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Gray-Code Input DAC Architecture for Clean Signal Generation

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OUTLINE

- Research Background・Objective
- Glitches
- Gray-code
- Gray-code Input DAC Architecture and Operation
- Simulation Verification by SPICE
- Conclusion

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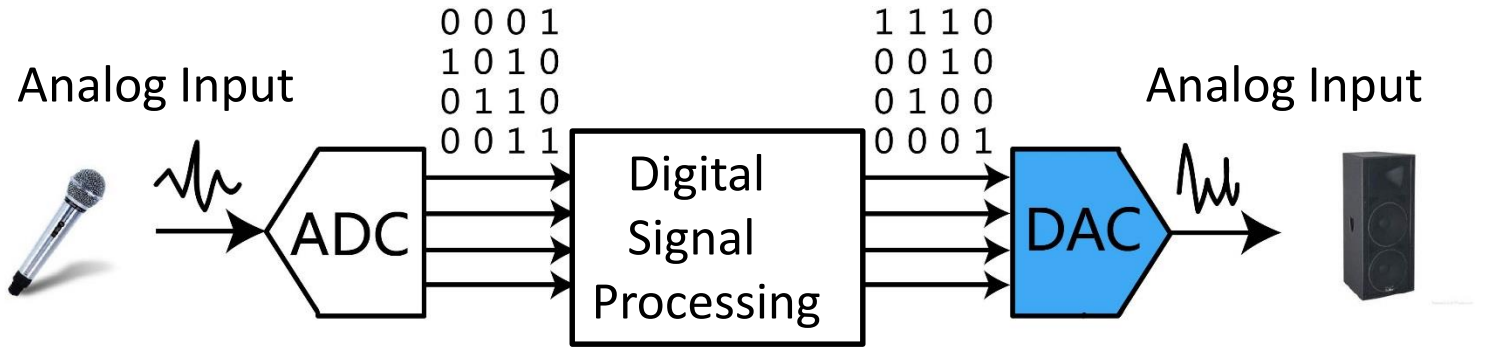
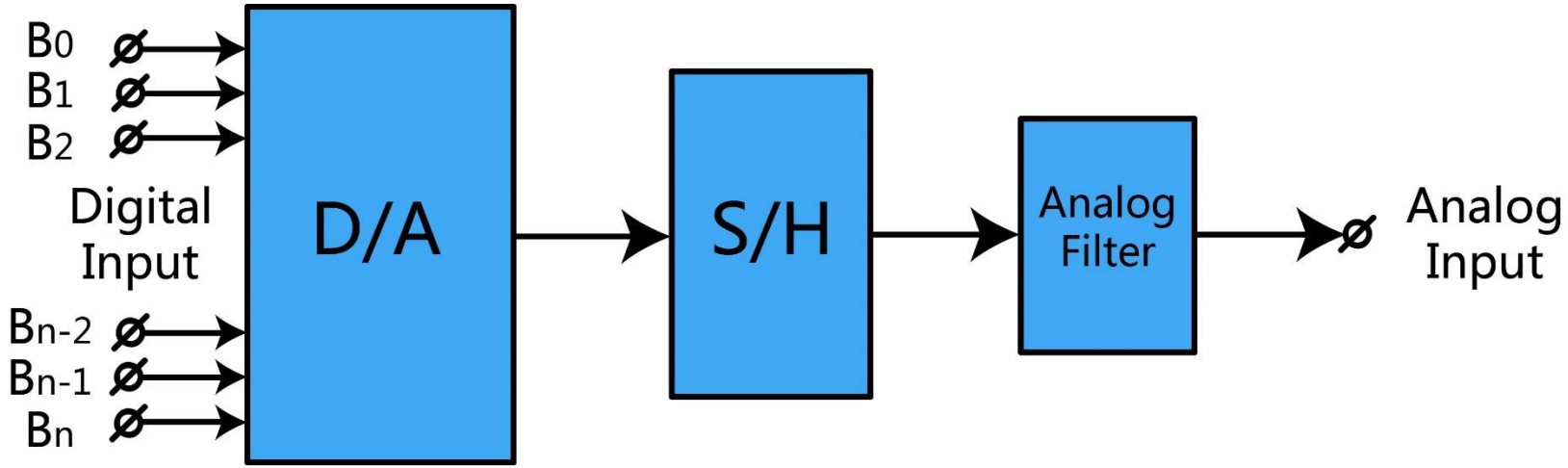
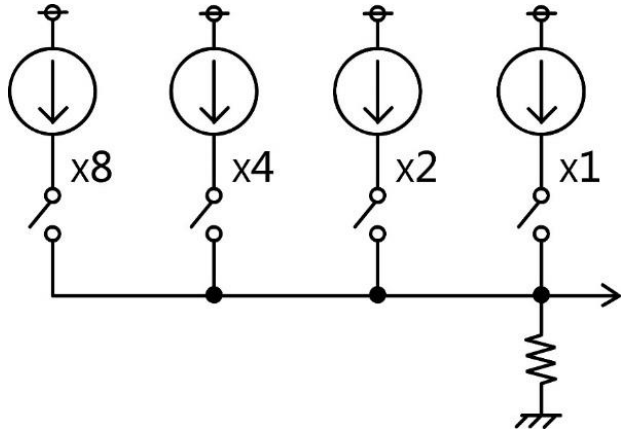
Research Background



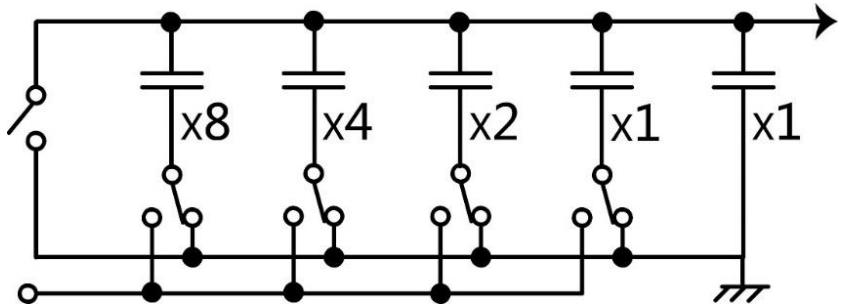


Research Background

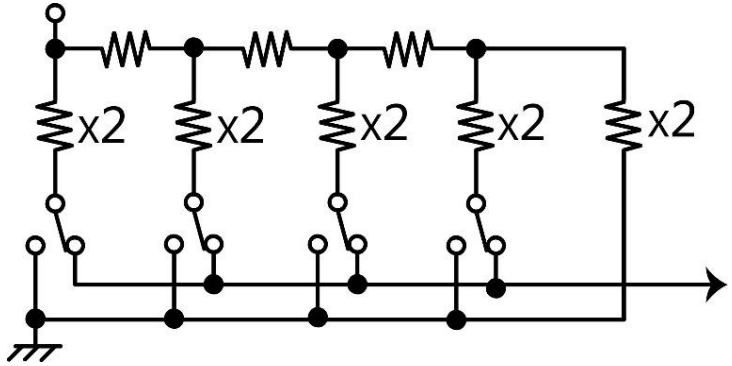
Basic architecture of DAC



Current Source DAC



Capacitive DAC



Resistance DAC

The switch is driven with a binary code → glitch

Research Objective

Objective

- Design Digital-to-Analog Converter (DAC) architectures for clean signal generation

Approach

- By reducing glitches with Gray-Code input topologies

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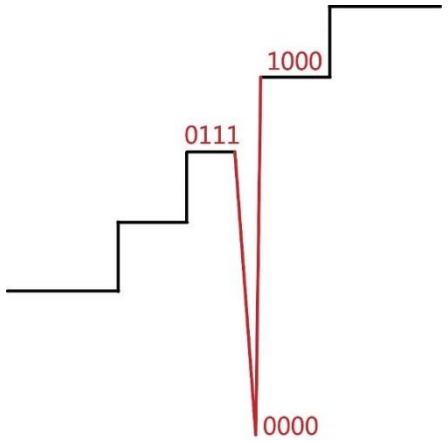
What are Glitches

- Voltage spikes
- Reasons for glitches

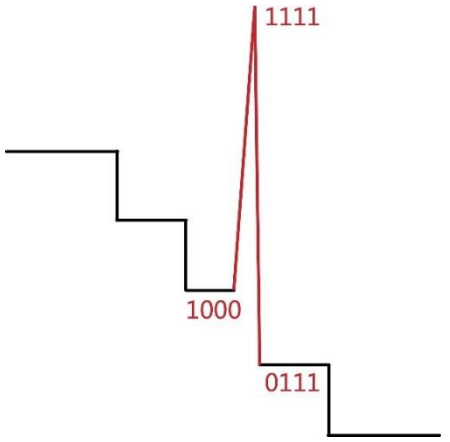
Decimal numbers	Natural Binary code
0	0 0 0 0
1	0 0 0 1
2	0 0 1 0
3	0 0 1 1
4	0 1 0 0
5	0 1 0 1
6	0 1 1 0
7	0 1 1 1
8	1 0 0 0
9	1 0 0 1
10	1 0 1 0
11	1 0 1 1
12	1 1 0 0
13	1 1 0 1
14	1 1 1 0
15	1 1 1 1

when 7→8



0111→0110→0100→**0000**→1000

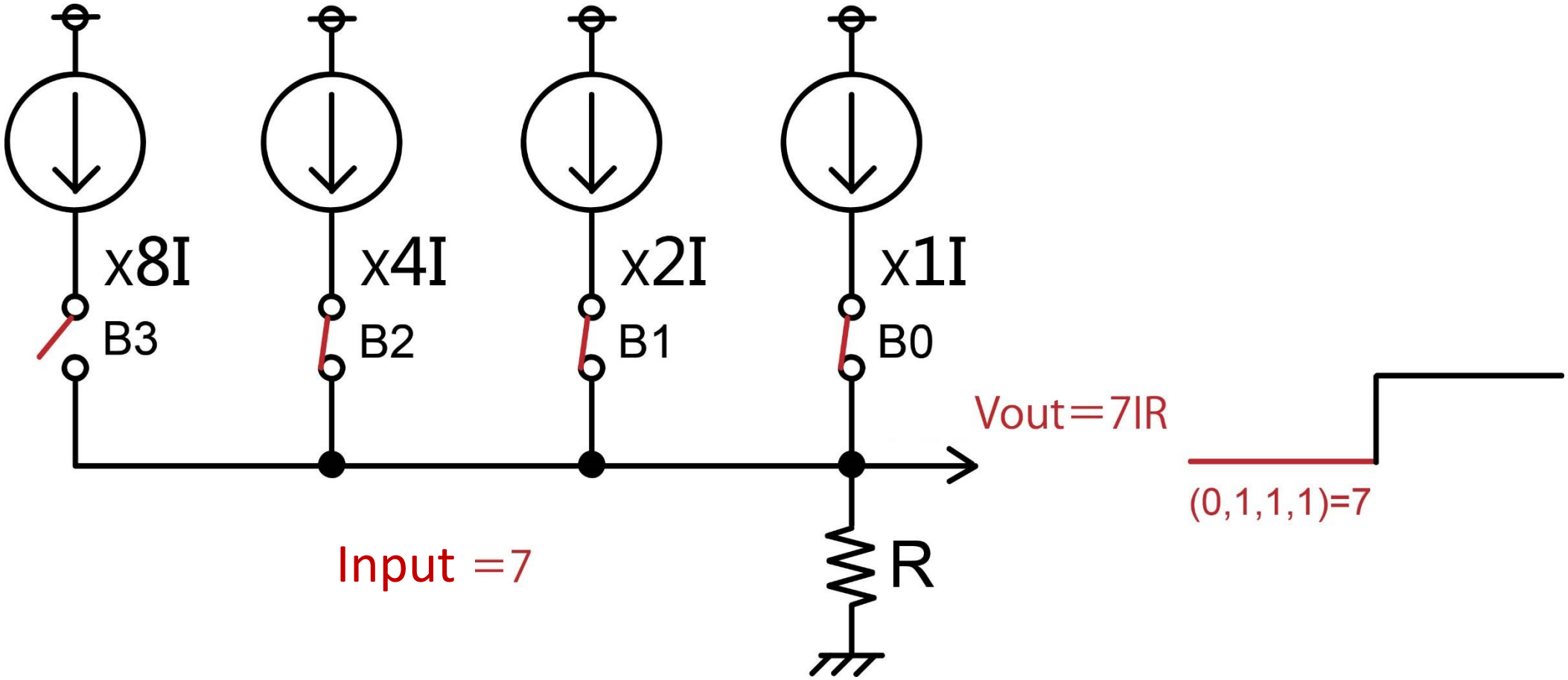
when 8→7



1000→1001→1011→**1111**→0111

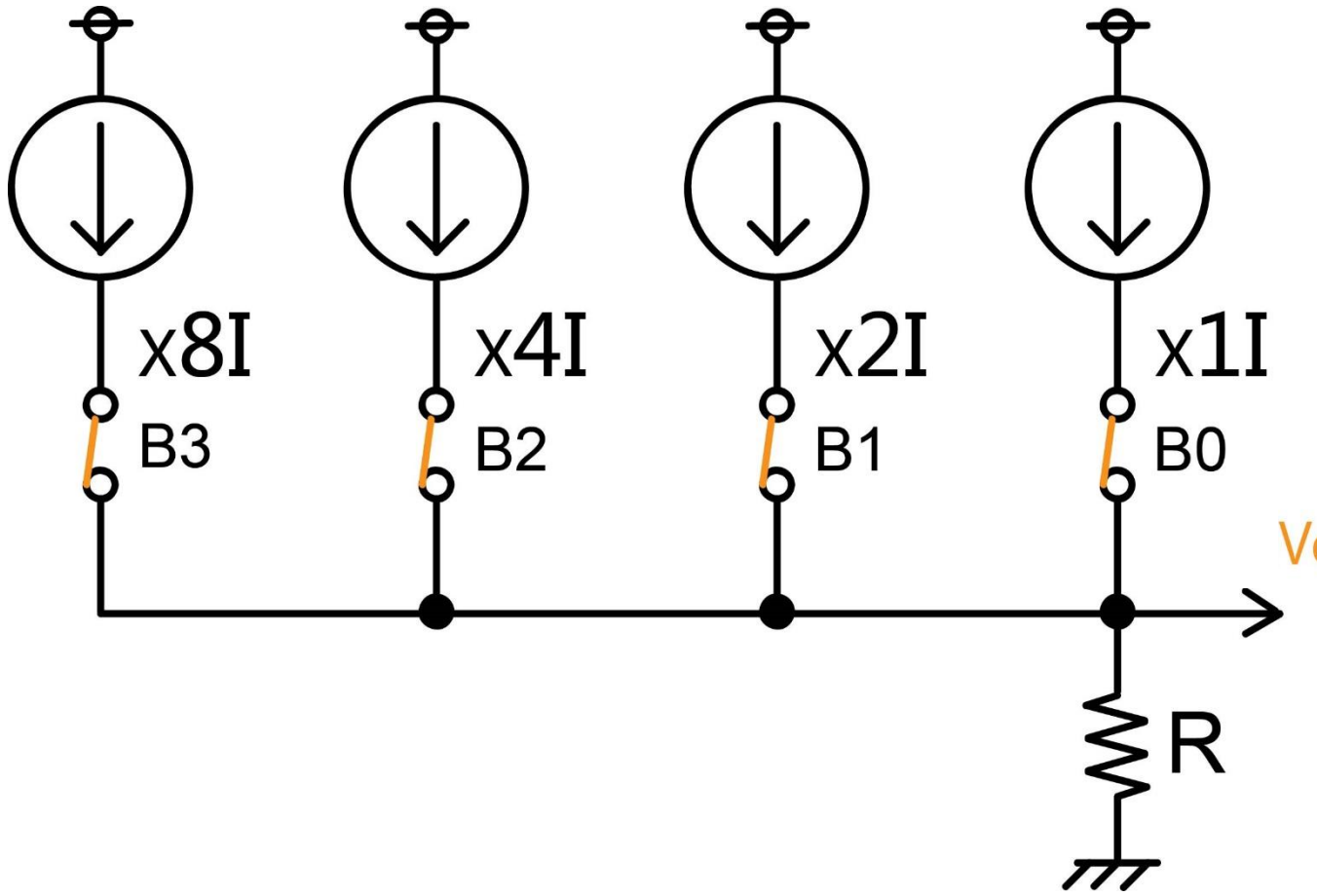
The most significant bit (MSB) changes (near the middle point)

