Analog Circuit Session 2

Oct. 23, 2020
15:45 - 16:00

Improved Nagata Current Source Insensitive to Temperature and Power Supply Voltage

Takashi Hosono, L. Sha, S. Yamamoto, M. Hirano,
T. Ida, A. Kuwana, H. Kobayashi,
Y. Moroshima, H. Harakawa, T. Oikawa

Gunma University
ASO Corp.

Outline

- Research Background and Objective
- Original Nagata Current Source
- Improvement to Supply Voltage Insensitivity
- Improvement to Temperature Insensitivity
- Simulation Verification
- Conclusion

Outline

- **Research Background and Objective**
- Original Nagata Current Source
- Improvement to Supply Voltage Insensitivity
- Improvement to Temperature Insensitivity
- Simulation Verification
- Conclusion

Research Background

Analog ICs require

Reference current / voltage source

Stable against PVT variation

P: Process
V: Supply voltage
T: Temperature

Bandgap reference circuit

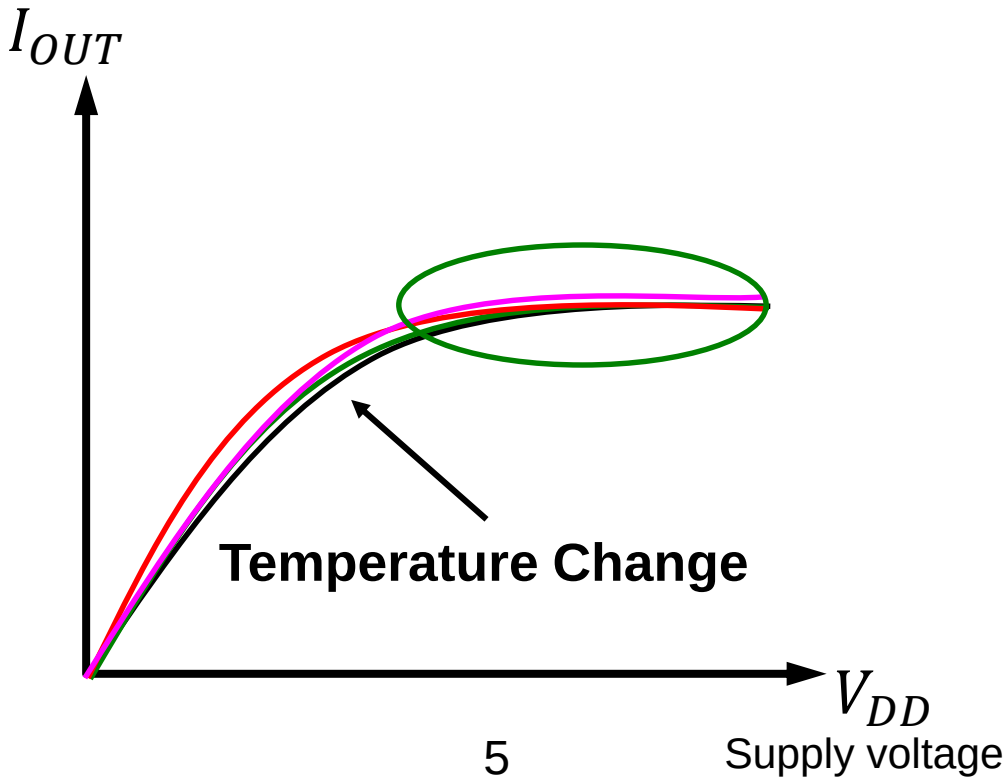
- **Complicated**
- **Large chip area**

Nagata current source

- **Simple, No start-up circuit**
- **Insensitive to supply voltage**

Research Objective

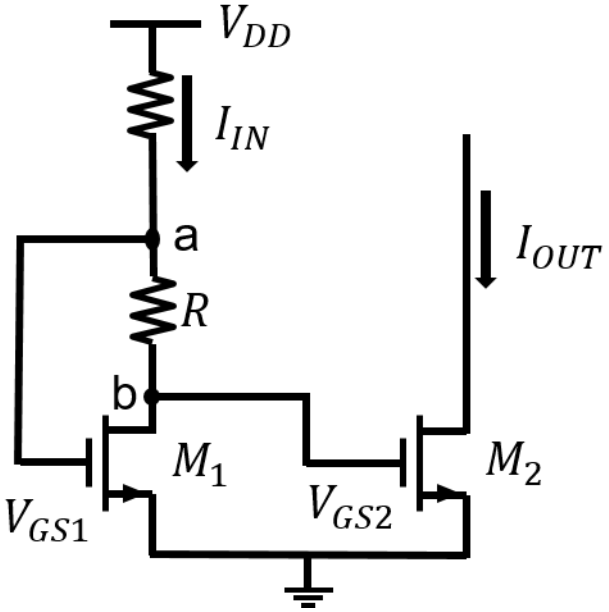
Improvement of Nagata current source insensitive to temperature as well as supply voltage



Outline

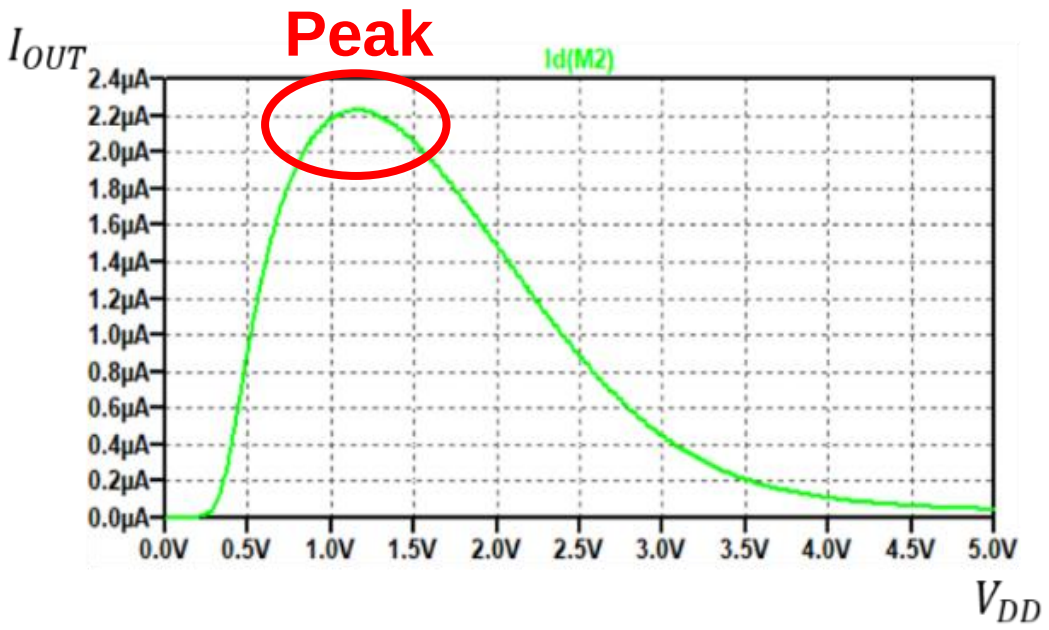
- Research Background and Objective
- **Original Nagata Current Source**
- Improvement to Supply Voltage Insensitivity
- Improvement to Temperature Insensitivity
- Simulation Verification
- Conclusion

Original Nagata Current Source



Nagata current source

[1] Inventor M. Nagata, Japanese Patent, Showa 46-16463 (Dec. 12, 1966)

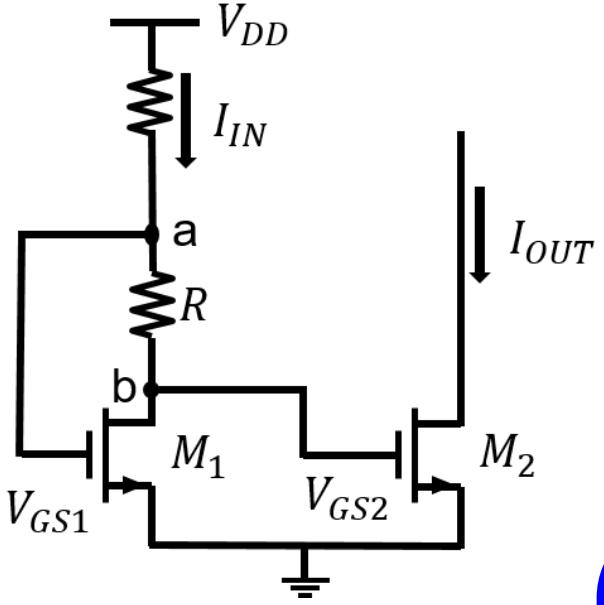


At peak vicinity

Small I_{OUT} change against V_{DD} change

Simple ➡ **Widely used. Ex: in DC-DC converter IC**

Reason for having a peak (1)

