
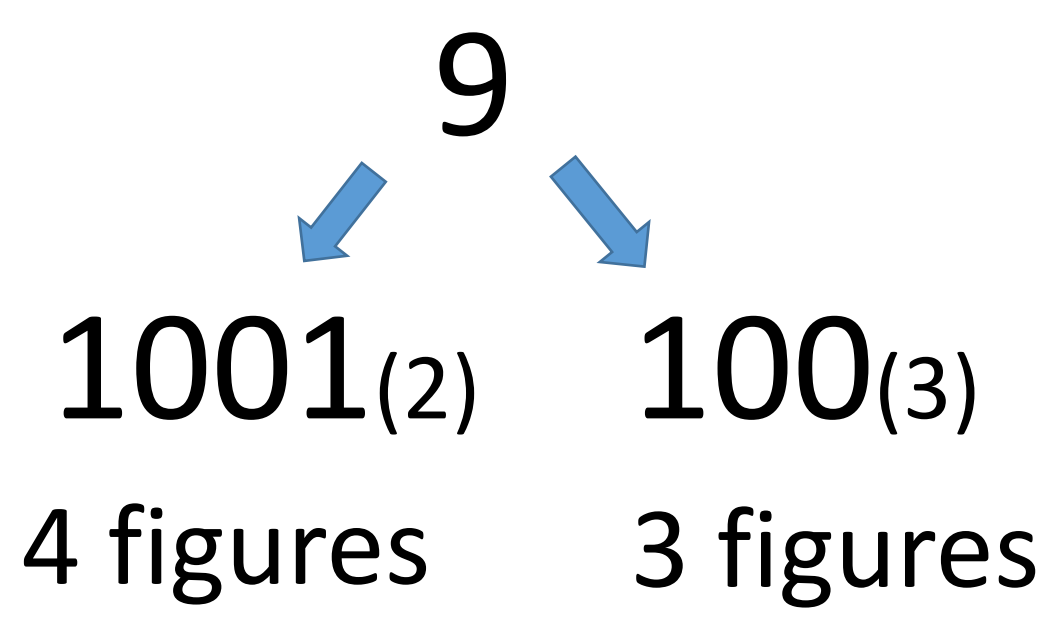


1. Introduction

When converting digital data into analog data

10010101... 

Ternary numbers has more information per digit than binary numbers do



2. Ternary numeral

Possible to express any value by combining addition and subtraction of ternary numbers whose coefficients are 1, 0 or -1.