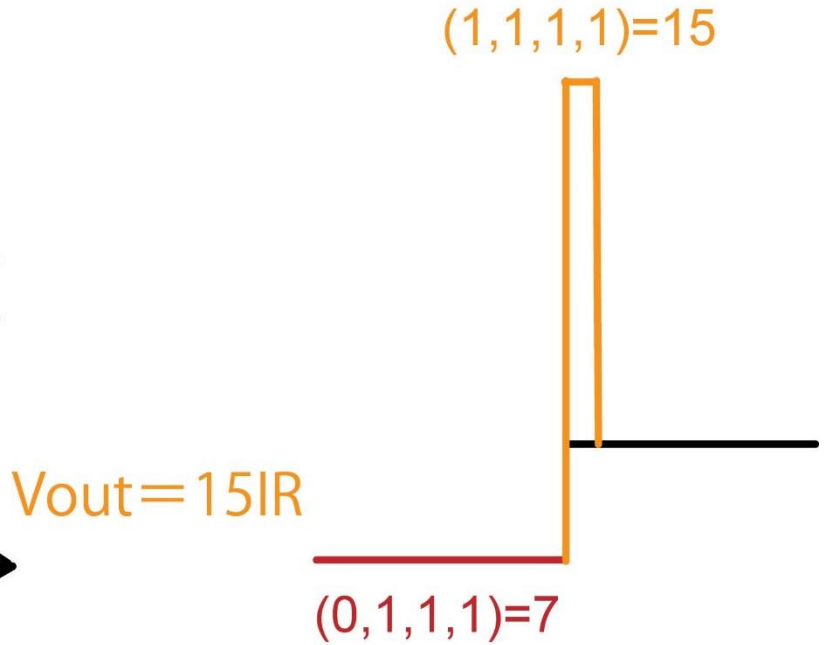
Generation of Glitch at Switching time



When the input changes 7 →8

Generation of Glitch at Switching time

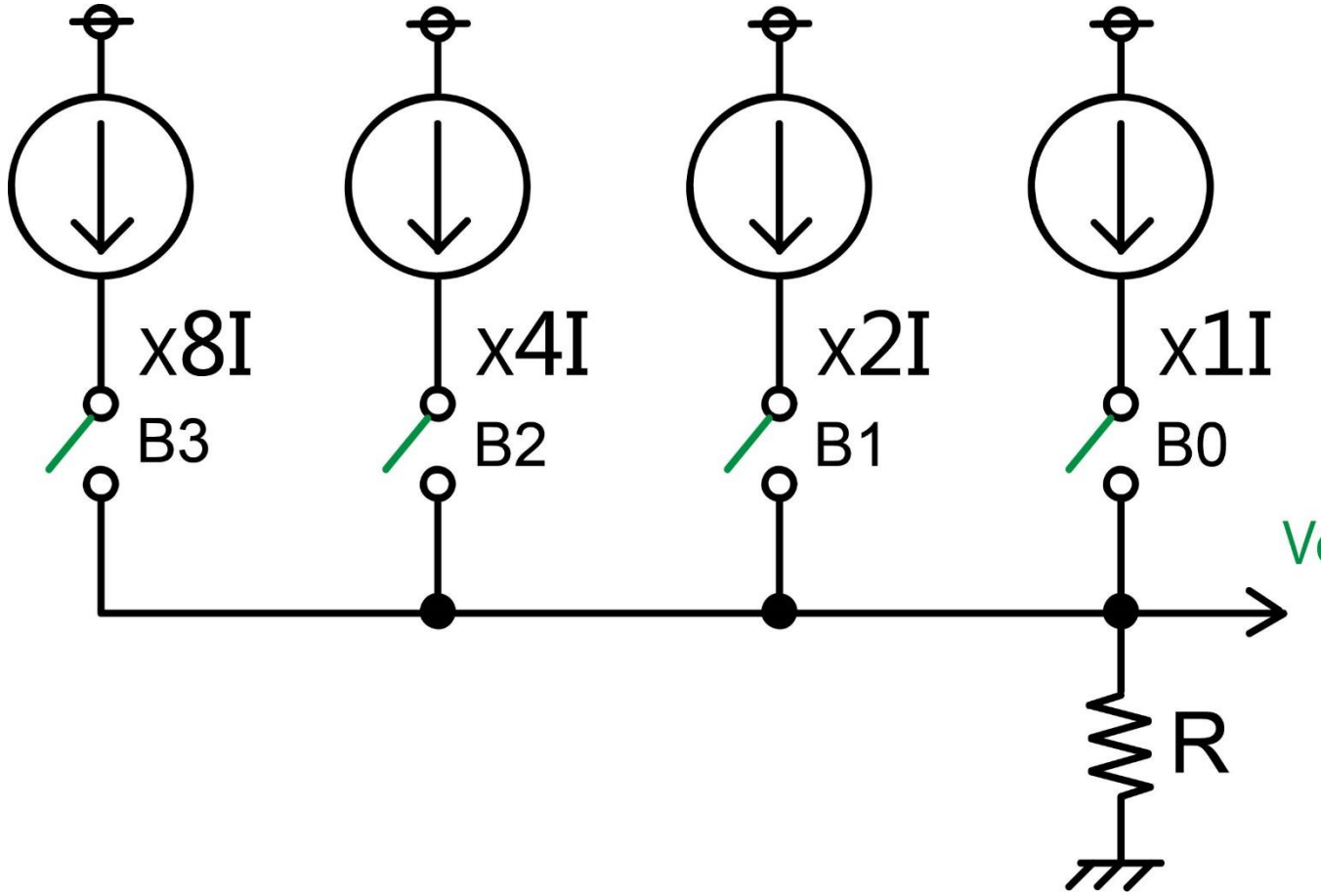




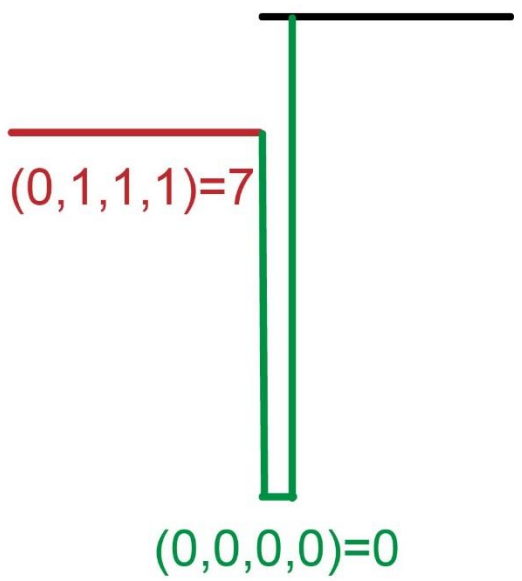
A big upward spike arises

When B3 switches first

Generation of Glitch at Switching time

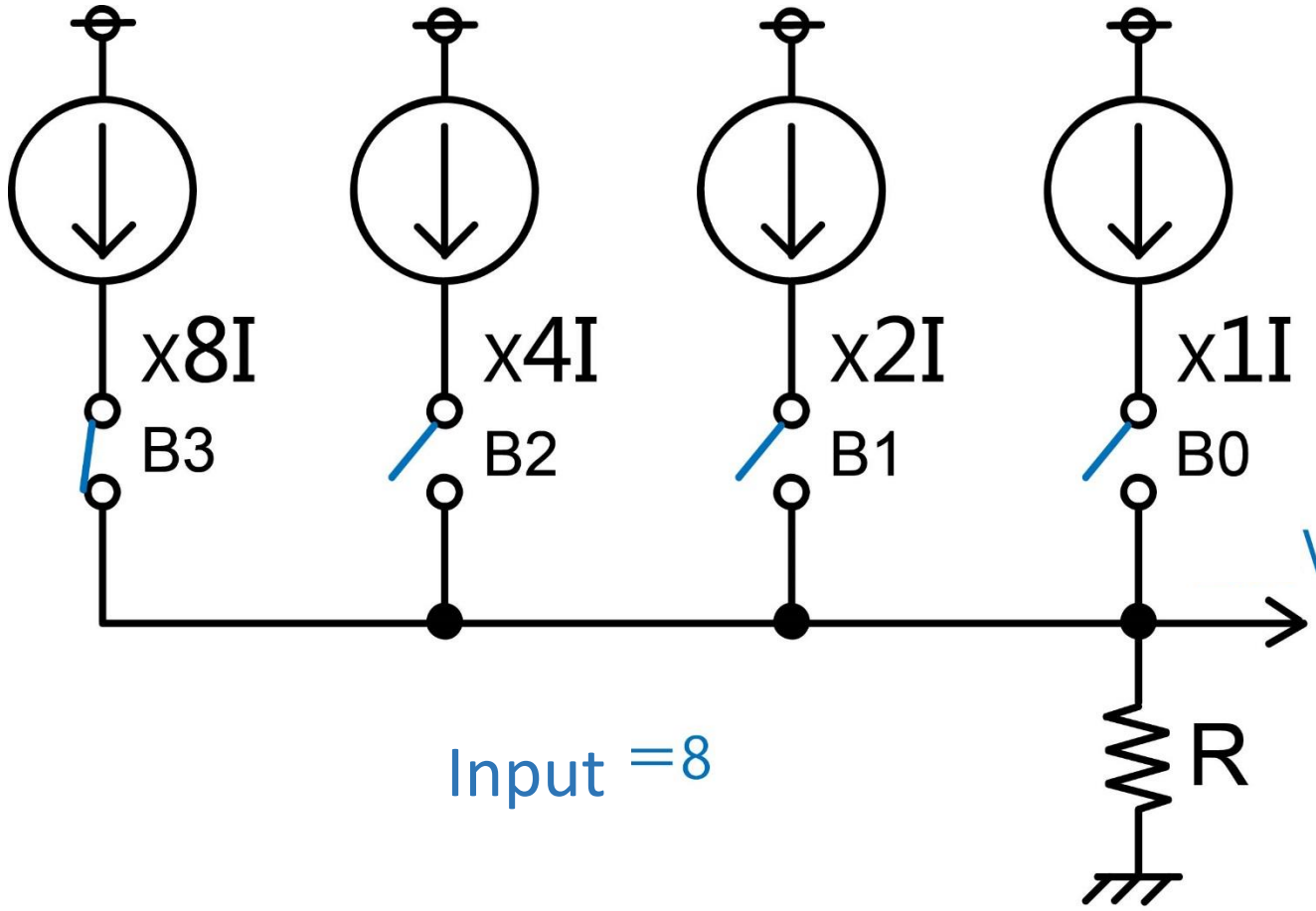


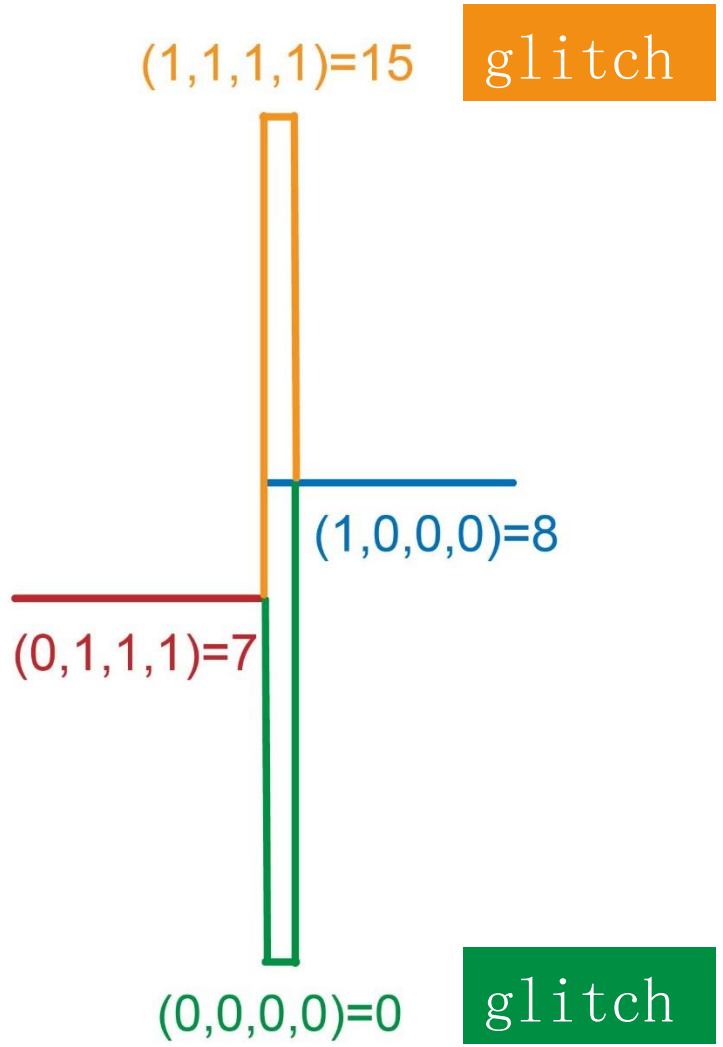
A big downward spike occur



When B3 switches last

Generation of Glitch at Switching time





Glitch Problem and Remedy

Effects of Glitch

- Serious deterioration of images, videos, sounds

Remedy

- Using high-order reconstruction filter
- Using track/hold circuitry at the DAC output

