Analog Circuit Session 2

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

Improved Nagata Current Source Insensitive to Temperature and Power Supply Voltage

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ASO Corp.

Outline

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

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- **Research Background and Objective**
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Research Background

Analog ICs require

Reference current / voltage source

Stable against PVT variation

P: Process
V: Supply voltage
T: Temperature

Bandgap reference circuit

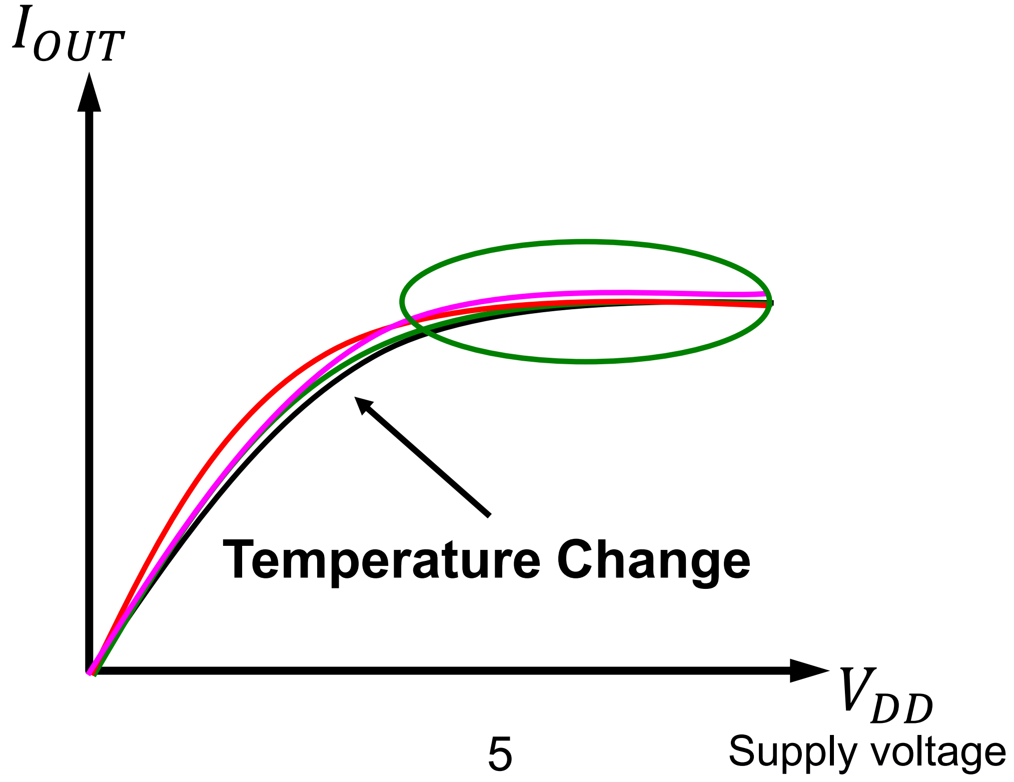
- Complicated
- Large chip area

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



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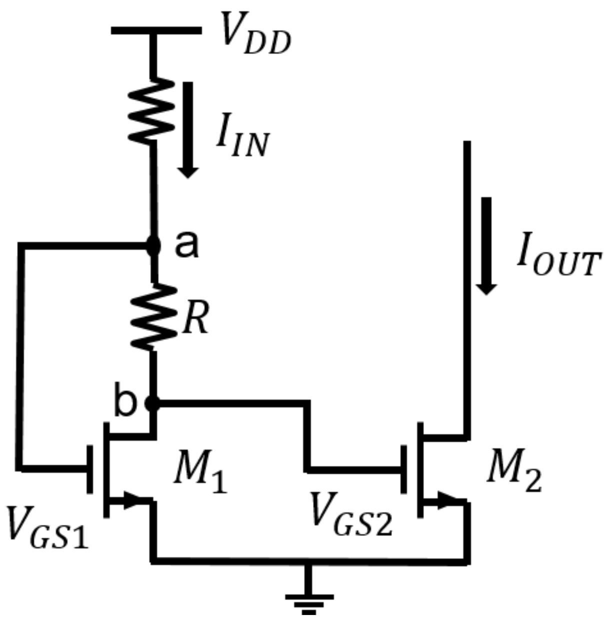
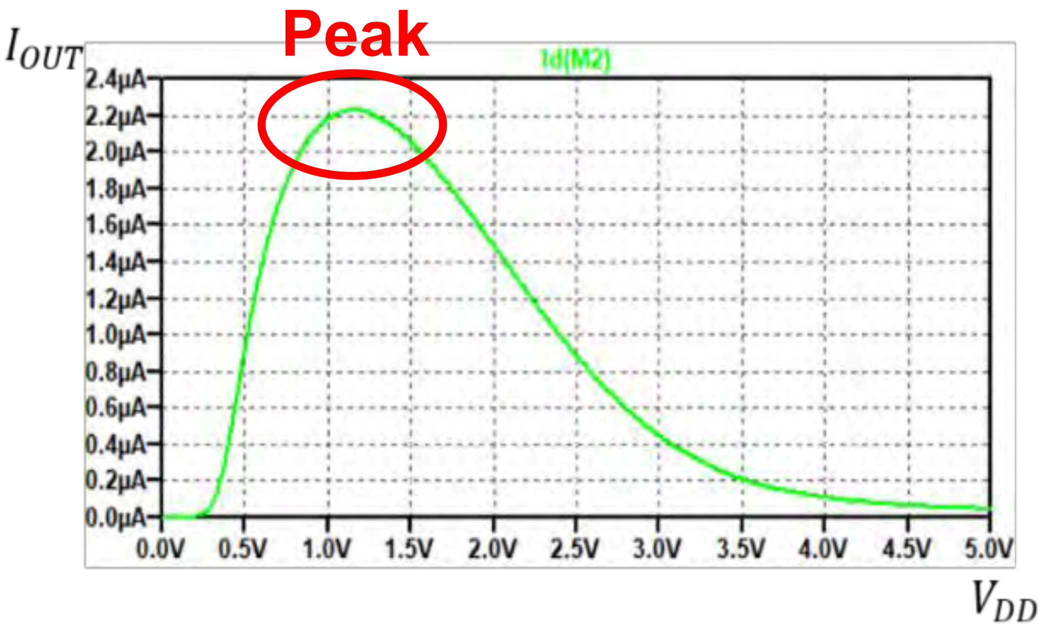
Original Nagata Current Source



Nagata current source

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

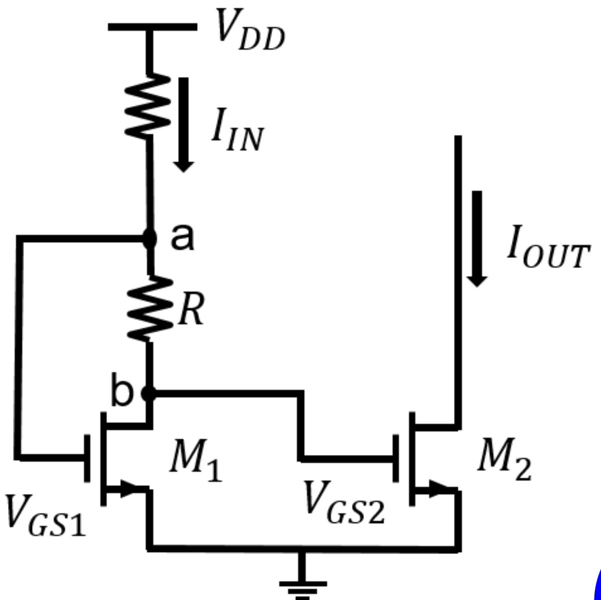


At peak vicinity

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

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

Reason for having a peak (1)

