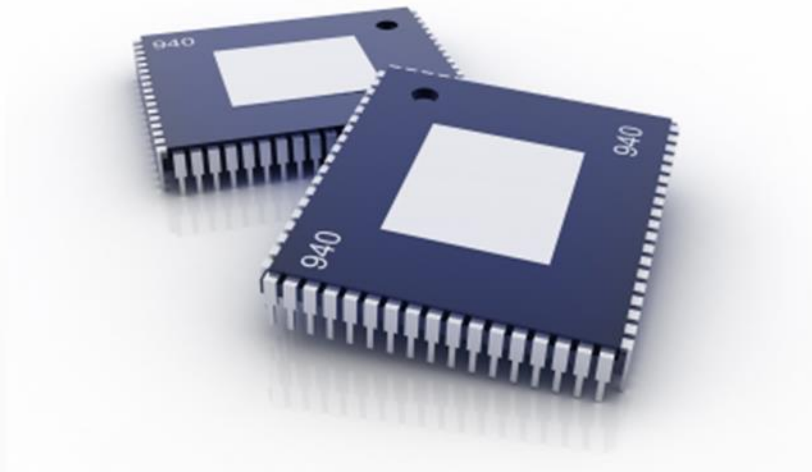


LECTURE 13

Soo-Won Kim

swkim@korea.ac.kr

Lecture 13

16. Nyquist-Rate D/A Converters

16.2 Binary-Scaled Converters

16.3 Thermometer-Code Converters

16.4 Hybrid Converters

Current-Mode Converters

Current-mode D/A converters → **Higher-speed** applications

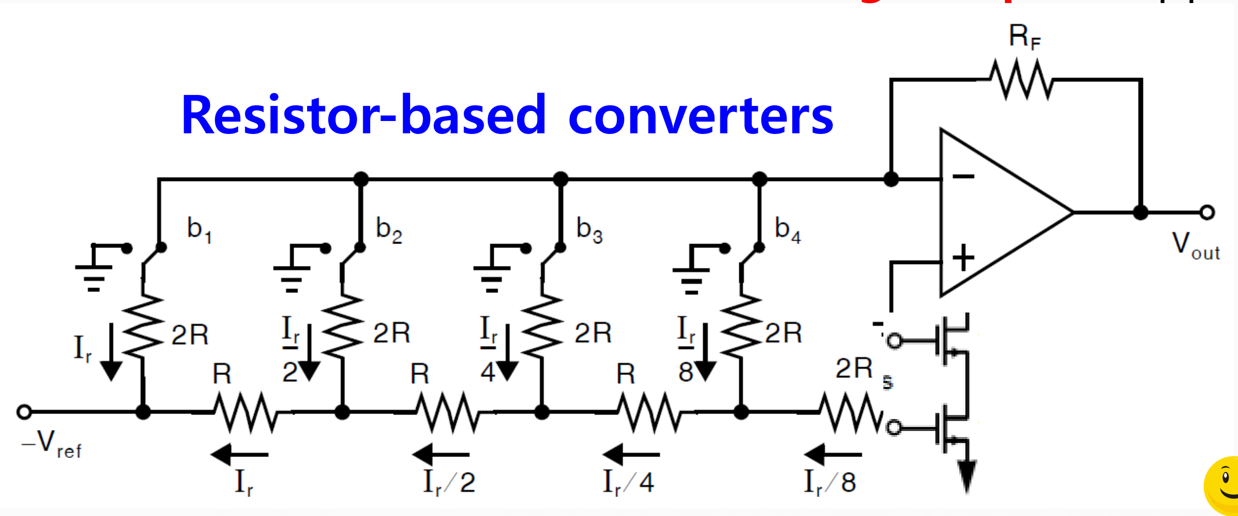
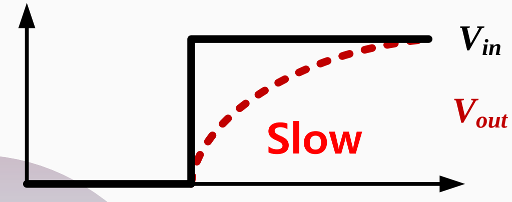


Fig. 16.10 4-bit R-2R-Based Converters



Response of resistor-based converter

Higher-speed

Glitch
Current matching

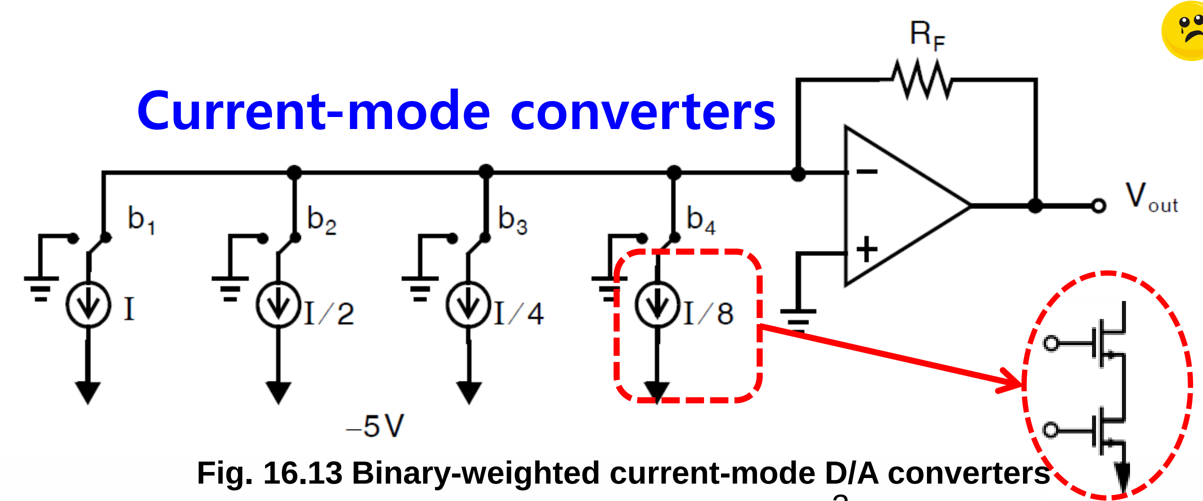
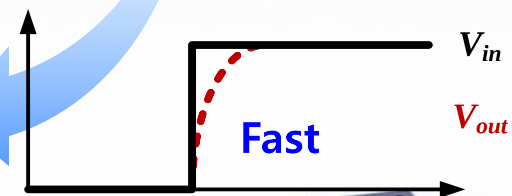