} Extra Space in IC, Expensive

- Using Gray-Code input DAC topologies

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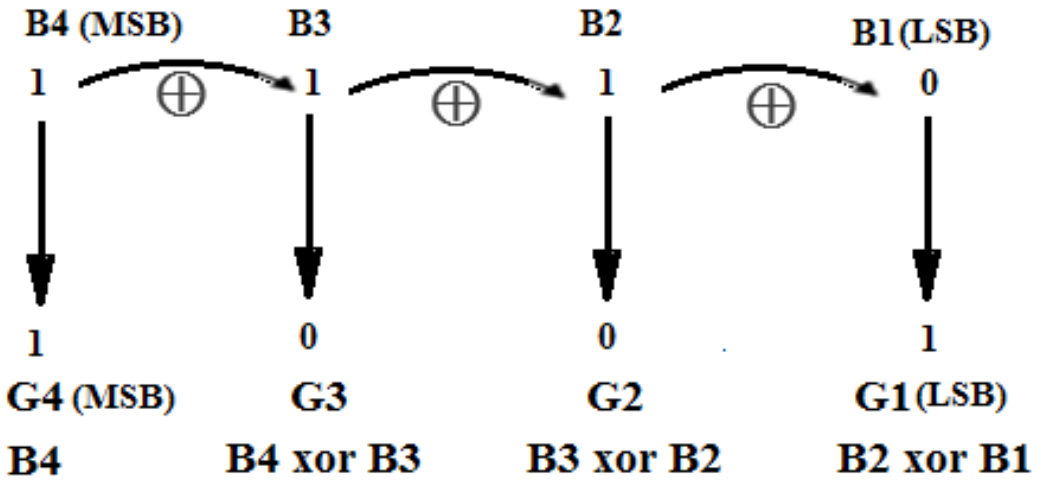
Gray-Code

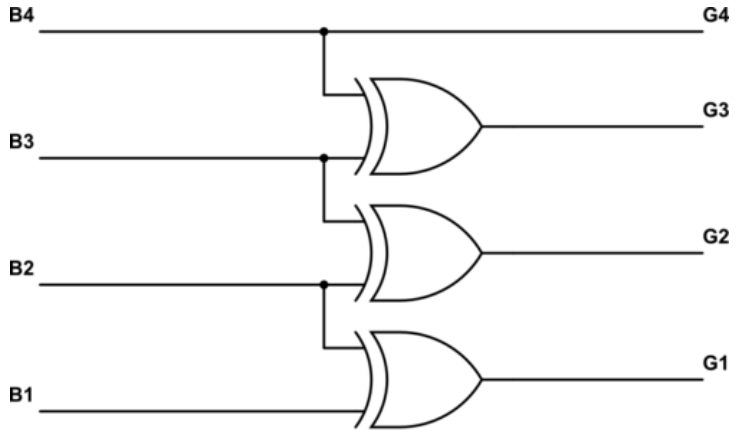
Gray-Code → Alternative representation of binary code

Two adjacent number → Only one bit change

$(G_n = B_{n+1} \oplus B_n)$



Binary to Gray code conversion diagram



Binary to Gray code converter

Gray Code

Compare with Binary code and Gray code

Decimal numbers	Binary Code	Gray Code
0	0000	0000
1	0001	0001
2	0010	0011
3	0011	0010
4	0100	0110
5	0101	0111
6	0110	0101
7	0111	0100
8	1000	1100
9	1001	1101
10	1010	1111
11	1011	1110
12	1100	1010
13	1101	1011
14	1110	1001
15	1111	1000

Binary code Multiple bits change at a time

Trigger more switches

Example. 1 → 2 --- 0001 → 0010 2 bits change

7 → 8--- 0111 →1000 all 4 bits change

Gray code Only one bit changes at a time

Triggers one switch

Example. 1 → 2 --- 0001 → 0011 one bit change

7 → 8 --- 0100→1100 one bit change

Less glitches

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- **Gray-code Input DAC Architecture and Operation**
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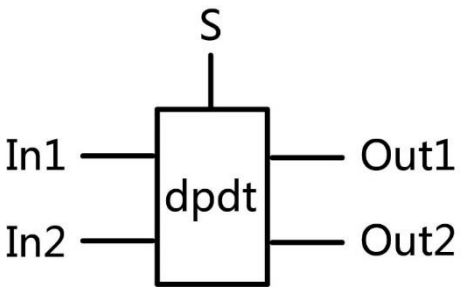
Gray-code Input DAC Architecture and Operation

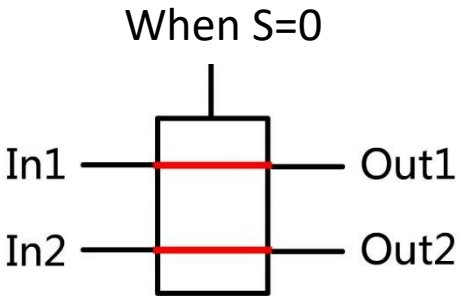
1. Current-steering Gray-Code DAC

2. Charge-mode Gray-Code DAC

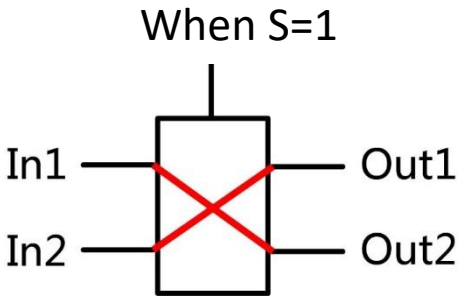
3. Voltage-mode Gray-Code DAC

Current/Voltage Switch Matrix

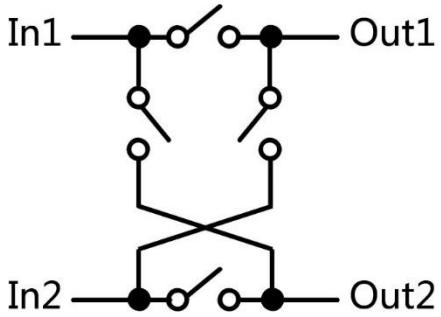


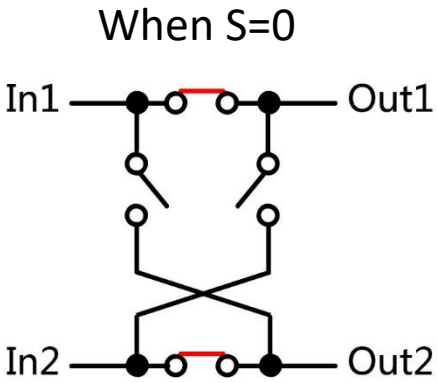


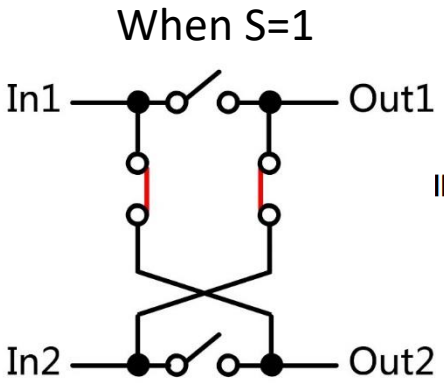
Parallel connection

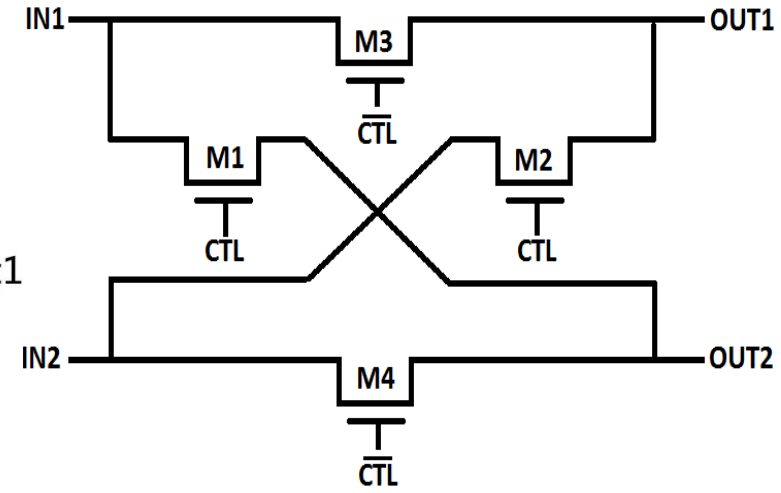


Cross connection



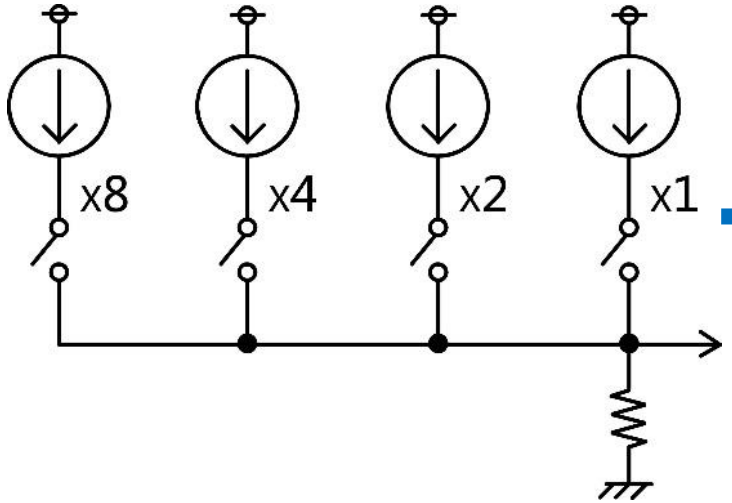




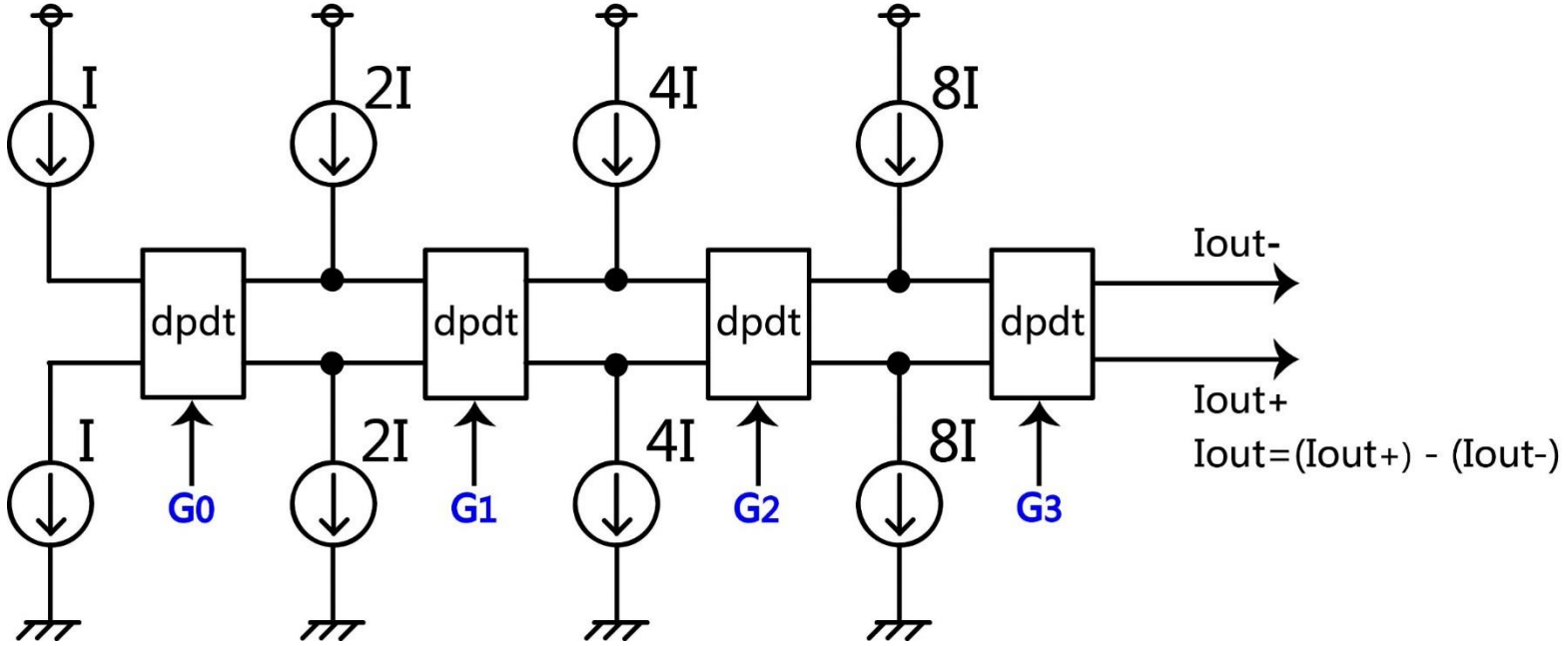


Switch is DPDT (Double-Pole Double-Throw)

