ICSICT2016
Oct. 25-28 2016

S05-6 Analog Circuits Ⅰ
15:00 - 15:15 PM
Oct.26, 2016

Simple Reference Current Source Insensitive to Power Supply Voltage Variation -Improved Minoru Nagata Current Source -

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GUNMA UNIVERSITY

Research Objective

Objective

- Development of
  simple reference current source
  insensitive to power supply voltage variation

Our Approach

- Peaking current source invented by
  Dr. Minoru Nagata (Japanese) in 1966.
- Using multiple current peaks and their sum.

Outline

- Research Background
- Nagata Current Mirror Circuit
- Improved circuit (Zach's Circuit)
- Proposed MOS Reference Current Source
  - Circuit Configuration and Operation
  - SPICE Simulated Characteristics
  - Component Variation Effects
- Proposed Bipolar Reference Current Source
- Temperature Effect
- Conclusion

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Research Background

Most 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 mirror
- ✓ Simple
- ✓ Only effective for voltage variation

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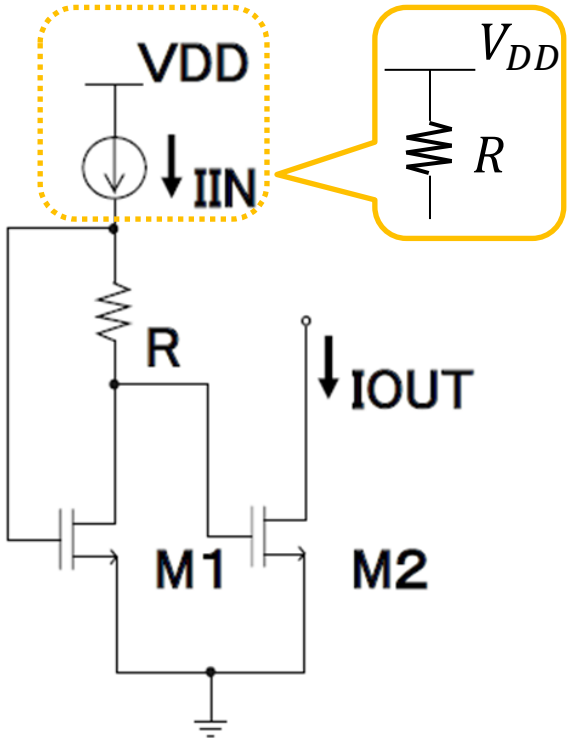
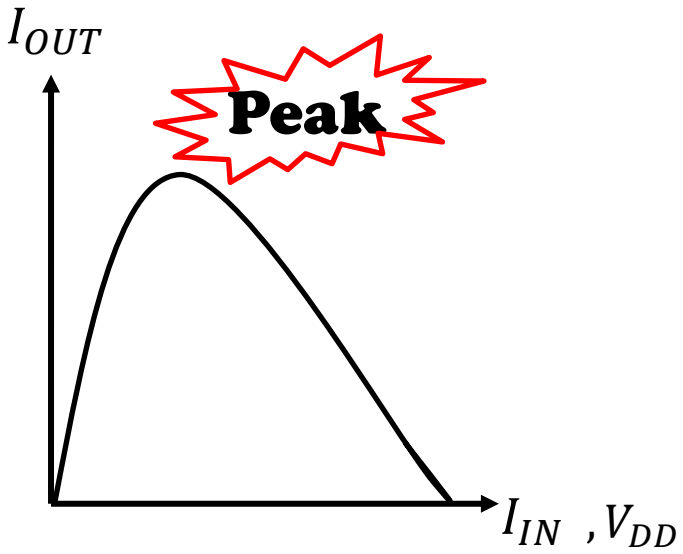
Original Nagata Current Mirror



MOS Nagata
Current Mirror Circuit



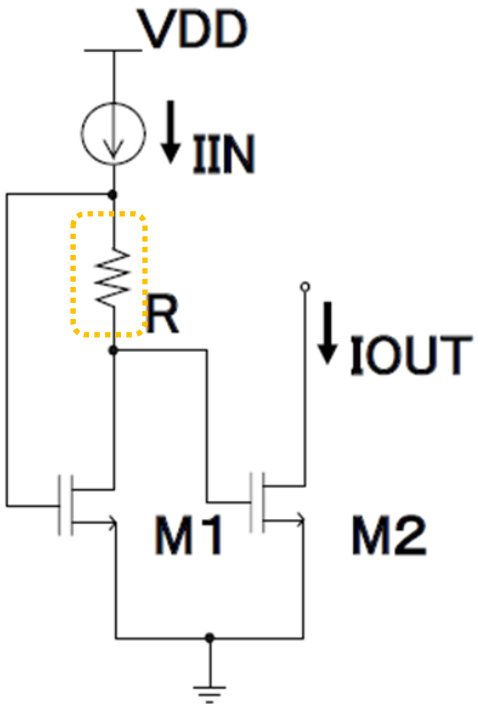
Peaking current characteristics

At peak vicinity

Small output current change
against input current change

Simple ⇨ Widely used. Ex: in DC-DC converter ICs

Circuit Configuration and Operation(1)

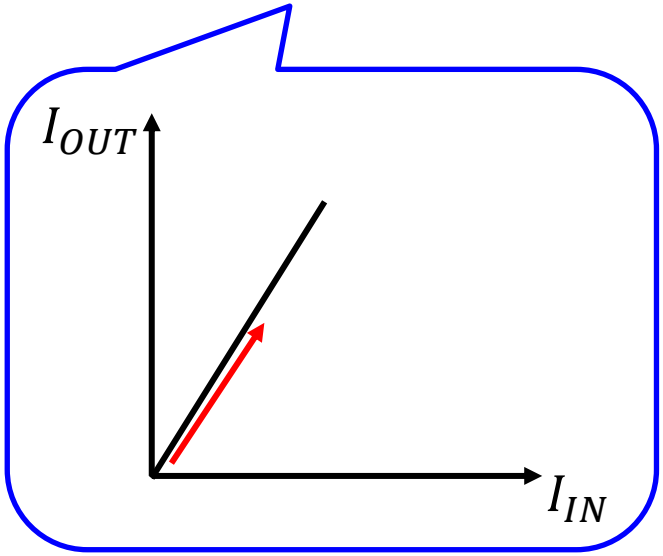


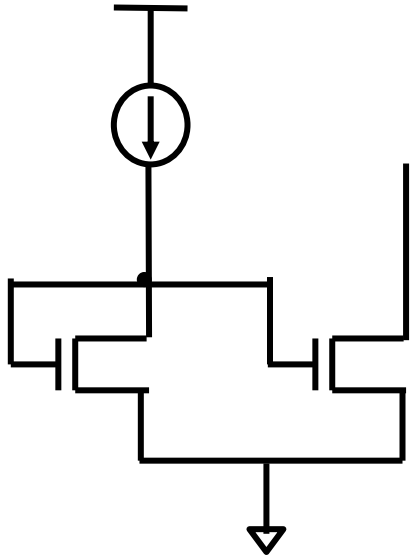
MOS Nagata
Current Mirror

I_{IN}: small

RI_{IN}: small

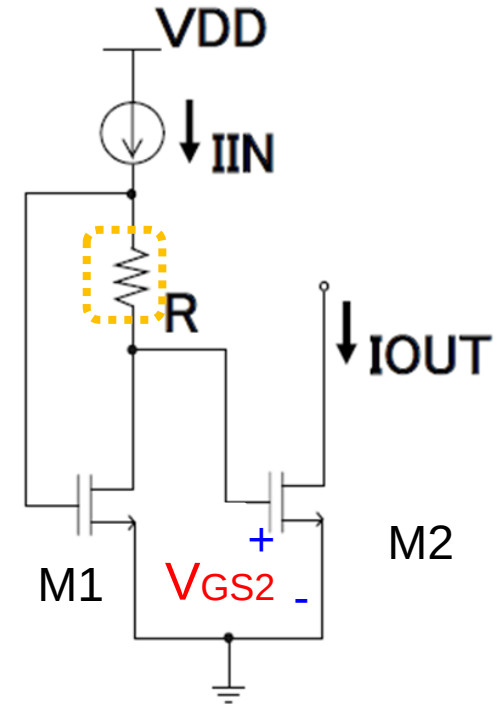
$I_{IN} = I_{OUT}$





Current Mirror

Circuit Configuration and Operation(2)