Fig. 16.13 Binary-weighted current-mode D/A converters



Response of current-mode converter

Glitches

Problem of current mode converters : Glitches

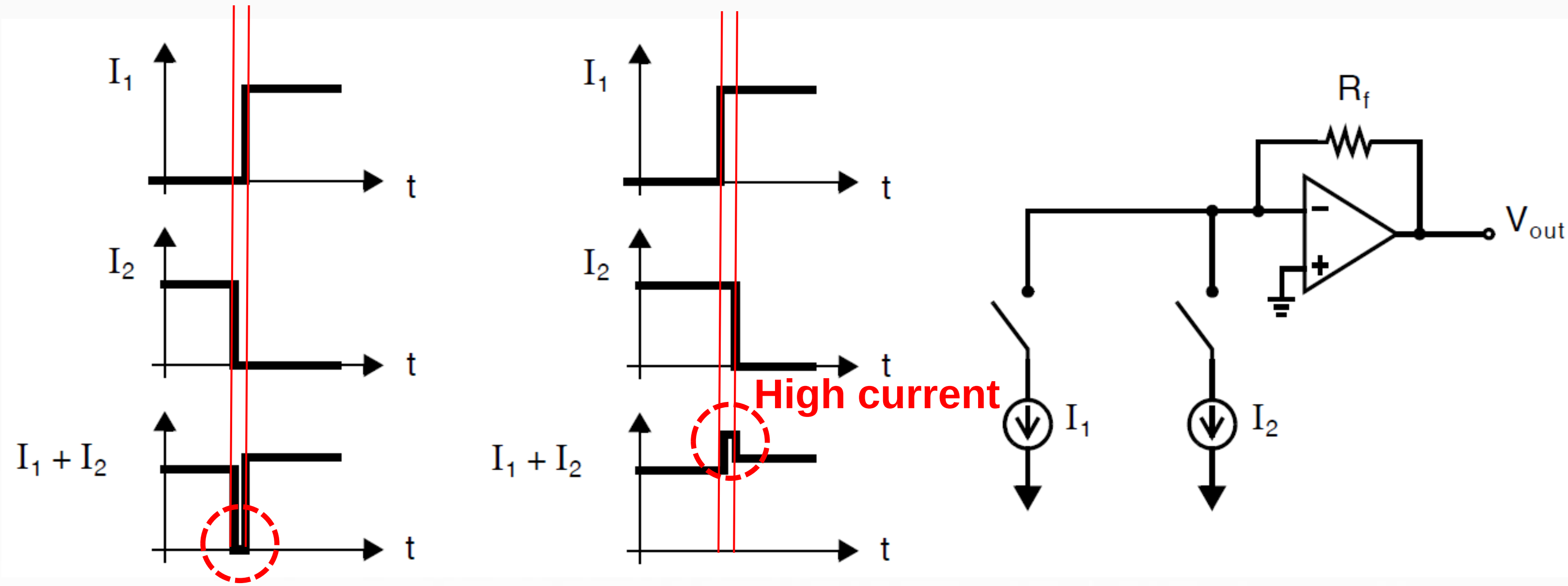


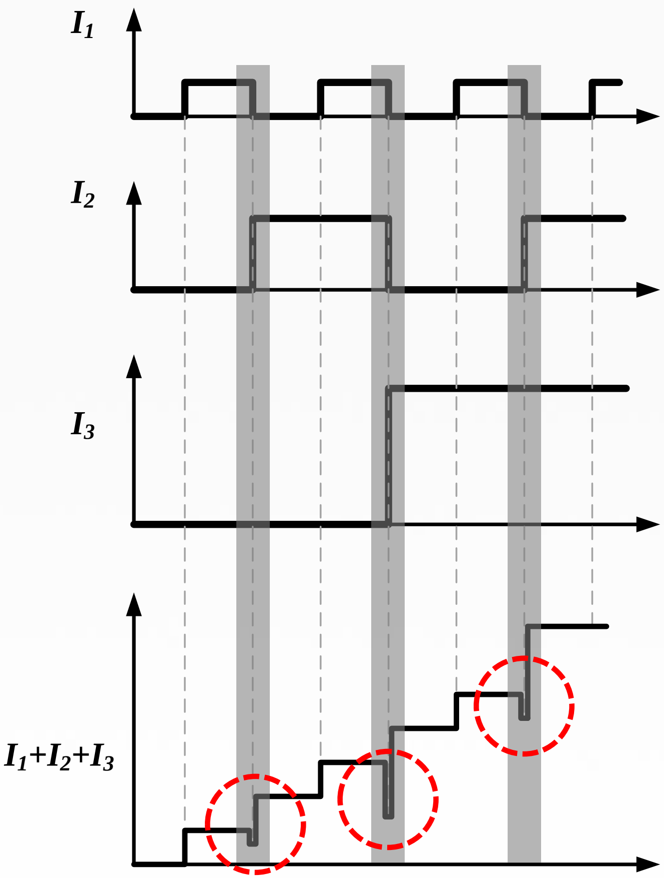
Fig. 16.14 Glitches. I_1 represents the MSB current, and I_2 represents the sum of the N-1 LSB currents