1.Current-steering Gray-Code DAC

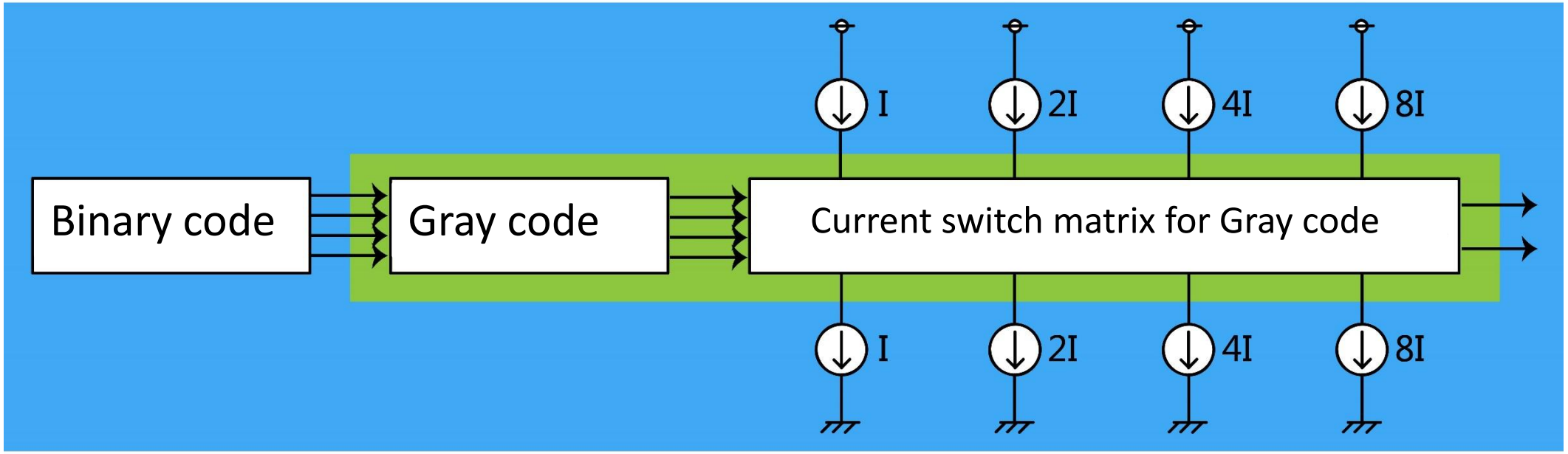


Conventional Binary-Weighted current-steering DAC



Gray-Code input current-steering DAC

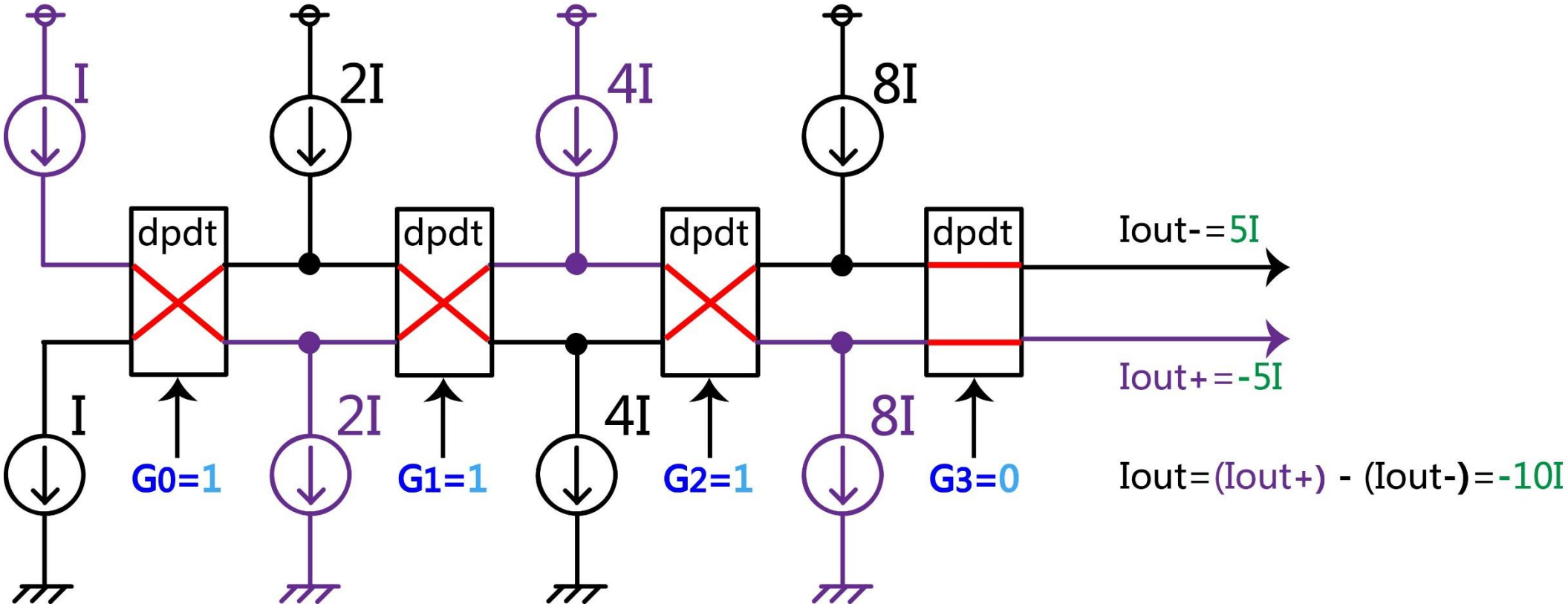
Code Conversion



Code domain in Gray-code input current-steering DAC

A Gray-code input current-steering DAC (data=5)

Data=5

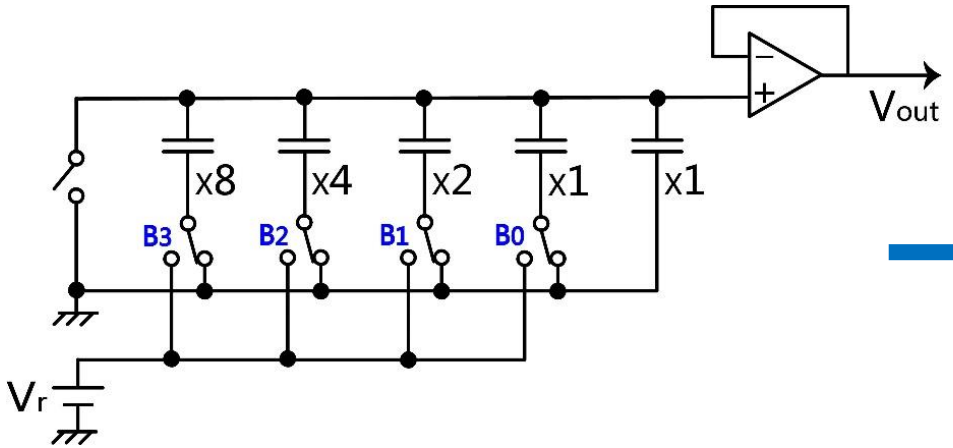


$$I_{out-} = -I + 2I - 4I + 8I = 5I$$

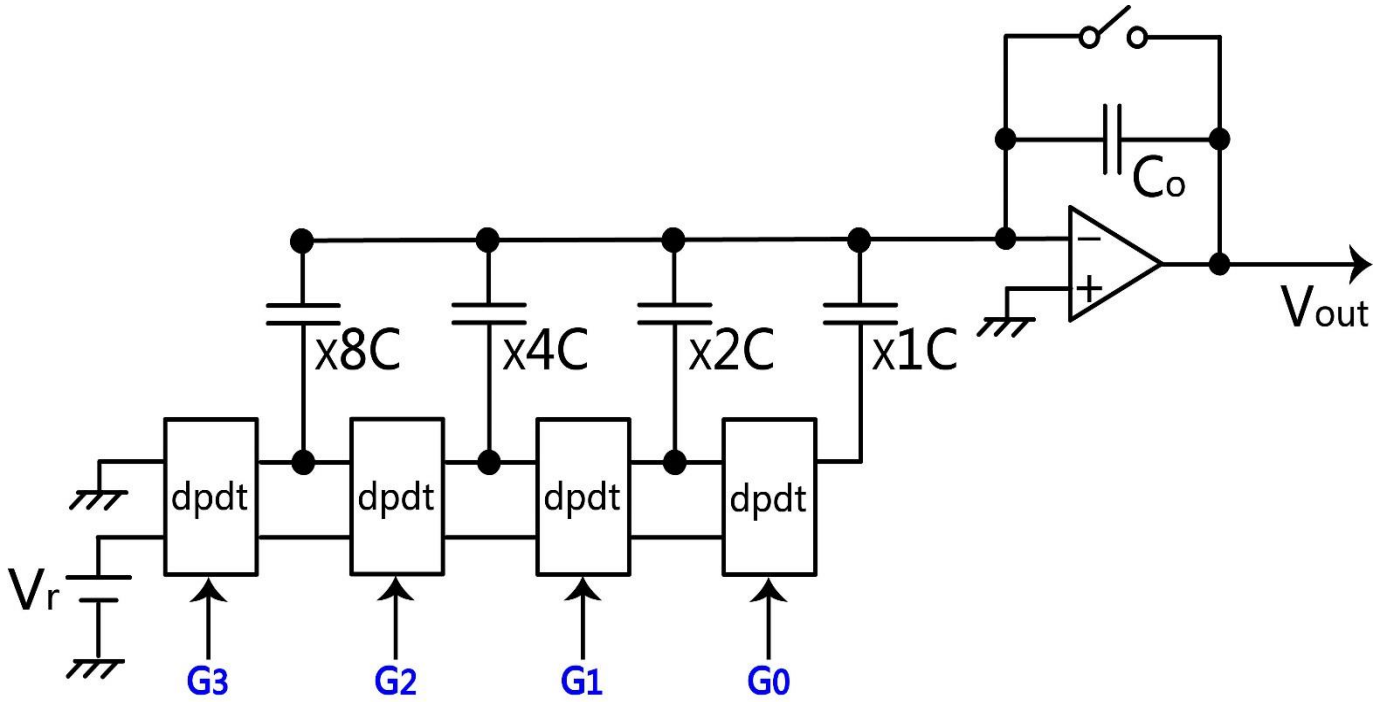
$$I_{out+} = I - 2I + 4I - 8I = -5I$$

$$I_{out} = (I_{out+}) - (I_{out-}) = -10I$$

2.Charge-mode Gray-code DAC

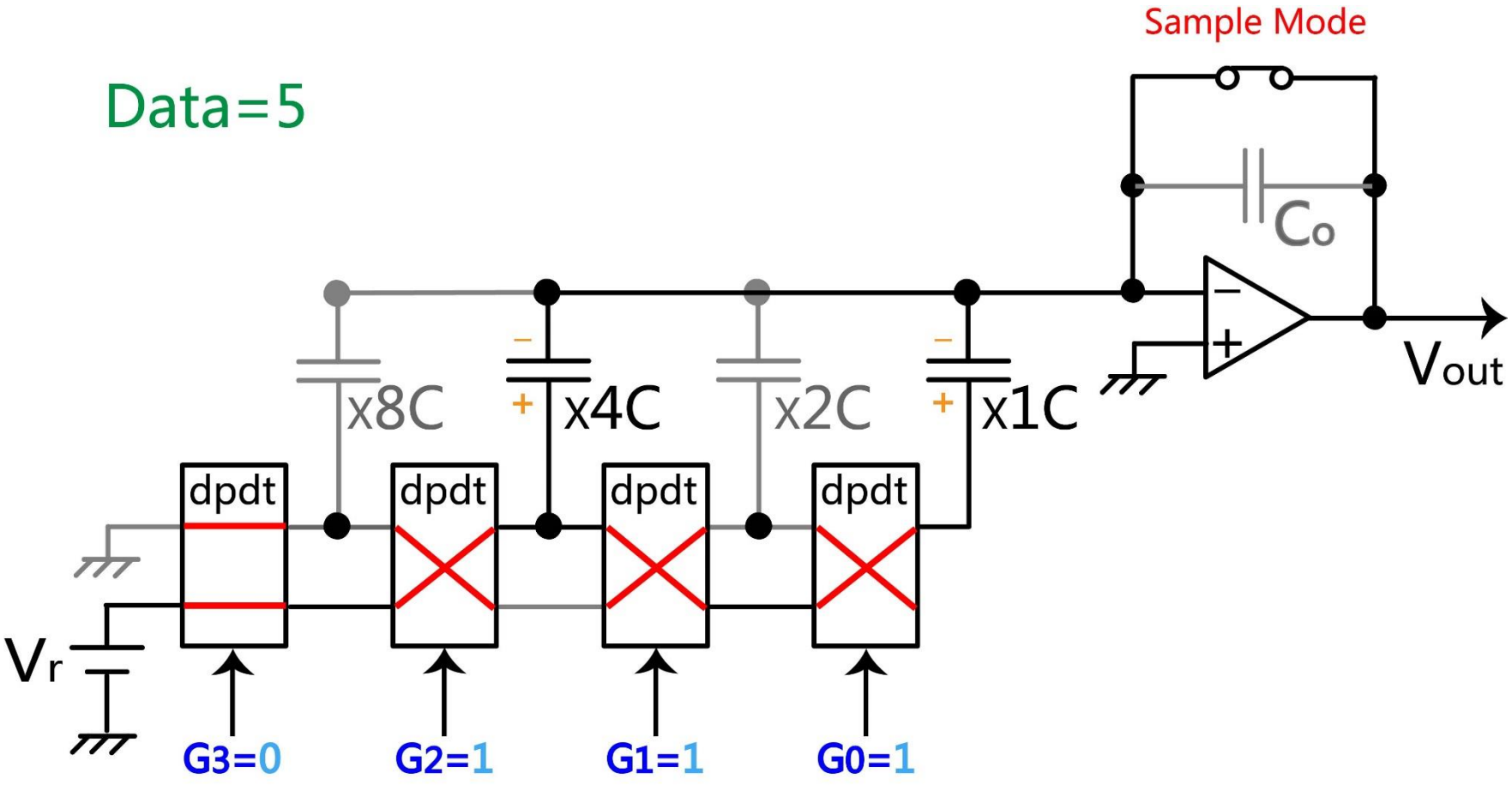


A binary-weighted capacitor DAC

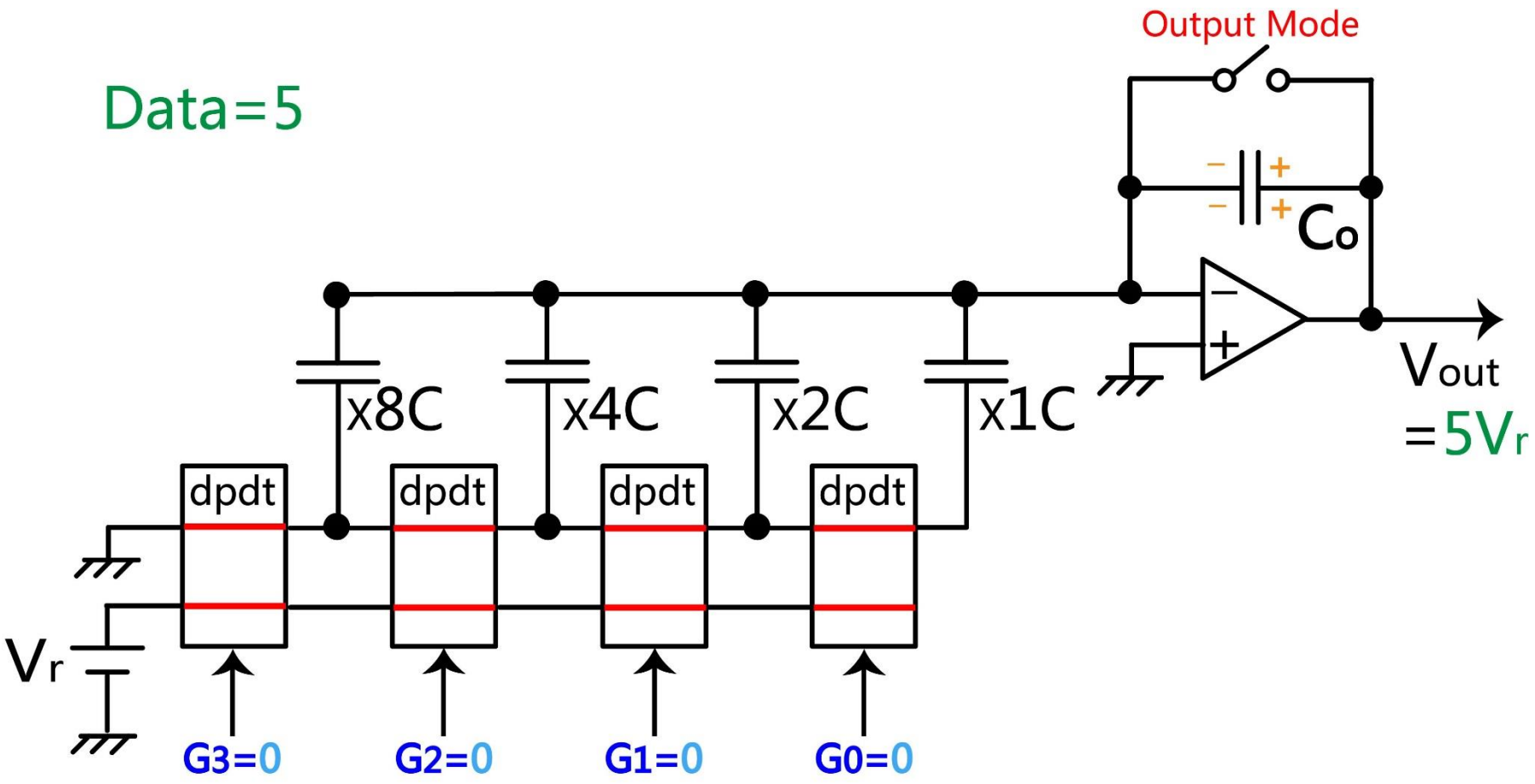


A Gray-code input charge-mode DAC

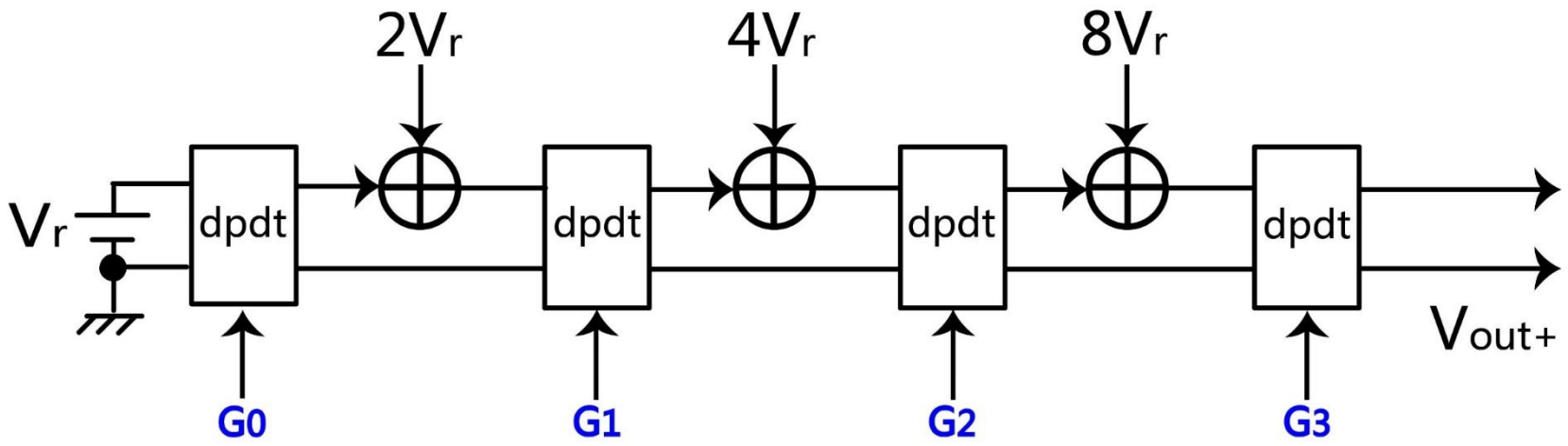
Sample Mode of a Gray-Code Input Charge-Mode DAC (data=5)



