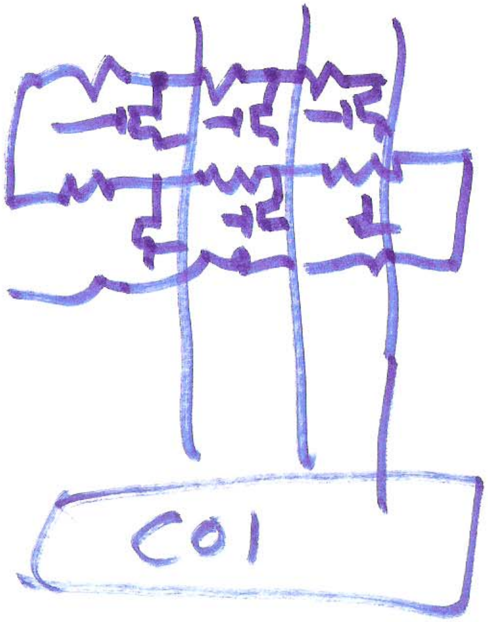
Sec. 29.1

Decimal	Binary	Thermometer	Gray	Two's Complement
0	000	0000000	000	000
1	001	0000001	001	111
2	010	0000011	011	110
3	011	0000111	010	101
4	100	0001111	110	100
5	101	0011111	111	011
6	110	0111111	101	010
7	111	1111111	100	001

Figure 29.1 Comparison of digital input codes.