Different currents, different branch
Delays are not matched
⇨ Temporarily fall to zero or high current

🙂 Use thermometer code to reduce glitches

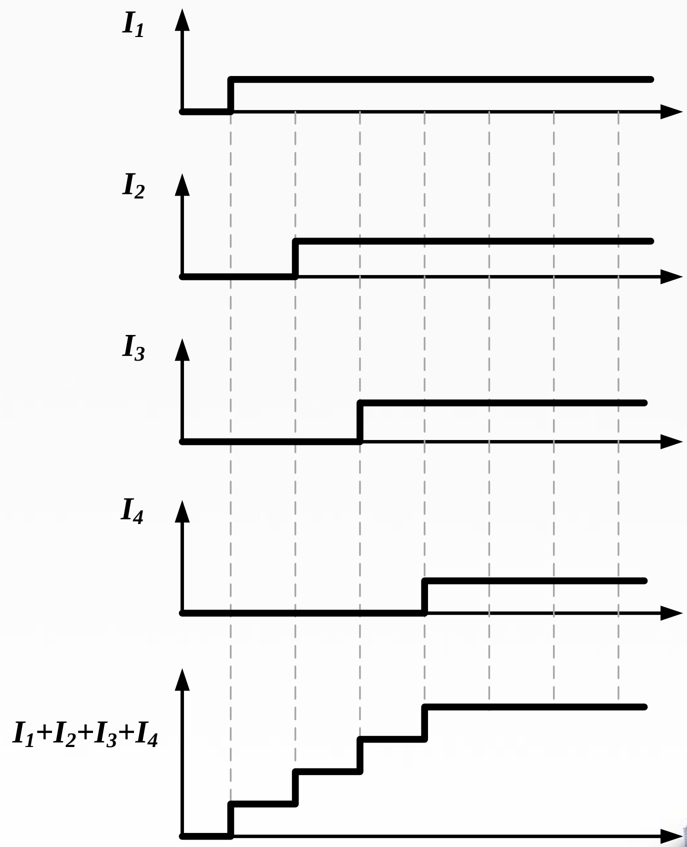
Binary code vs Thermometer code

Binary code(3bit)



Glitch may be occurred

Thermometer code(2bit)



Glitch can be reduced

Thermometer-Based D/A Converters

Glitch problems → Thermometer-code

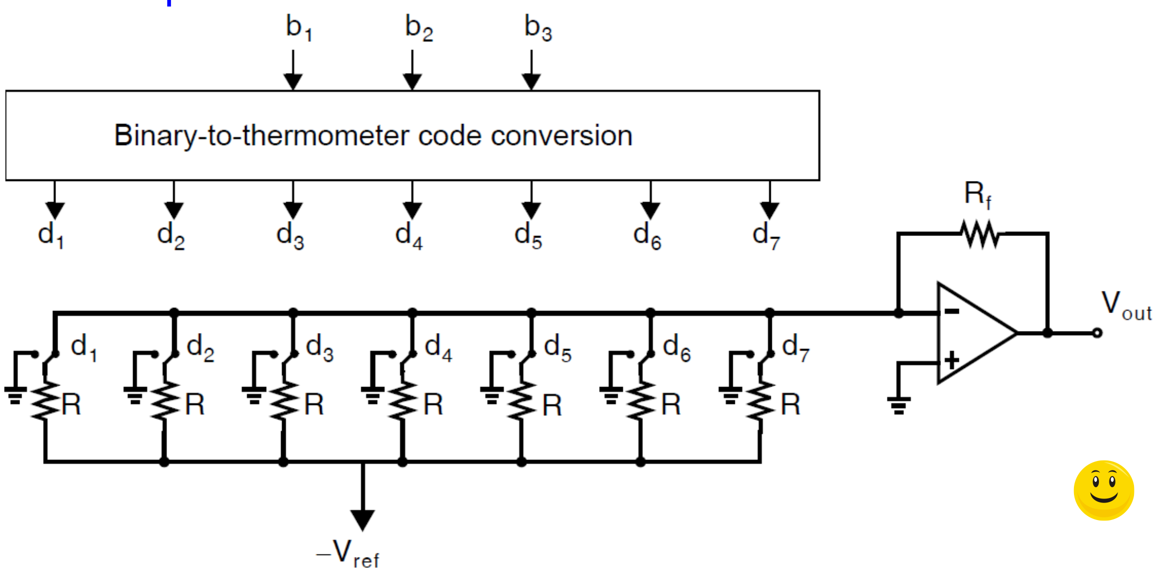


Fig. 16.15 A 3-bit thermometer-based D/A converters

	Binary			Thermometer Code						
Decimal	b_1	b_2	b_3	d_1	d_2	d_3	d_4	d_5	d_6	d_7
0	0	0	0	0	0	0	0	0	0	0
1	0	0	1	0	0	0	0	0	0	1
2	0	1	0	0	0	0	0	0	1	1
3	0	1	1	0	0	0	0	1	1	1
4	1	0	0	0	0	0	1	1	1	1
5	1	0	1	0	0	1	1	1	1	1
6	1	1	0	0	1	1	1	1	1	1
7	1	1	1	1	1	1	1	1	1	1