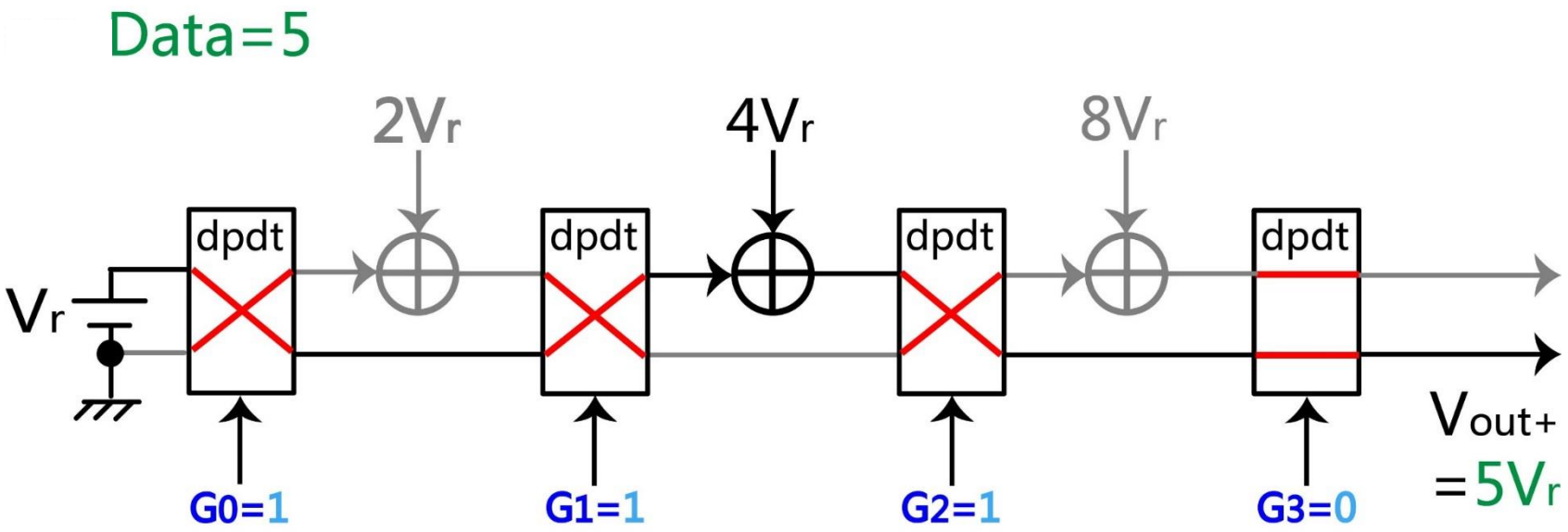
Sample Mode of a Gray-Code Input Charge-Mode DAC (data=5)



3.Voltage-mode Gray-Code DAC



A Gray-Code Input Voltage-mode DAC (data=5)



$$V_{out+} = V_r + 4V_r = 5V_r$$

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Simulation Verification by SPICE

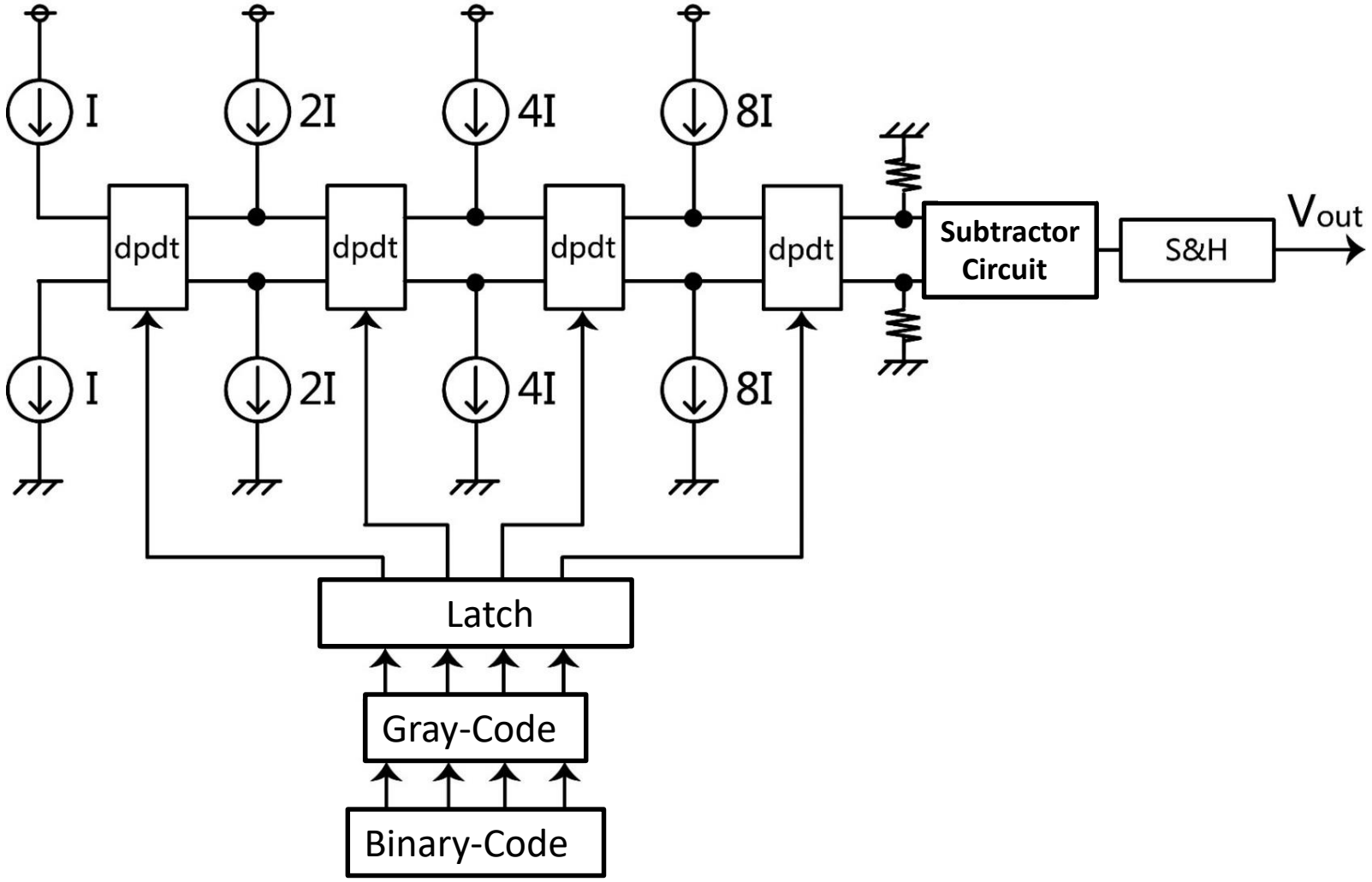
1.Simulation of current-steering Gray-Code DAC

2.Simulation of charge-mode Gray-Code DAC

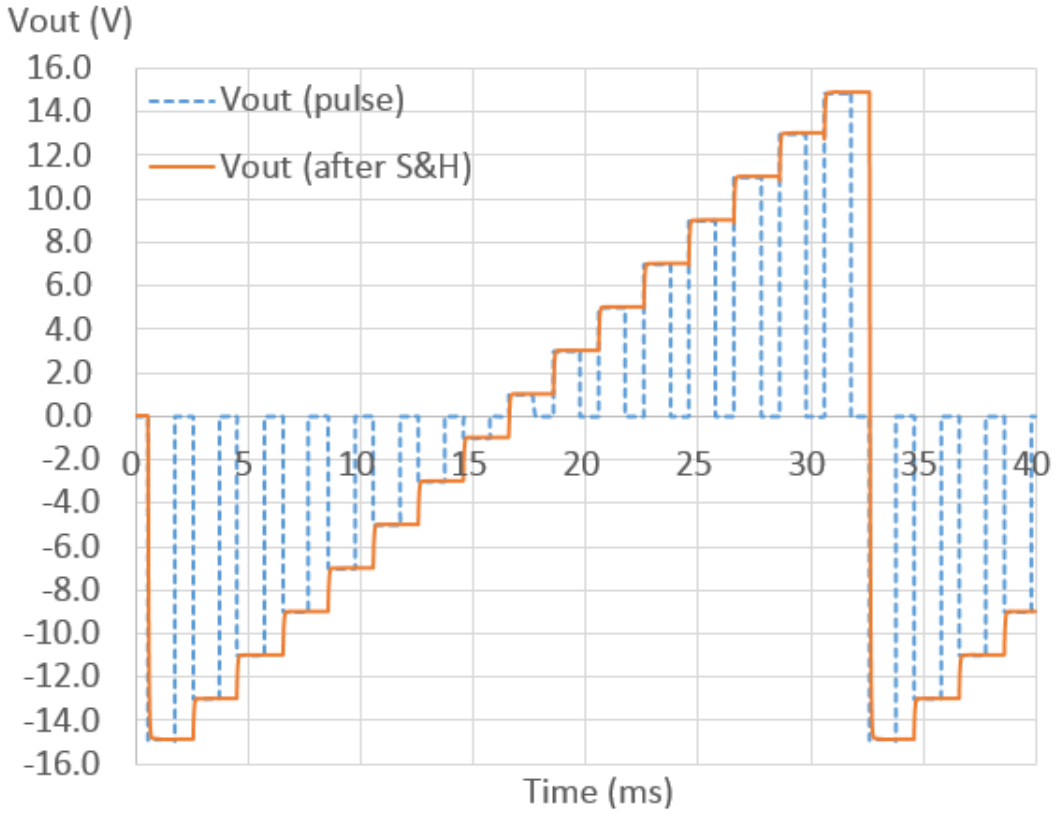
3.Simulation of voltage-mode Gray-Code DAC

4.Verification of glitch reduction

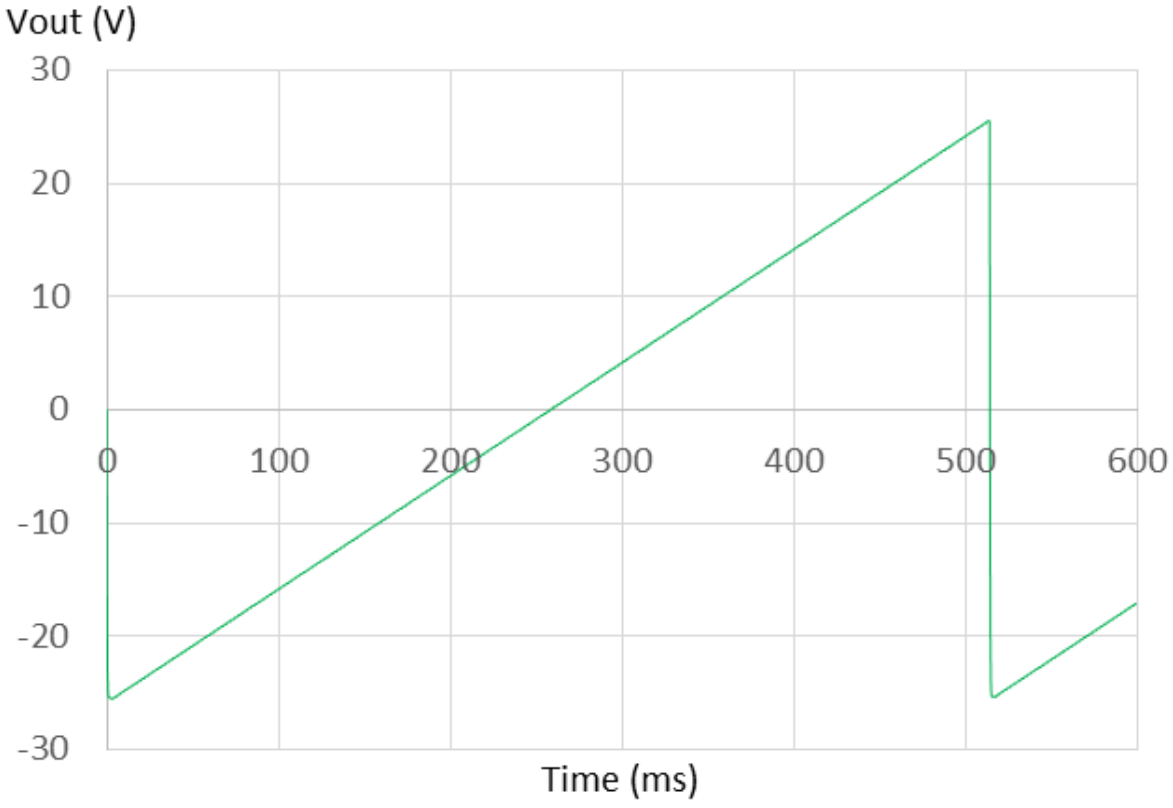
1.SPICE Realization of Current-Steering of Gray-Code Input