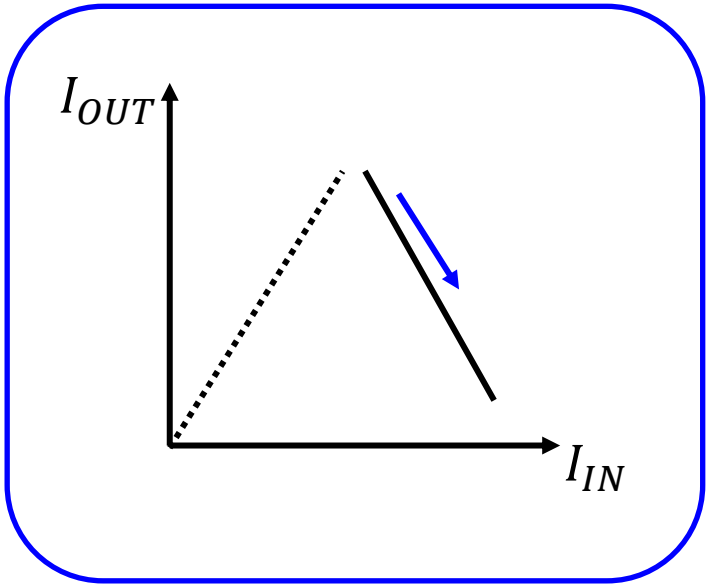


MOS Nagata
Current Mirror Circuit

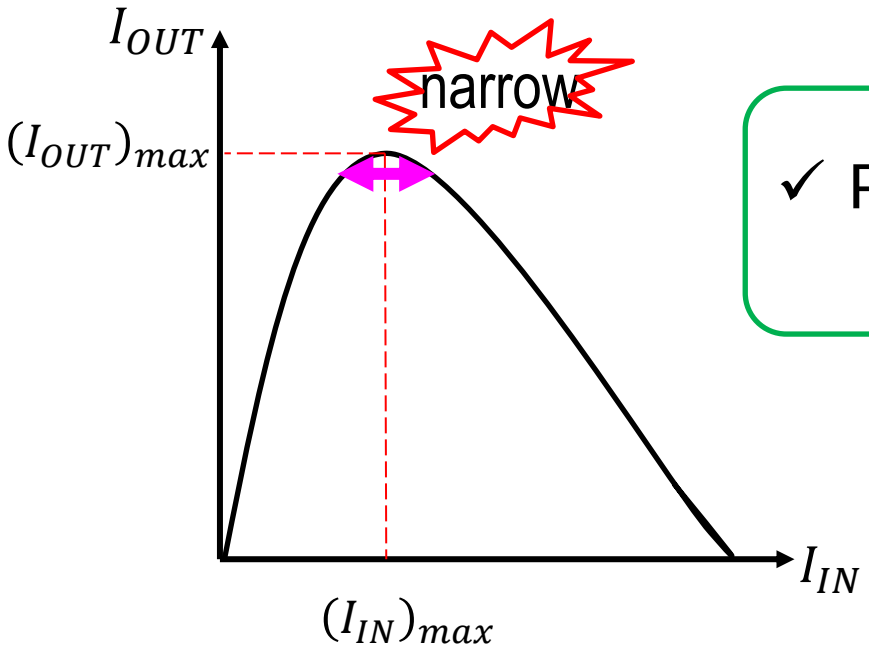
➡ I_{IN}: $large$

➡ RI_{IN}: $large$

➡ V_{GS2} $becomes$ $smaller$



I_{IN}-I_{OUT} Characteristics



Improved point

✓ Peak vicinity is narrow

↳ Wider

$$(I_{IN})_{max} = \frac{1}{4R^2K_1(1+\lambda V_{DS1})} \quad \cdots(1)$$

$$(I_{OUT})_{max} = \frac{(W/L)_2}{4(W/L)_1} \cdot \frac{1}{4R^2K_1} \frac{(1+\lambda V_{DS2})}{(1+\lambda V_{DS1})} \quad \cdots(2)$$

$$K_1 = \frac{1}{2}\mu C_{ox}\left(\frac{W}{L}\right)_1$$

λ:

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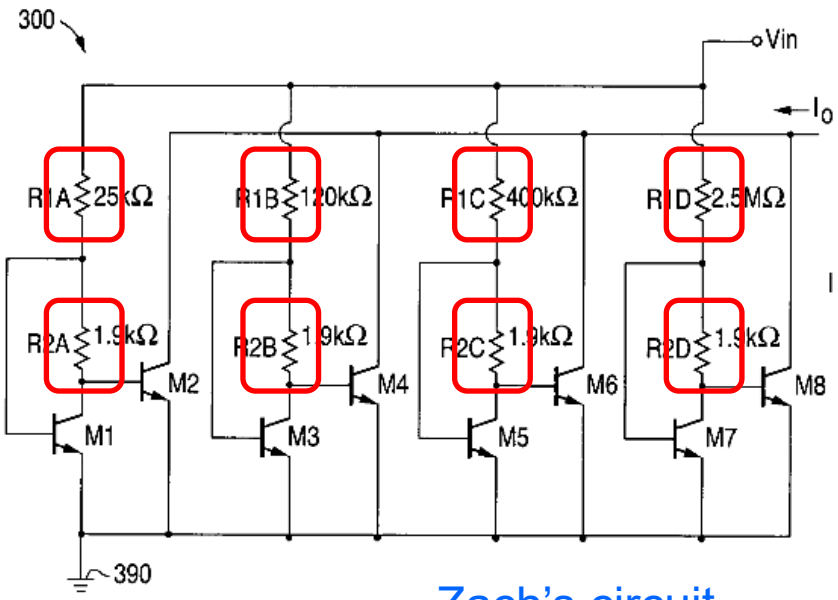
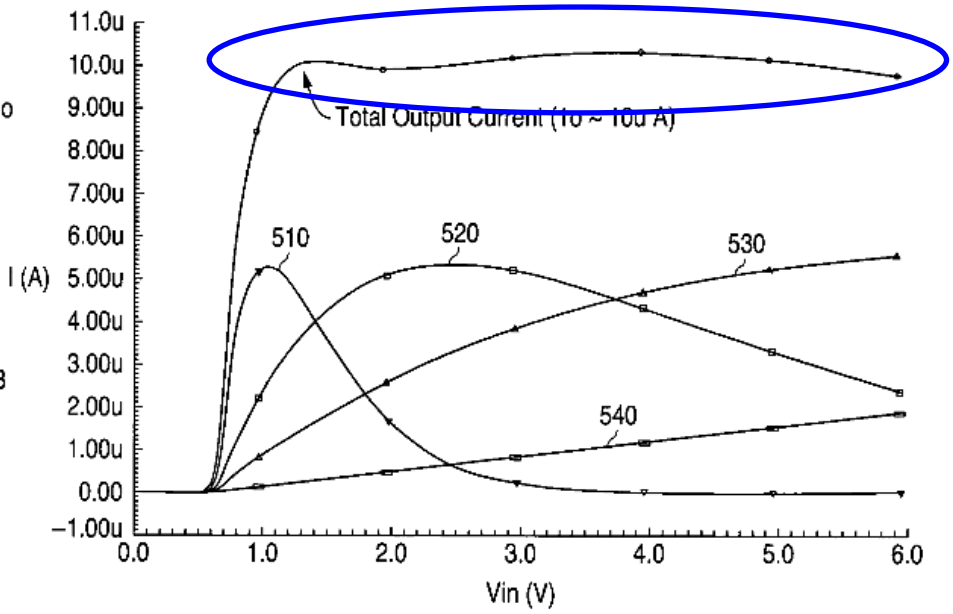
Previous Improved Circuit



Zach's circuit



Inventor
Zachary Zehner Nosker
Obtained Ph.D.
from Gunma Univ.
Kobayashi Lab.

Problem

Parallel Resistors → Large chip area

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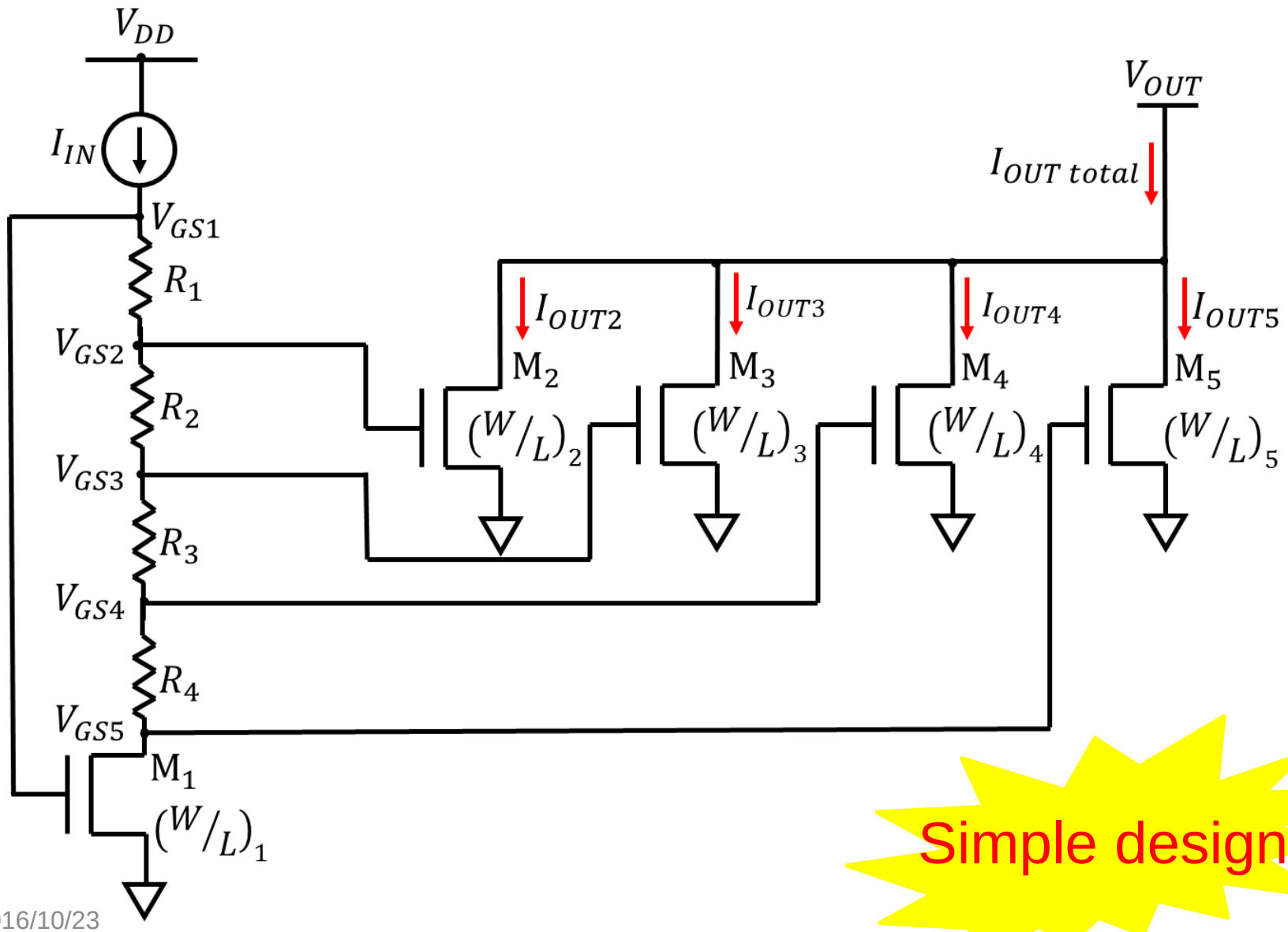
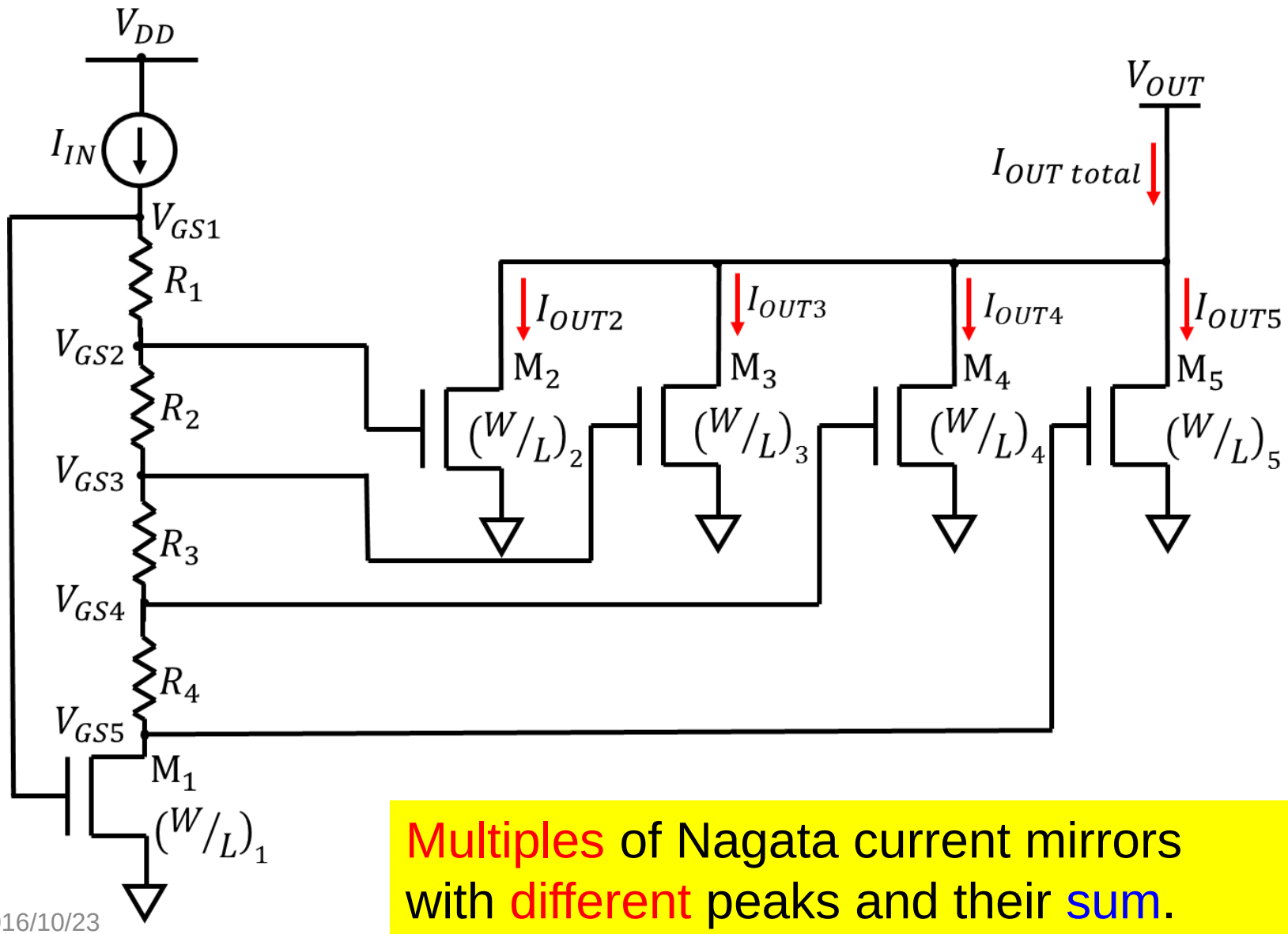
Proposed MOS Reference Current Source