Guaranteed monotonicity
Glitch ↓

2^N-1 resistor

Thermometer-Code Charge-redistribution D/A Converters

Binary-array D/A converters

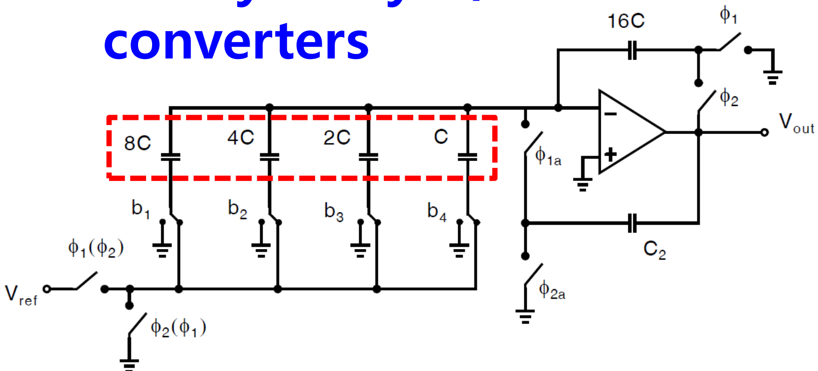
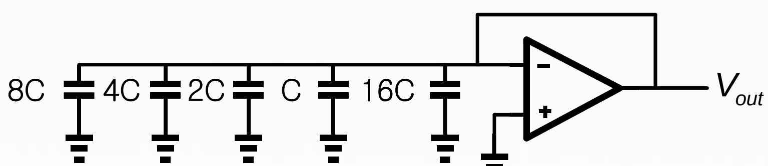
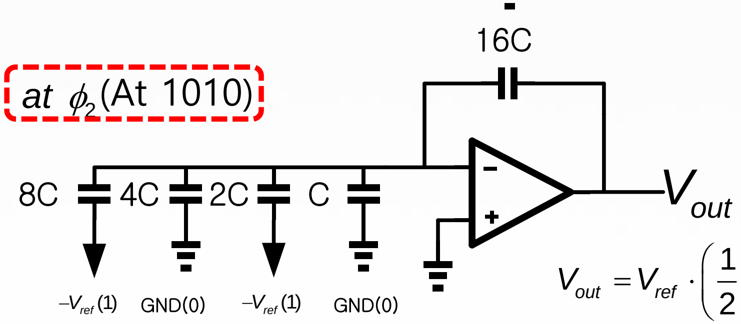


Fig. 16.12 Binary-array charge-redistribution D/A converter

at ϕ_1



at ϕ_2(At 1010)