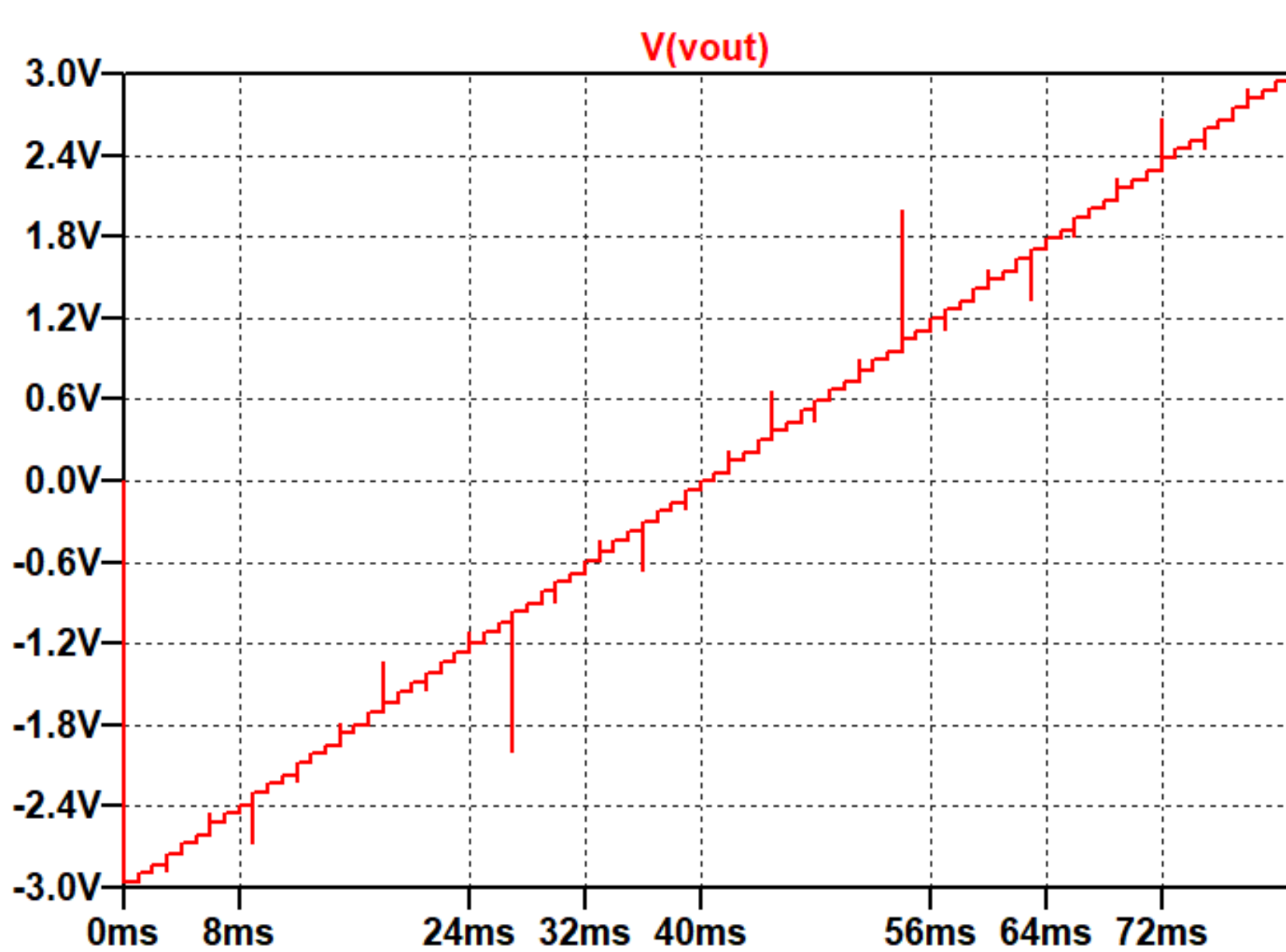
➔ Differential output DAC

$$\begin{aligned} \text{ex) } 120_{(3)} &= 1 \times 3^2 + 2 \times 3^1 + 0 \times 3^0 \\ &= 1 \times 3^3 - 1 \times 3^2 - 1 \times 3^1 \end{aligned}$$

decimal	ternary	decimal	ternary
1	3^0	9	3^2
2	$3^1 - 3^0$	10	$3^2 + 3^0$
3	3^1	11	$3^2 + 3^1 - 3^0$
4	$3^1 + 3^0$	12	$3^2 + 3^1$
5	$3^2 - 3^1 - 3^0$	13	$3^2 + 3^1 + 3^0$
6	$3^2 - 3^1$	14	$3^3 - 3^2 - 3^1 - 3^0$
7	$3^2 - 3^1 + 3^0$	15	$3^3 - 3^2 - 3^1$
8	$3^2 - 3^0$	16	$3^3 - 3^2 - 3^1 + 3^0$

5. Simulation

- Conditions:
Turning each switch ON / OFF
 $I = 270 \mu\text{A}$, normalized resistance $R = 5 \text{ k}\Omega$