1.Simulation of current-steering Gray-Code DAC

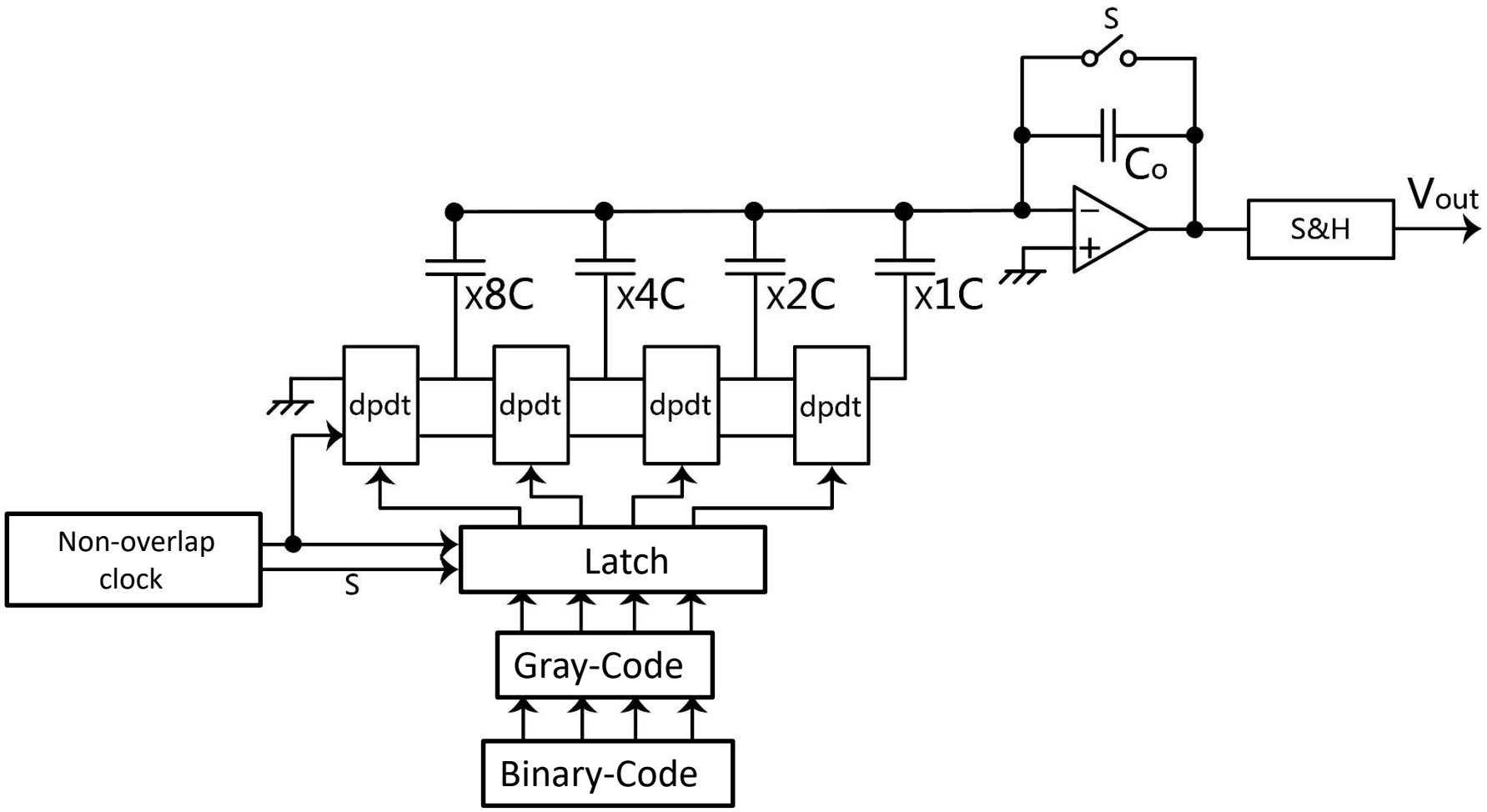


4bit Current-steering DAC

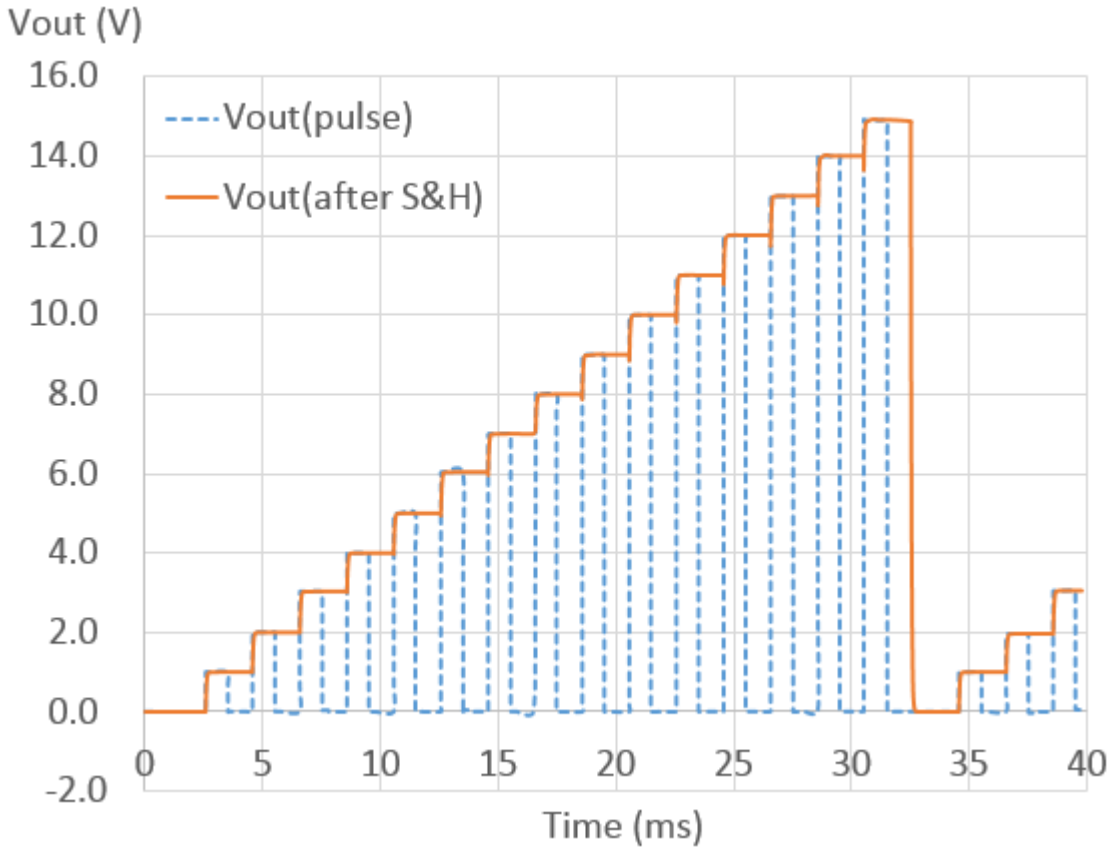


8bit Current-steering DAC

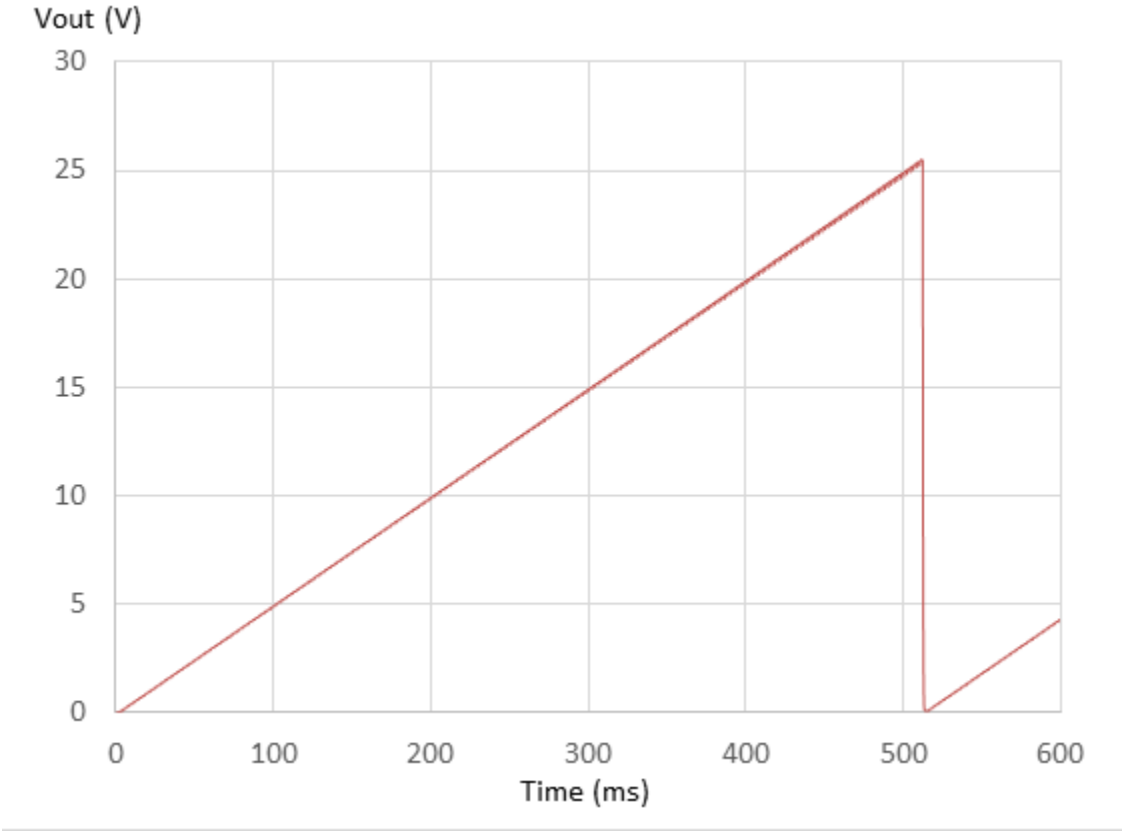
2.SPICE Realization of charge-mode of Gray-Code Input