$$V_{out} = V_{ref} \cdot \left(\frac{1}{2} + \frac{1}{8}\right)$$

Thermometer-code D/A converters

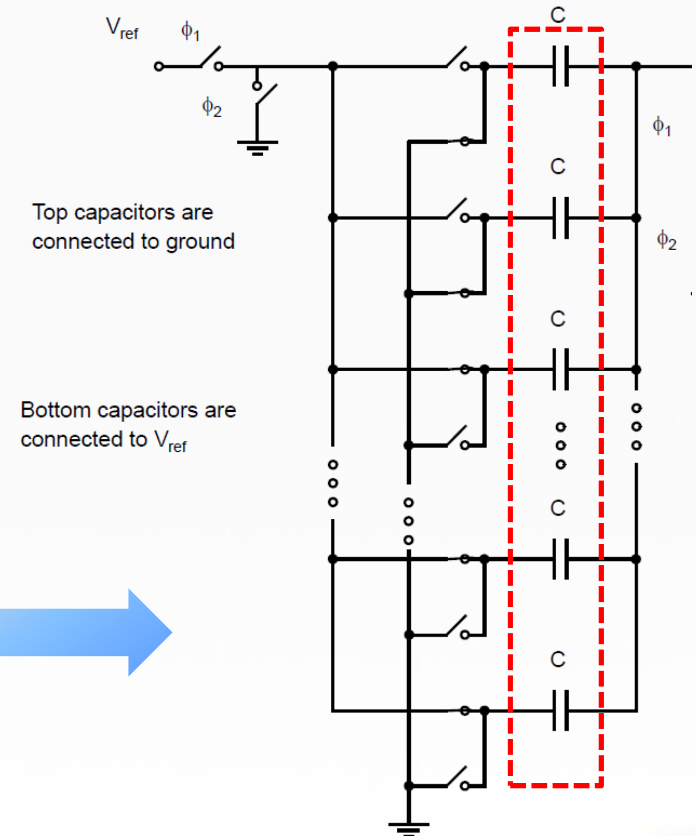


Fig. 16.16 Thermometer-code charge-redistribution D/A converters

- Guaranteed monotonicity Glitch ↓
- 2^N-1 capacitor

Example 1

Calculate the V_{out} when $b_1b_2b_3b_4b_5b_6b_7$ = 0000001, 0011111

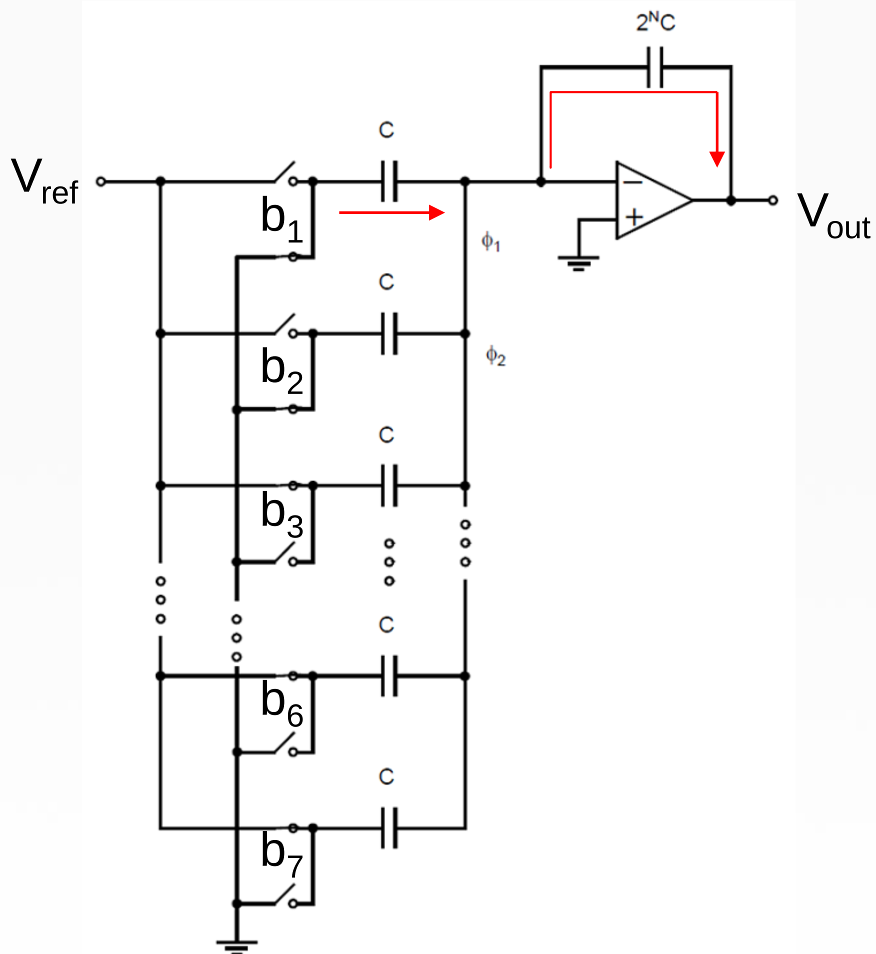


Fig. 16.16 Thermometer-code charge-redistribution D/A converters

$$b_1b_2b_3b_4b_5b_6b_7 \Rightarrow N = 3\text{bit}$$

$$(-V_{out})2^N C = (-V_{ref})(nC)$$

$$V_{out} = \frac{nC}{2^N C} V_{ref}, \quad (n = \text{number of } 1)$$

- $b_1b_2b_3b_4b_5b_6b_7$ = 0000001

$$V_{out} = \frac{1C}{2^3 C} V_{ref} = \frac{1}{8} V_{ref}$$

- $b_1b_2b_3b_4b_5b_6b_7$ = 0011111

$$V_{out} = \frac{5C}{2^3 C} V_{ref} = \frac{5}{8} V_{ref}$$

Thermometer-Code Current-Mode D/A Converters

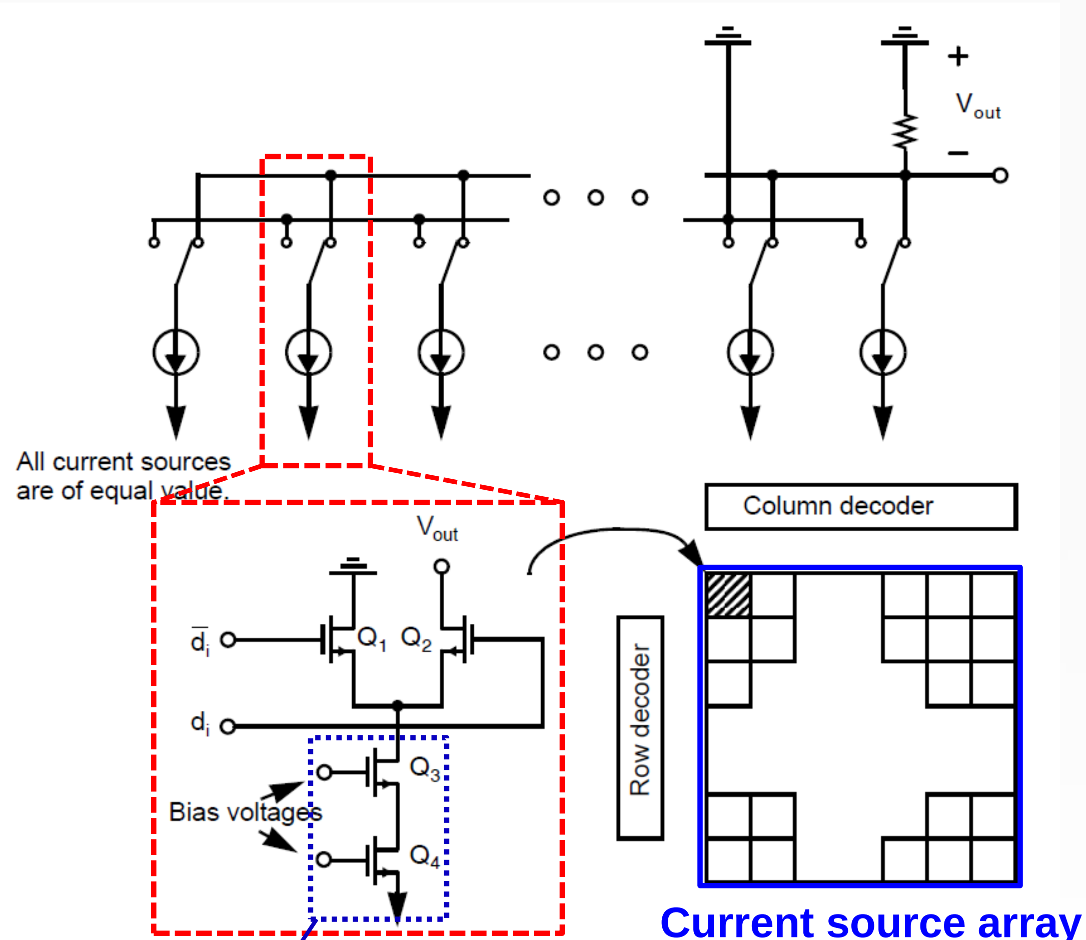
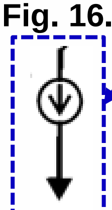