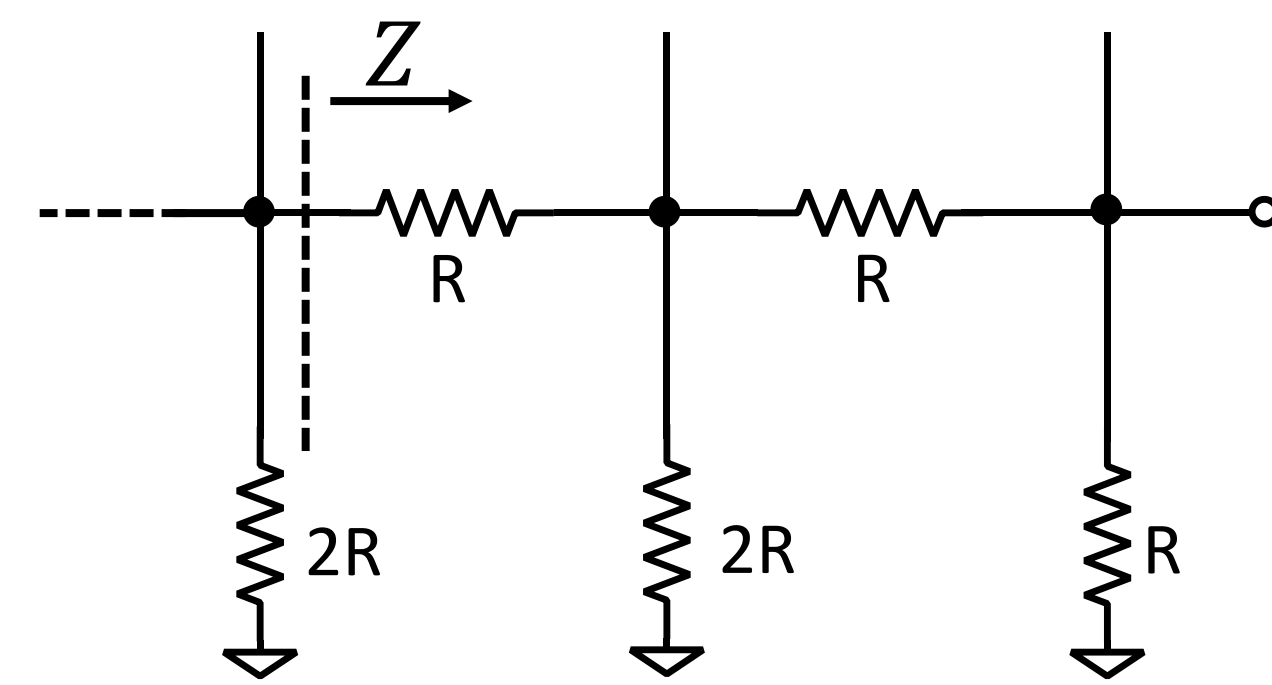