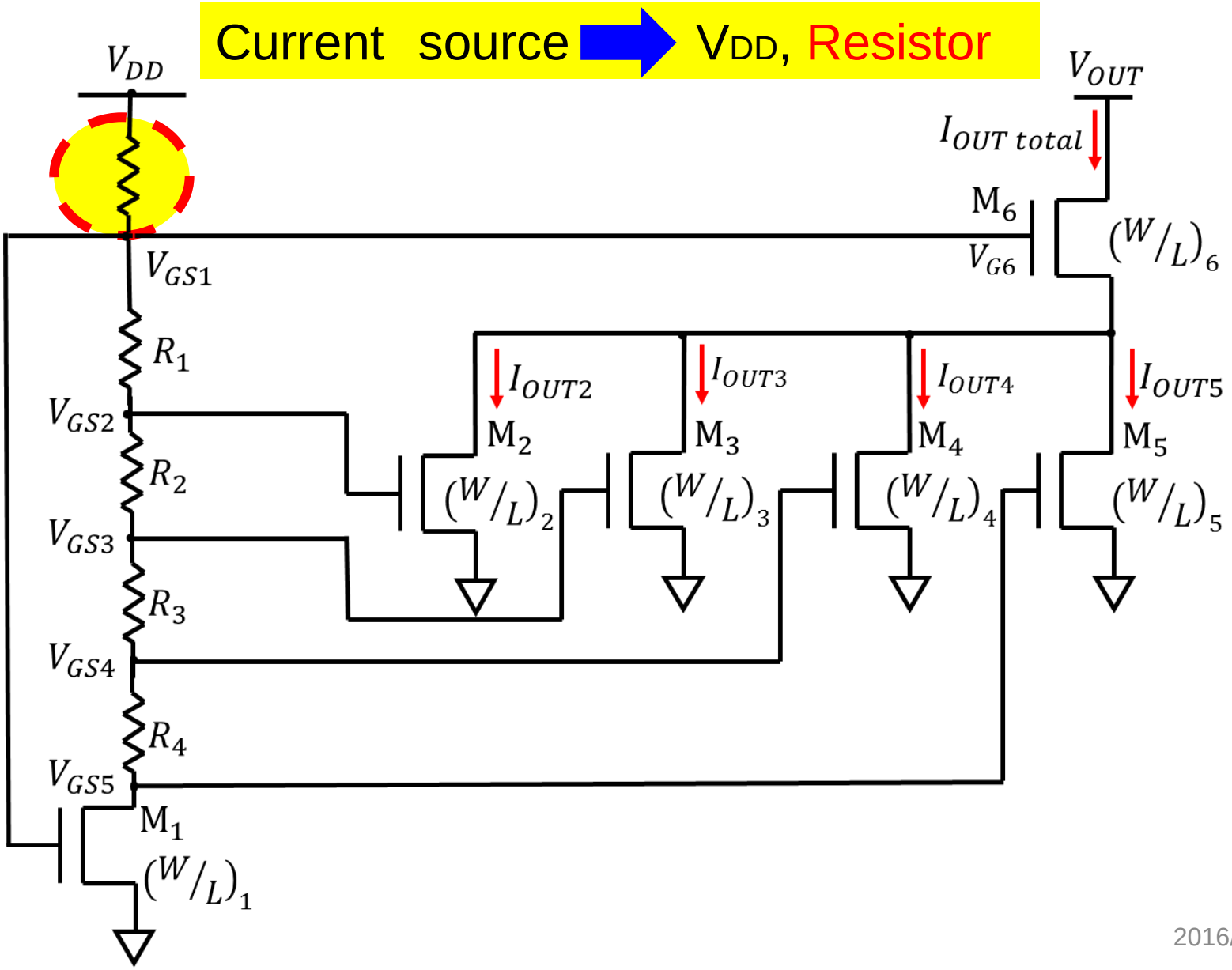
Simple design

Proposed MOS Reference Current Source

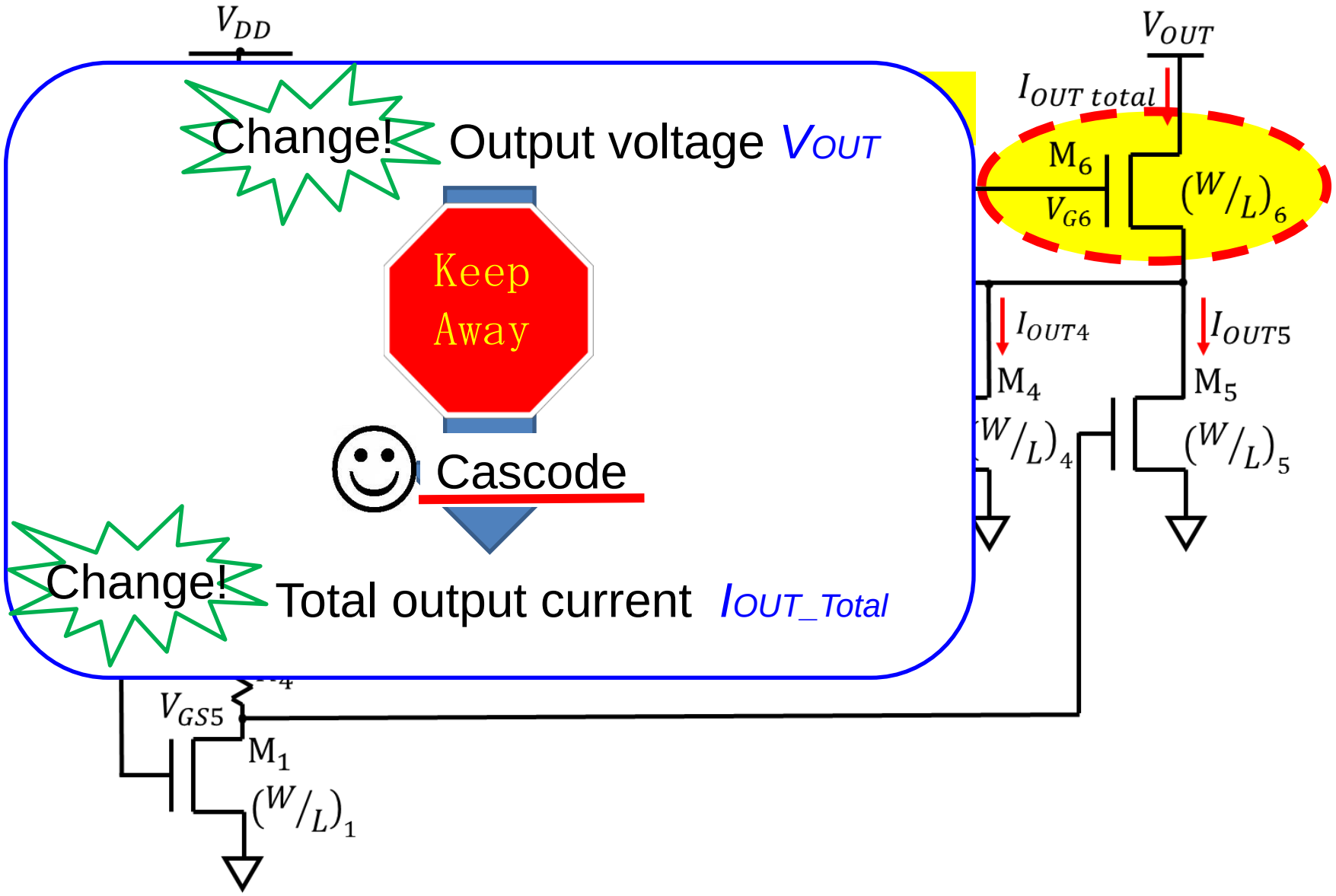


Multiples of Nagata current mirrors with different peaks and their sum.