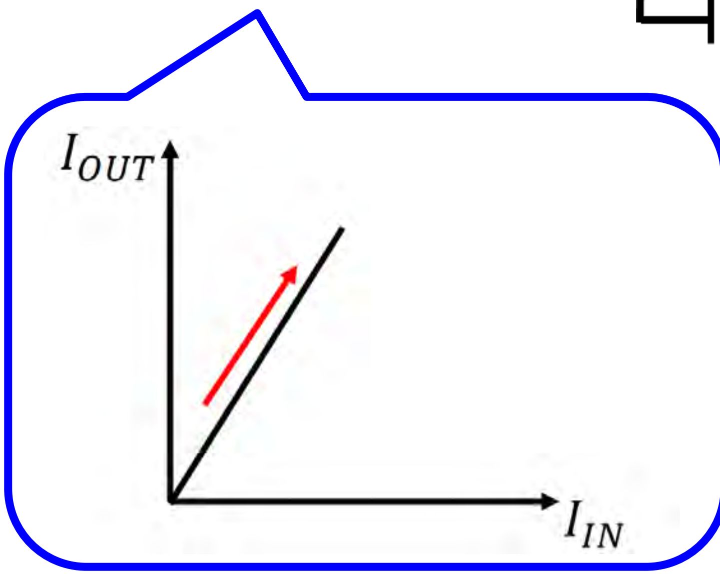


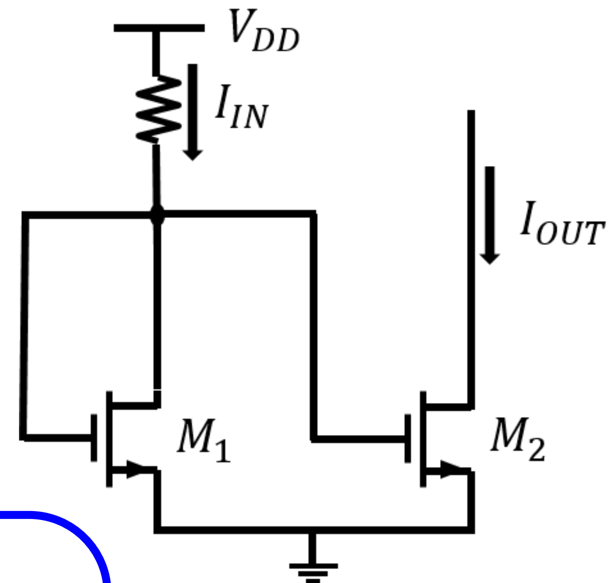
Nagata current source

I_{IN}: small

RI_{IN}: small

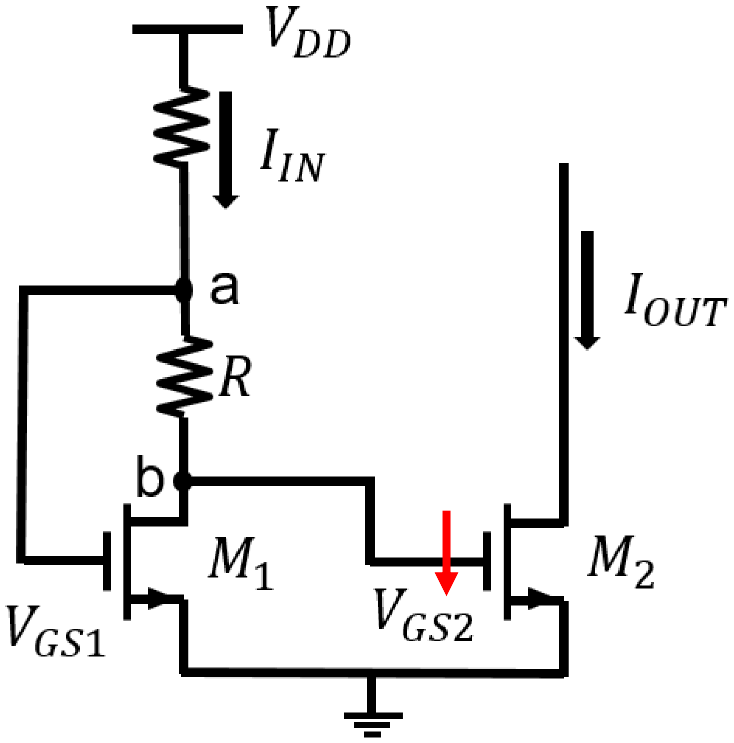
$\Rightarrow I_{IN} = I_{OUT}$





Current Mirror

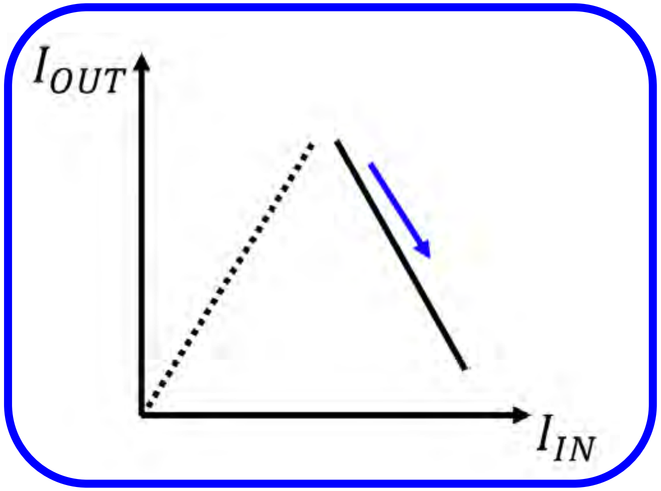
Reason for having a peak (2)



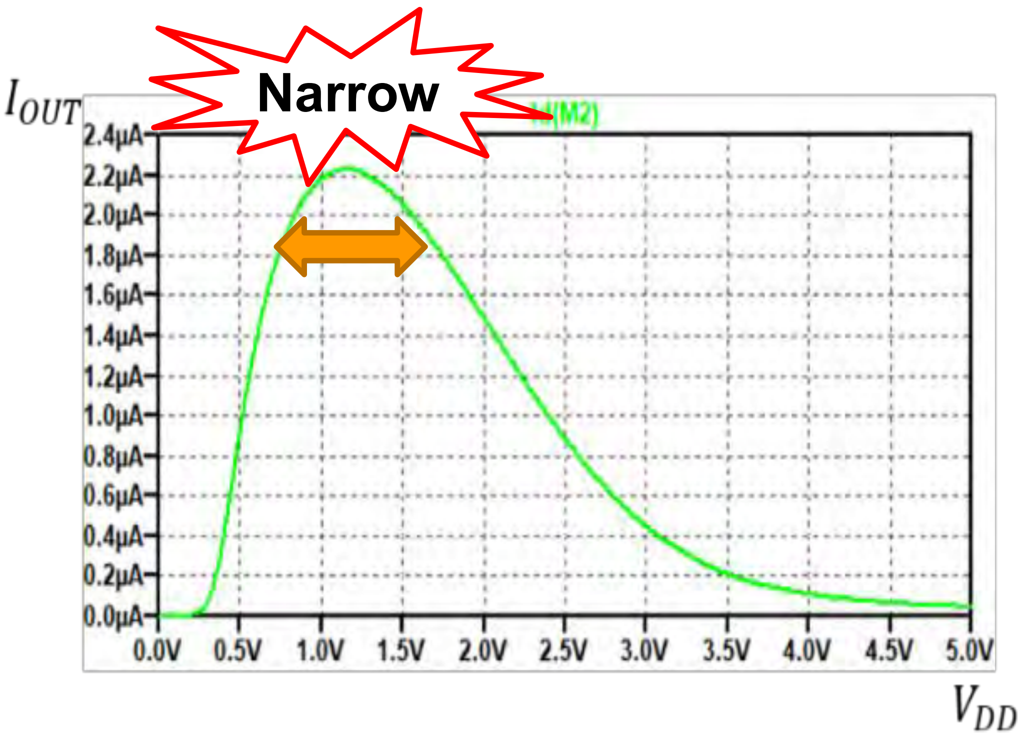
I_{IN}: **large**

➡ 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.

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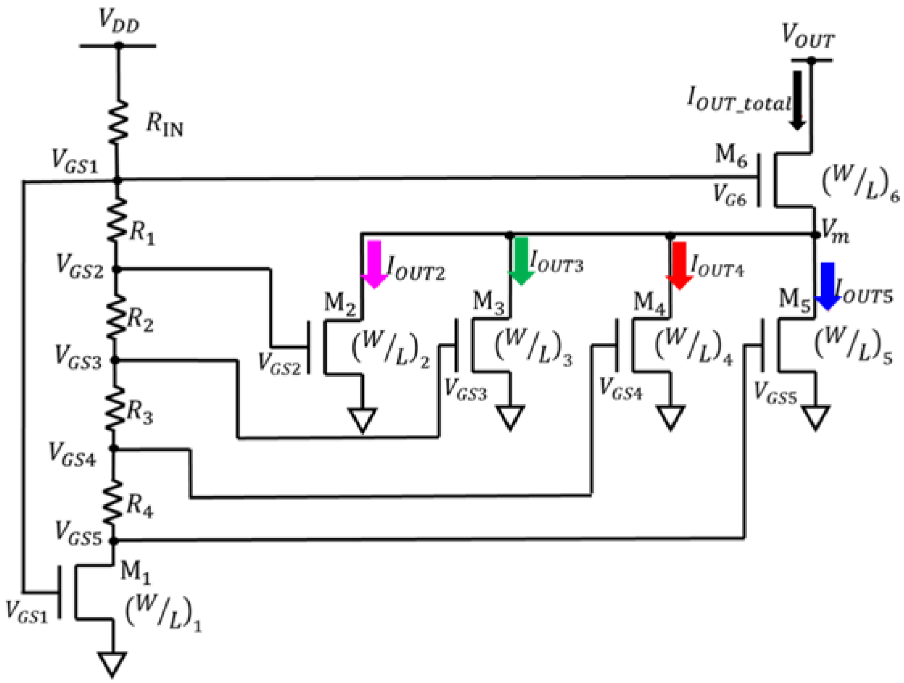
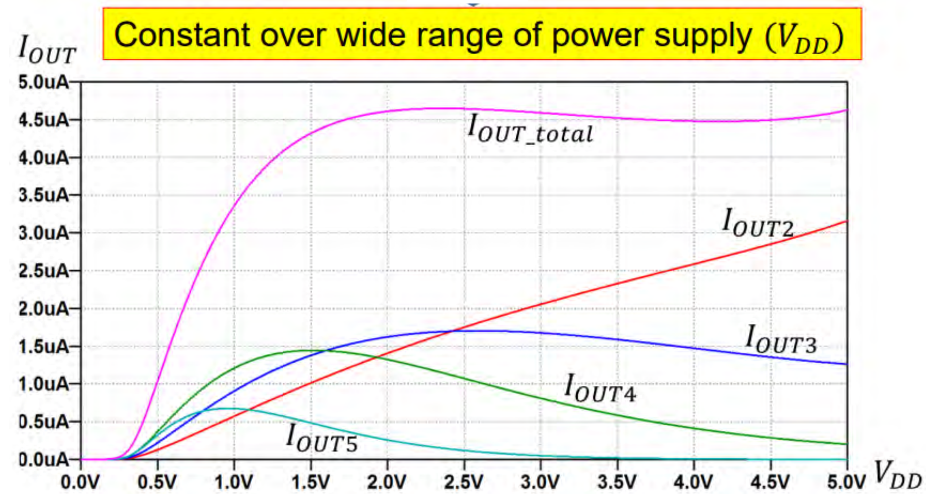
Widened Flat Range