unit elements



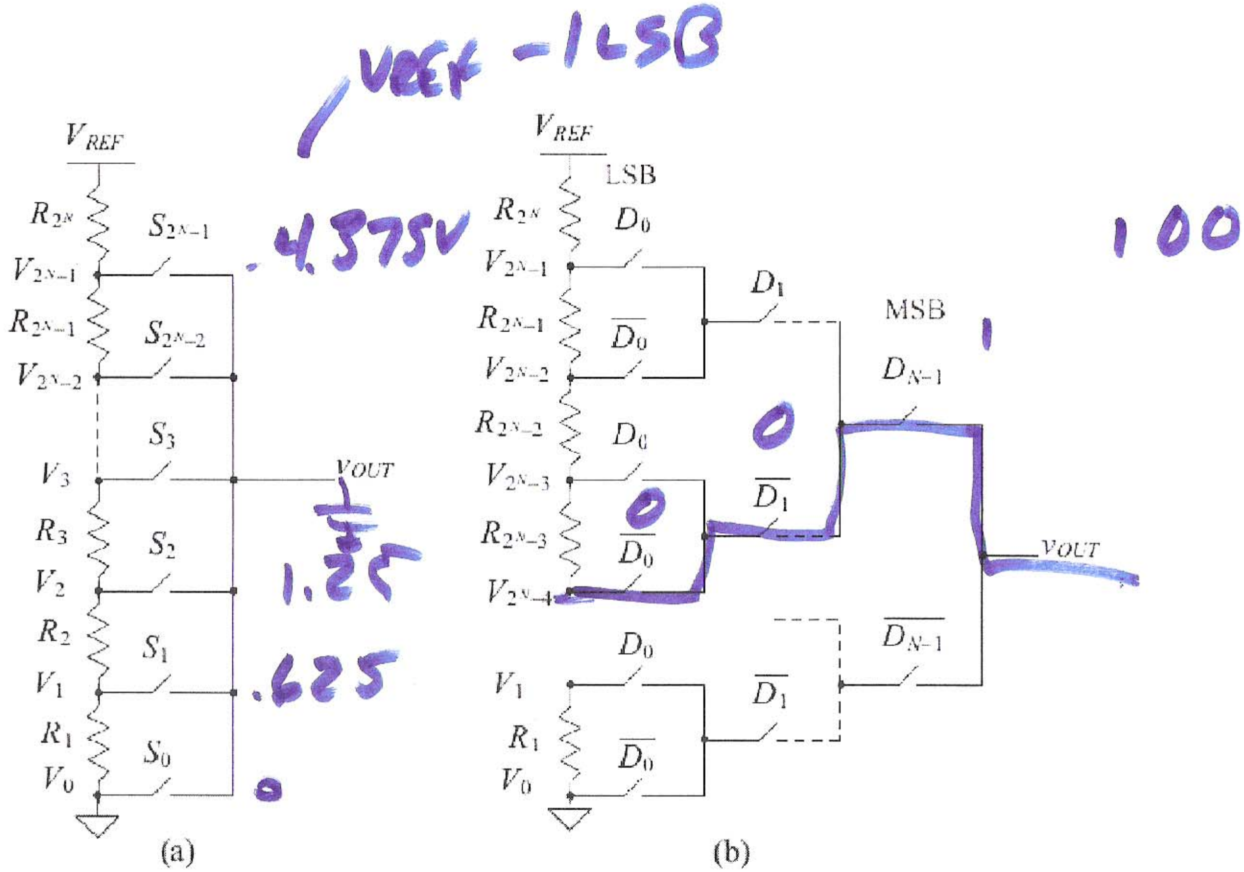


Figure 29.2 (a) A simple resistor-string DAC and (b) the use of a binary switch array to lower the output capacitance.

$$1\,LSB = \frac{V_{REF}}{2^N} = \frac{5\,V}{2^3} = 0,625$$

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2)

$$\frac{\Delta R}{R} = 0.01$$

R_3

R_2

R_1

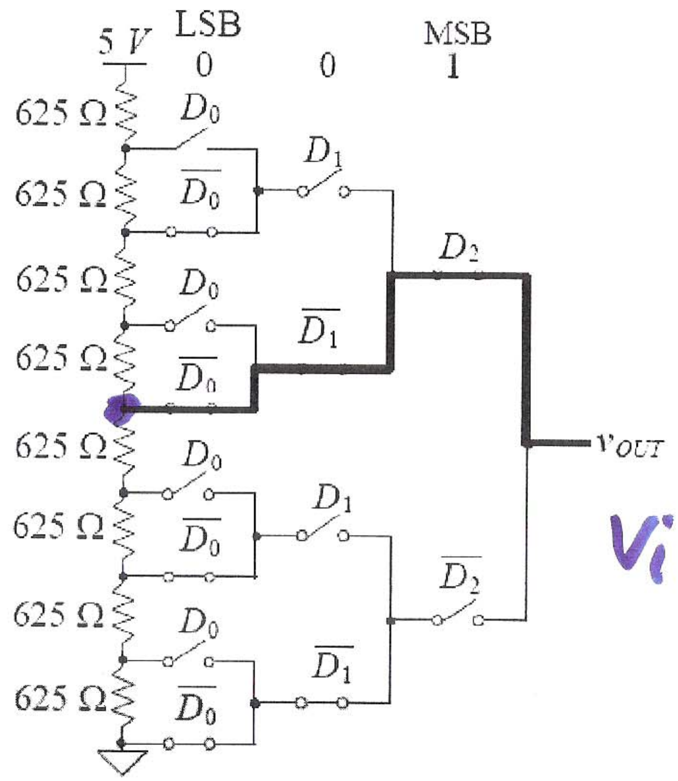

Figure 29.3 A 3-bit resistor string DAC used in Ex. 29.1

$$V_i = \frac{\sum_{k=1}^{i} R_k}{\sum_{k=1}^{2N} R_k} \cdot V_{REF} = \frac{2500}{5000}$$

$$\frac{\sum_{k=1}^{2^N} R_k}{2^N} = R$$

AVG VALUE

$$R_K = R + \Delta R_K$$

3)

$$V_i = \frac{V_{REF}}{2^N} \cdot \frac{\sum_{k=1}^{i}(R+\Delta R_k)}{R}$$

$$= \frac{V_{REF}}{2^N} \cdot \frac{1}{R}\left(i \cdot R + \sum_{k=1}^{i} \Delta R_k\right)$$

What is the ideal value of V_i

$$V_{i,ideal} = \frac{V_{REF}}{2^N} \cdot i$$

$$V_i = V_{i,ideal} + \underbrace{1LSB}_{\frac{V_{REF}}{2^N}} \sum_{k=1}^{i} \frac{\Delta R_k}{R}$$