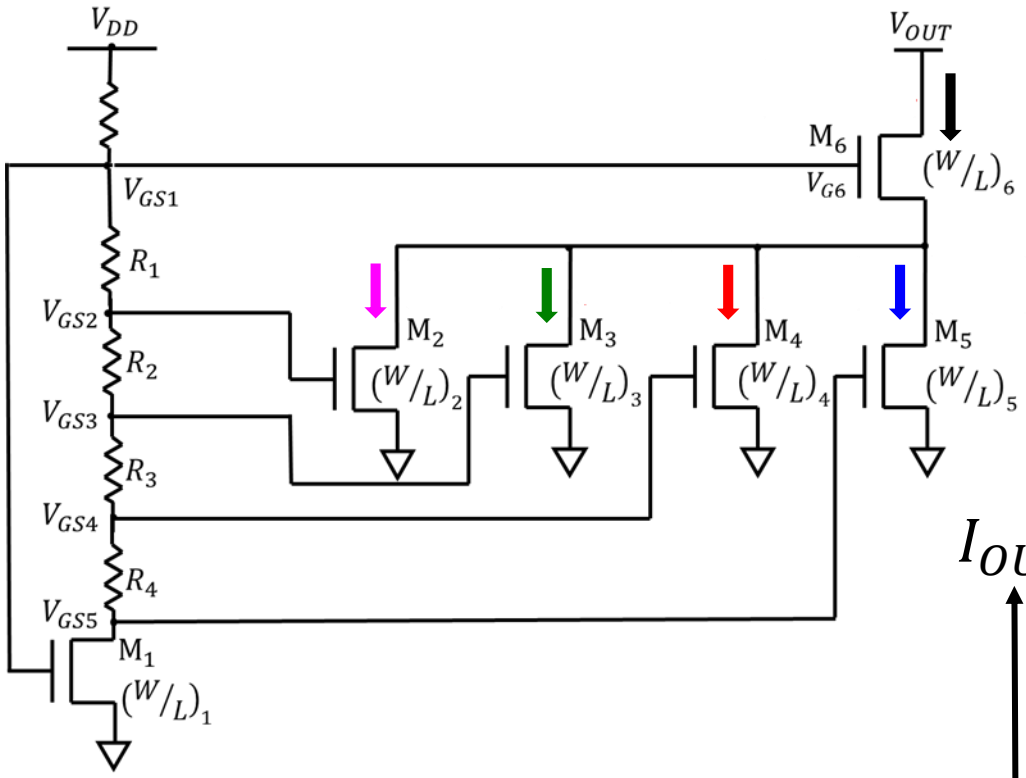
MOS Reference Current Source Details



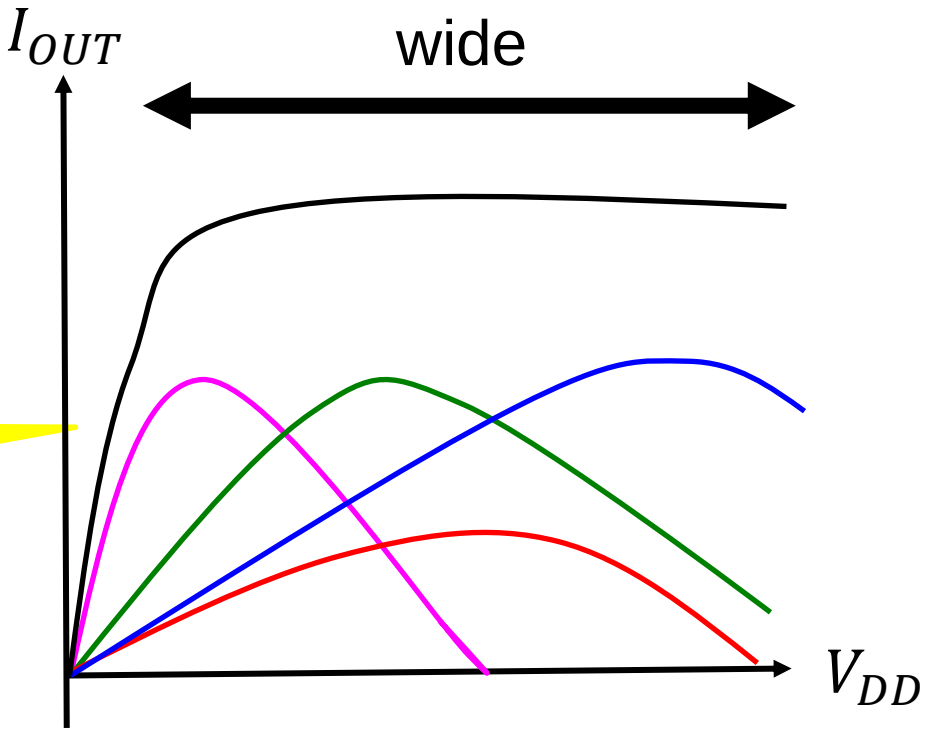
Cascode Configuration



MOS Reference Current Source Operation



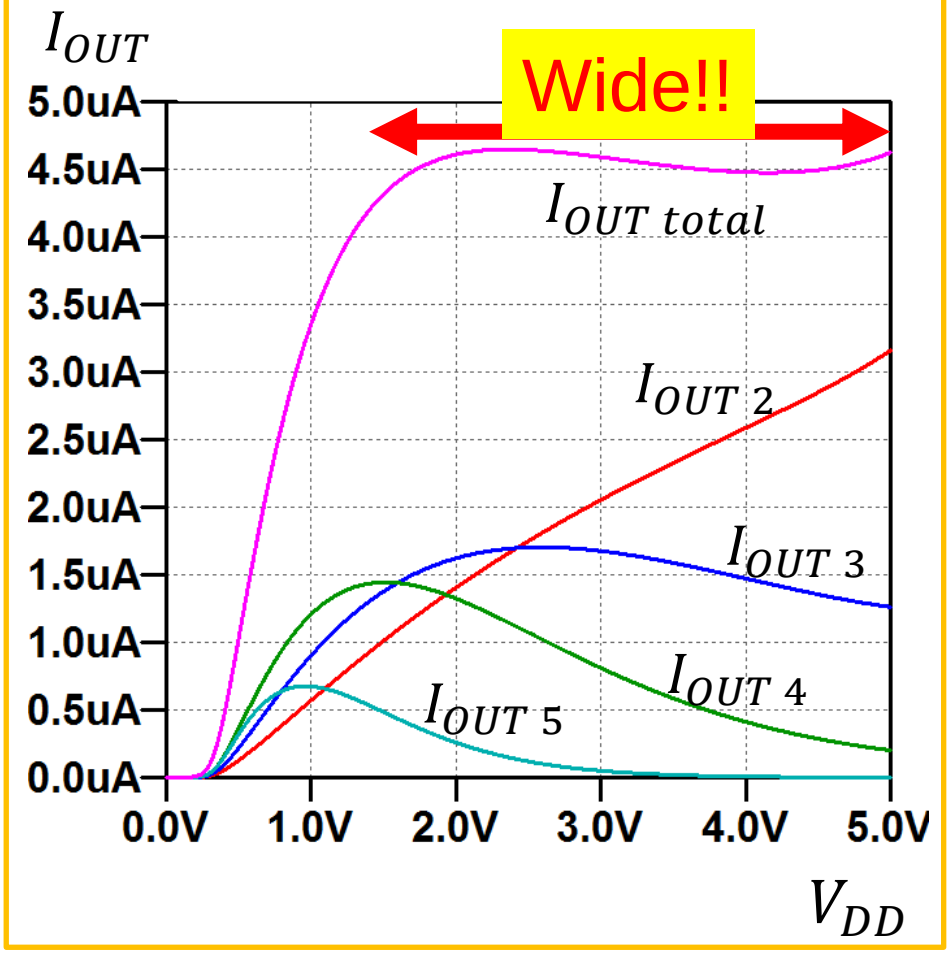
Almost constant total current



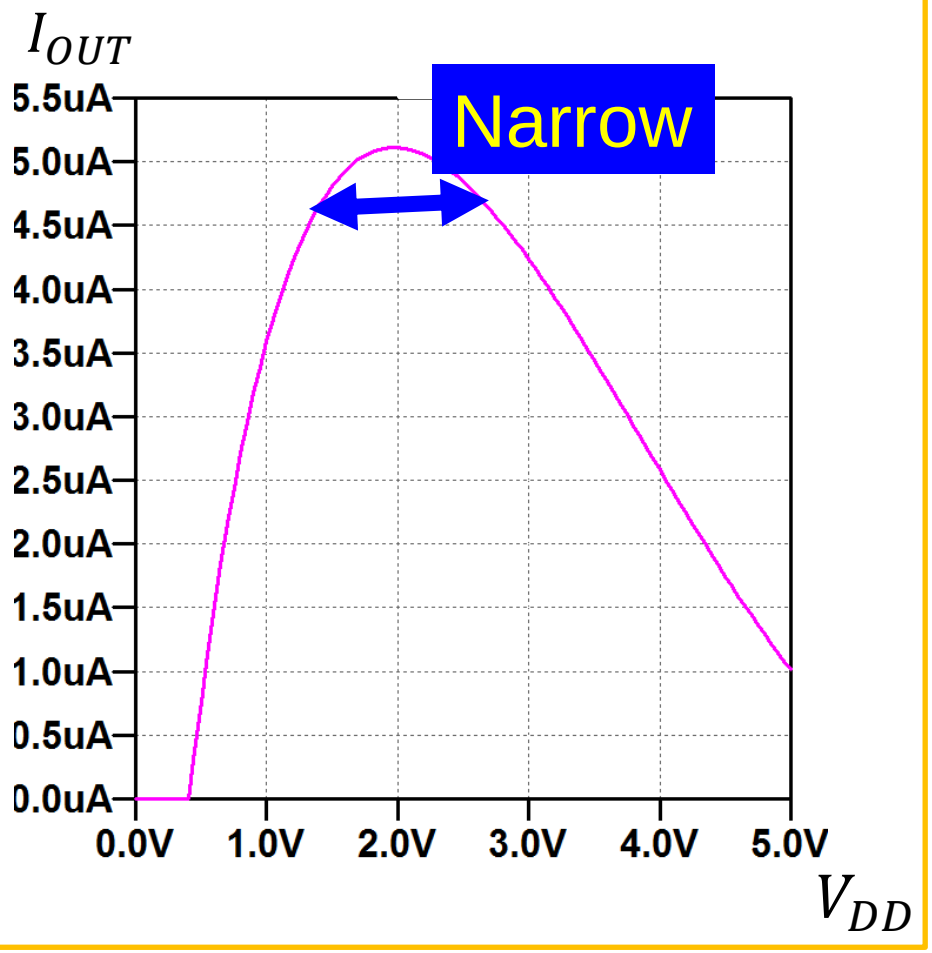
Simple Reference Current Source

Advantage of Proposed Circuit

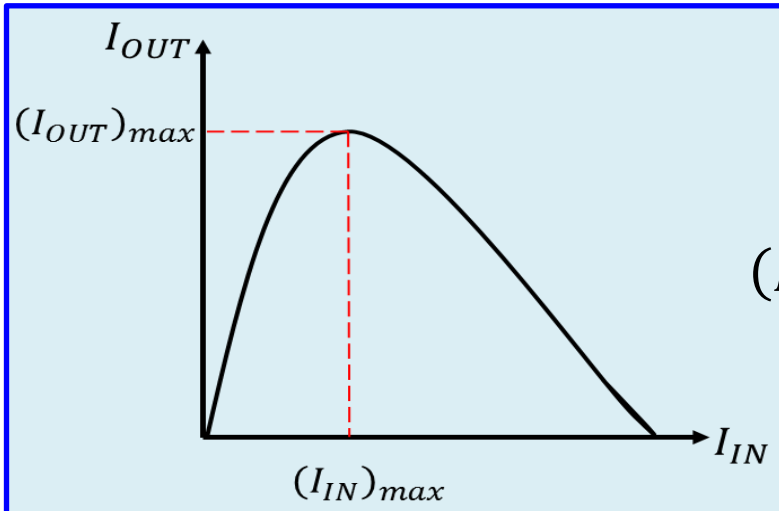
Proposed



Original



Analysis of Proposed Circuit



$$(I_{IN})_{max} = \frac{1}{4R_{n-1}^2 K_1 (1 + \lambda V_{DS1})} \quad \cdots(3)$$