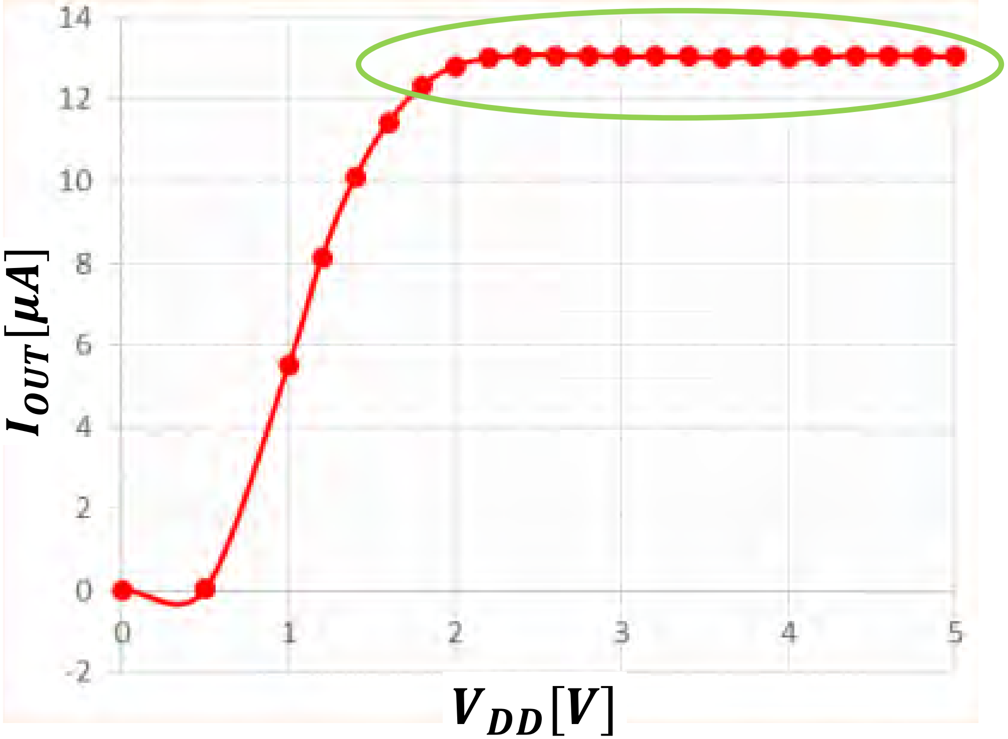


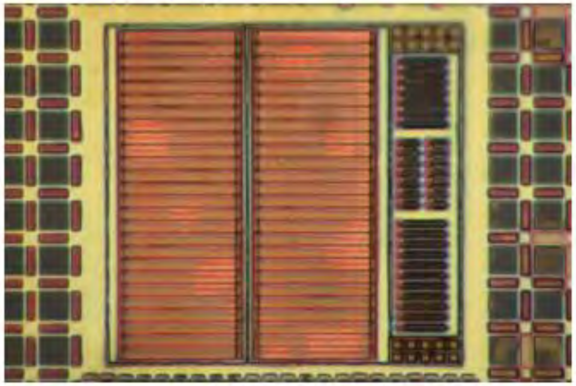


Using multiple current peaks and their sum

[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

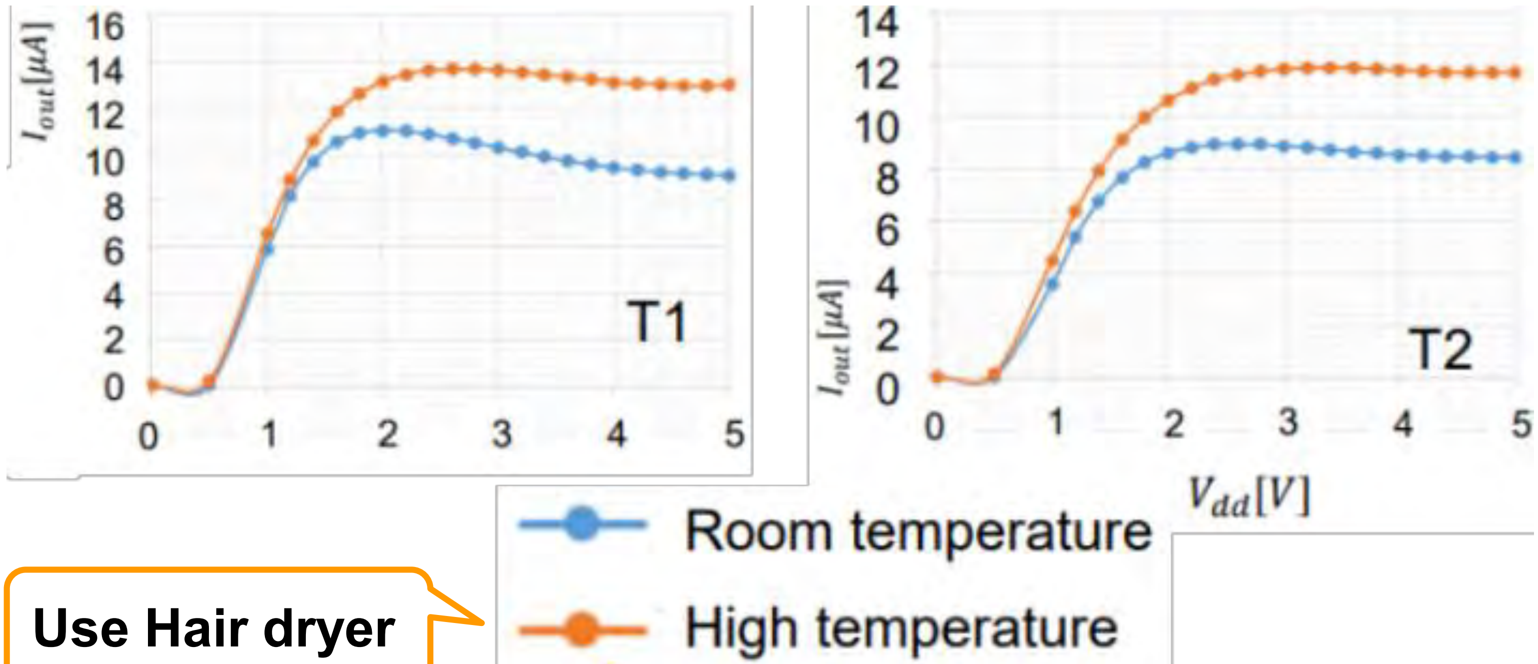




Total output current is constant against VDD variation

[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

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- **Improvement to Temperature Insensitivity**