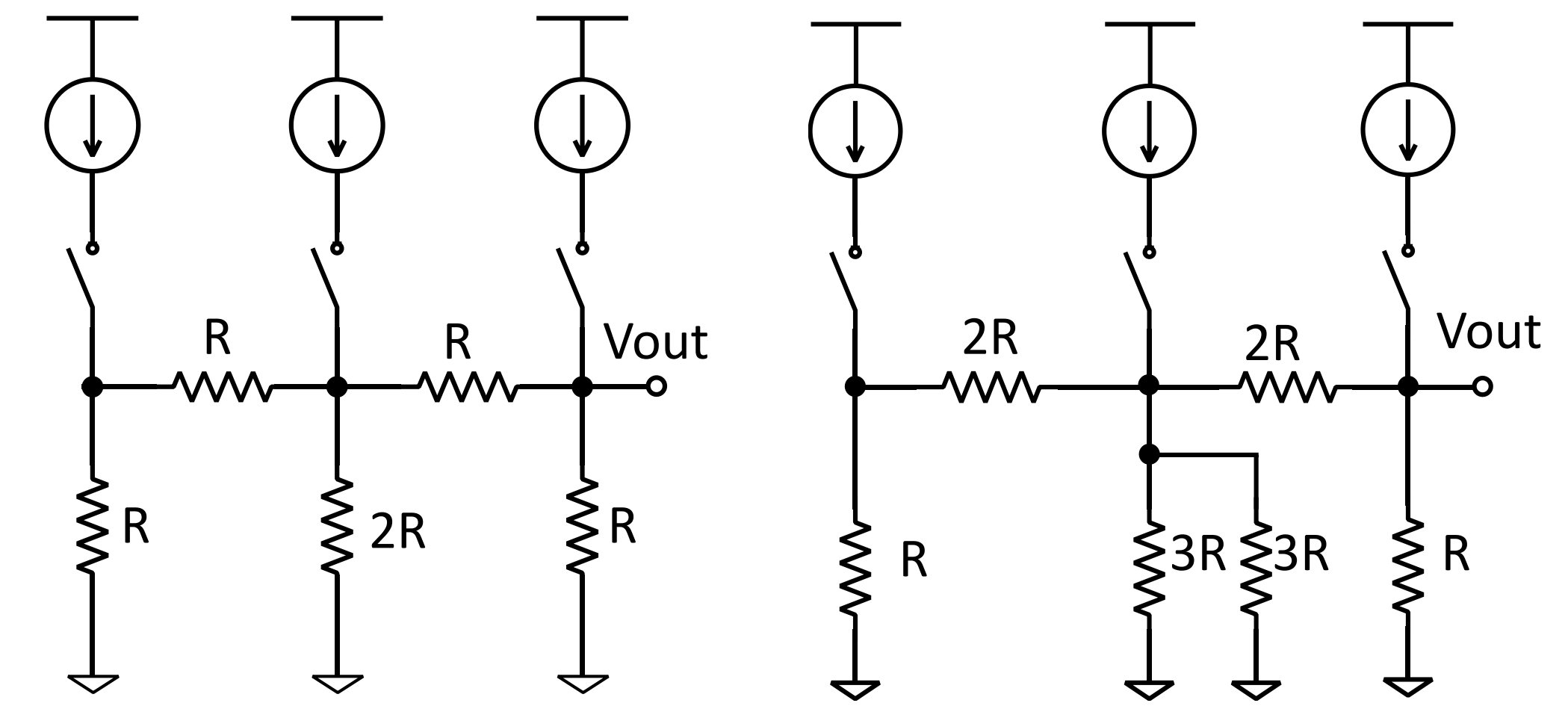