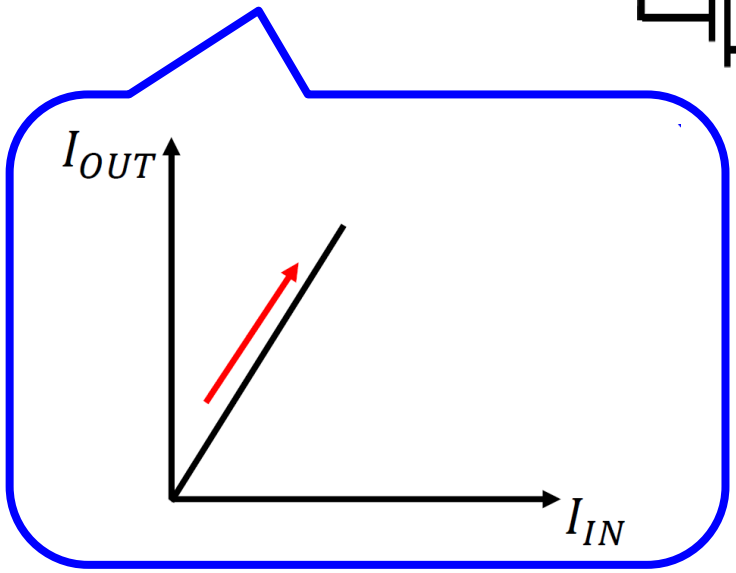


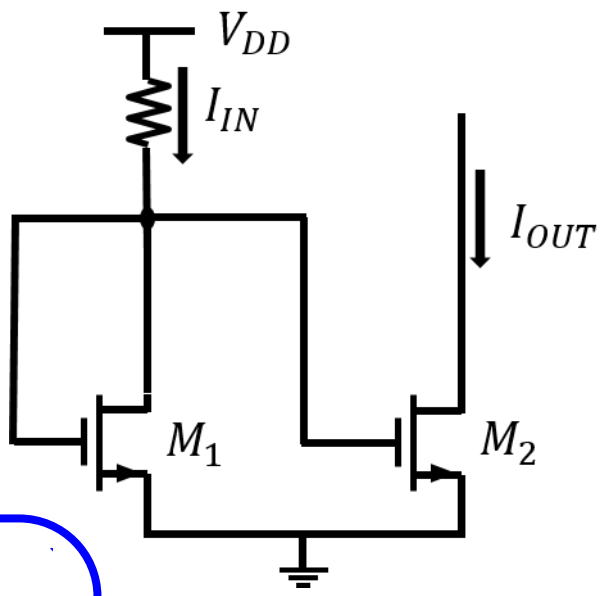
Nagata current source

I_{IN}: small

RI_{IN}: small

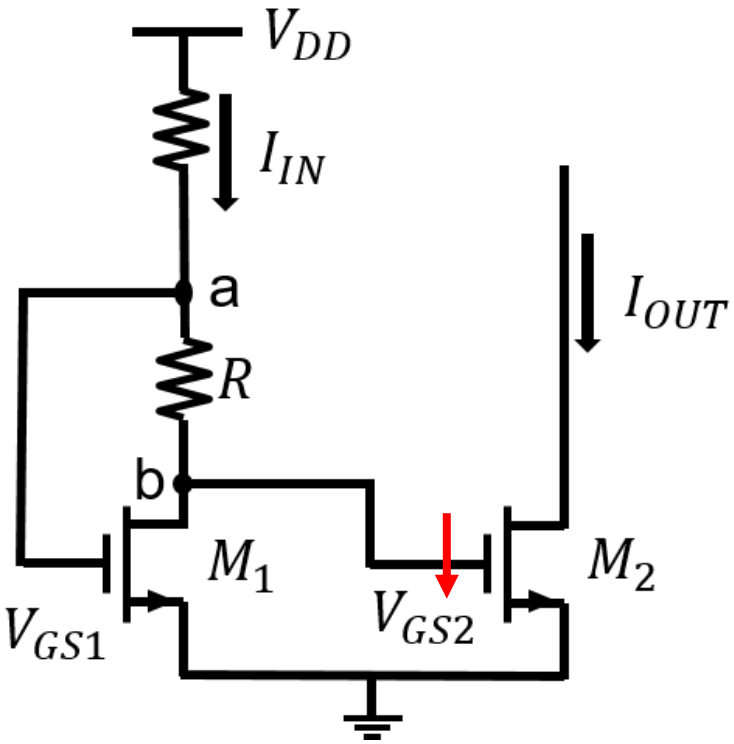
$I_{IN} = I_{OUT}$





Current Mirror

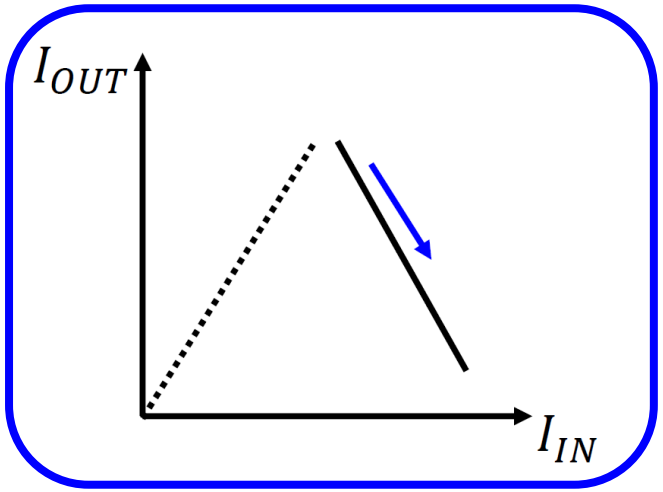
Reason for having a peak (2)



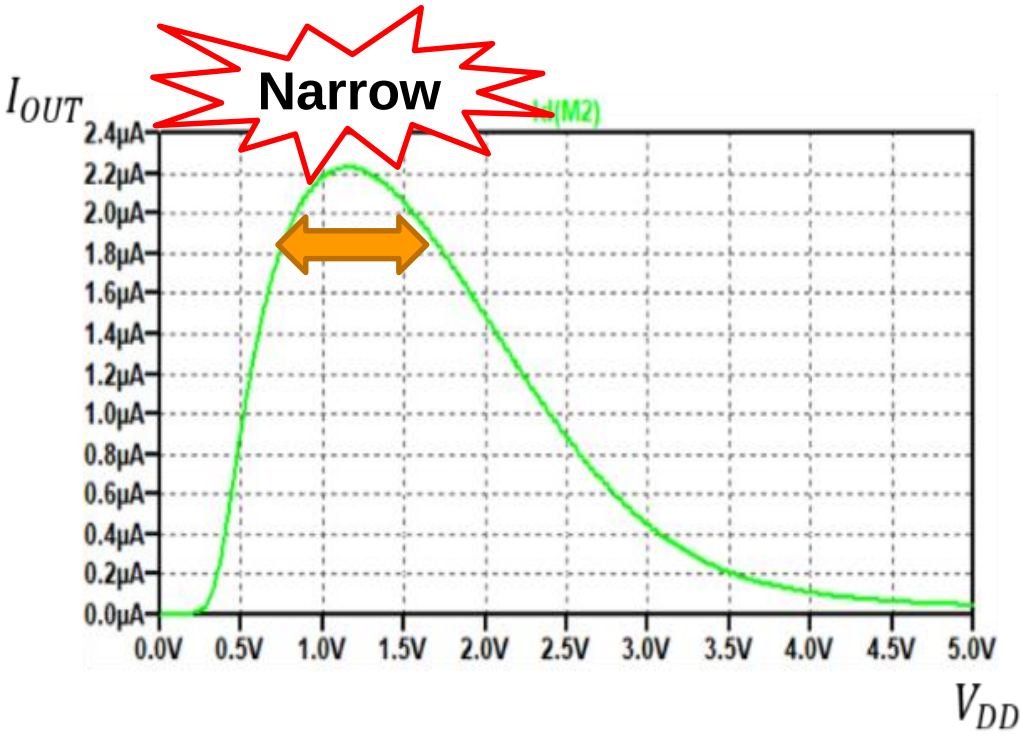
I_{IN}: large

⇒ RI_{IN}: large

⇒ V_{GS2} becomes smaller



Improvement to Widen Flat Range



Point

Peak vicinity is narrow → Wider

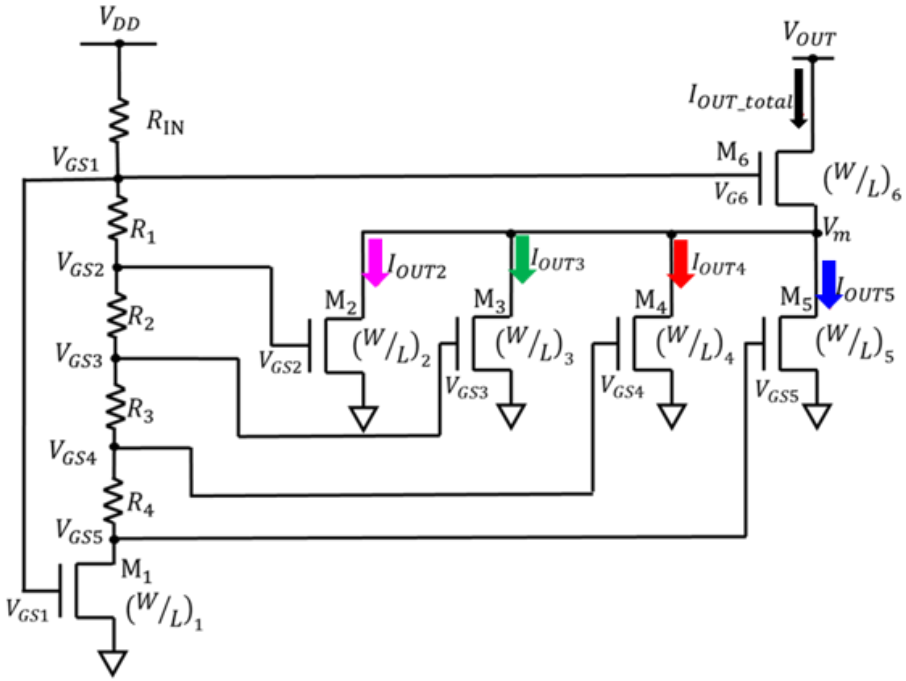
Our Approach

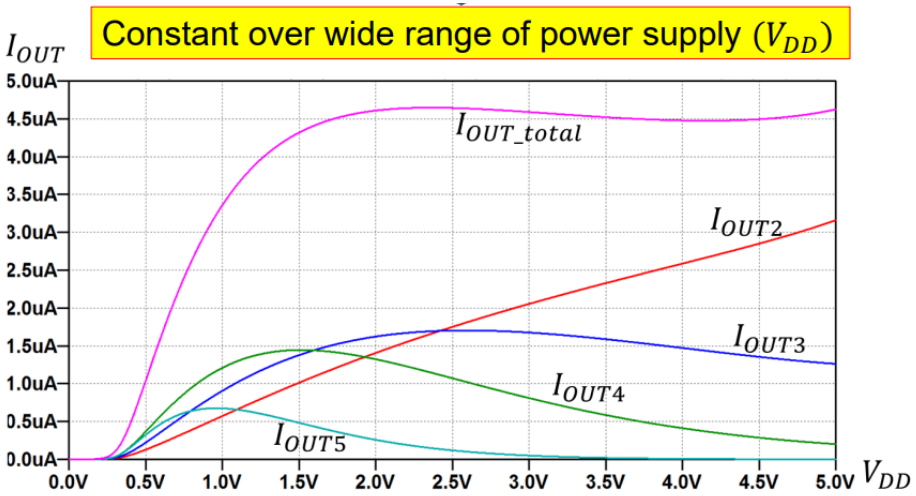
Use multiple current peaks and their sum.