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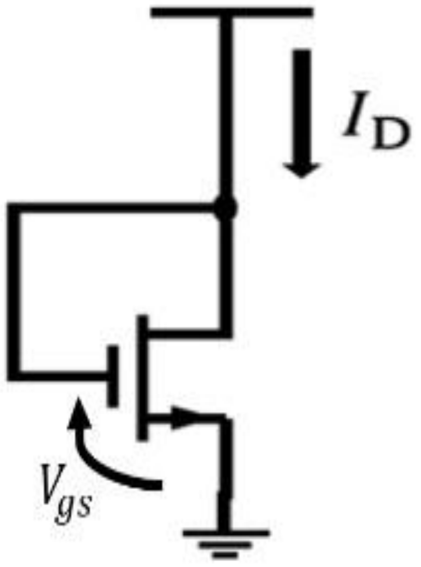
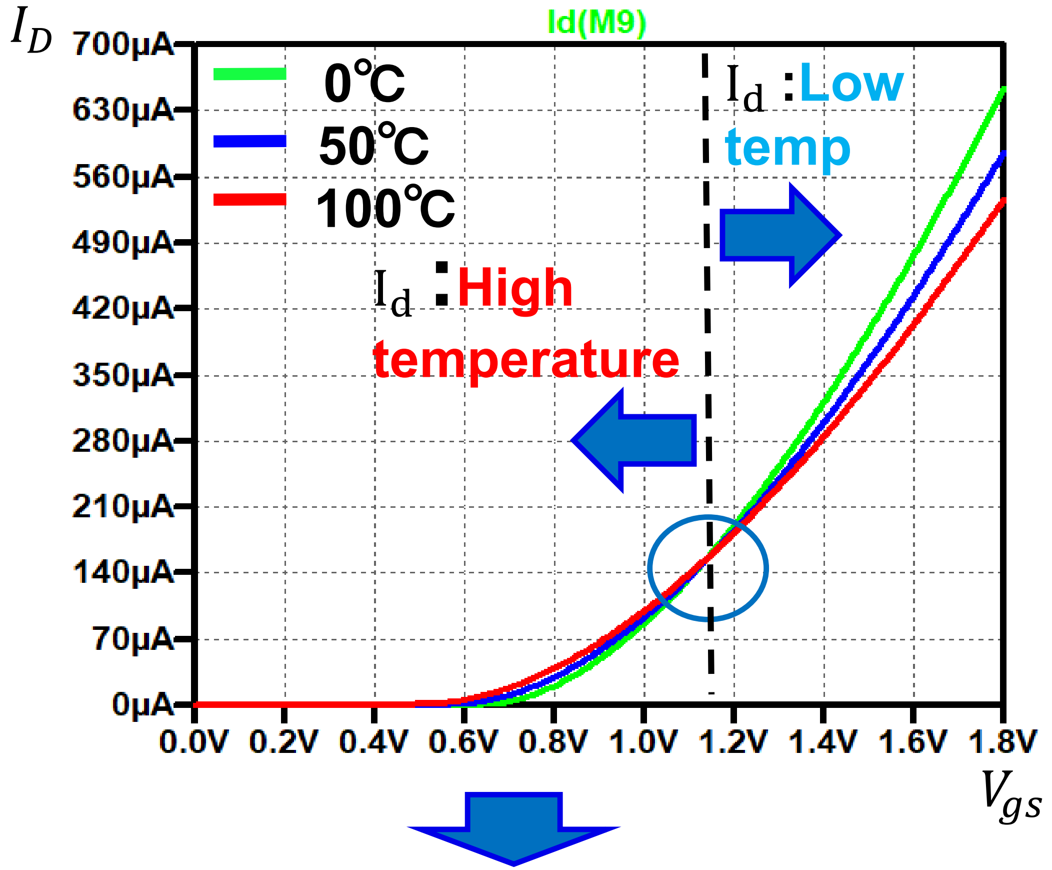
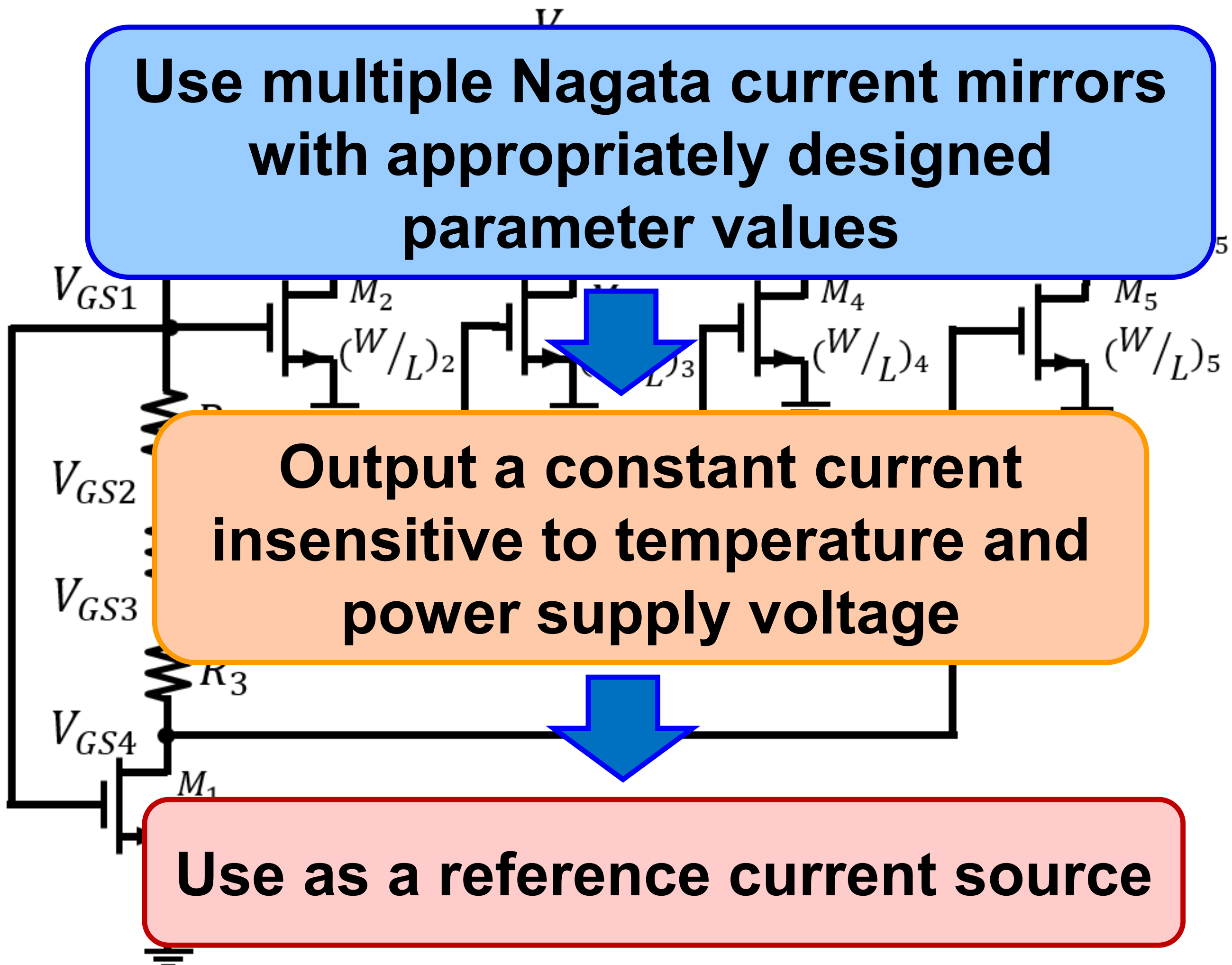
MOSFET Temperature Characteristics





Utilize for temperature-insensitive reference current source

Proposed Reference Current Source

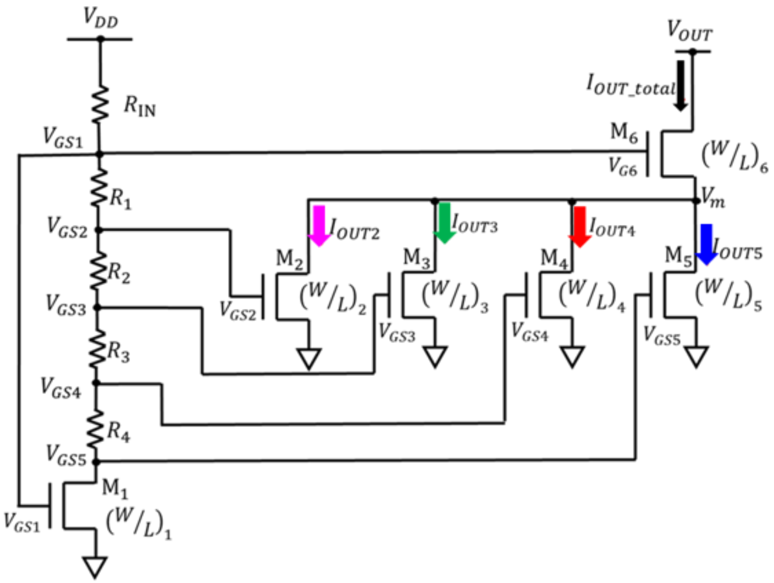


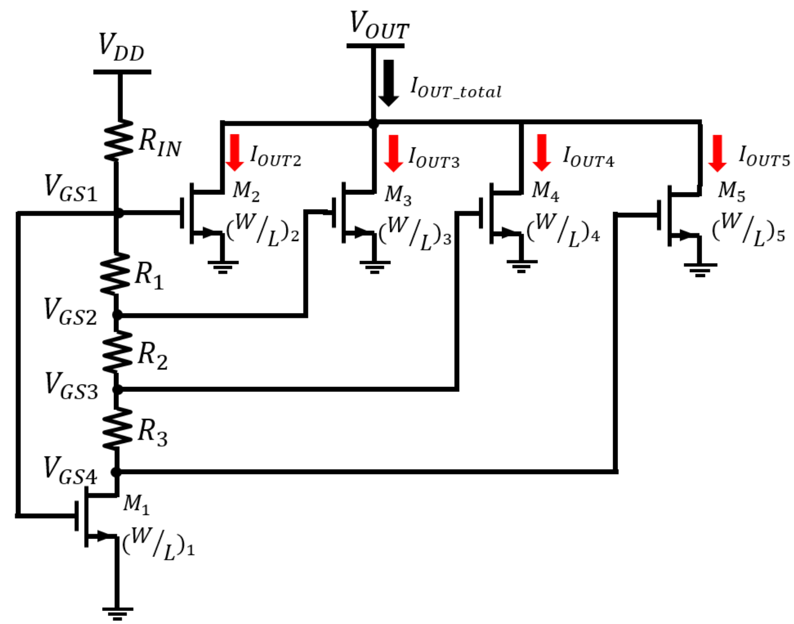
Use multiple Nagata current mirrors with appropriately designed parameter values