Proposed ternary DAC can output equal interval differential voltage

3. Resistor ladder

Characteristic of Resistor ladder

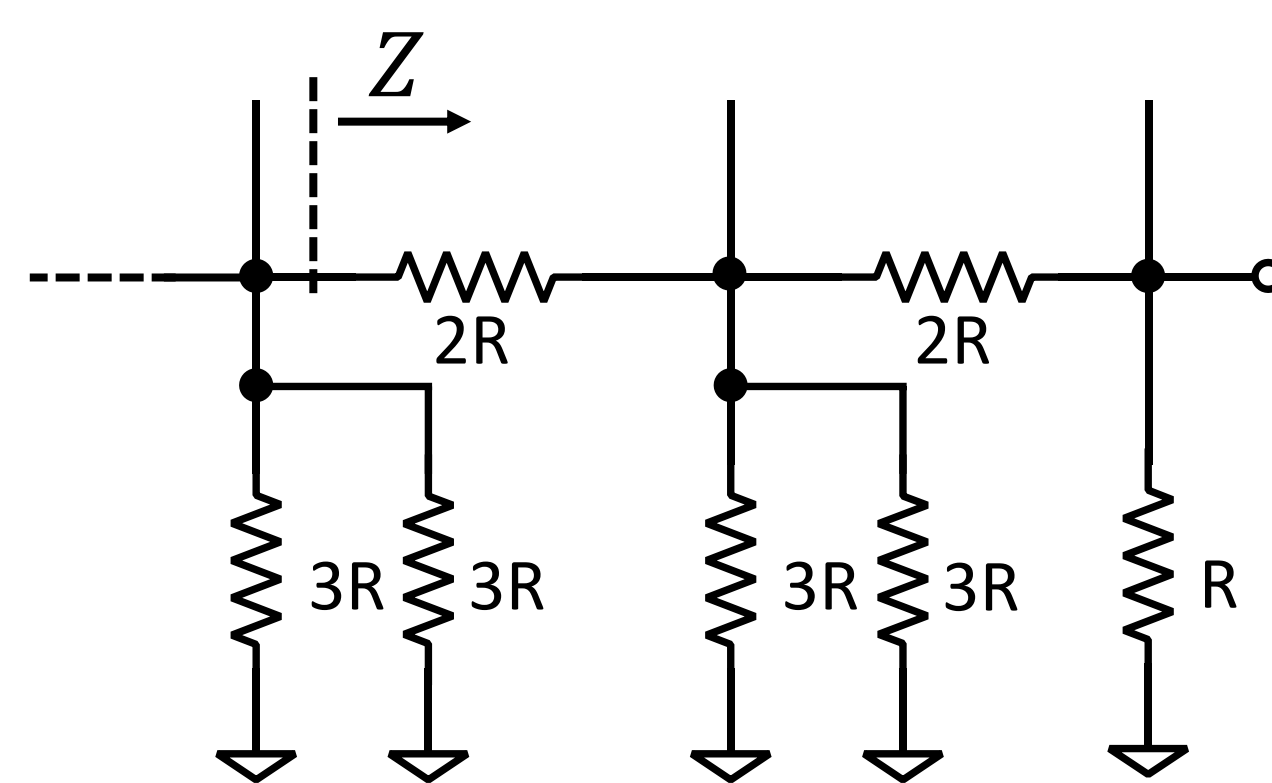
- Control the output of current or voltage
- Arranging resistance values from each node to right / left