Outline

- Research Background and Objective
- Original Nagata Current Source
- **Improvement to Supply Voltage Insensitivity**
- Improvement to Temperature Insensitivity
- Simulation Verification
- Conclusion

Widened Flat Range

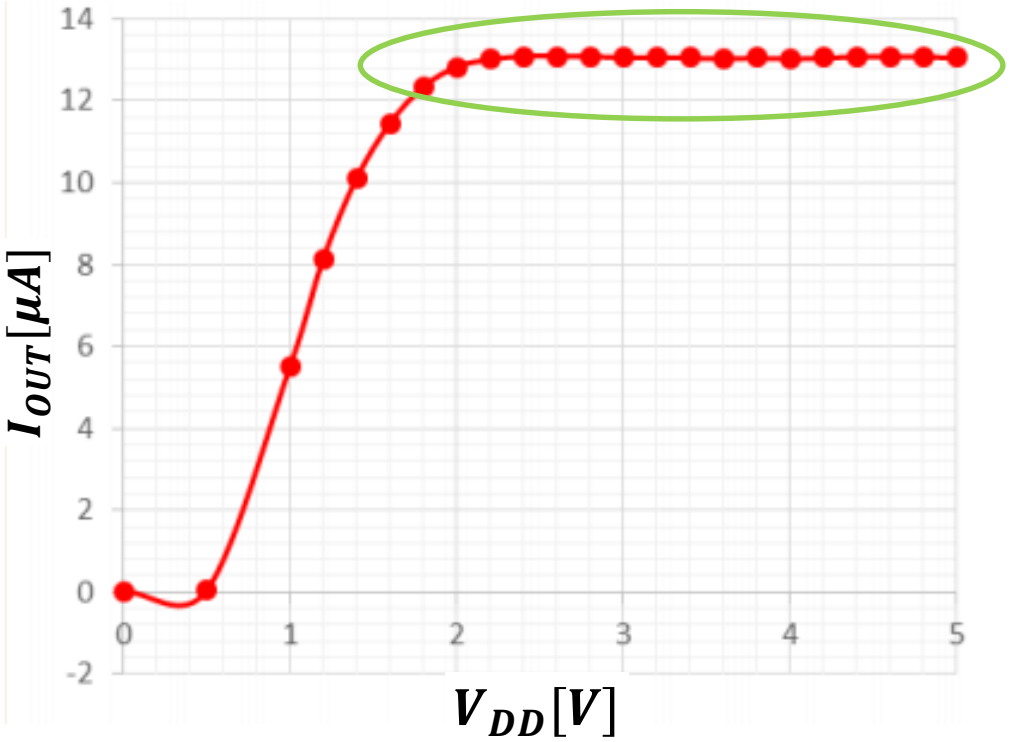


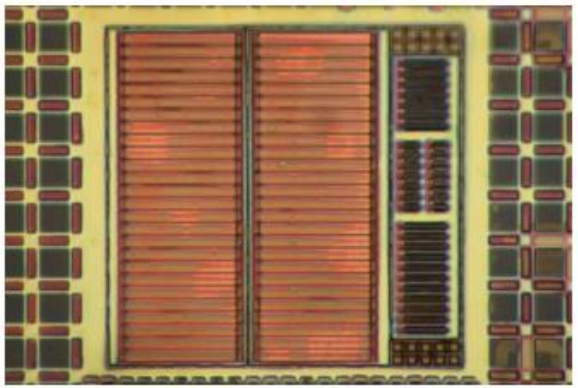


Using multiple current peaks and their sum

[2] M. Hirano, N. Tsukiji, H. Kobayashi, "Simple Reference Current Source Insensitive to Power Supply Voltage Variation - Improved Minoru Nagata Current Source", IEEE 13th International Conference on Solid-State and Integrated Circuit Technology, Hangzhou, China (Oct. 2016)

Measurements of Supply Voltage Sensitivity

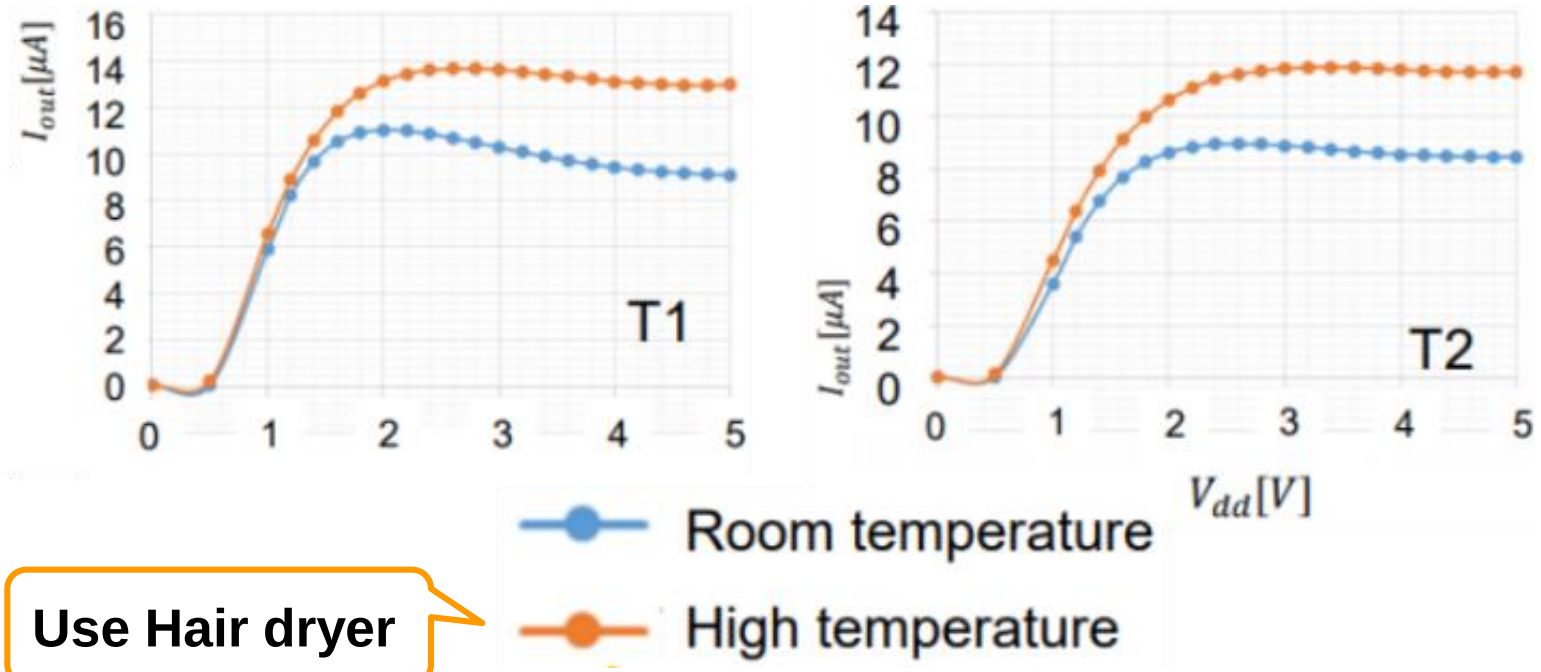




Total output current is constant against V_{DD} variation

[3] M. Hirano, N. Kushita, Y. Moroshima, H. Harakawa, T. Oikawa, N. Tsukiji, T. Ida, Y. Shibasaki, H. Kobayashi, "Silicon Verification of Improved Nagata Current Mirrors", IEEE 14th International Conference on Solid-State and Integrated Circuit Technology, Qingdao, China (Nov. 2018)

Measurements of Temperature Sensitivity



Use Hair dryer

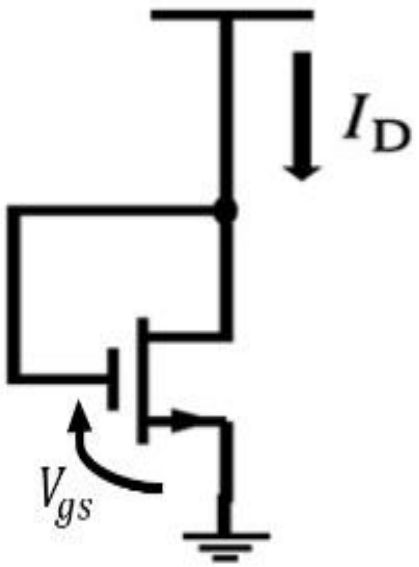
Problem !