2. Simulation of charge-mode Gray-Code DAC

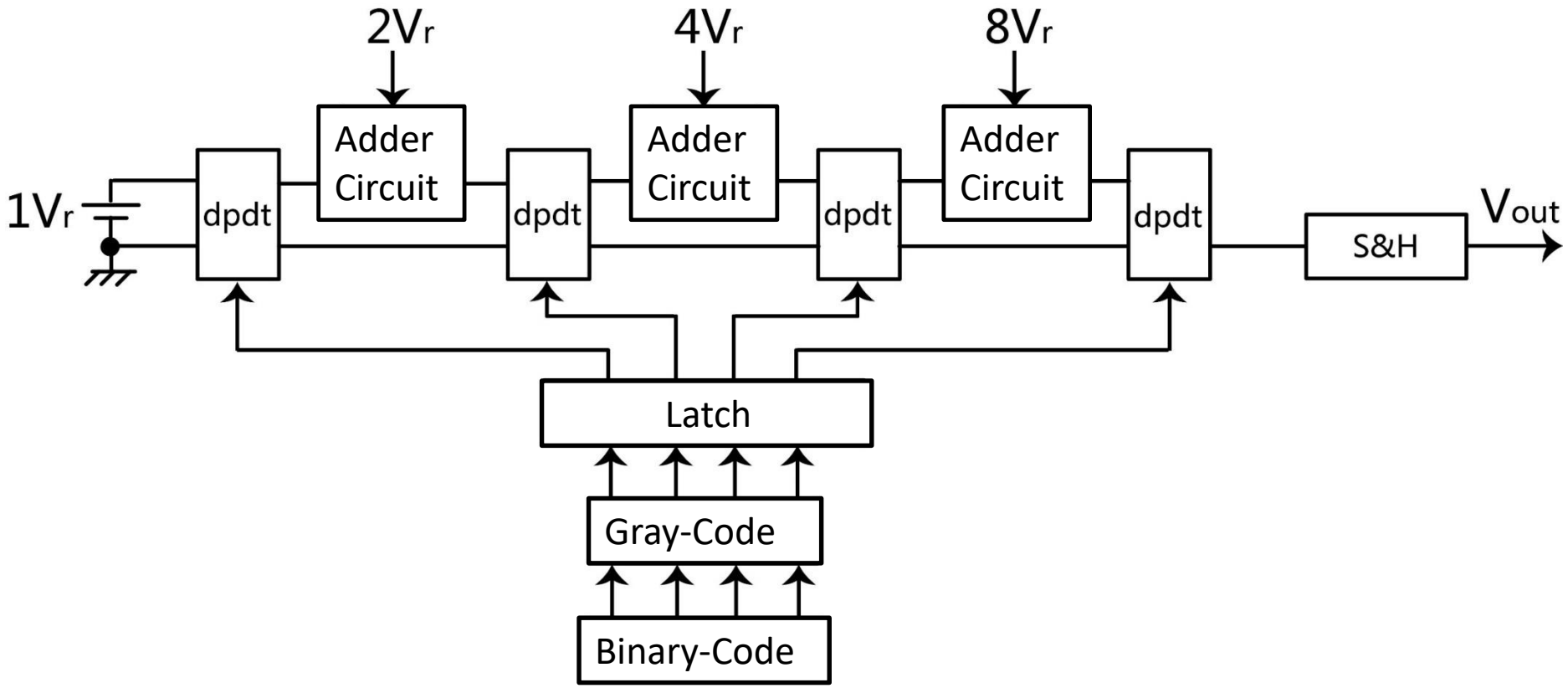


4bit Charge-mode DAC

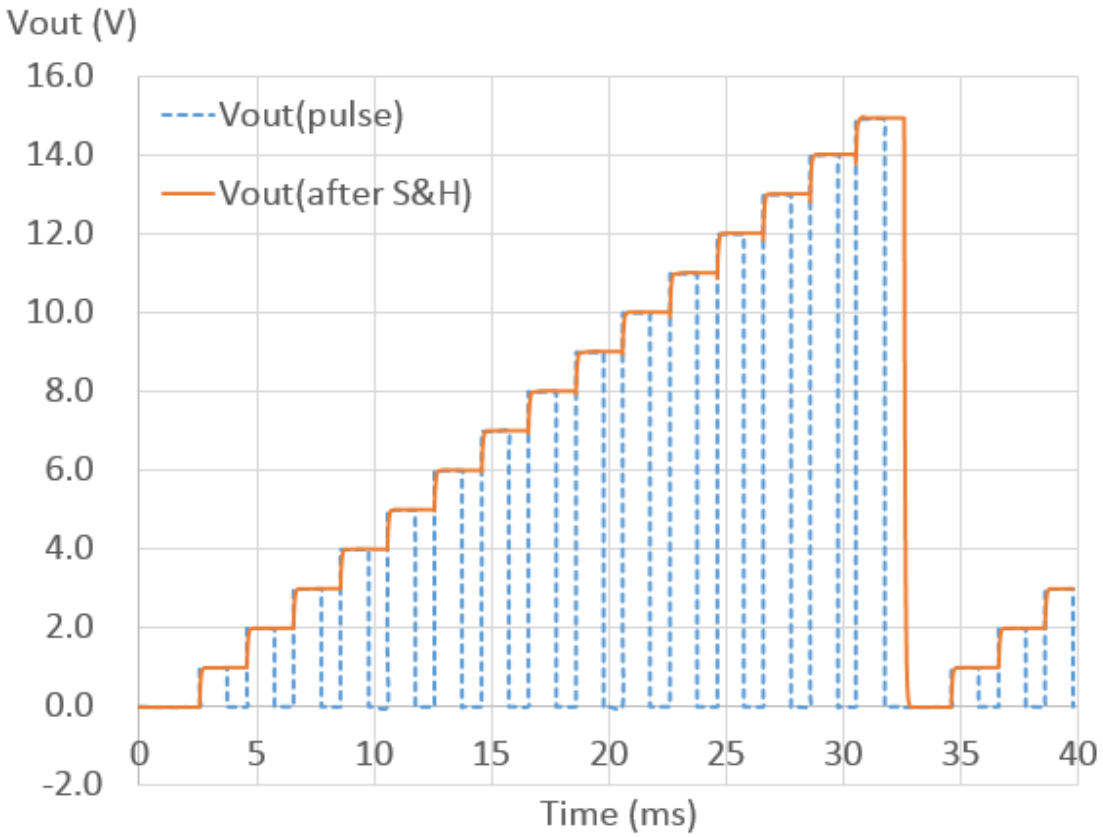


8bit Charge-mode DAC

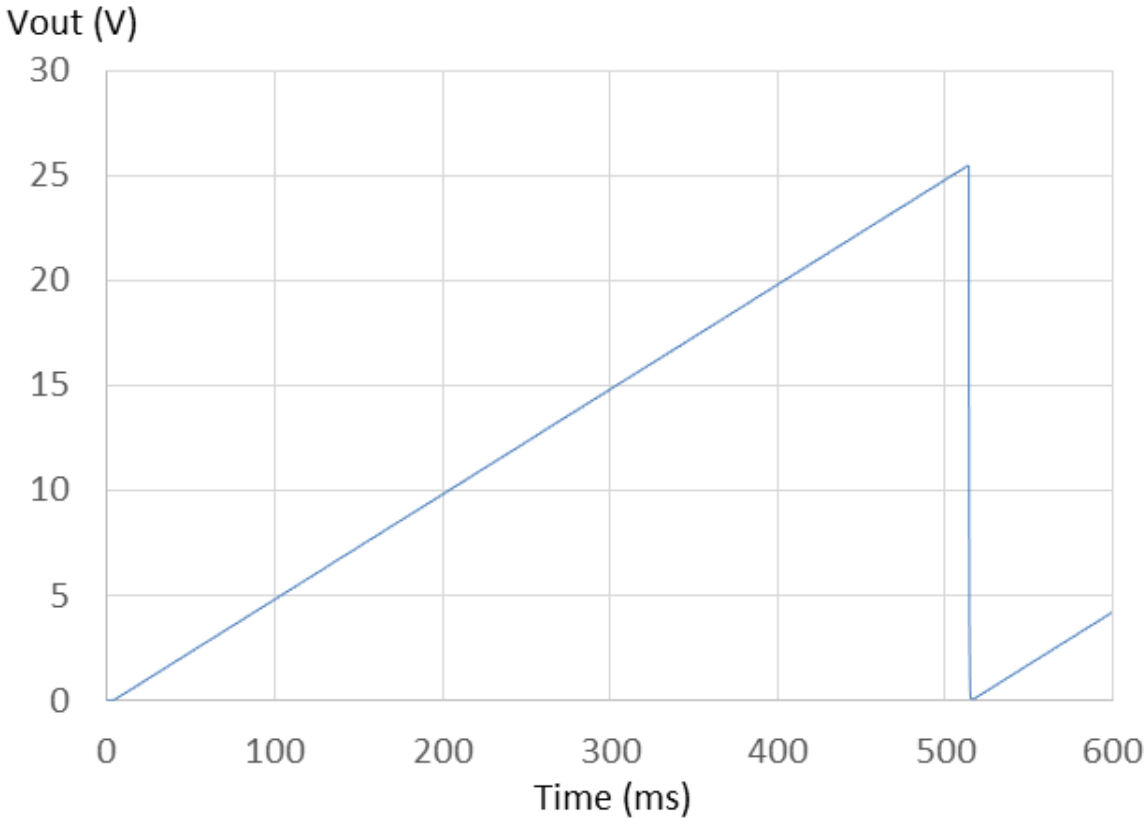
3.SPICE Realization of Voltage-mode of Gray-Code Input



3. Simulation of Voltage-mode Gray-Code DAC

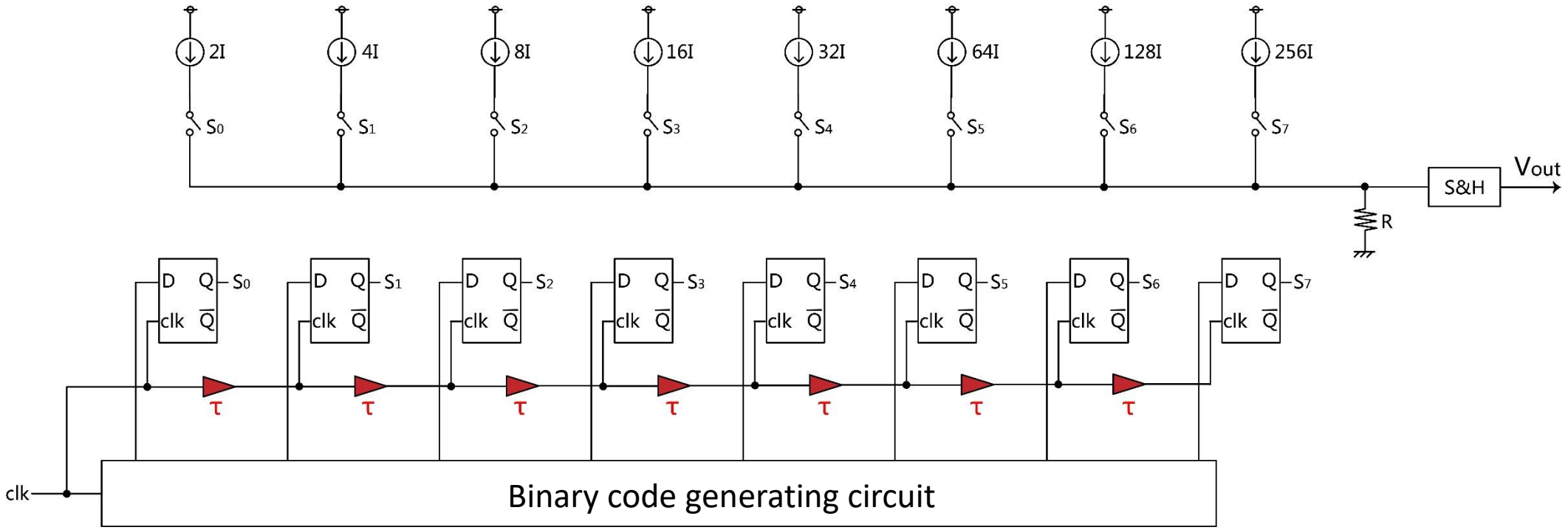


4bit Voltage-mode DAC



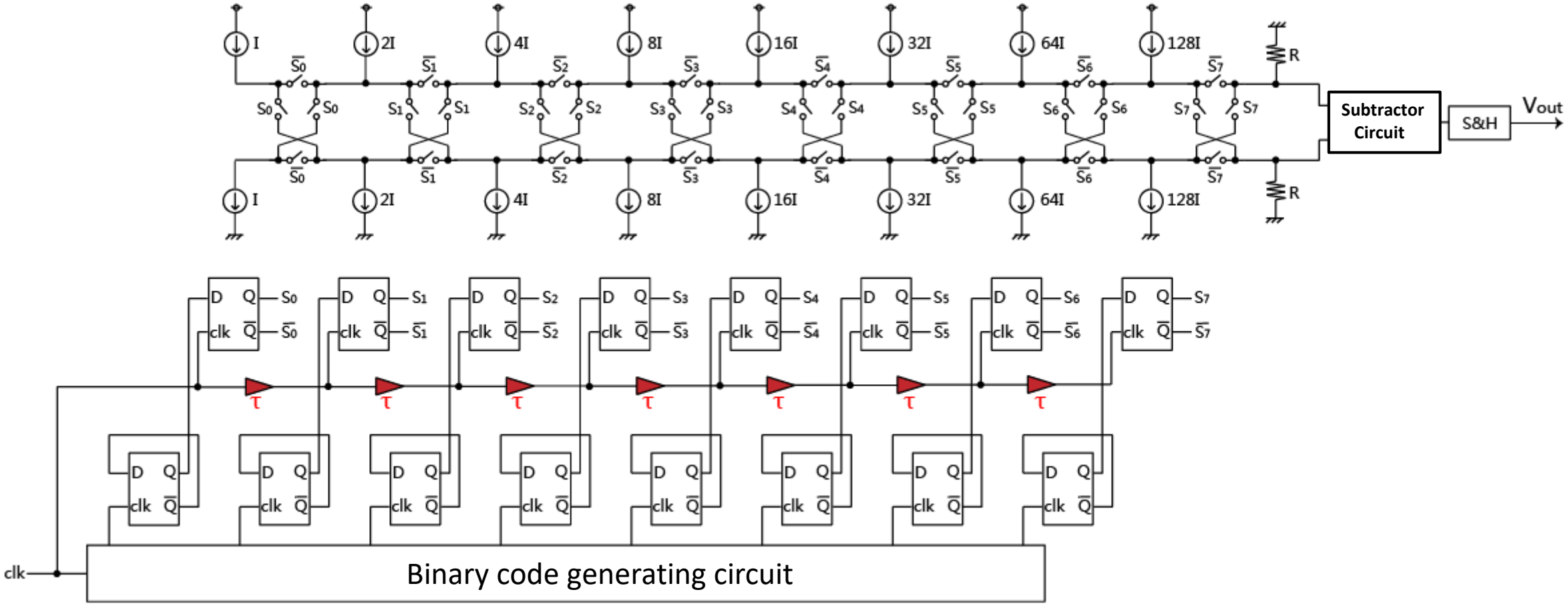
8bit Voltage-mode DAC

4.Verification of glitch reduction



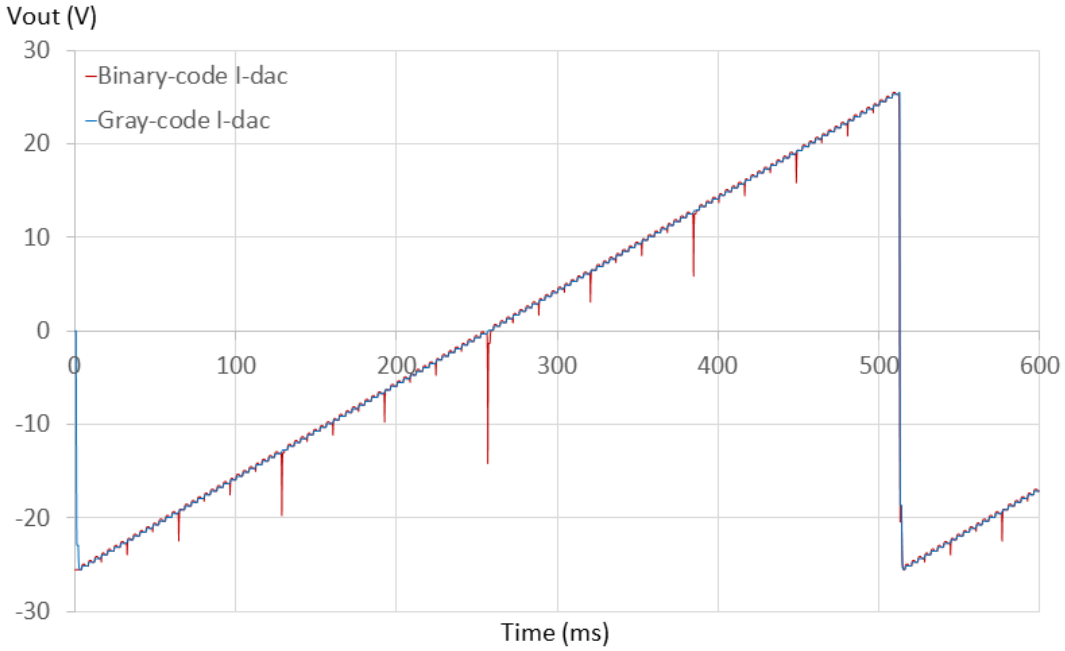
Conventional Current-Steering DAC with switching delay (8bit)

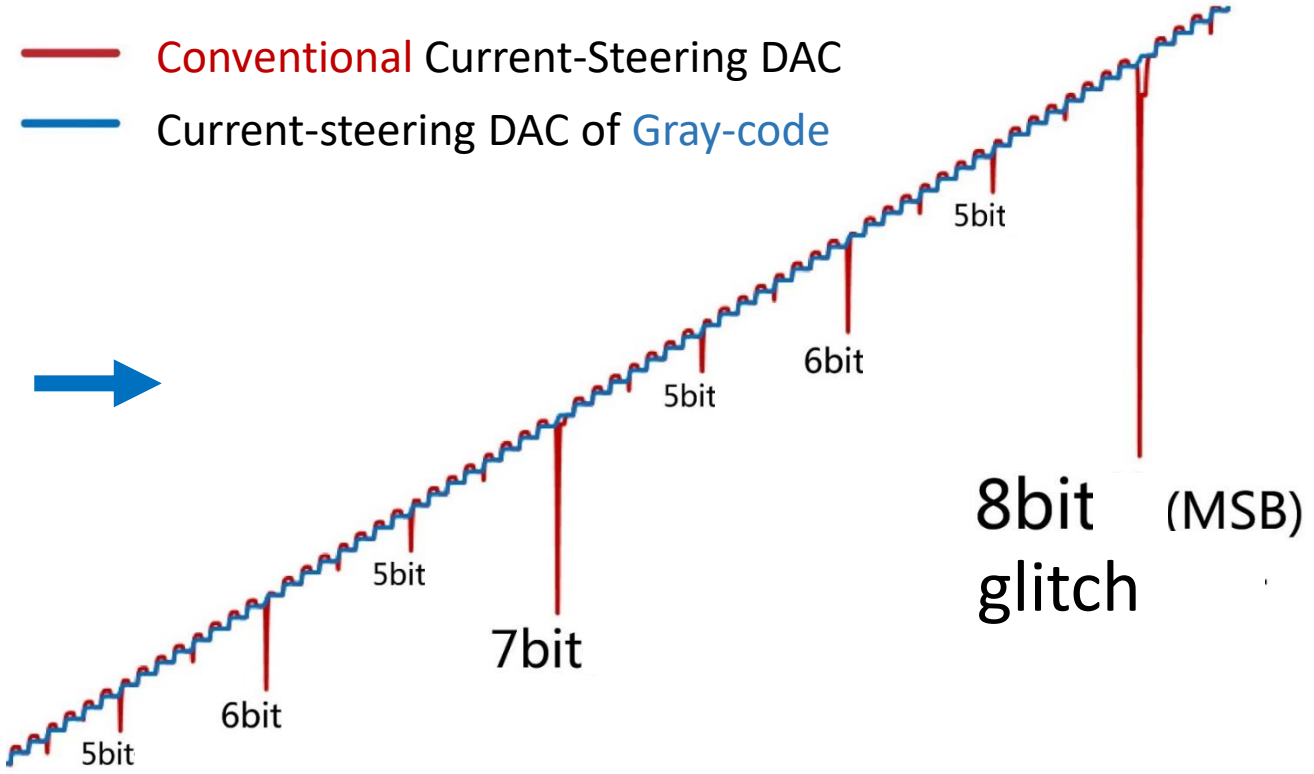
4.Verification of glitch reduction



Current-Steering Gray-code input DAC with switching delay (8bit)