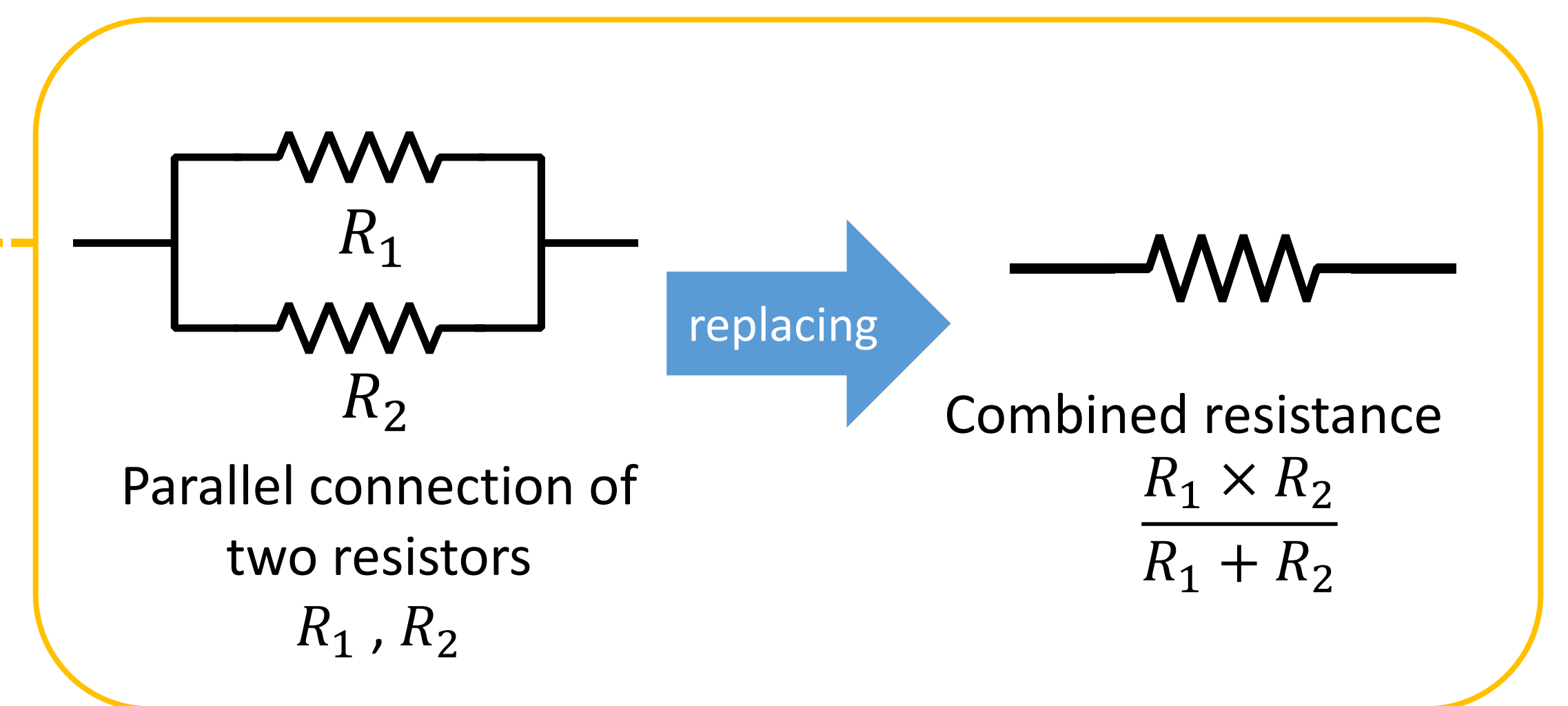