Output a constant current insensitive to temperature and power supply voltage

Use as a 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

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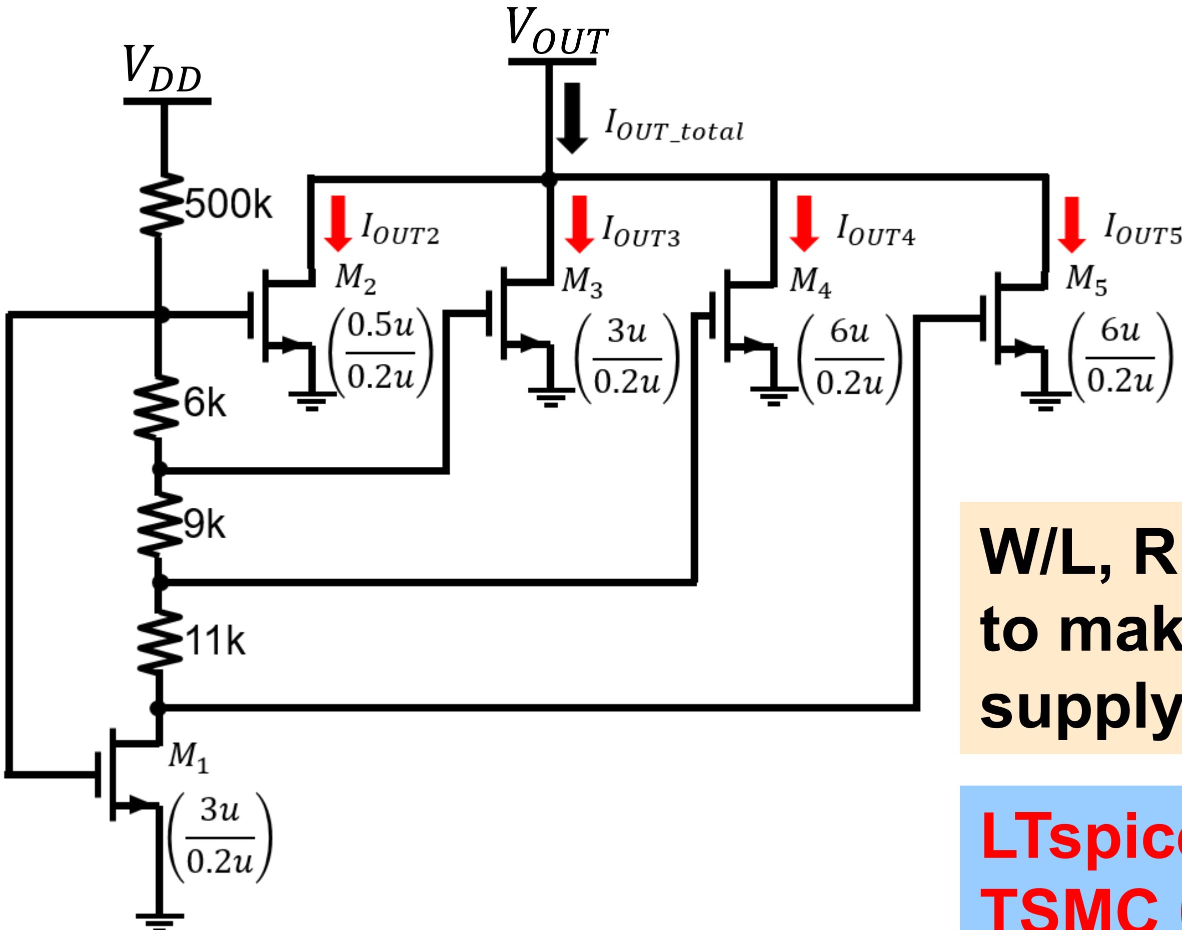
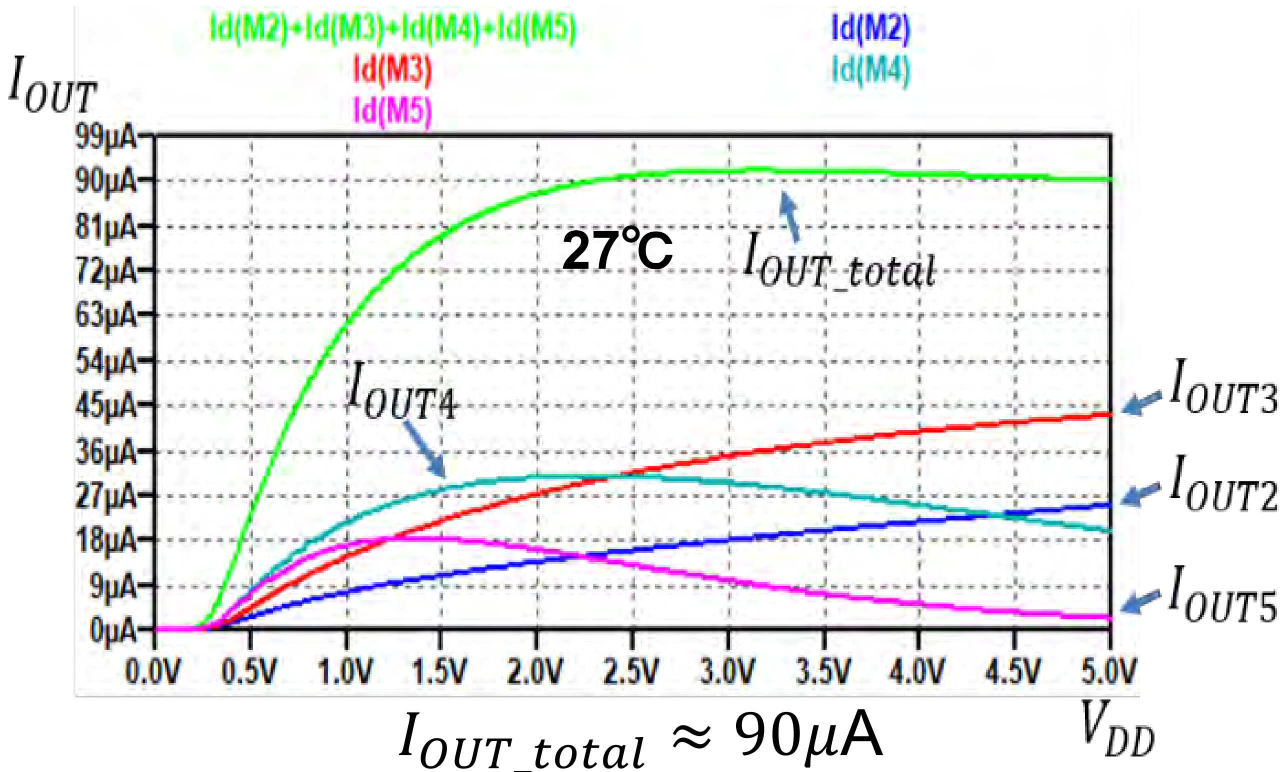
SPICE Simulation Circuit



W/L, R values are designed to make I_{OUT} temperature-, supply voltage-insensitive.