$$(I_{OUT})_{max} = \frac{K_n}{4K_1} \cdot \frac{1}{4R_{n-1}^2 K_1} \frac{(1 + \lambda V_{DSn})}{(1 + \lambda V_{DS1})}$$

$$= \frac{(W/L)_n}{4(W/L)_1} \cdot (1 + \lambda V_{DSn})(I_{IN})_{max} \quad \cdots(4)$$

Change resistor values and MOSFET sizes

$(I_{OUT})_{max}$ $(I_{IN})_{max}$ Adjusted

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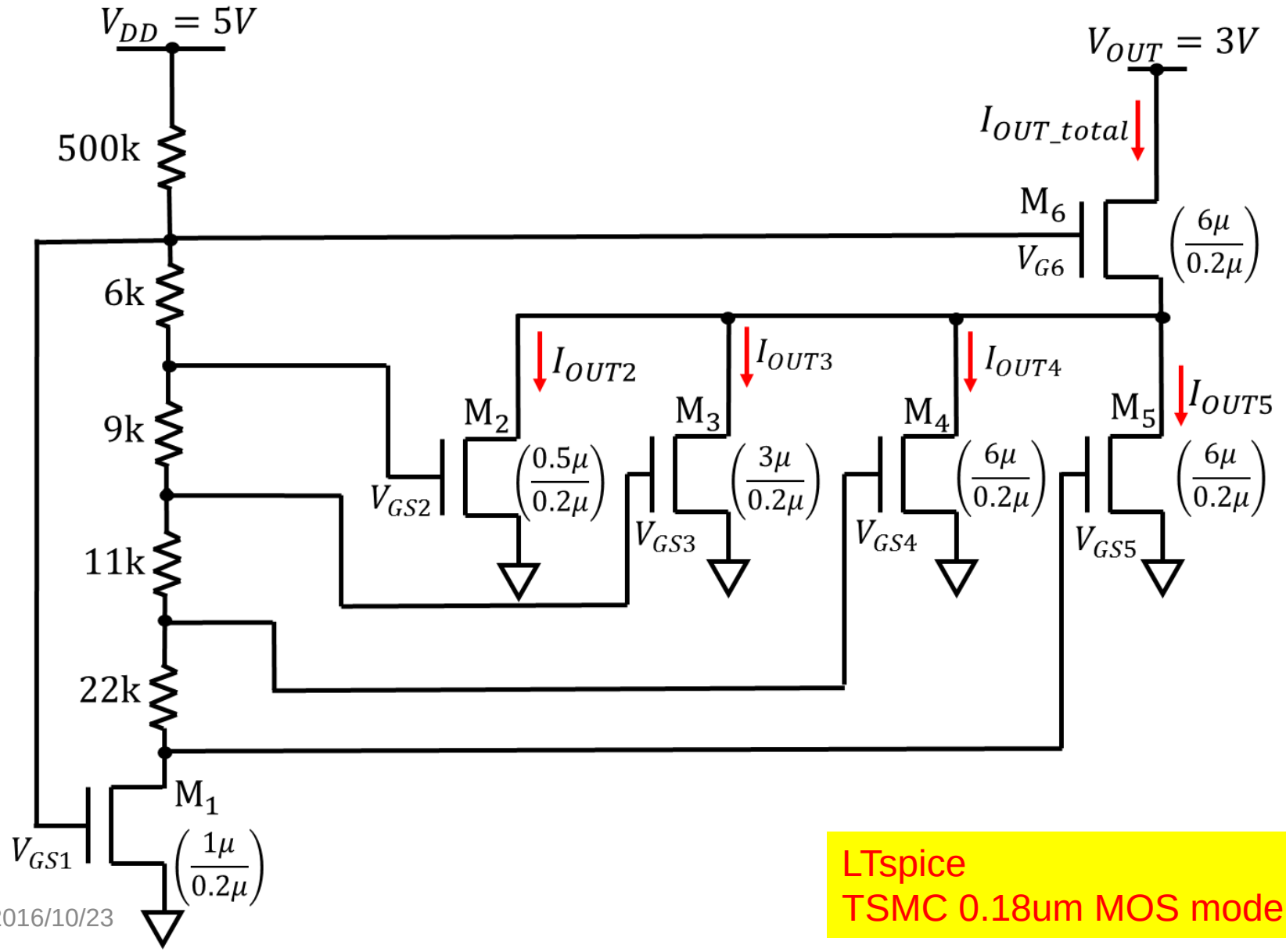
SPICE Simulation Circuit

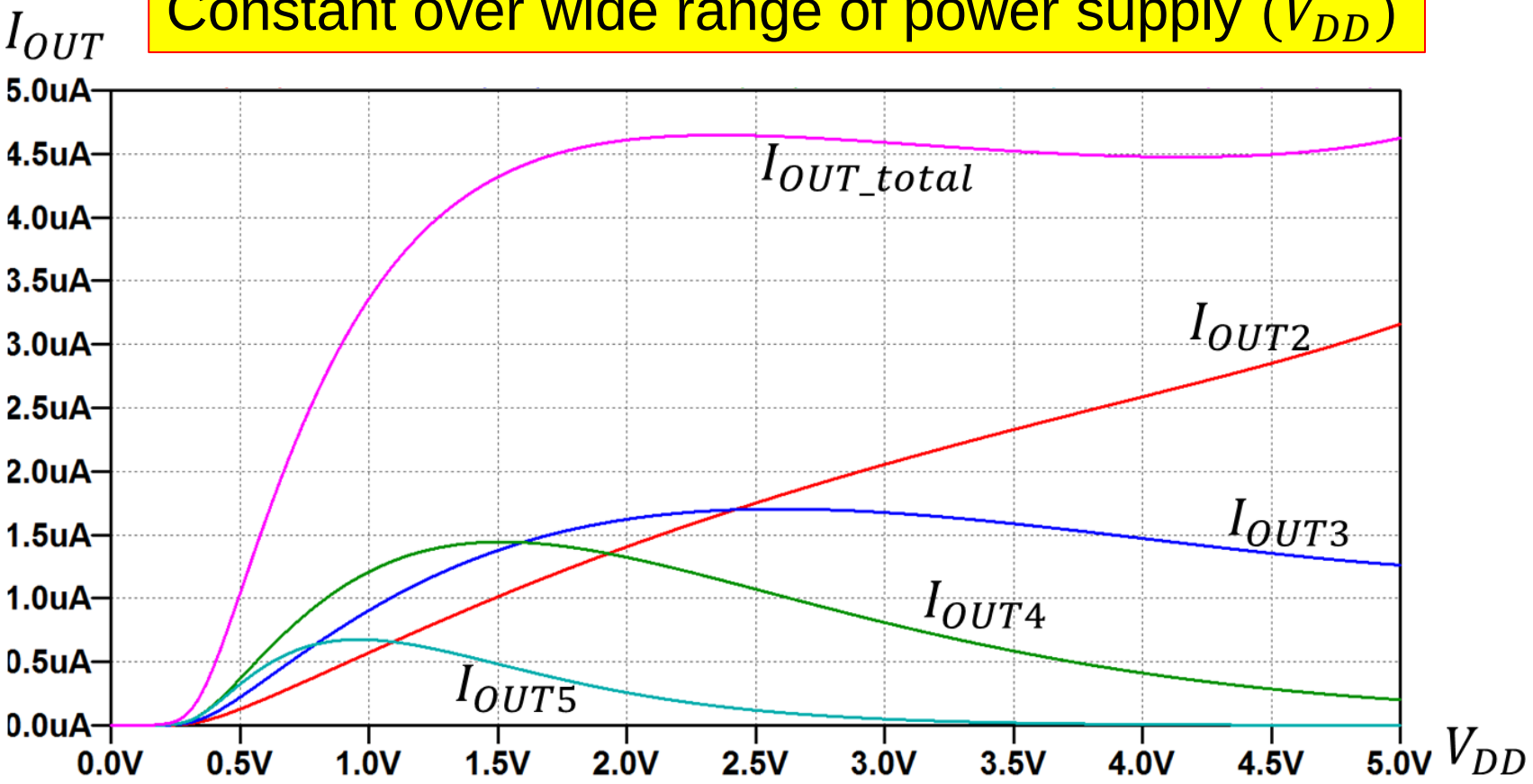


LTspice
TSMC 0.18um MOS model

SPICE Simulated Characteristics

$I_{OUT\_total} \sim 4.56\mu A$

Constant over wide range of power supply (V_{DD})