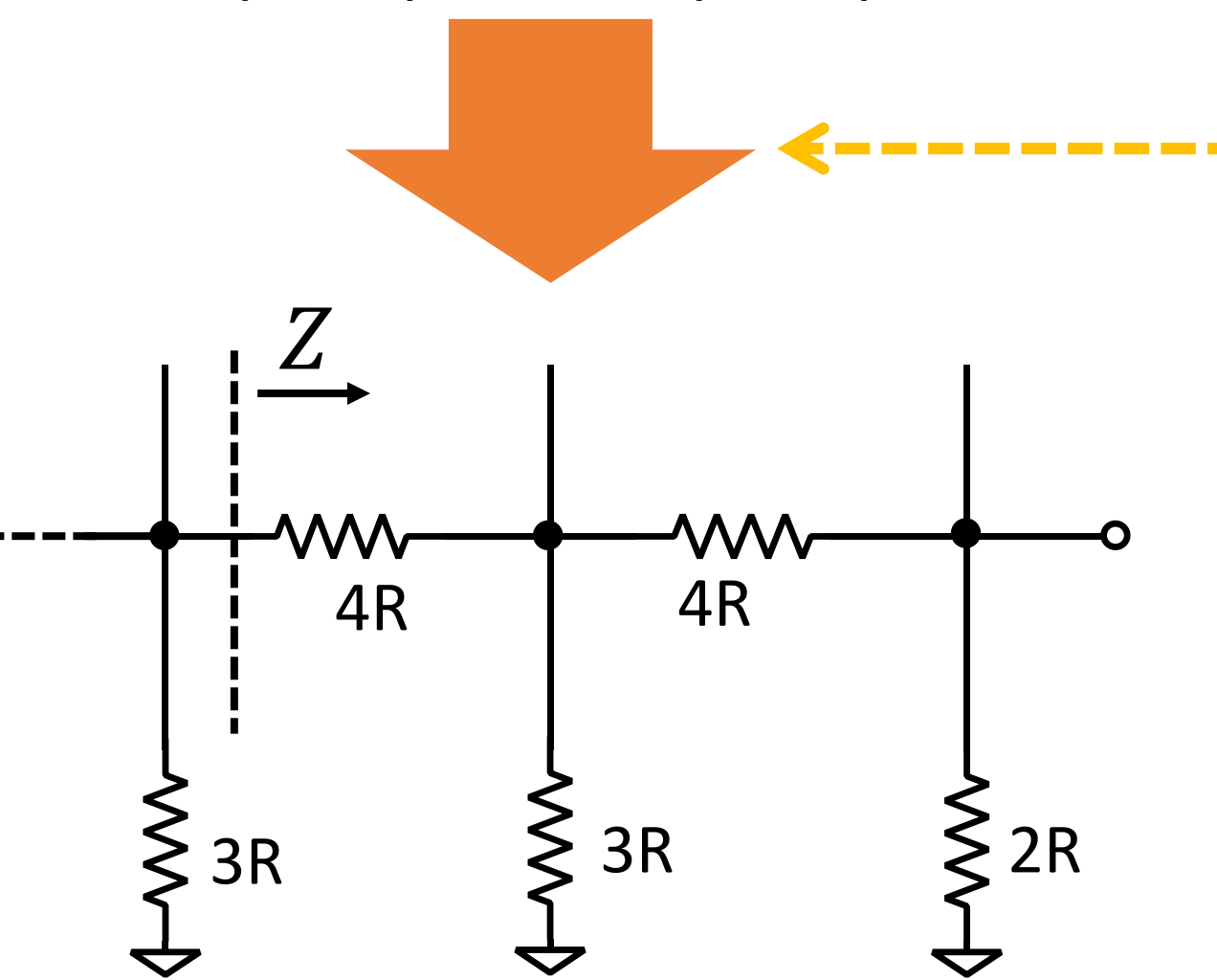
$$Z = 2R$$