LTspice
TSMC 0.18μm MOS model

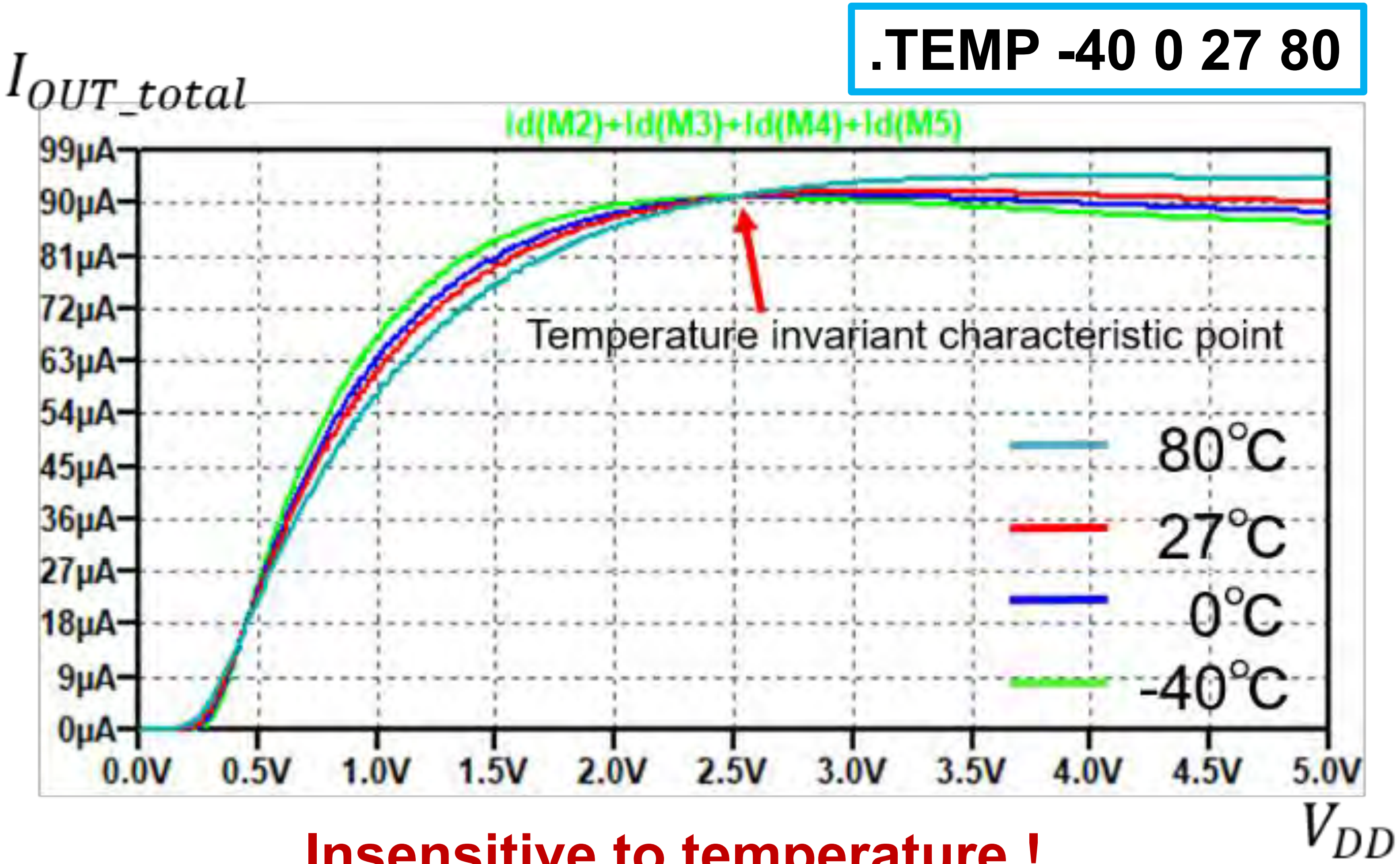
Simulation for Supply Voltage



$I_{OUT\_total} \approx 90\mu A$

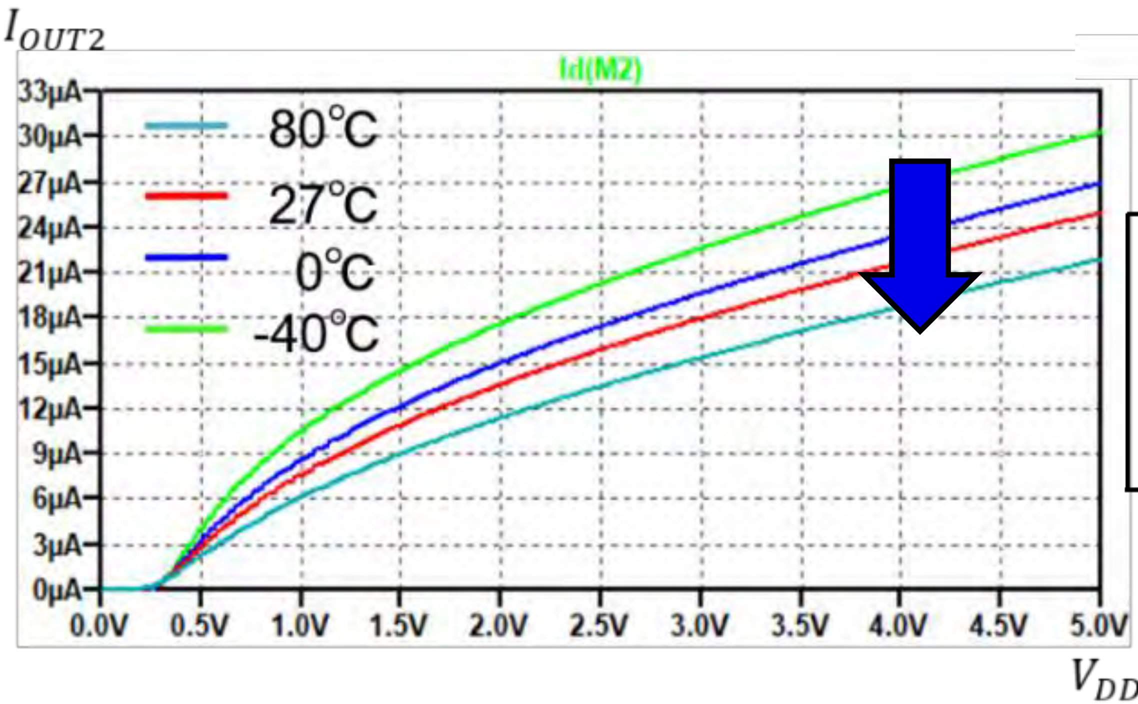
Total output current is constant over wide range of supply voltage

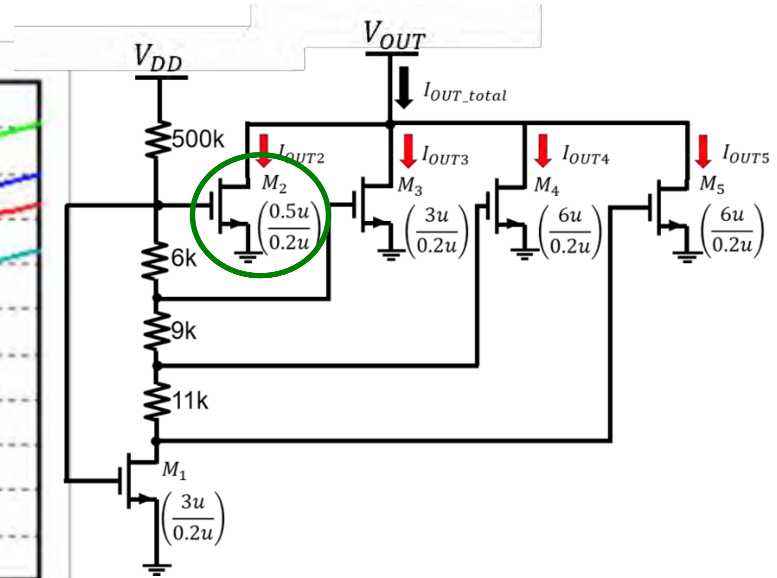
Simulation Result for Temperature



Insensitive to temperature !