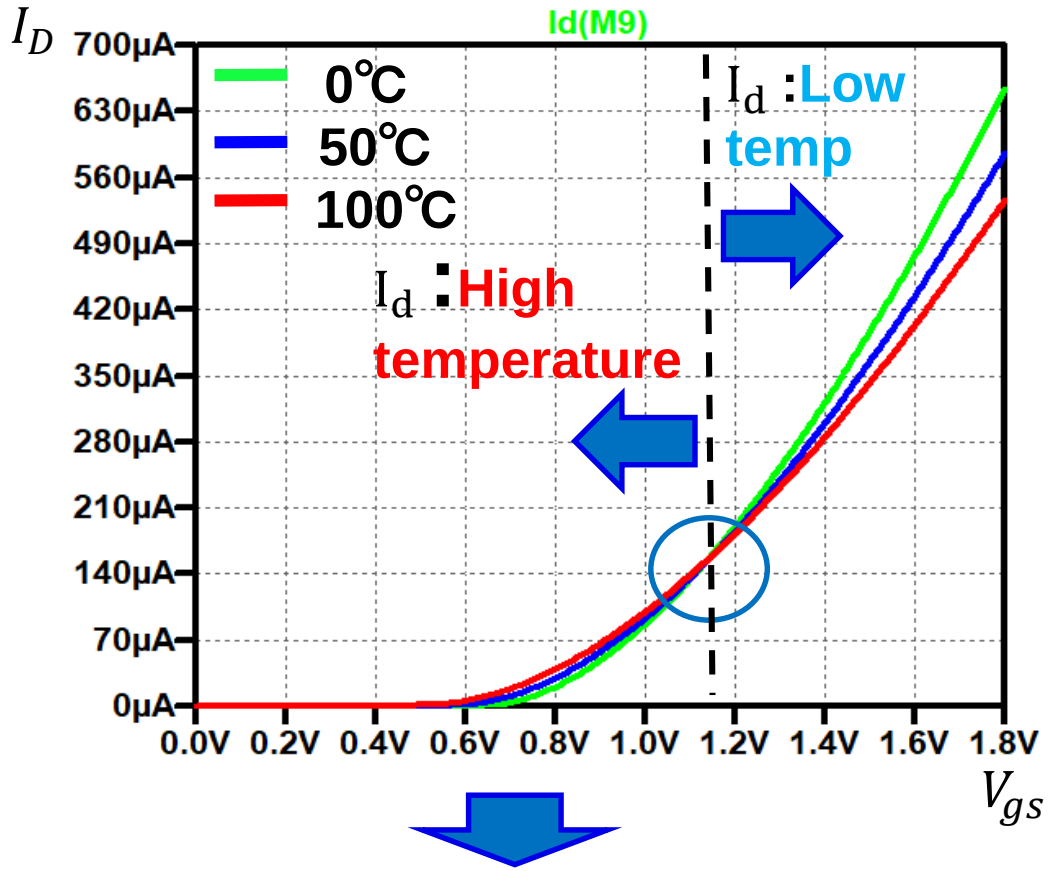
Need for improvement

Outline

- Research Background and Objective
- Original Nagata Current Source
- Improvement to Supply Voltage Insensitivity
- **Improvement to Temperature Insensitivity**
- Simulation Verification
- Conclusion