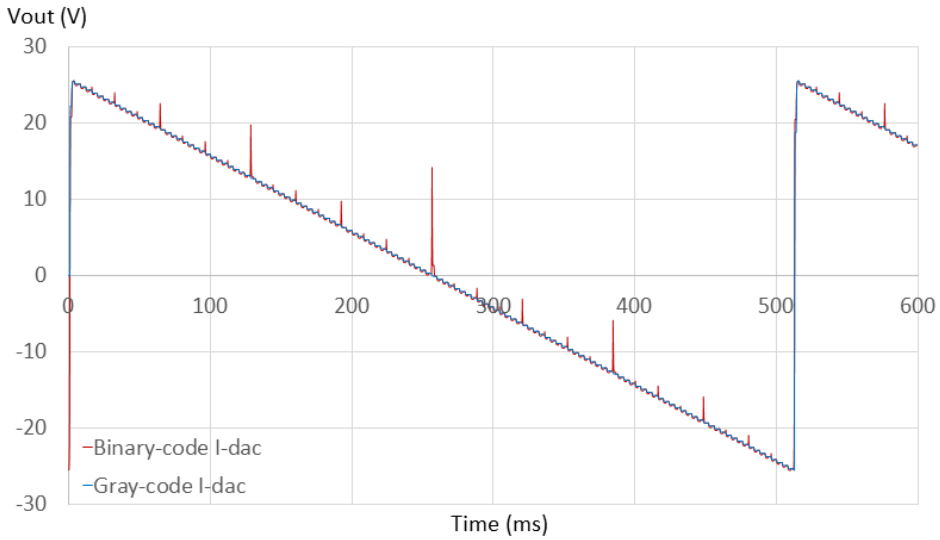
4.Simulation Result (Up Sweeping)

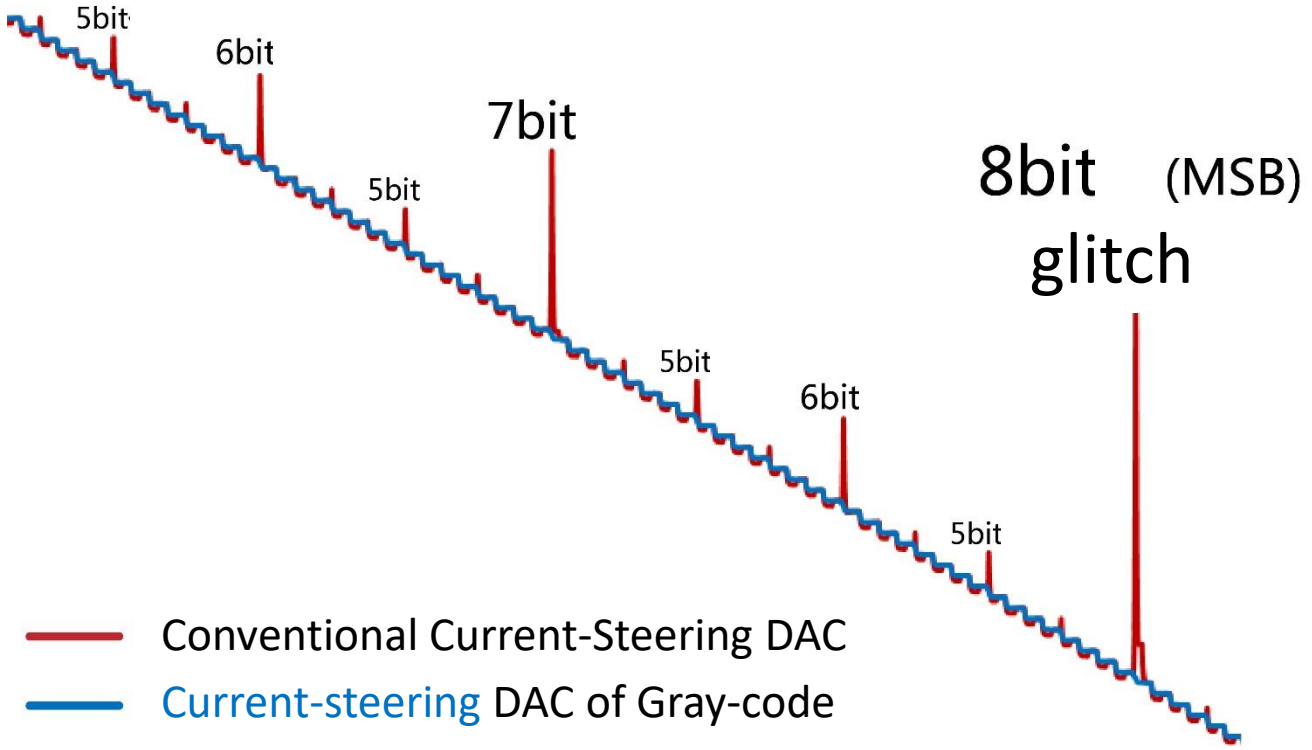




Conventional Current-Steering DAC vs. Current-steering DAC of Gray-code

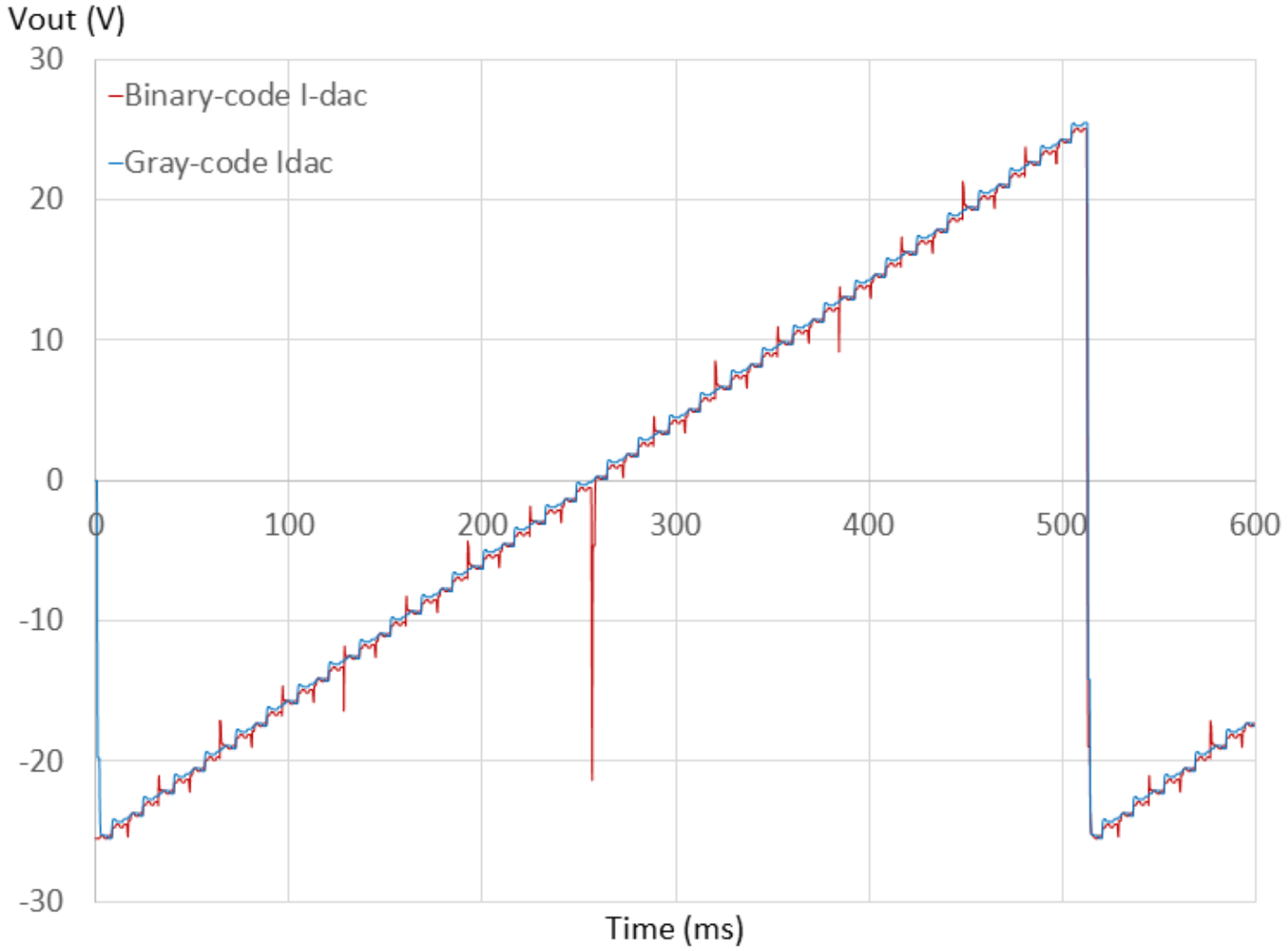
4.Simulation Result (Down Sweeping)





Conventional Current-Steering DAC vs. Current-steering DAC of Gray-code

4.Simulation Result (Random Switching Delay)

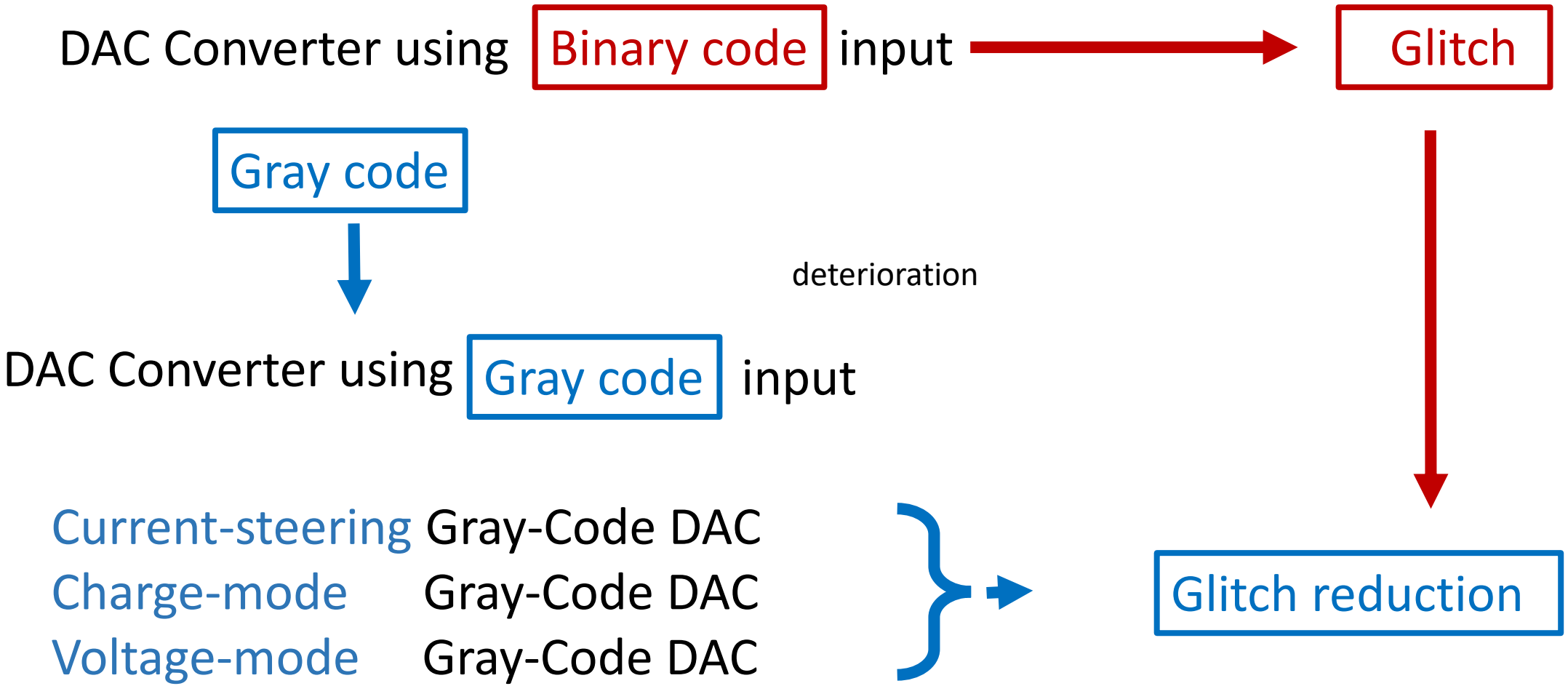


Conventional Current-Steering DAC vs. Current-steering DAC of Gray-code

OUTLINE

- Research Background・Objective
- What are Glitches
- Gray-code
- Gray-code Input DAC Architecture and Operation
- Simulation Verification by SPICE
- Conclusion

Conclusion

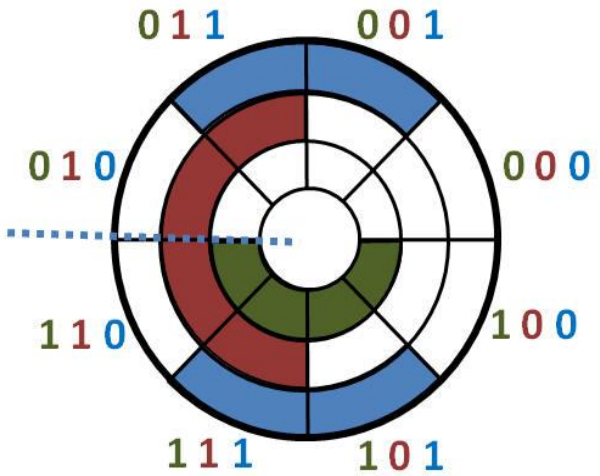

DAC Converter using
Binary code
input
Glitch
Gray code
deterioration
DAC Converter using
Gray code
input
Current-steering Gray-Code DAC
Charge-mode Gray-Code DAC
Voltage-mode Gray-Code DAC
Glitch reduction

Final statement

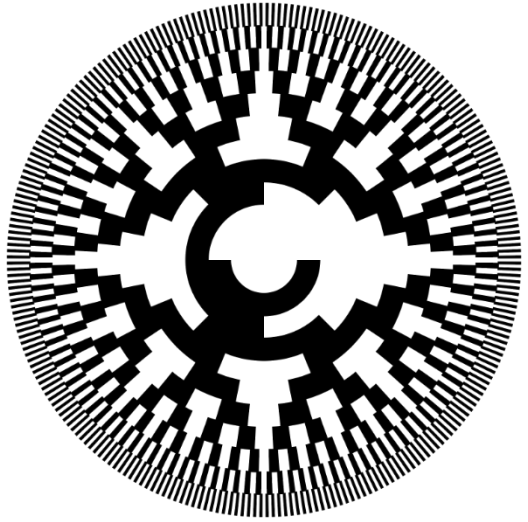
- Coding method can lead to robust mixed-signal circuit design.

  Gray code was invented by Frank Gray at Bell Lab in 1947.

FRANK GRAY and A. L. Johnsrud in television booth. Behind the glass panels at sides and top are the photo-electric cells.



$Q_2Q_1Q_0$
000
001
011
010
110
111
101
100



Thank you for listening

谢谢