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$$INL = V_i - V_{i,ideal}$$

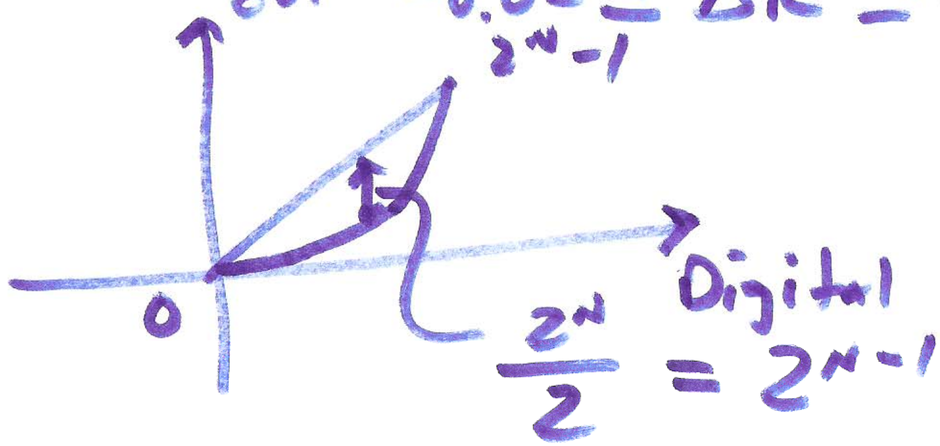
$$INL = \frac{V_{REF}}{2^N} \cdot \sum_{k=1}^{i} \frac{\Delta R_k}{R}$$

Assume the

$i < \frac{2^N}{2}$ then $\Delta R_k = -\max \Delta R$

$i > \frac{2^N}{2}$ then $\Delta R_k = +\max \Delta R$

$-0.02 \le \Delta R \le 0.02$ (2% match)



$$INL_{MAX} = \frac{V_{REF}}{2^N} \sum_{k=1}^{2^{N-1}} \frac{\Delta R_k}{R}$$

$$= \frac{V_{REF}}{\cancel{2^N}} \cdot \cancel{2^{N-1}} \cdot \frac{\Delta R_k}{R} = \frac{V_{REF}}{2} \cdot \frac{\Delta R_k}{R}$$

1LSB

$$= \frac{1}{2} LSB \cdot 2^N \underbrace{\frac{\Delta R_k}{R}}_{\text{matching}}$$

CMOS process matching

poly R $1\% = \frac{\Delta R}{R} = 0.01$

$$INL_{MAX} = \frac{V_{REF}}{2} \cdot 0.01$$

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WANT $\frac{1}{2}$ LSB INL

0.01

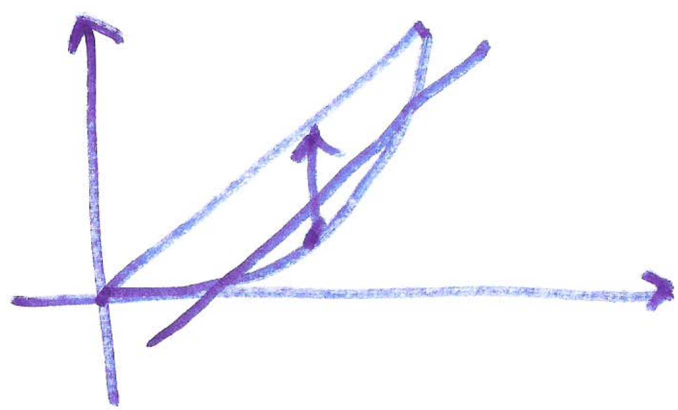
$$INL_{MAX} = \frac{1}{2} LSB = \frac{V_{REF}}{2^N} \cdot \frac{1}{2} = \frac{V_{REF}}{2} \frac{\Delta R}{R}$$

$$\frac{\Delta R}{R} < \frac{1}{2^N}$$

for 0.01 mismatch

N = [redacted] bits

5 to 6 bits!