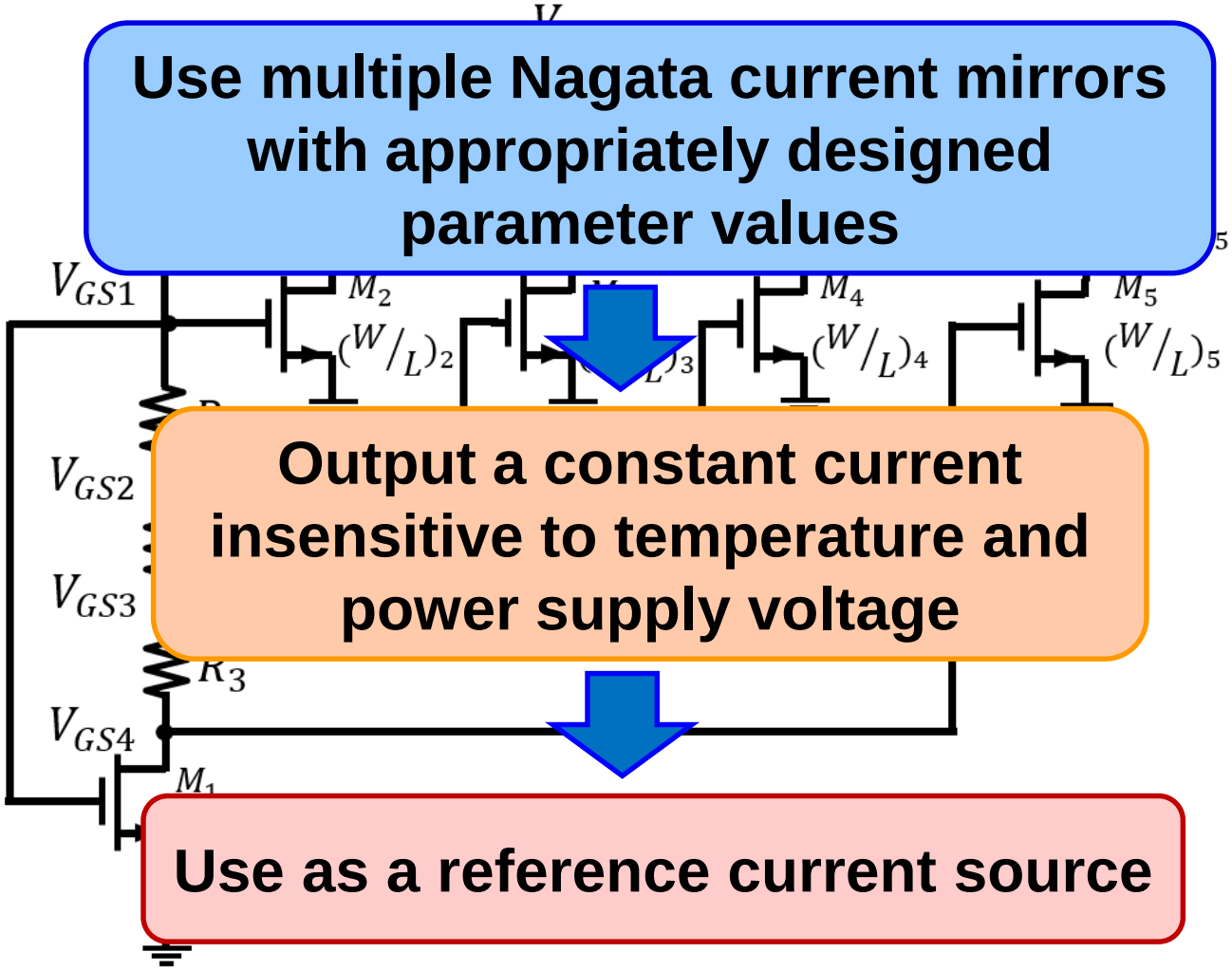
MOSFET Temperature Characteristics



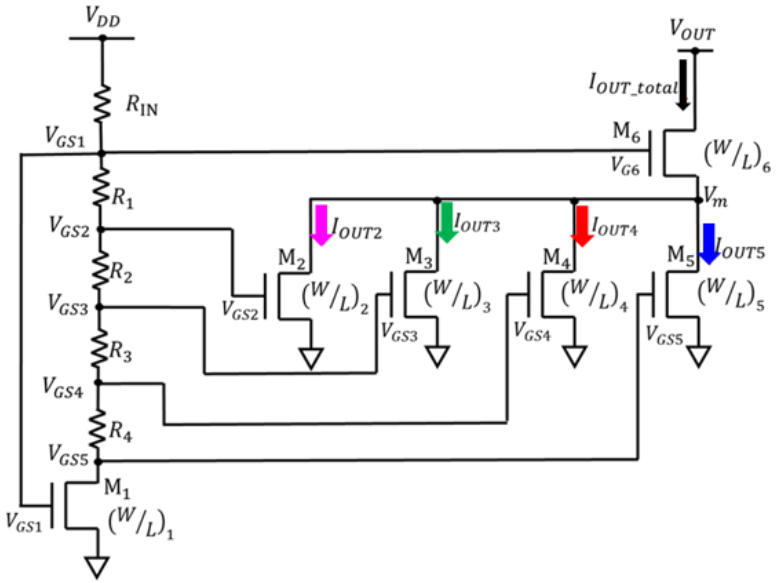


Utilize for temperature-insensitive reference current source

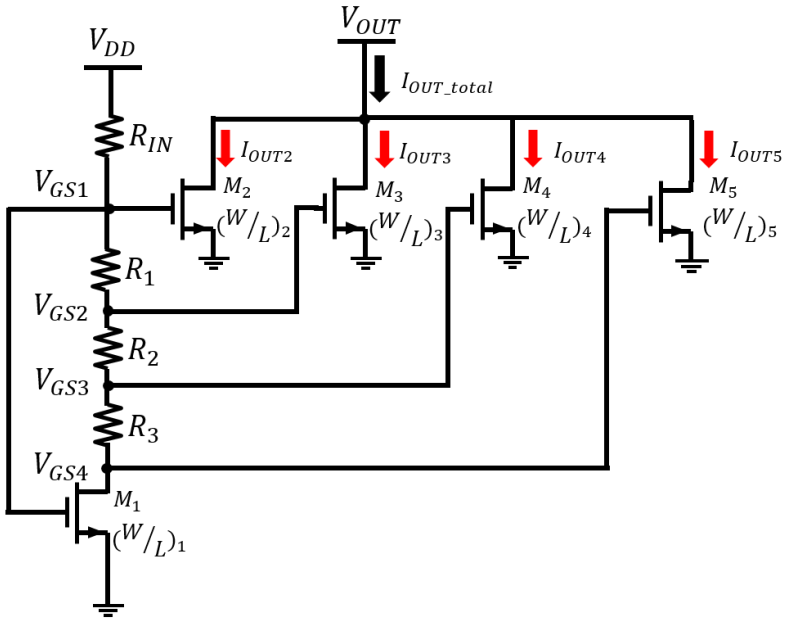
Proposed Reference Current Source



Comparison



Insensitive to supply voltage



Insensitive to temperature as well as supply voltage

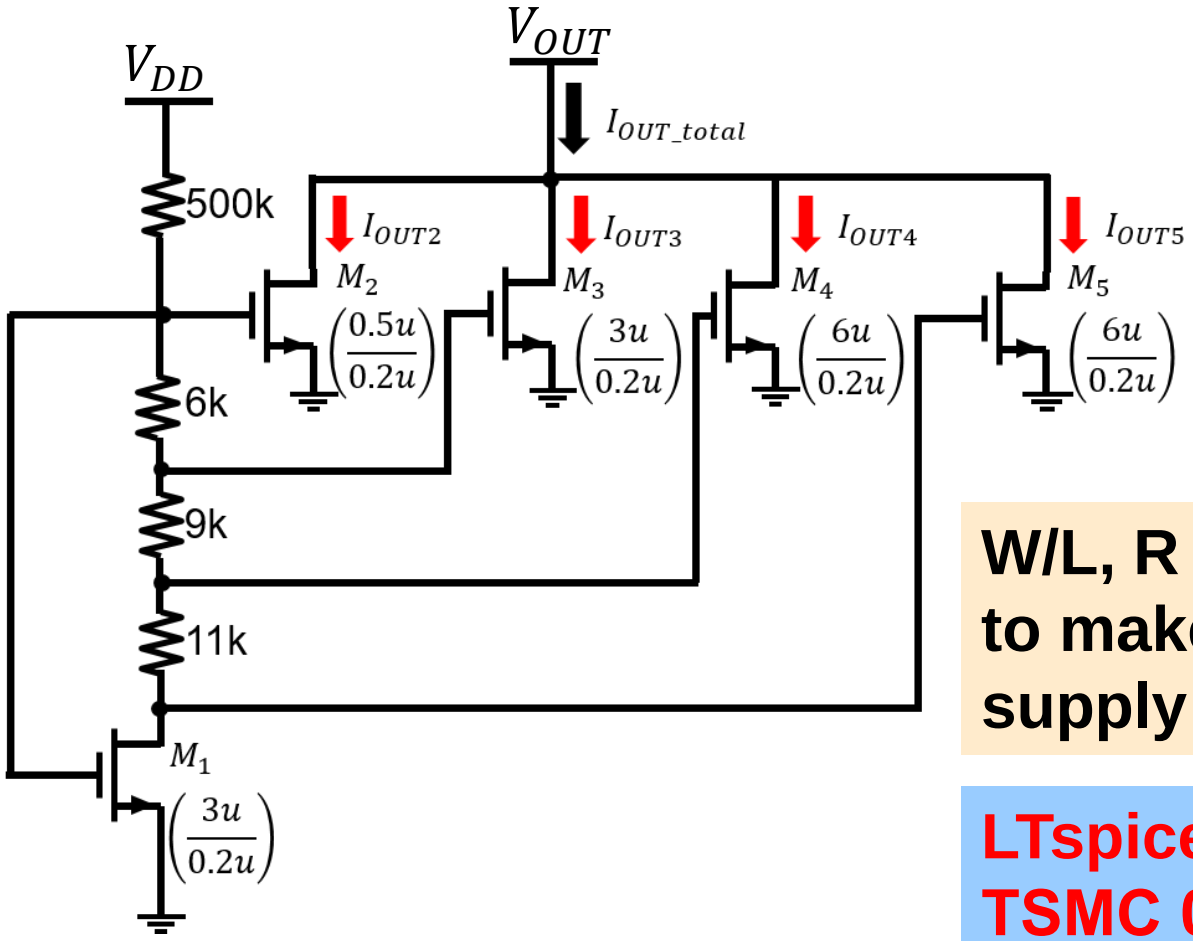
Careful design of W/L, R values

Basically, the same circuit topology

Outline

- Research Background and Objective
- Original Nagata Current Source
- Improvement to Supply Voltage Insensitivity
- Improvement to Temperature Insensitivity
- **Simulation Verification**
- Conclusion

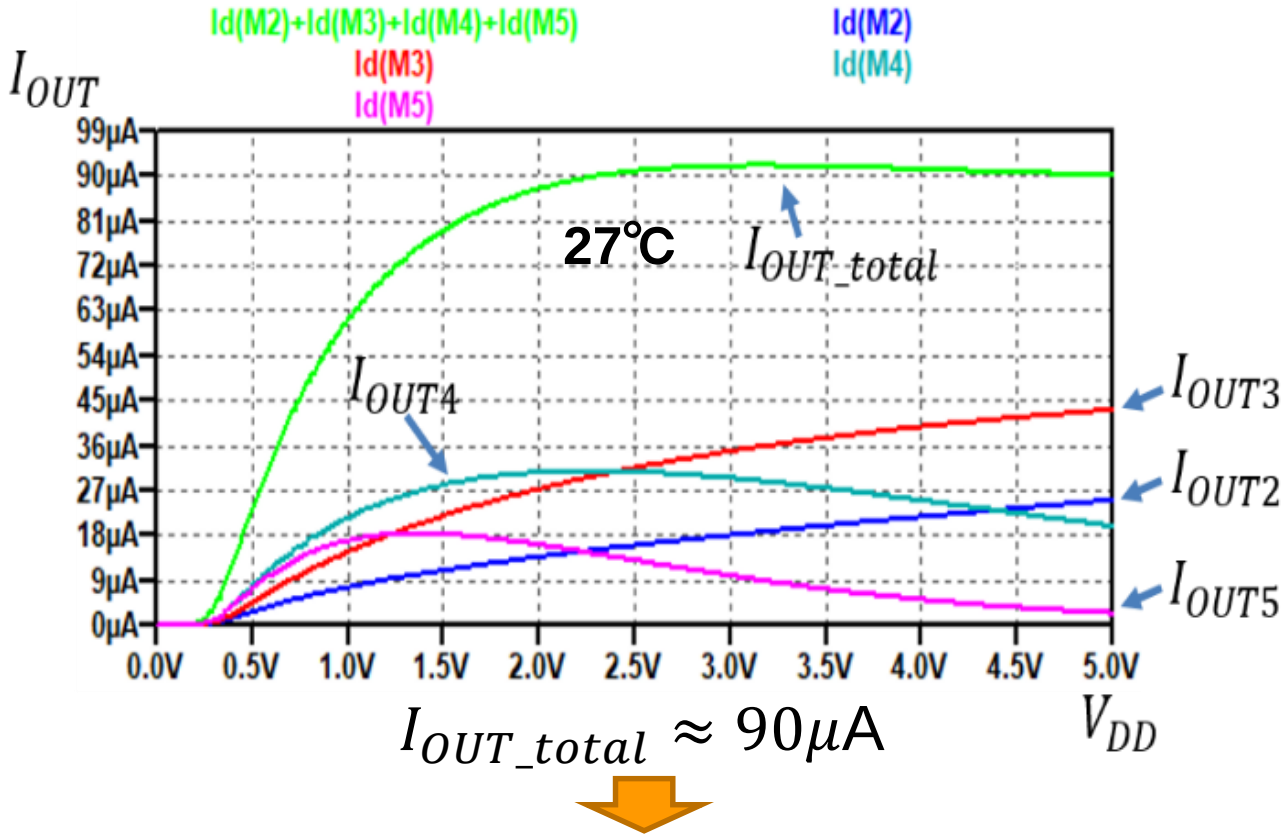
SPICE Simulation Circuit



W/L, R values are designed to make *I*OUT temperature-, supply voltage-insensitive.

