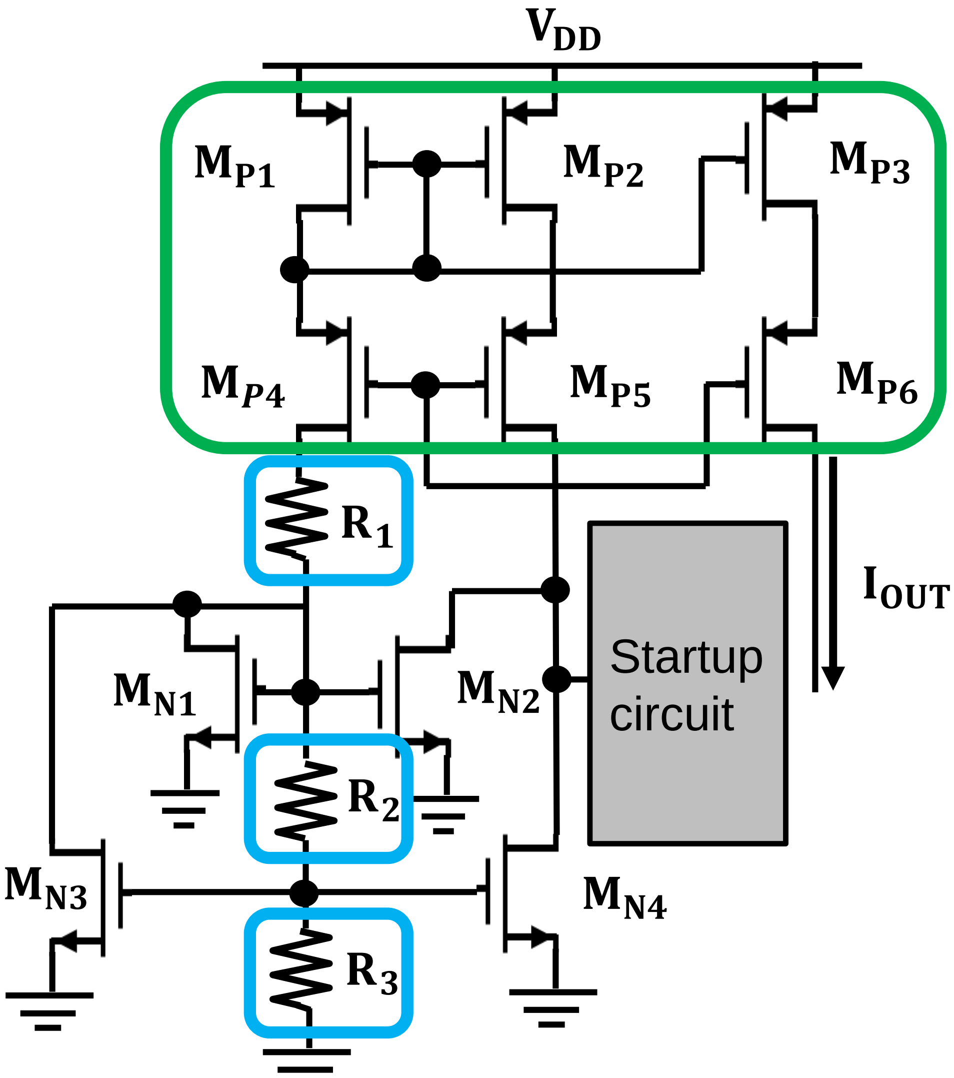
Role of NMOSFETs

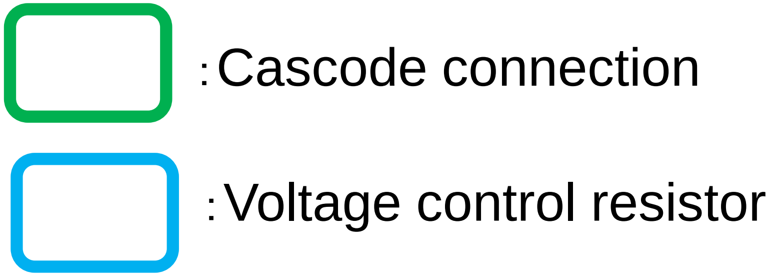


: Main current generating circuit

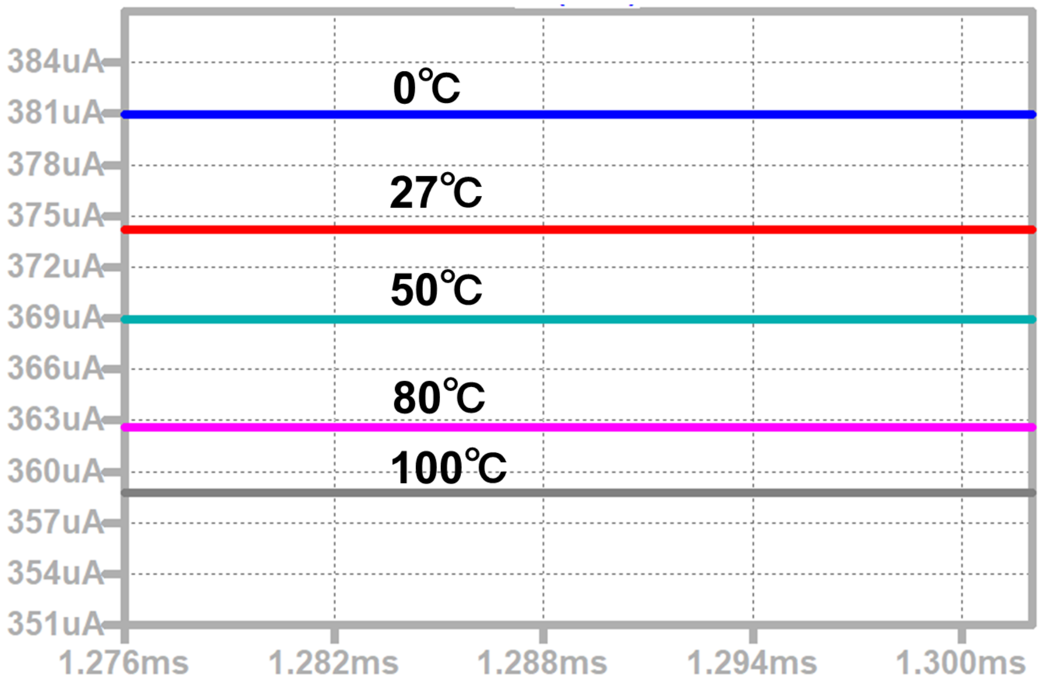
: For negative feedback

Role of Resistors, PMOSFETs





Simulation Result：Output Current



Temperature[%]	Value[uA]	Difference from 27℃[%]
0	381	1.9
27	374	0
50	369	1.3
80	363	2.9
100	359	4.0

Conclusion

- We proposed MOS reference current source insensitive to temperature variation