DNL

$$|V_i - V_{i-1}| =$$

$$\left| \left[i \cdot \frac{V_{REF}}{2^N} + \frac{V_{REF}}{2^N} \sum_{K=1}^{i} \frac{\Delta R_K}{R} \right] - \left[(i-1) \cdot \frac{V_{REF}}{2^N} + \frac{V_{REF}}{2^N} \sum_{K=1}^{i-1} \frac{\Delta R_K}{R} \right] \right|$$

$$= \left| \frac{V_{REF}}{2^N} \left(1 + \frac{\Delta R_i}{R} \right) \right|$$

$$DNL = \left(\quad \downarrow \quad \right) - \frac{V_{REF}}{2^N} \Rightarrow DNL = 1\,LSB \cdot \frac{\Delta R}{R}$$

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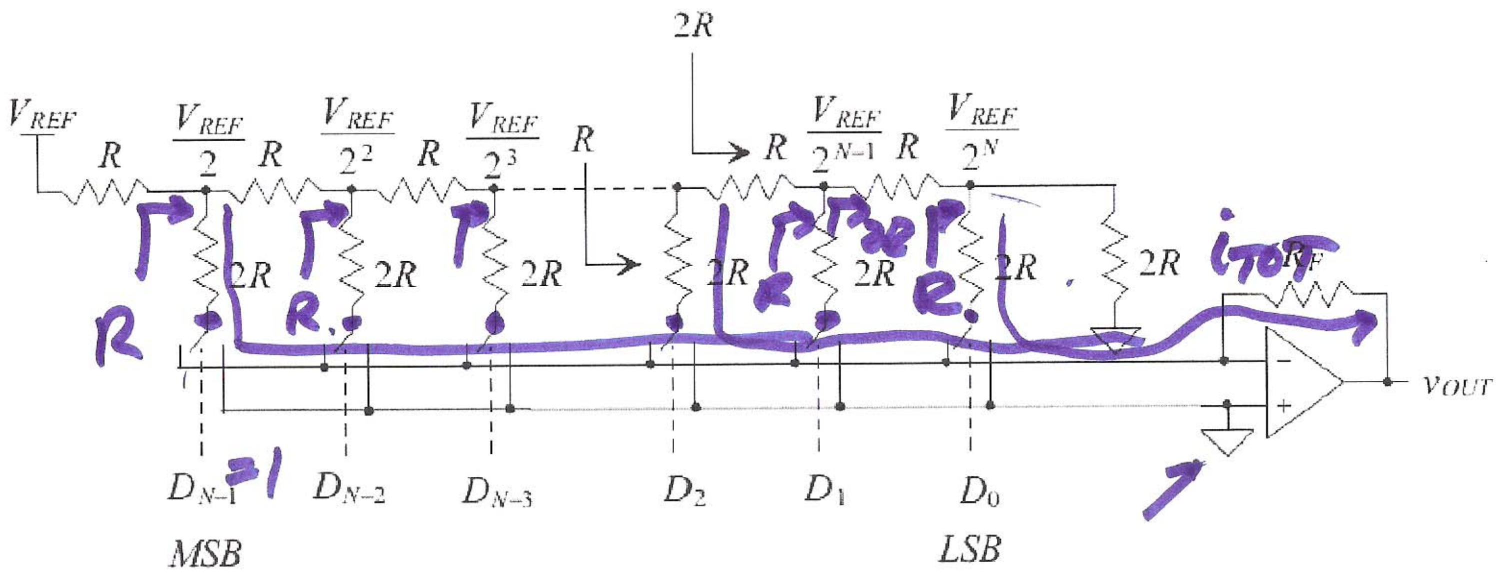


Figure 29.5 An R-$2R$ digital-to-analog converter.

$$V_{OUT} = -\,i_{TOT} \cdot R_F$$

$$i_{TOT} = \sum_{k=0}^{N-1} D_k \cdot \frac{V_{REF}}{2^{N-k}} \cdot \frac{1}{2R}$$