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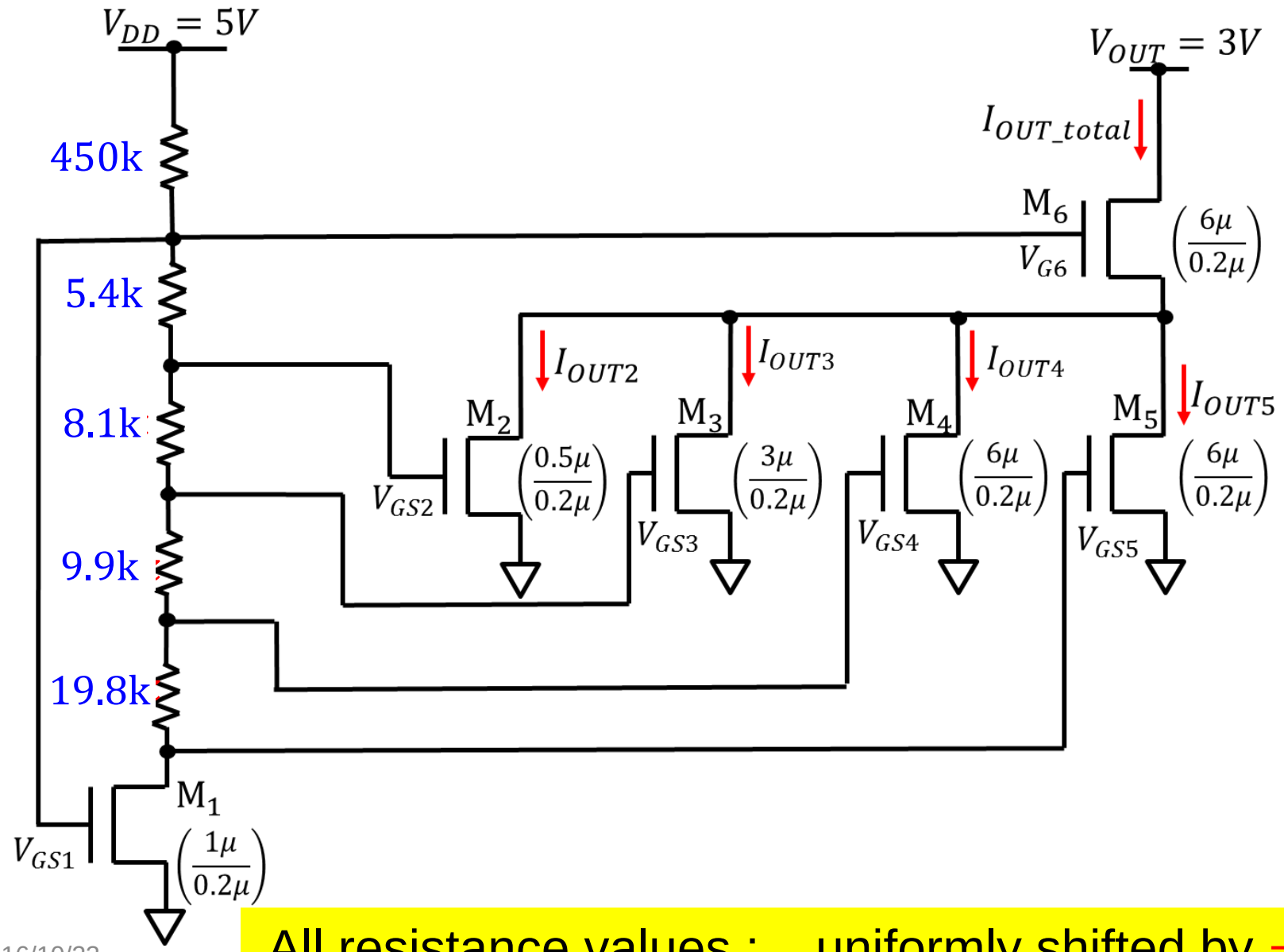
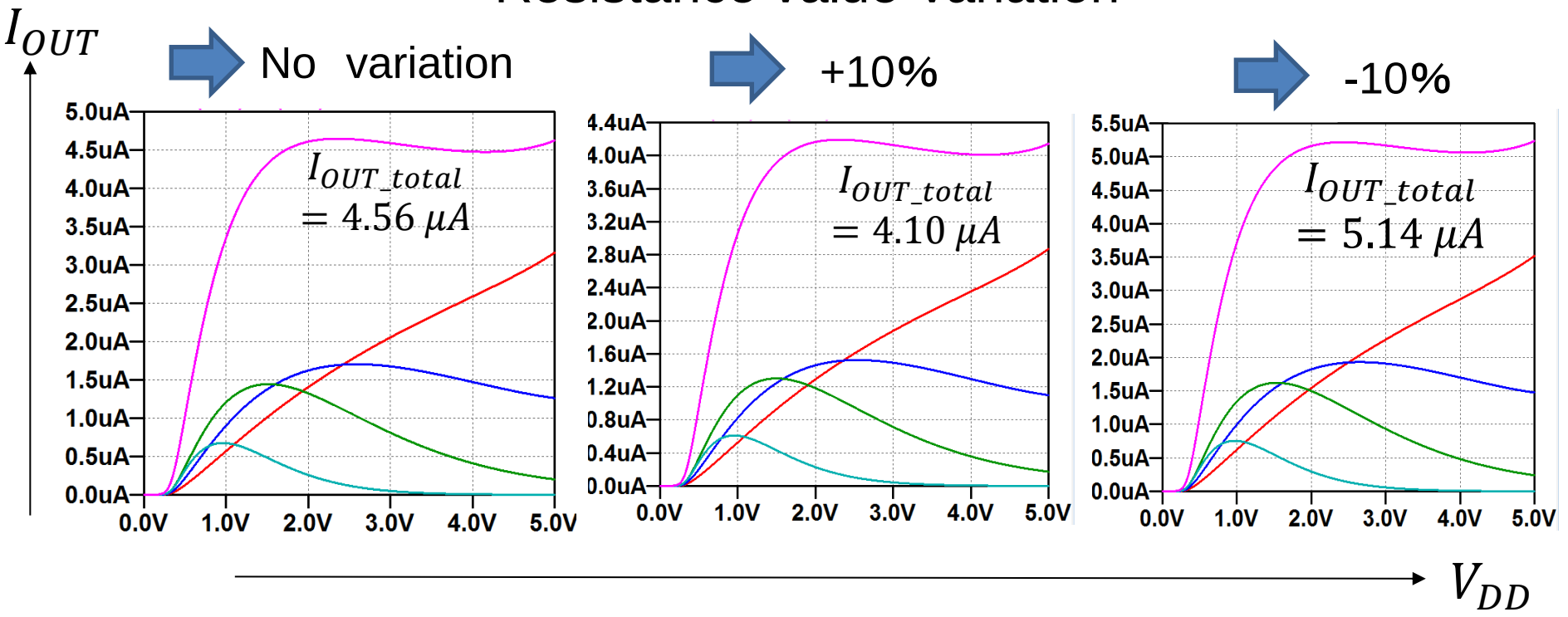
Influence of Resistor Variation



All resistance values : uniformly shifted by ±10%

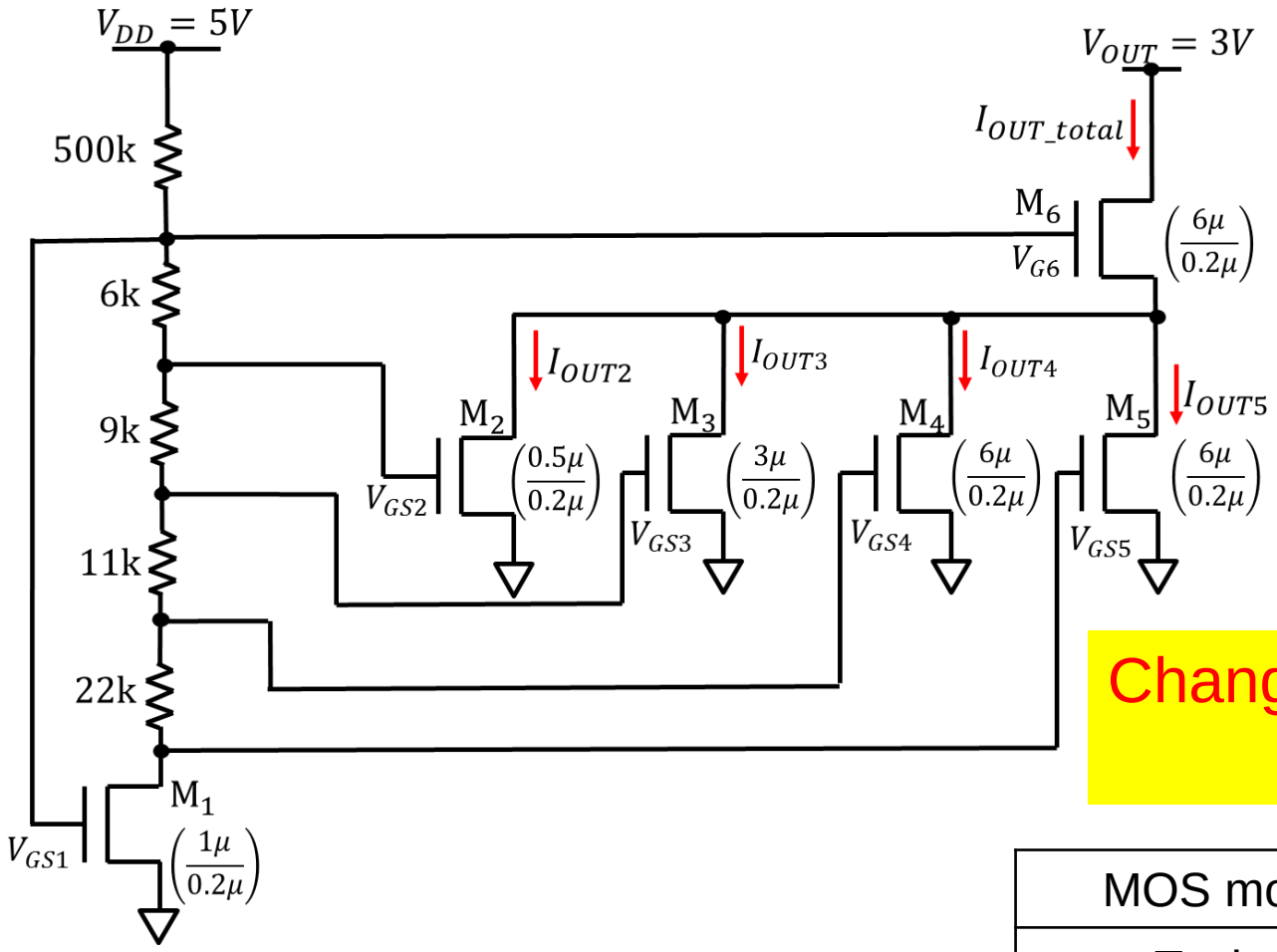
Simulation Result

Resistance value Variation



Resistance value Variation [%]	+10	-10
Total output current change rate [%]	2.4	1.6