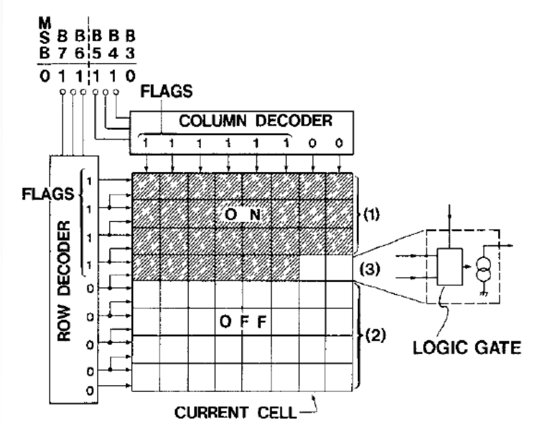
Fig. 16.17 Thermometer-code current mode D/A converter



Operation

- d_i = 0, current source = off
- d_i = 1, current source = on
- Row/Column

→ monotonicity, decoder area ↓



Matched Current Sources

Current sources should be **matched** each other → **Calibrated!**

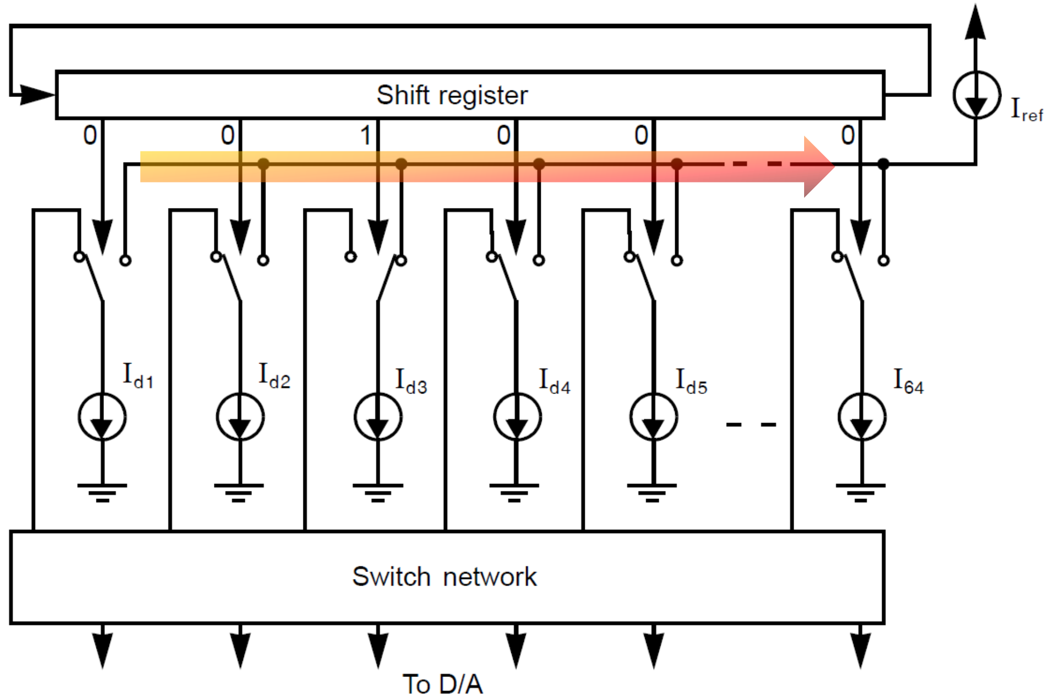


Fig. 16.19 Dynamically matching current sources for 6 MSB

Operation

1. Shift register shifts
2. I_{di} is connected to I_{ref}
3. I_{di} is set to I_{ref}

I_{di} = I_{ref} (accurately match)