LTspice
TSMC 0.18μm MOS model

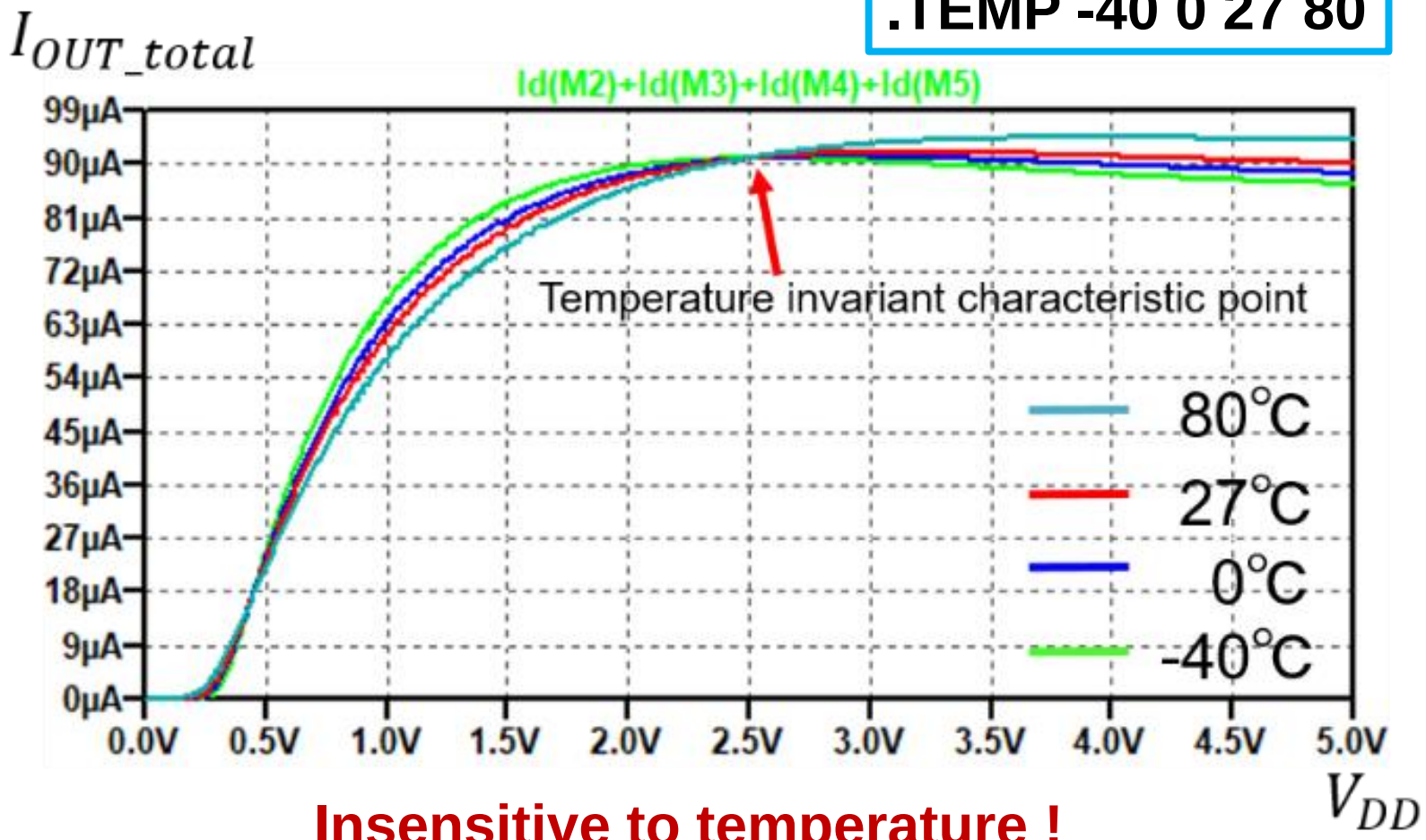
Simulation for Supply Voltage



Total output current is constant over wide range of supply voltage

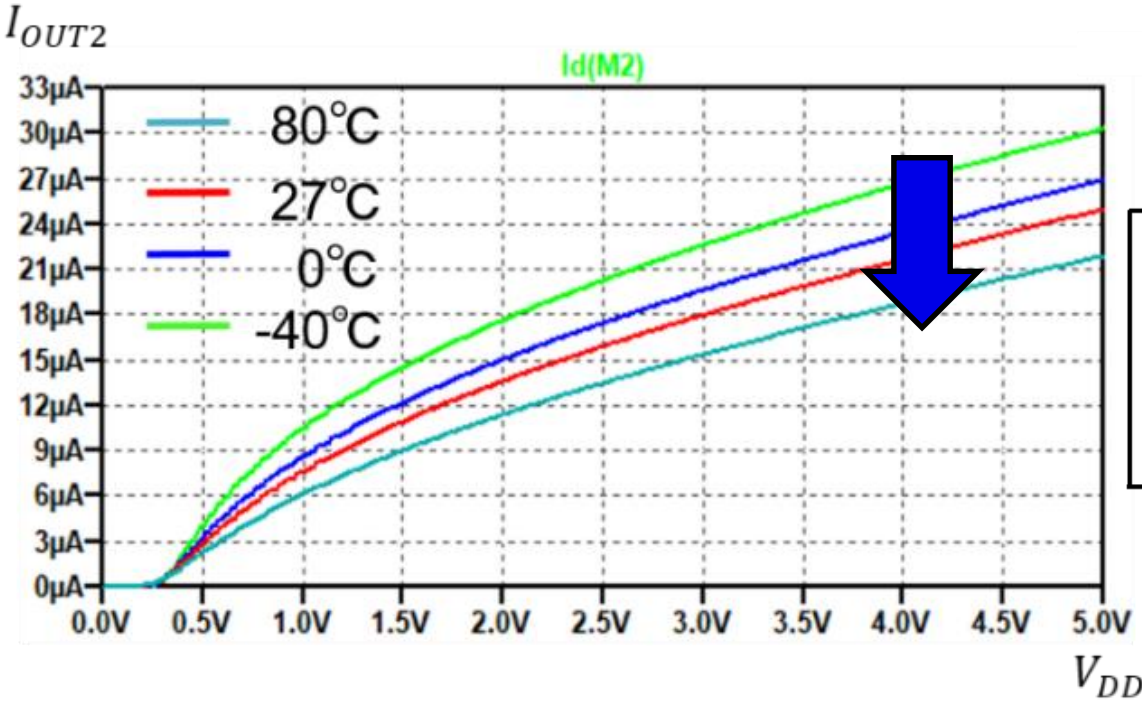
Simulation Result for Temperature

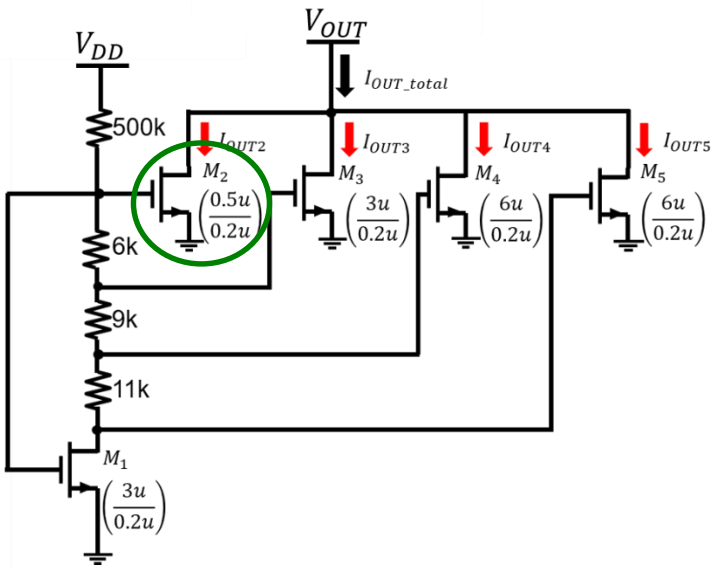
.TEMP -40 0 27 80



Insensitive to temperature !