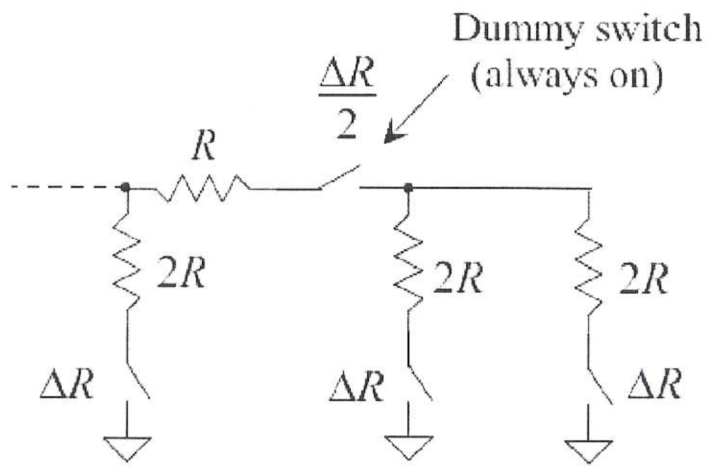
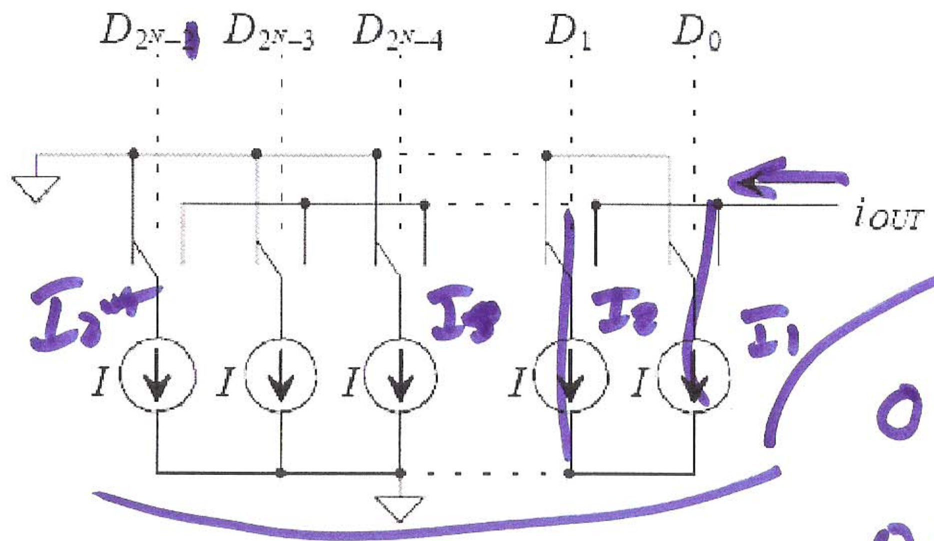


Figure 29.6 Use of dummy switches to offset switch resistance.



$2^N - 1$

$0 \to 2^N - 1$

$0 \to 7$

$I = 1\,LSB$
$= 1\,\mu A$

Figure 29.9 A generic current steering DAC.