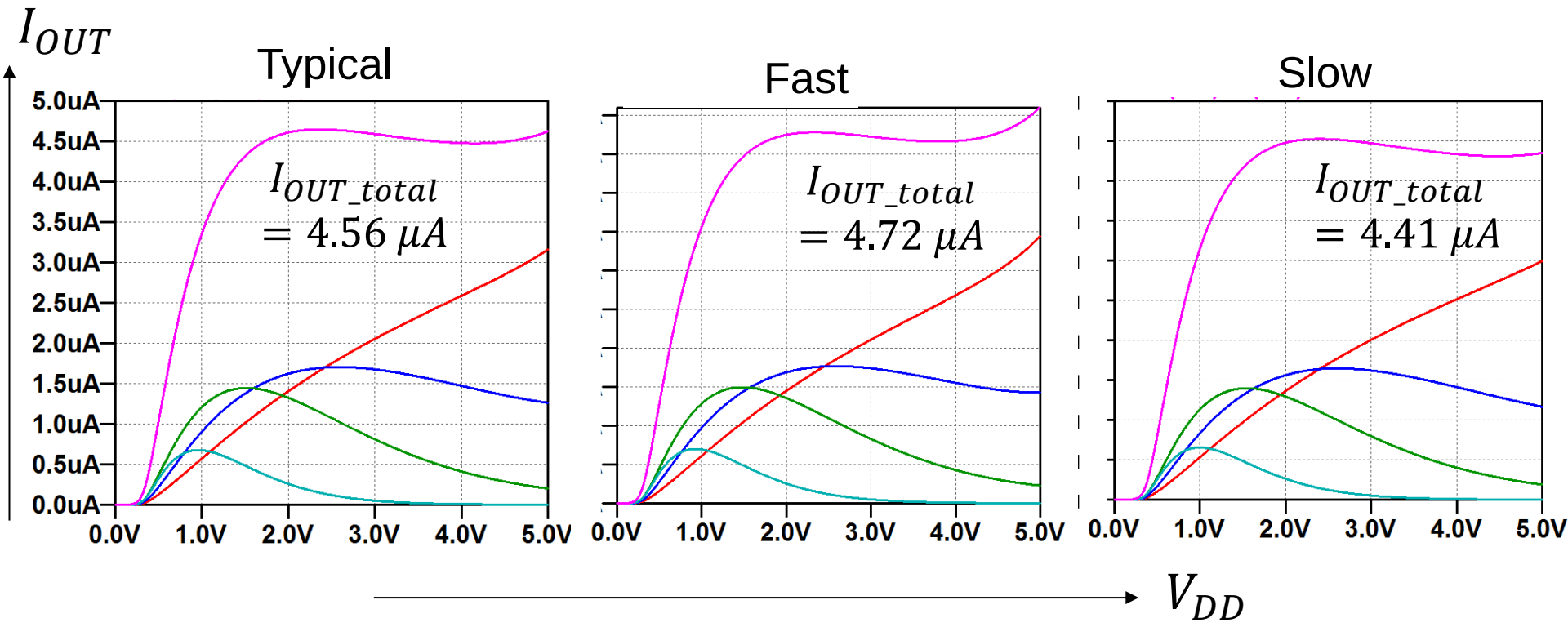
MOS Fast and Slow Models



Change threshold voltage by ±10%

MOS model	Threshold [V]
Typical	0.369
Fast	0.332
Slow	0.406

Simulation Results with Fast & Slow Models



MOS model	Fast	Slow
Total output current change rate [%]	4.4	2.5

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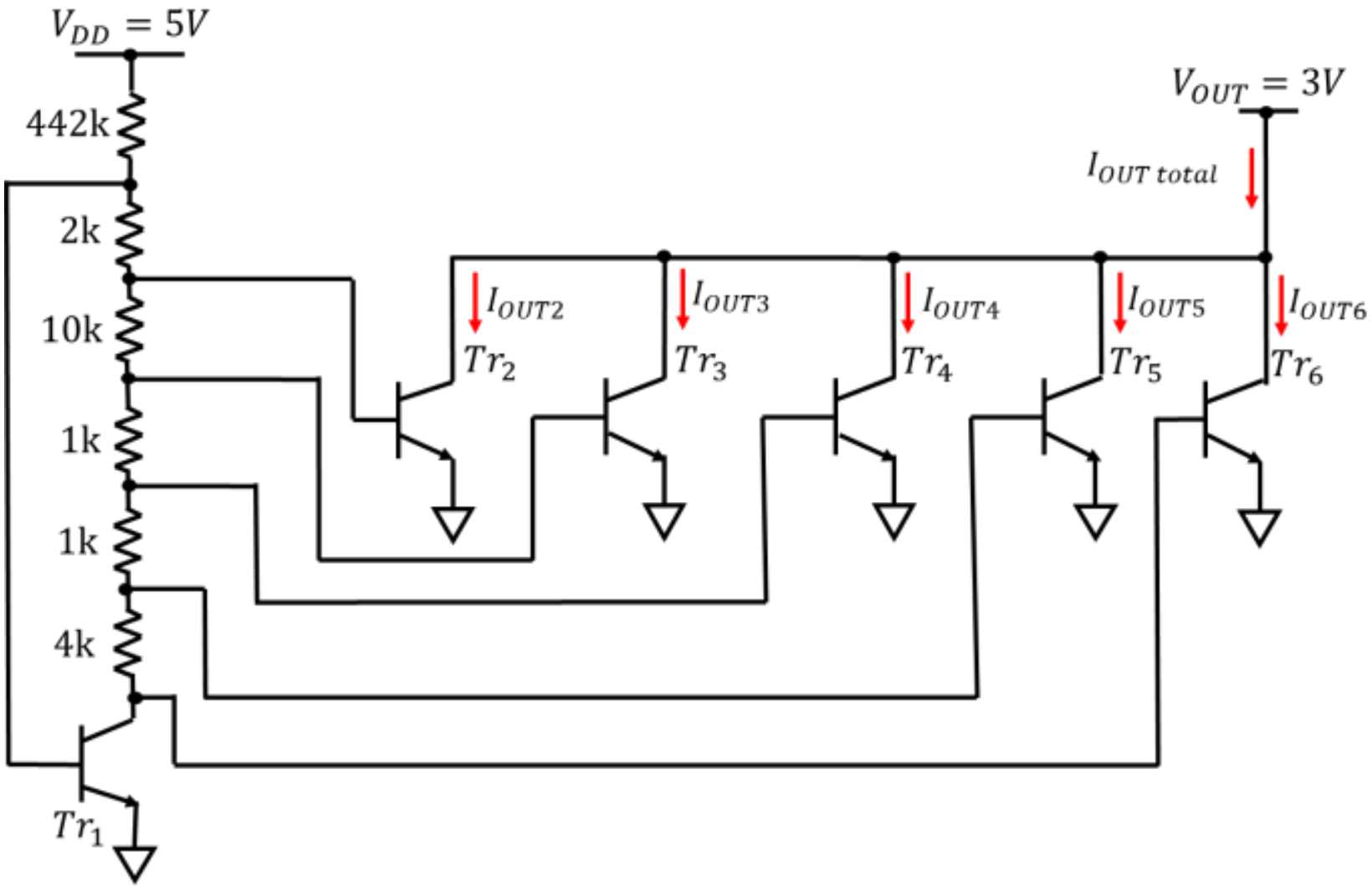
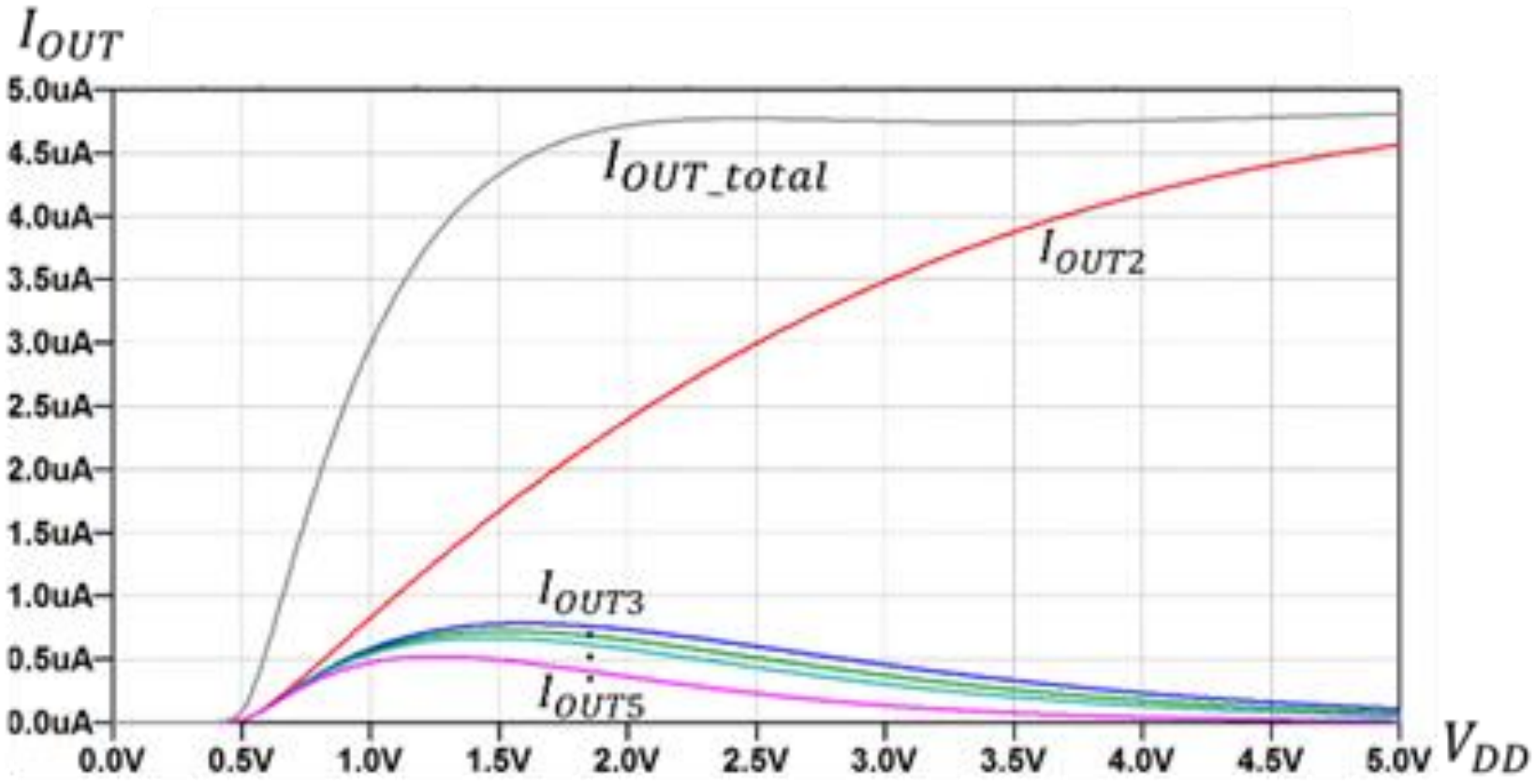
Proposed Bipolar Reference Current Source