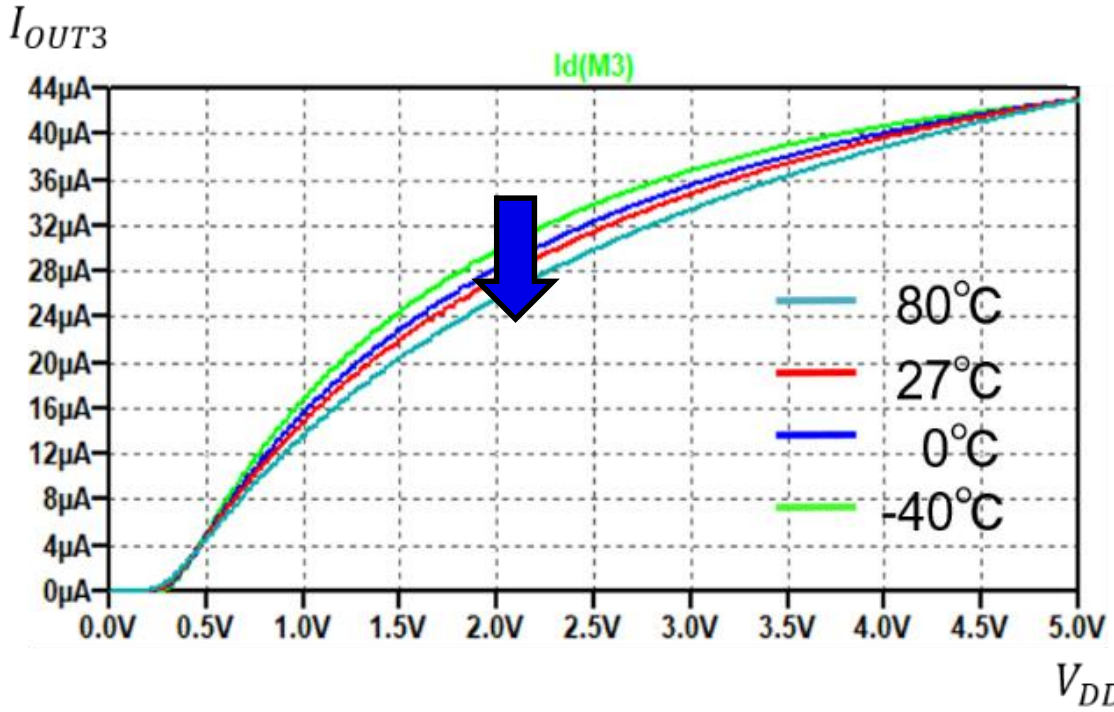
Analysis: M2 drain current

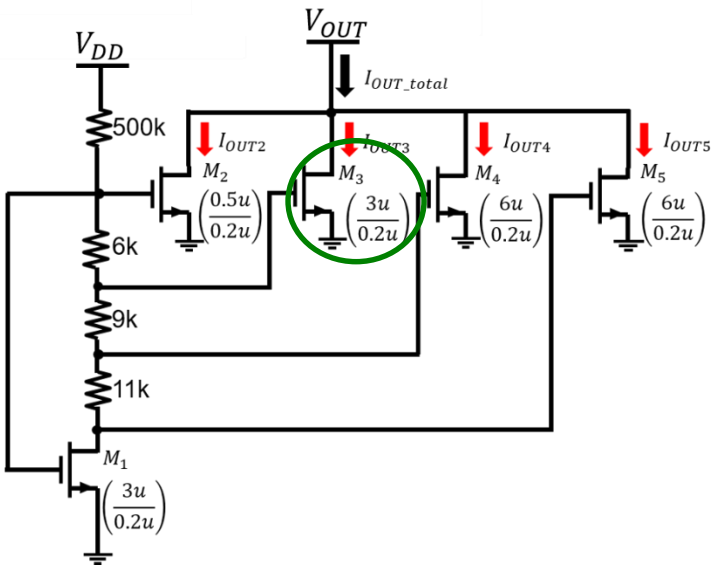




Negative temperature characteristics

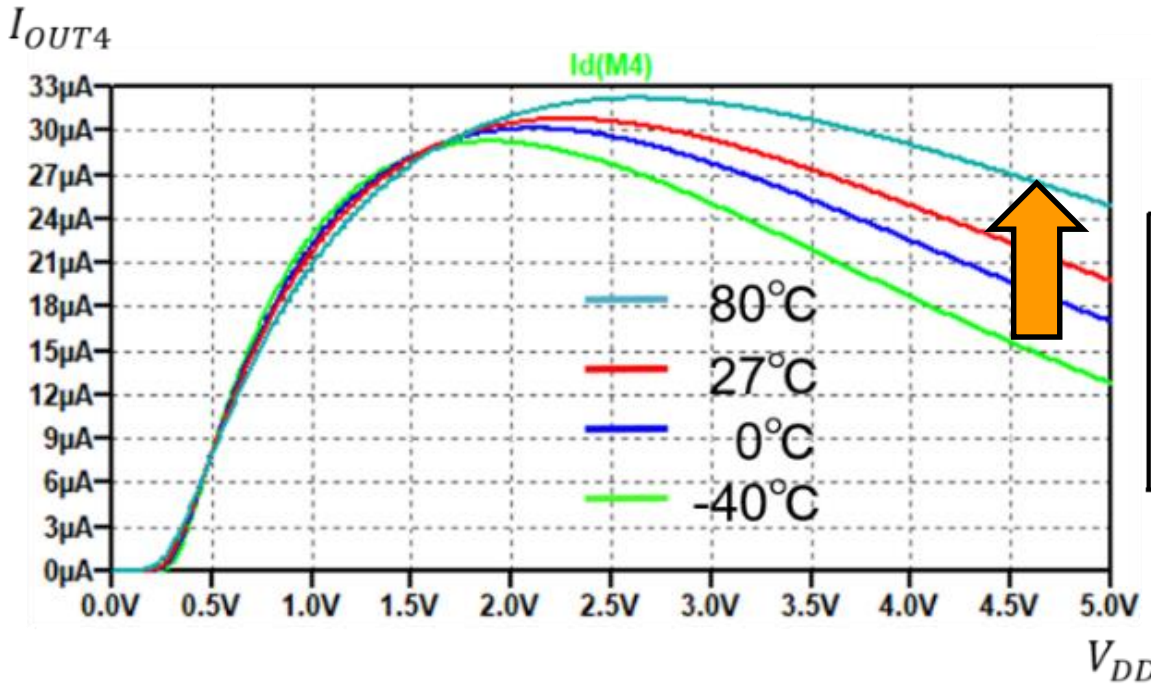
Analysis: M3 drain current

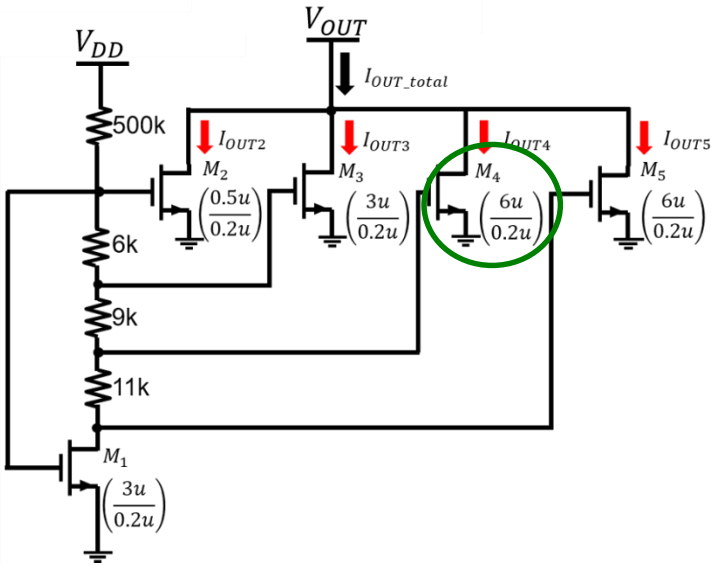




Negative temperature characteristics

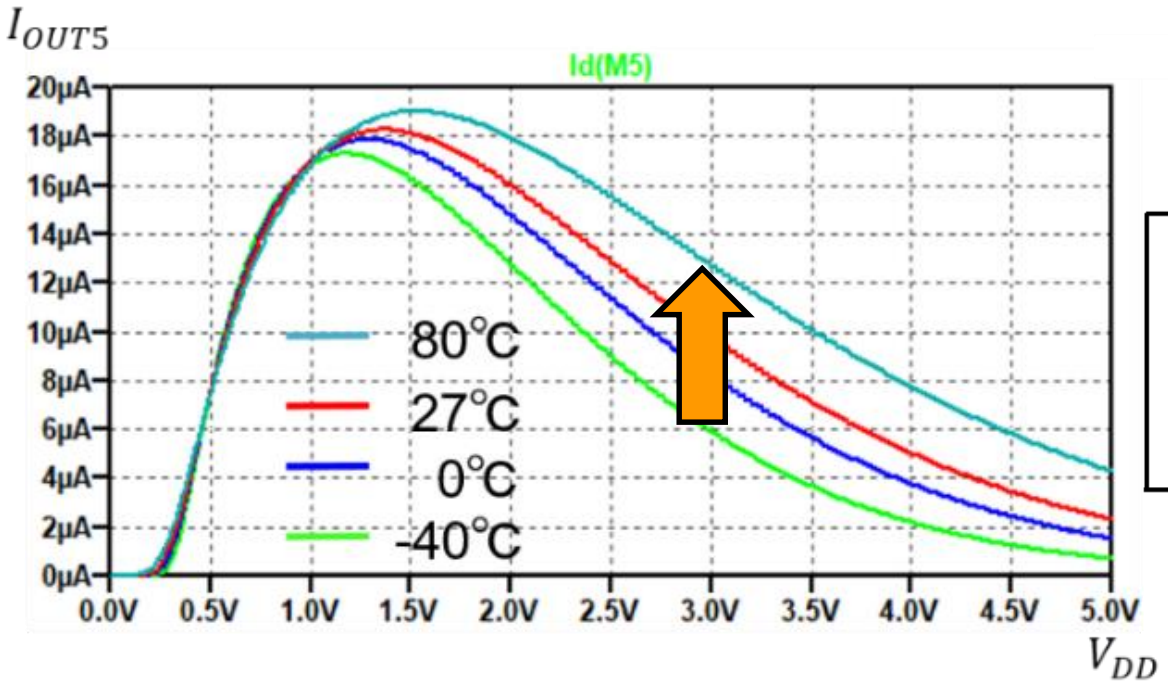
Analysis: M4 drain current

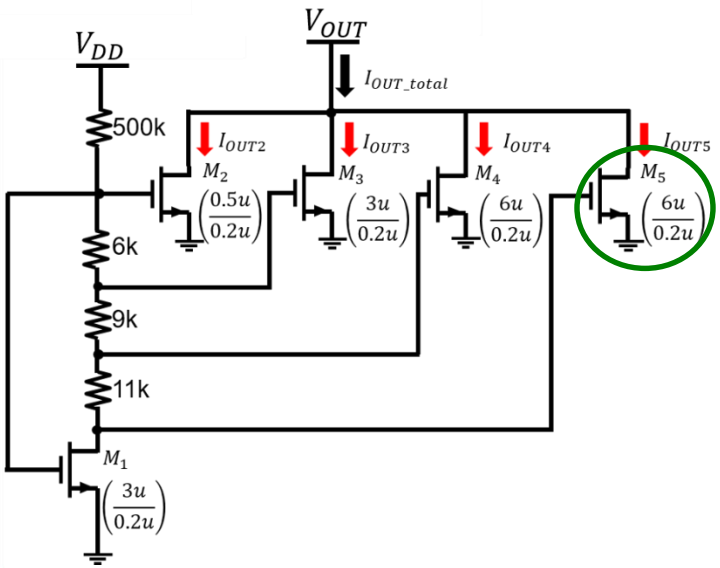




Positive temperature characteristics

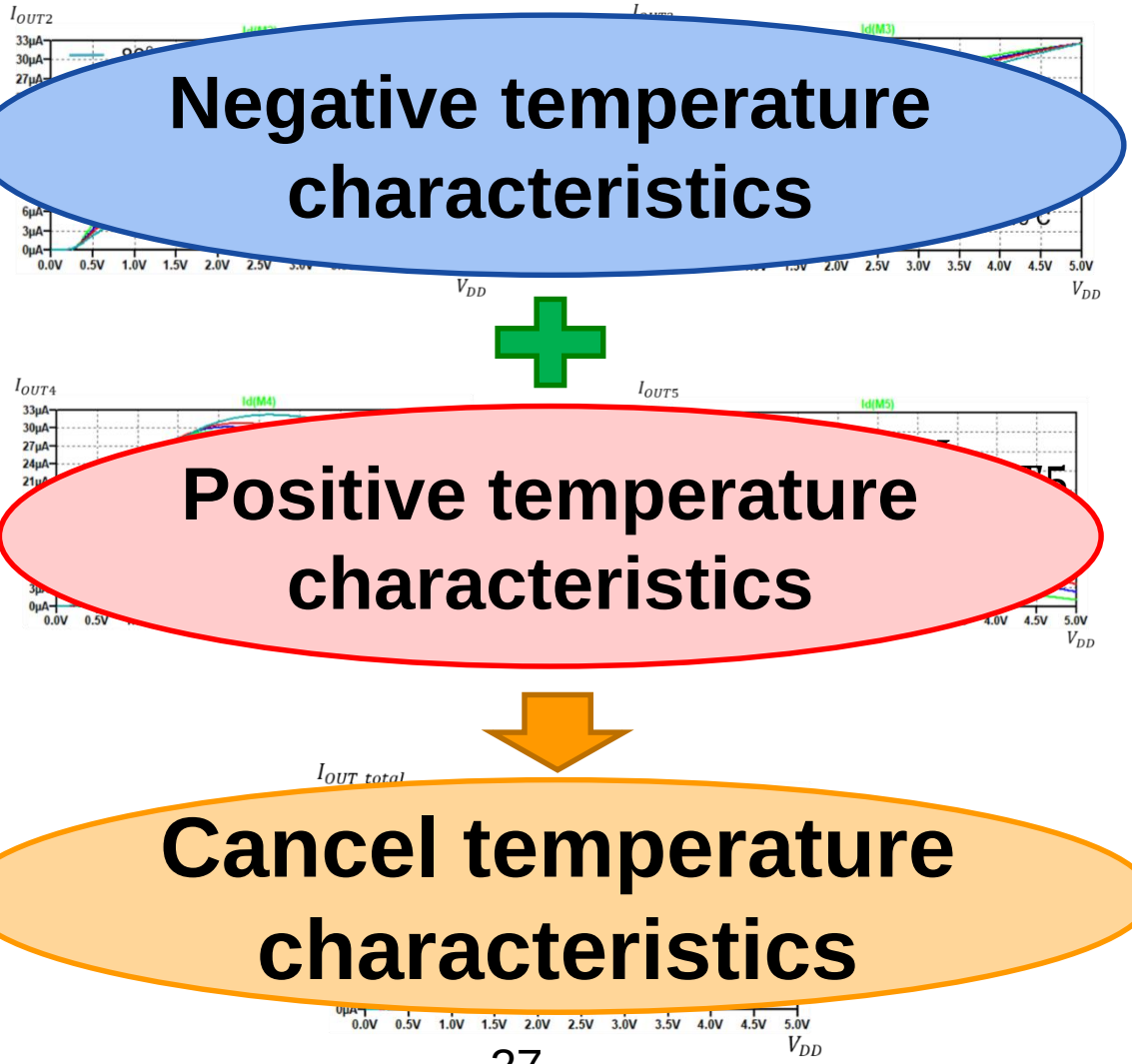
Analysis: M5 drain current



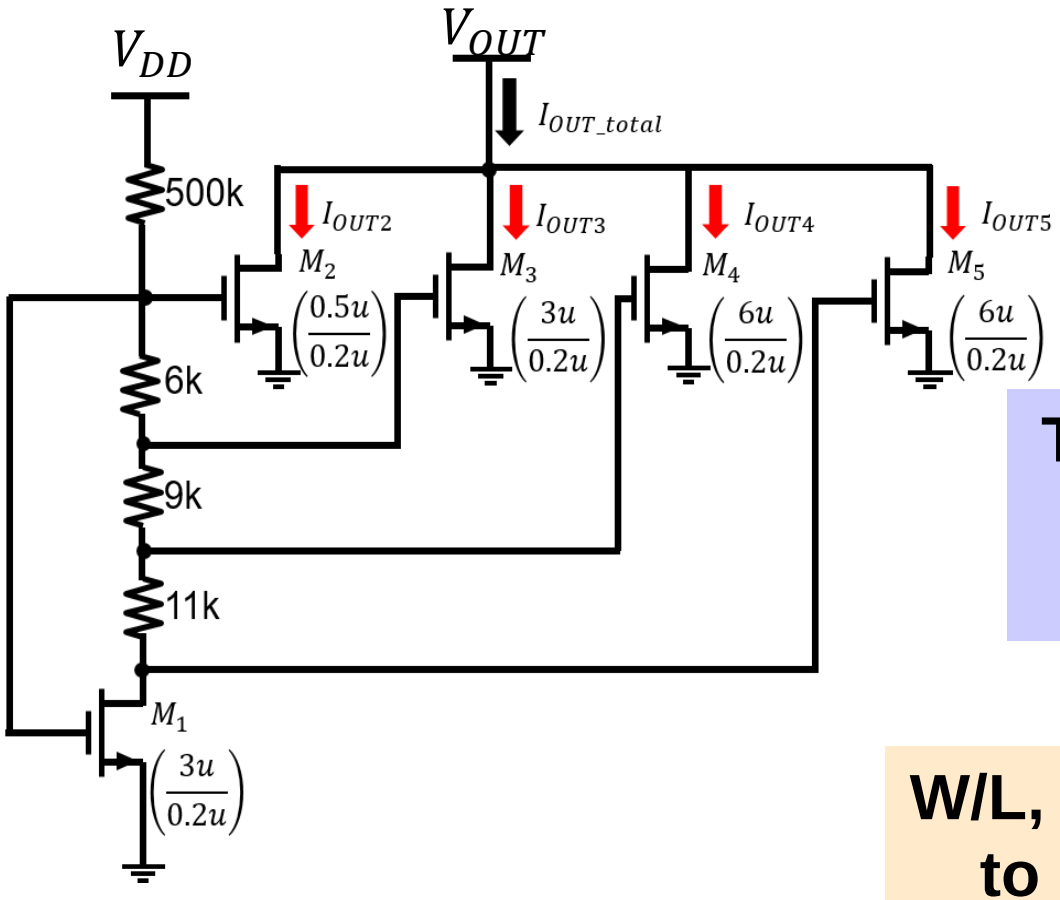


Positive temperature characteristics

Reason for Temperature Insensitivity



Resistor Temperature Coefficient

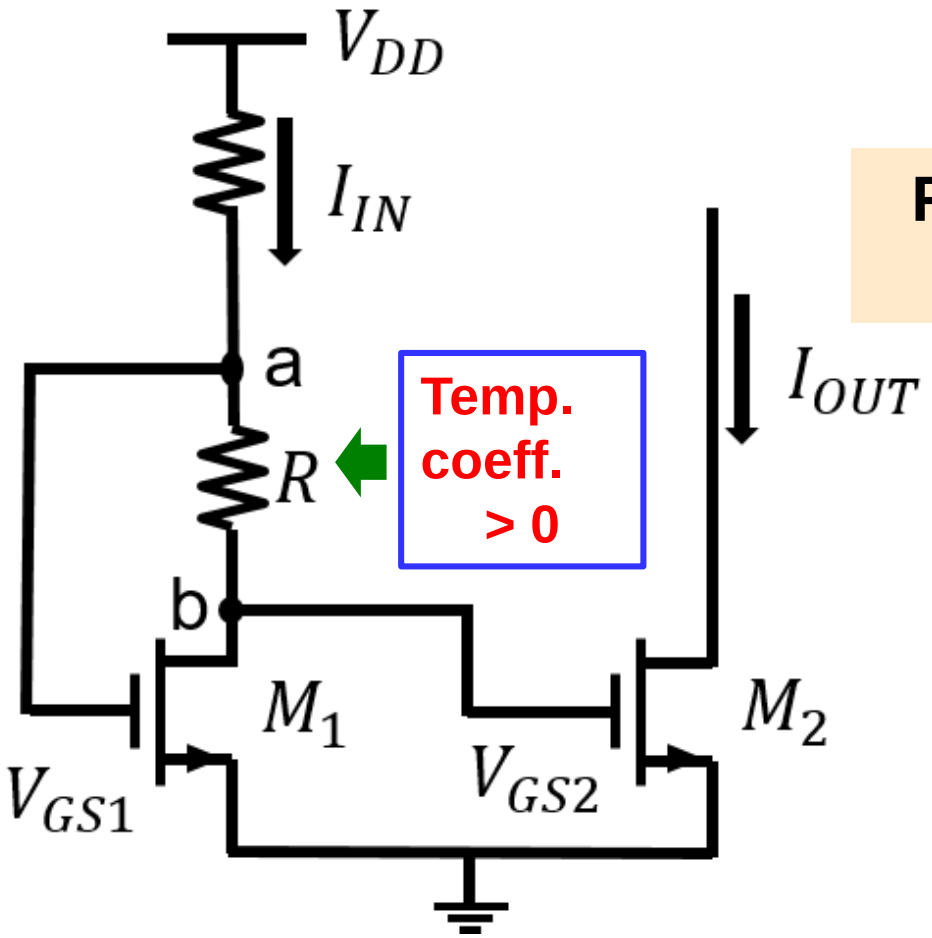


Big advantage of our circuit

Temperature coefficient of resistors can be positive or negative

W/L, R values can be designed to make *I*OUT temperature-, supply voltage-insensitive.

Point of Our Temperature Compensation



Conventional circuit

Conventional circuit

Rely on positive temperature coefficient of R

Proposed circuit

Can be positive, negative or zero

Outline

- Research Background and Objective
- Original Nagata Current Source
- Improvement to Supply Voltage Insensitivity
- Improvement to Temperature Insensitivity
- Simulation Verification
- **Conclusion**

Conclusion

- **Proposal of MOS reference current sources**
- **Temperature insensitivity has been improved.**
- **Comparison**

Circuit	Current constant range	Temperature
Original Nagata current source	Fair	Fair
Previously improved circuit	Excellent	Fair
Proposed circuit today	Excellent	Good