Division ratio at each node based on

- Combined resistance, Z
- Resistance value to GND



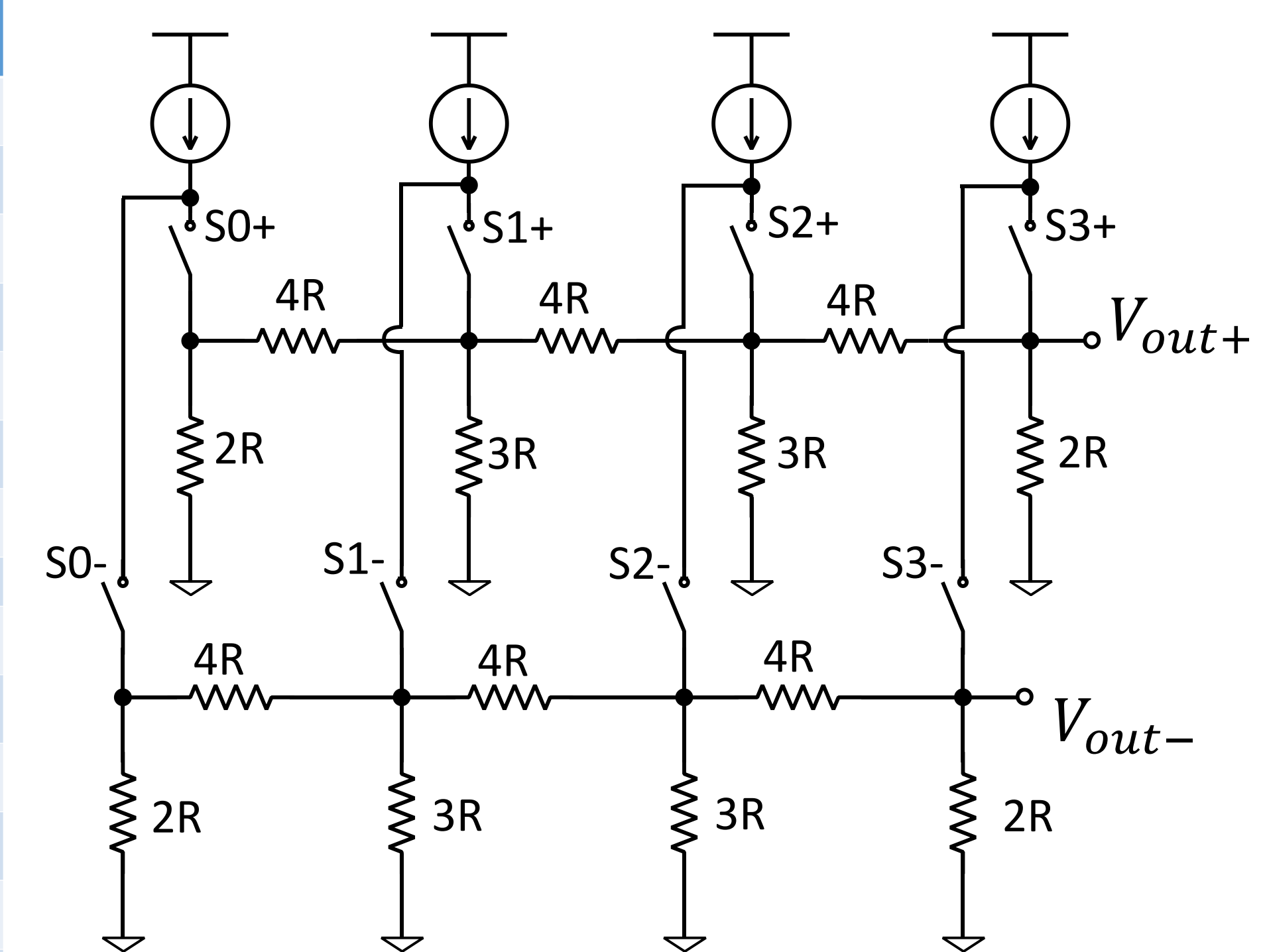
$$Z = 3R$$



4. Differential Ternary Resistor Ladder DAC

- Ternary numeral
 - Ternary resistor ladder
- ➔ Equally spaced-Differential Output voltage $V_{out} = V_{out+} - V_{out-}$

decimal	Ternary	Turn on switch								Vout
		S3+	S3-	S2+	S2-	S1+	S1-	S0+	S0-	
-7	$-3^2 + 3^1 - 3^0$				ON	ON			ON	$-\frac{7}{36}$
-6	$-3^2 + 3^1$				ON	ON				$-\frac{6}{36}$
-5	$-3^2 + 3^1 + 3^0$				ON	ON		ON		$-\frac{5}{36}$
-4	$-3^1 - 3^0$						ON	ON		$-\frac{4}{36}$
-3	-3^1						ON			$-\frac{3}{36}$
-2	$-3^1 + 3^0$						ON	ON		$-\frac{2}{36}$
-1	-3^0							ON		$-\frac{1}{36}$
0	0									0
1	3^0							ON		$\frac{1}{36}$
2	$3^1 - 3^0$				ON			ON		$\frac{2}{36}$
3	3^1				ON					$\frac{3}{36}$
4	$3^1 + 3^0$				ON		ON			$\frac{4}{36}$
5	$3^2 - 3^1 - 3^0$			ON			ON	ON		$\frac{5}{36}$
6	$3^2 - 3^1$			ON			ON			$\frac{6}{36}$
7	$3^2 - 3^1 + 3^0$			ON			ON	ON		$\frac{7}{36}$
8	$3^2 - 3^0$			ON				ON		$\frac{8}{36}$



6. Summary

- 😊 • Less current sources than R-2R DAC
- 😊 • Small circuit, low power
- 😞 • Output common-mode voltage depends on digital input

Reference

[1] Hirotaka Arai, Shuhei Yamamoto, Anna Kuwana, Haruo Kobayashi, Kazuyoshi Kubo, "AD / DA Converters Based on Ternary Number", IEEJ Tochigi Gunma Branch Workshop, Oyama, Tochigi (March 2019)