Simulation Result

Constant over wide range of power supply (V_{DD})



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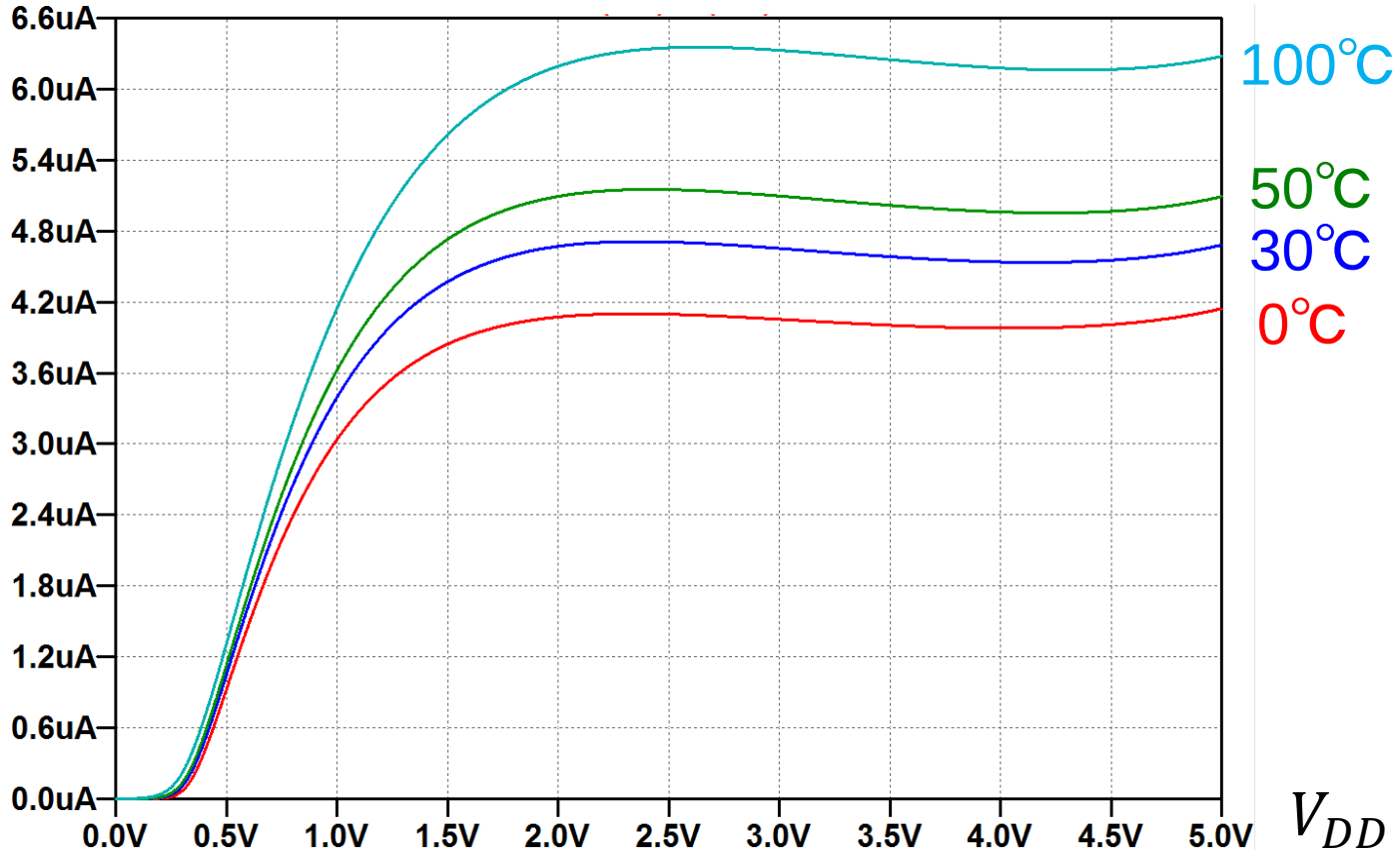
Temperature Effect (1)

Proposed MOS circuit

I_{OUT_total}

1℃ UP ⇨ about $0.023\mu A$ UP

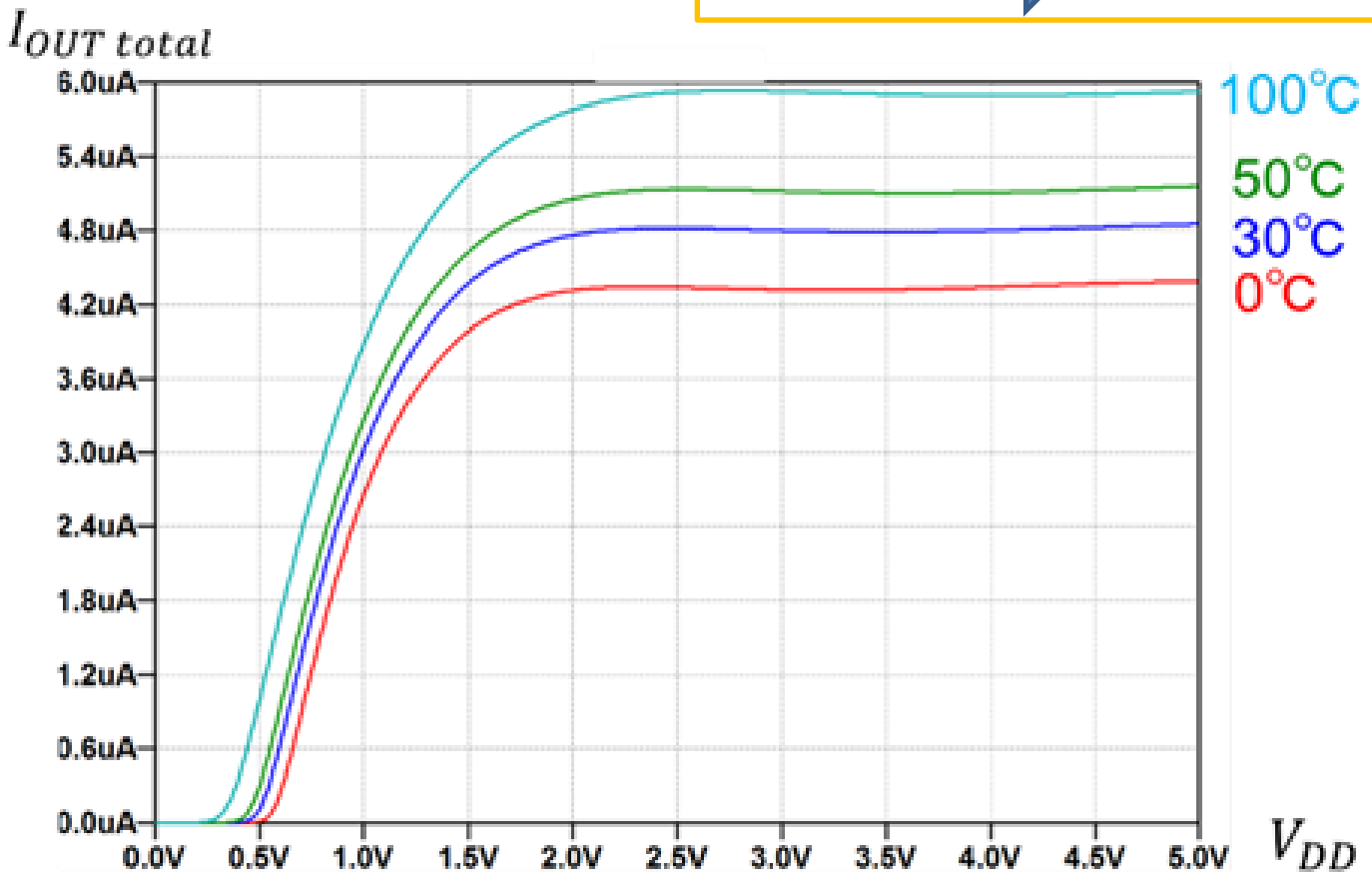


Proposed reference current source dose not consider temperature variation effect

Temperature Effect

Proposed Bipolar transistor circuit

1℃ UP ⇨ about $0.015\mu A$ UP



Proposed reference current source dose not consider temperature variation effect

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Conclusion

- Proposal of MOS & Biploar reference current sources

  ⇒ Sum of multiple peaking currents

- Comparison

Circuit	Circuit Simplicity	Chip Area	Insensitivity to V_{DD}
Nagata Current Mirror	◎	◎	△
Zach's Circuit	△	×	◎
BandGap Reference	×	○	△
Proposed Reference Current Source	○	◎	◎

Design guidelines of R, W/L values are now ready for reporting elsewhere.

Analog circuit is art & craft

温故知新

Old invention by Dr. Nagata in 1966.

&

New idea

↓

Very good analog circuit !!

Thank you for listening

謝 謝

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