Matched Current Sources

The method for calibrating and using one of the current sources

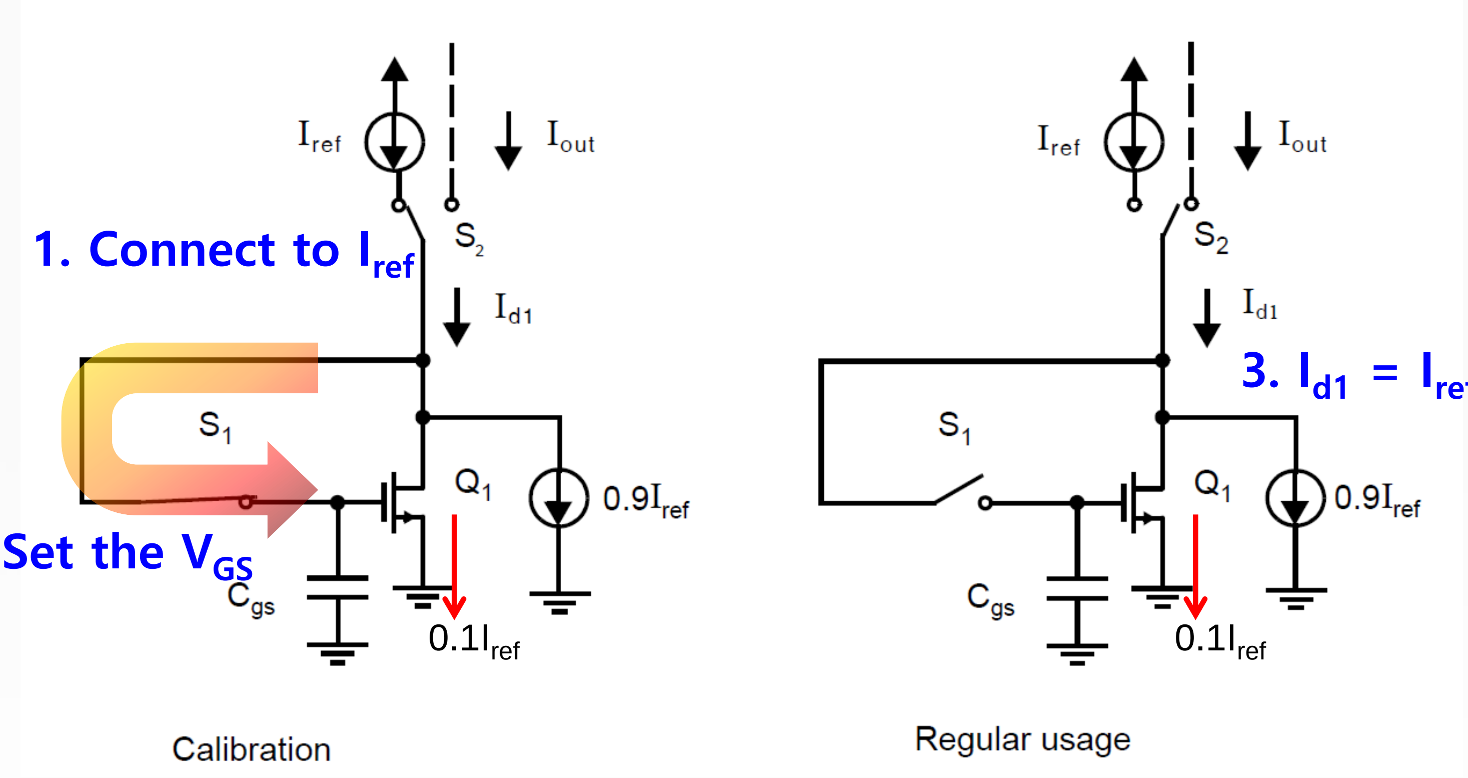


Fig. 16.20 Dynamically setting a current source, I_{d1}

Example 2

1) Find W/L for the Q_1.

Assume that V_{GS} = 3V when I_{ref} = 500μA, V_{TH} = 1V, $\mu_n C_{ox}$ = 92 μA/V².

2) **What is the expected variation of the current?**

If switch S_1 cause a random charge injection by 1mV,

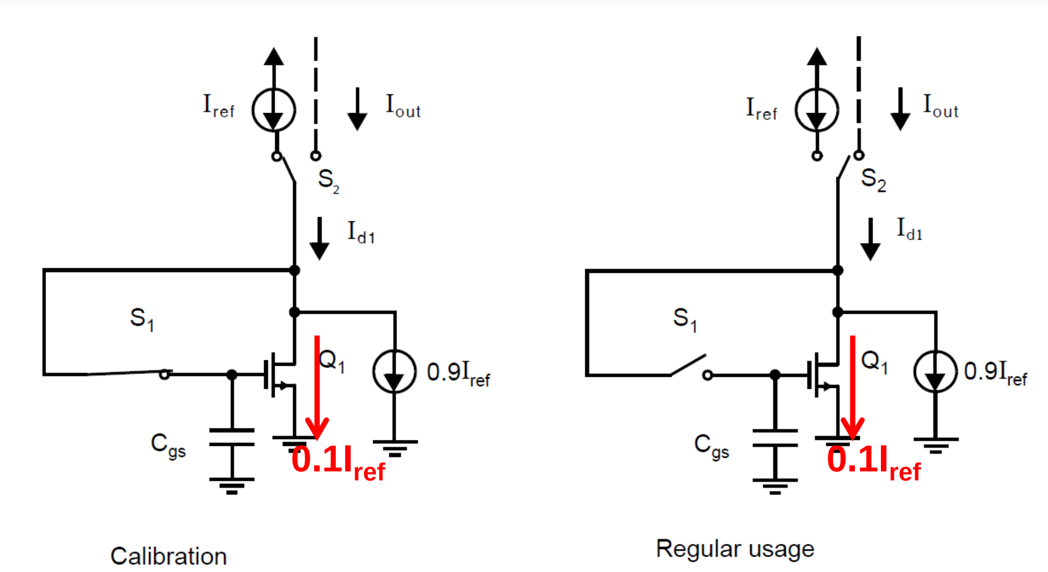


Fig. 16.20 Dynamically setting a current source, I_{d1}

- W/L = 0.27
- V_{GS} = 3V

- W/L = 0.35
- V_{GS} = 2.76V

Sol 1)

$$0.1 \cdot I_{ref} = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}\left(V_{GS} - V_{TH}\right)^2$$

$$\frac{W}{L} = \frac{0.2 \cdot 500\mu A}{92\mu A / V^2 \left(3-1\right)^2} = 0.27$$

Sol 2)

$$I_{out} = 0.9 I_{ref} + \frac{1}{2}\mu_n C_{ox}\frac{W}{L}\left(V_{GS} \pm 1mV - V_{TH}\right)^2$$

$$I_{out} = 450\mu A + \frac{1}{2}\mu_n C_{ox}\frac{W}{L}\left(V_{GS} \pm 1mV - V_{TH}\right)^2$$

$$= 500\mu A \pm 0.3\mu A$$

Example 2(Cont.)