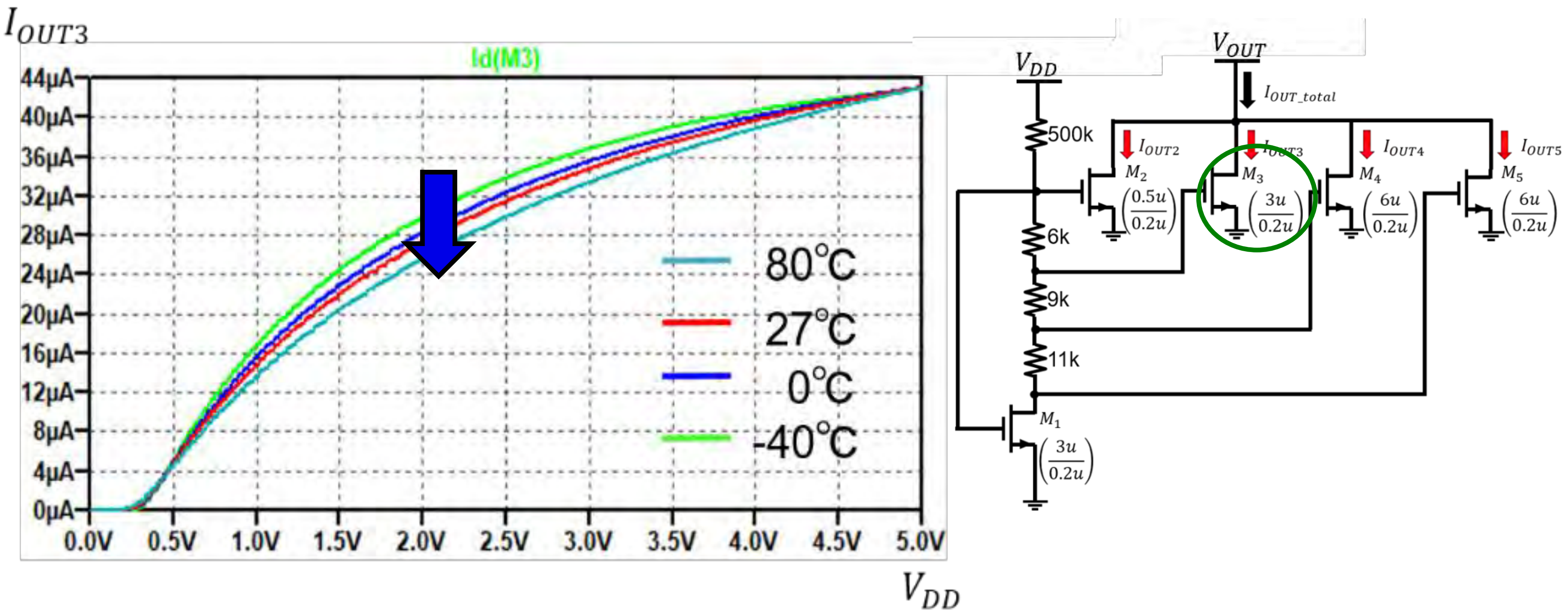
Analysis: M2 drain current





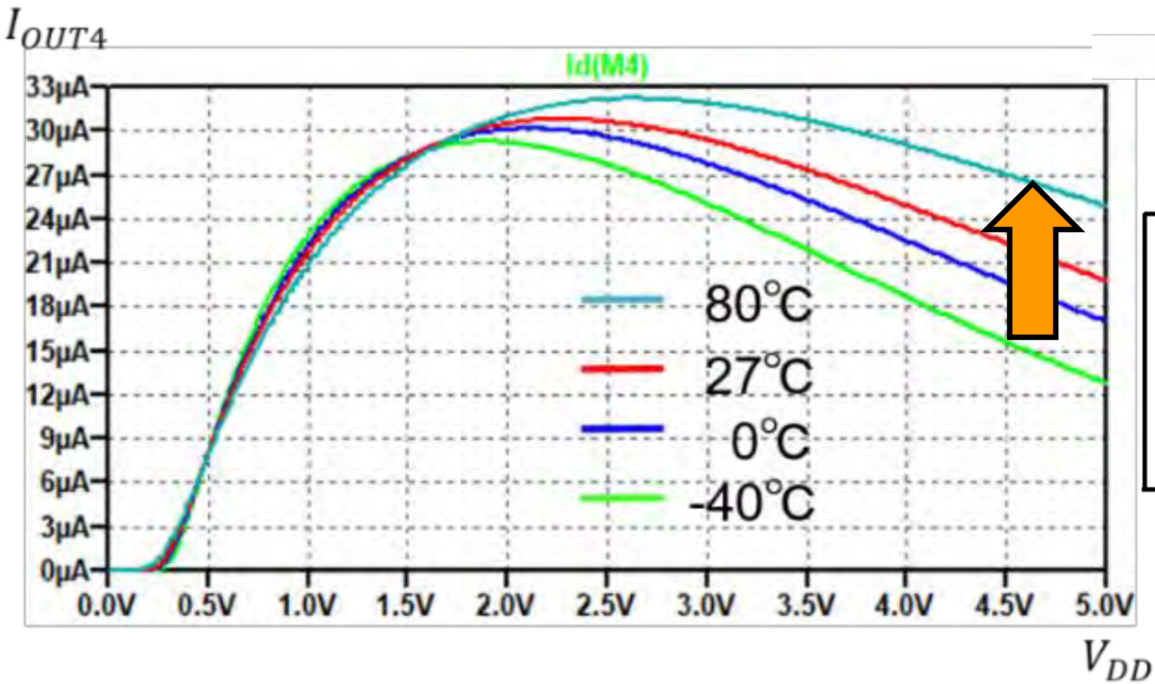
Negative temperature characteristics

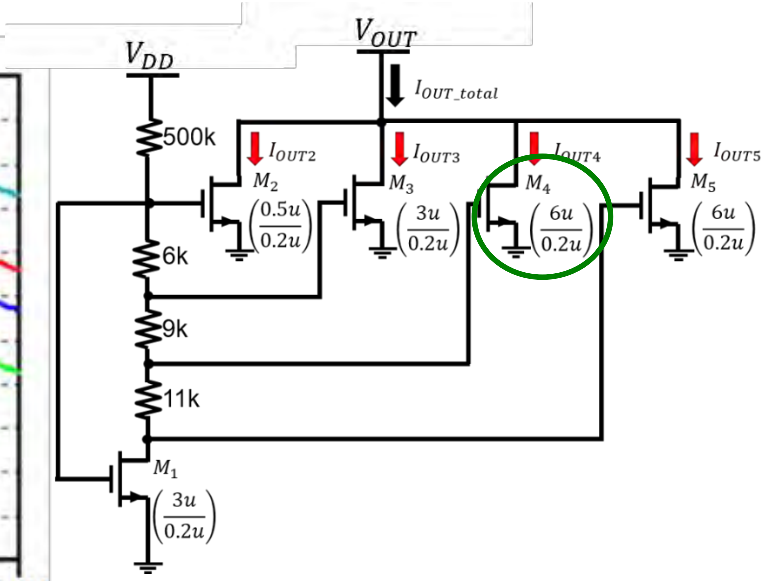
Analysis: M3 drain current



Negative temperature characteristics

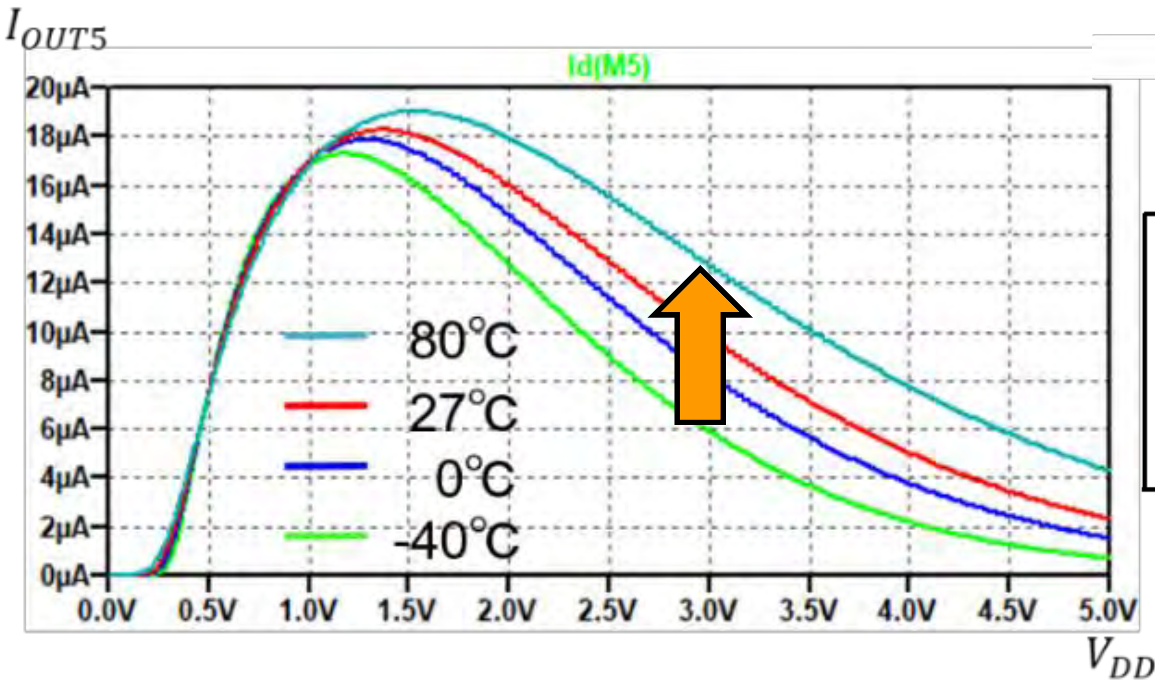
Analysis: M4 drain current

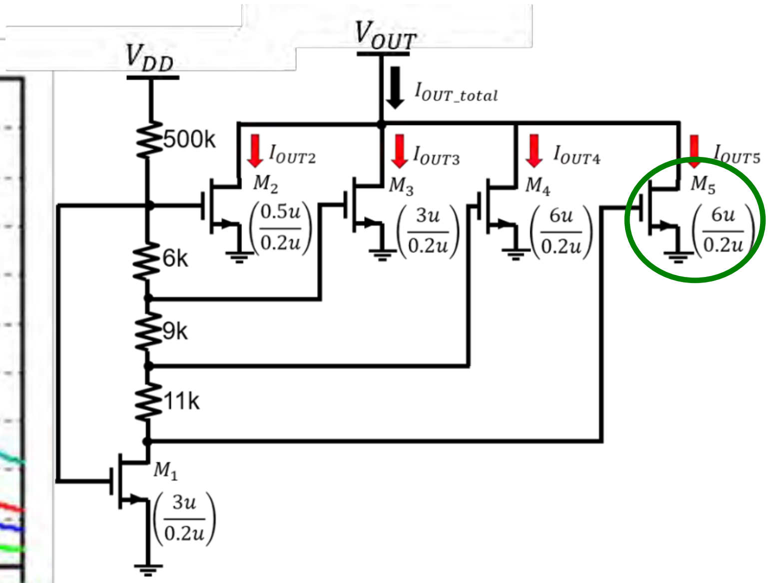




Positive temperature characteristics

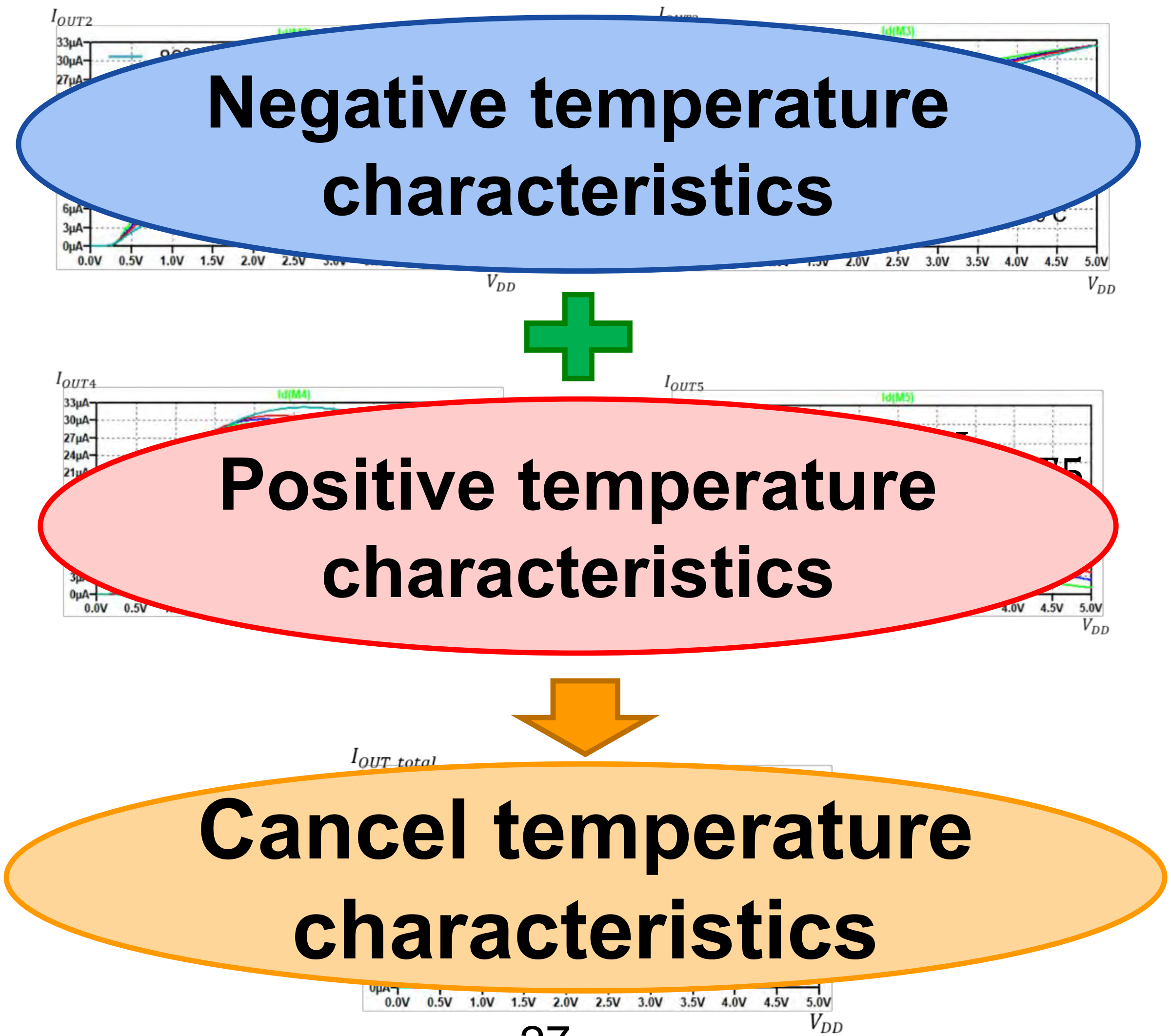