	I
000	0
001	$1\mu A$
010	$2\mu A$

Unit elements

$$\sum_{k=1}^{2^N-1} I_k = \ldots$$

$I + \Delta I_k$

$$I = I_{AVG} = \frac{I_k(2^N - 1)}{2^N}$$

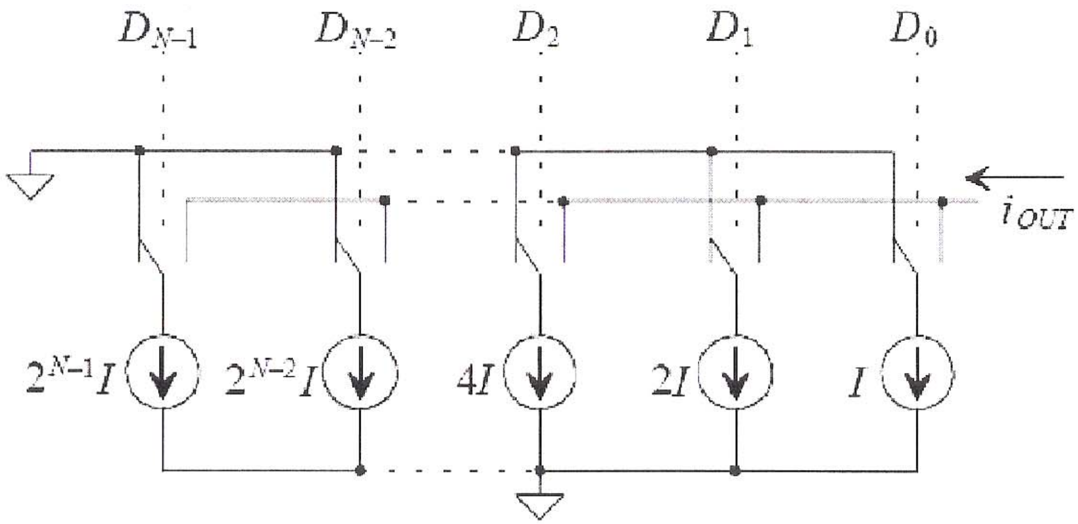
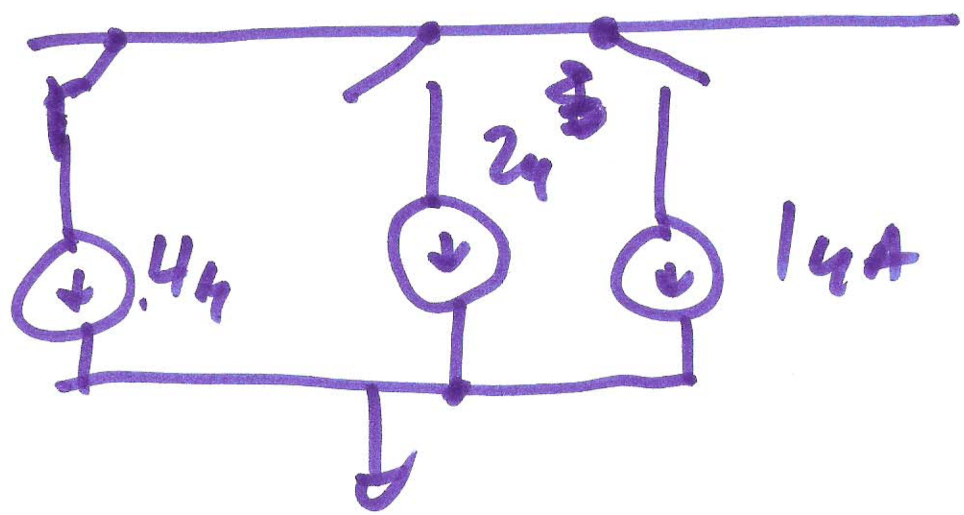


Figure 29.10 A current steering DAC using binary-weighted current sources.

$N=3$ $\quad$ $I = 1\mu A$



101

4μ $\quad$ 1μ

$= 5\mu A$

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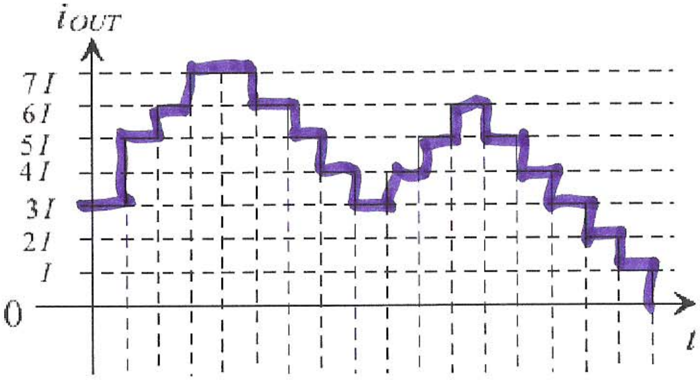
12)

(a)



(b)

D_6	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
D_5	0	0	1	1	1	1	0	0	0	0	0	1	0	0	0	0	0	0
D_4	0	1	1	1	1	1	1	0	0	0	1	1	1	0	0	0	0	0
D_3	0	1	1	1	1	1	1	1	0	1	1	1	1	1	0	0	0	0
D_2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0
D_1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
D_0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0

Figure 29.11 (a) Output of a 3-bit current-steering DAC and (b) the thermometer code input.

13)