1) Find W/L for the Q_1.

Assume that V_{GS} = 3V when I_{ref} = 500μA, V_{TH} = 1V, $\mu_n C_{ox}$ = 92 μA/V^2.

2) **What is the expected variation of the current?**

If switch S_1 cause a random charge injection by 1mV,

Without current source

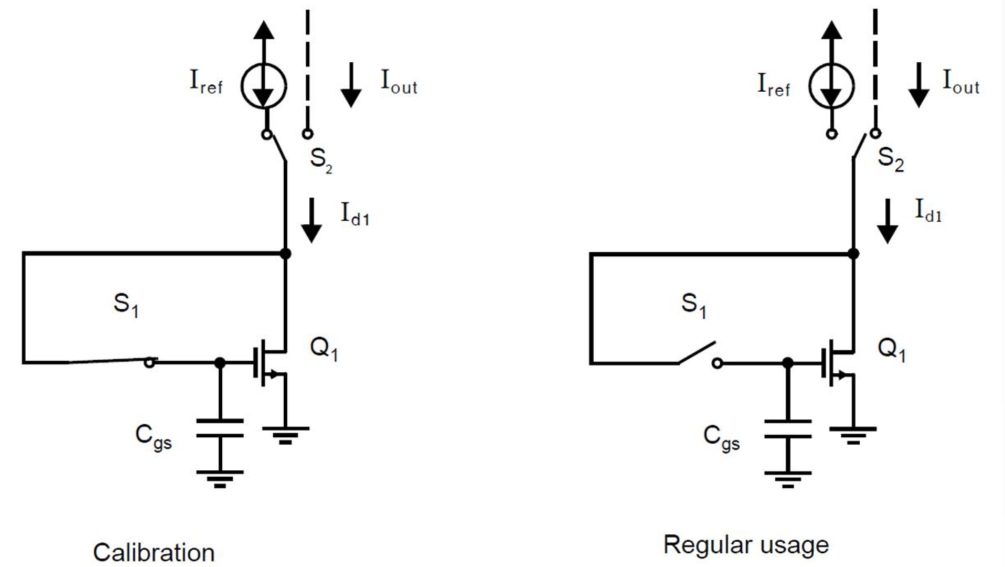


Fig. 16.20 Dynamically setting a current source, I_{d1}

Sol 1)

$$I_{ref} = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS} - V_{TH})^2$$

$$\frac{W}{L} = \frac{2 \cdot 500\mu A}{92\mu A / V^2 (3-1)^2} = 2.7$$

Sol 2)

$$I_{out} = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS} \pm 1mV - V_{TH})^2$$

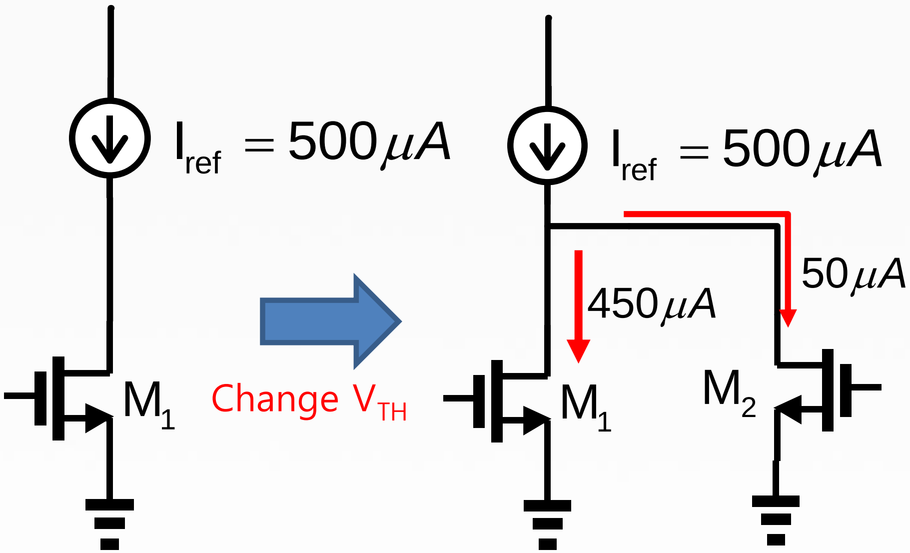
$$= \boxed{500\mu A \pm 3\mu A}$$

Charge injection effect ↑

Example 3

Find W/L of the M_2 . (V_{TH} = 0.7V → V_{TH} = 0.82V)

Assume that V_{GS} = 3V, $(W/L)_{M1}$ = 15, I_{ref} = 500μA, $\mu_n C_{ox}$ = 12.6 μA/V².



Sol)

$$I_{ref} = \frac{1}{2}\cdot \mu_n C_{ox}\cdot\left(\frac{W}{L}\right)\cdot(V_{GS}-V_{TH})^2$$

$$500\mu A = \frac{1}{2}\cdot 12.6\mu A/V^2\cdot 15\cdot(3-0.7)^2$$

$$450\mu A = \frac{1}{2}\cdot 12.6\mu A/V^2\cdot 15\cdot(3-0.82)^2$$

$$50\mu A = \frac{1}{2}\cdot 12.6\mu A/V^2\cdot\left(\frac{W}{L}\right)_{M2}\cdot(3-0.82)^2$$

$$\left(\frac{W}{L}\right)_{M2} = 1.67$$