Analysis: M5 drain current



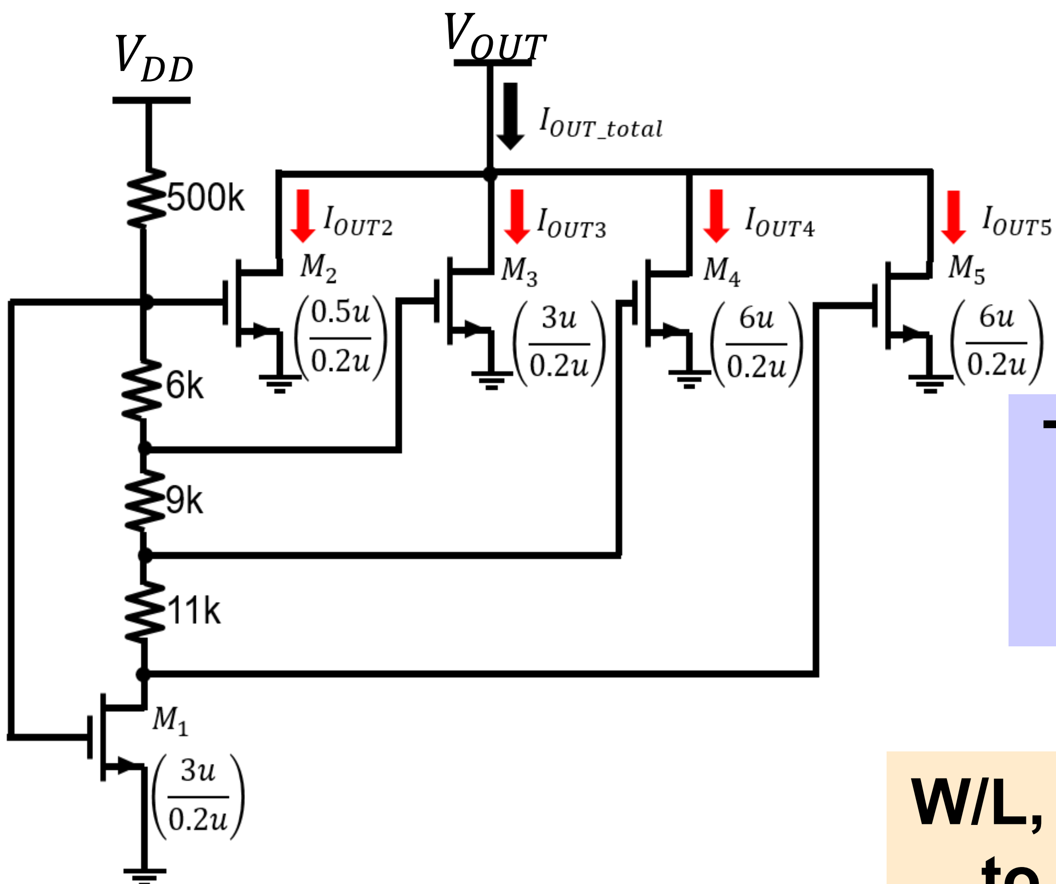


Positive temperature characteristics

Reason for Temperature Insensitivity



Resistor Temperature Coefficient

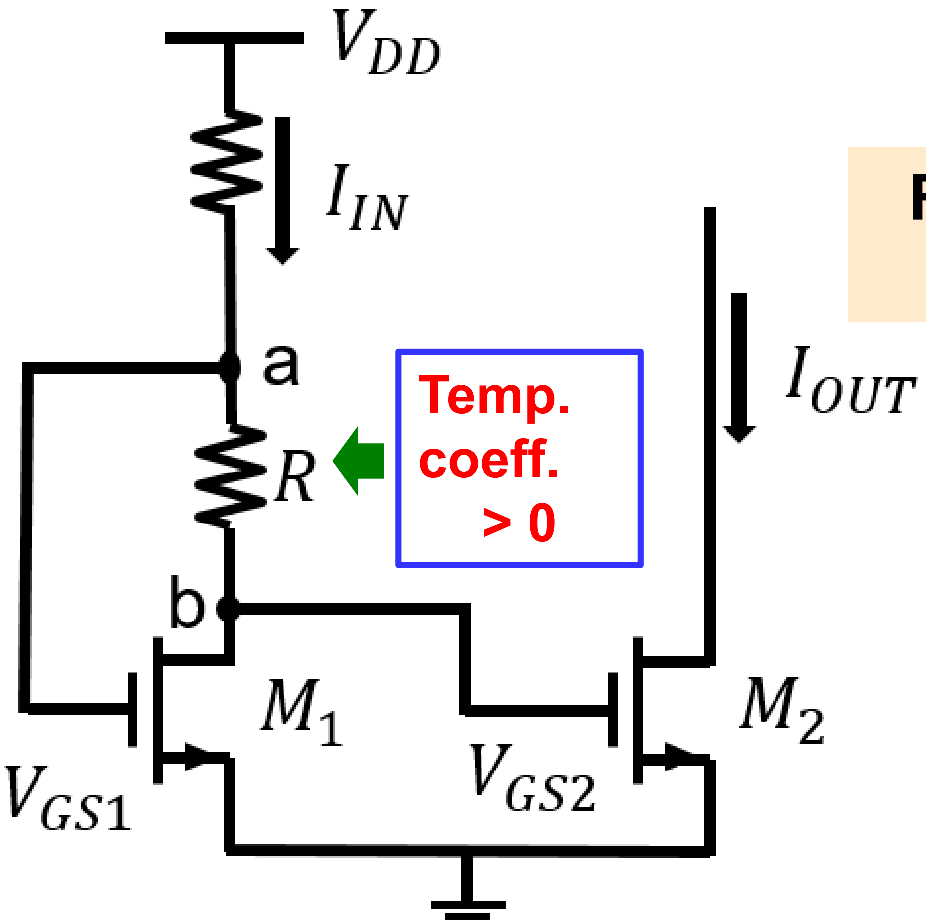


Big advantage of our circuit

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

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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