- Operation confirmation by SPICE simulation

Future works

- Proposal of circuit configuration independent of power supply voltage
- Circuit design and verification using JEDAT EDA
- Silicon verification of proposed circuit

Start up circuit

スタートアップ回路の参考

①がOFF状態

↓

T1がON

↓

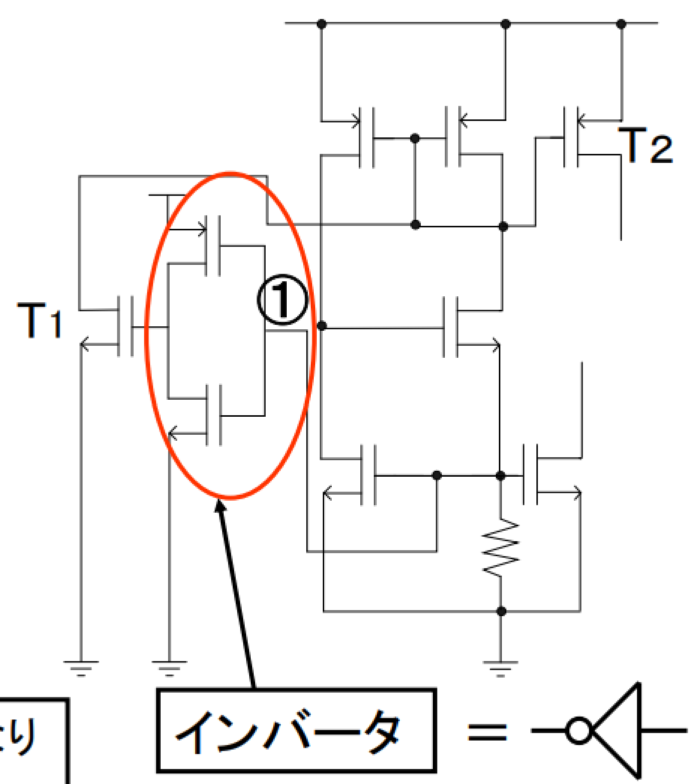
T1がONになり
回路の動作開始

ポイント

起動回路が動作すれば
右側の回路が動作

↓

すると起動回路が動作しなくなり
起動回路は関係なくなる



Reference model parameters

CMOS Circuit Design, Layout, and Simulation, Third Edition