

Nyquist-Rate D/A Converters

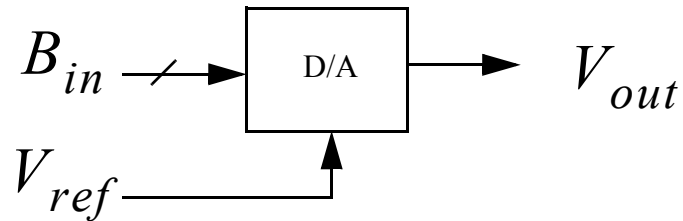
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slide 1 of 20

D/A Converter Basics.



- B_{in} is a digital signal (or word),

$$B_{in} = b_1 2^{-1} + b_2 2^{-2} + \dots + b_N 2^{-N} \quad (1)$$

- b_i equals a “1” or a “0” (i.e. a binary digit).
- V_{ref} — an analog reference; V_{out} — output .

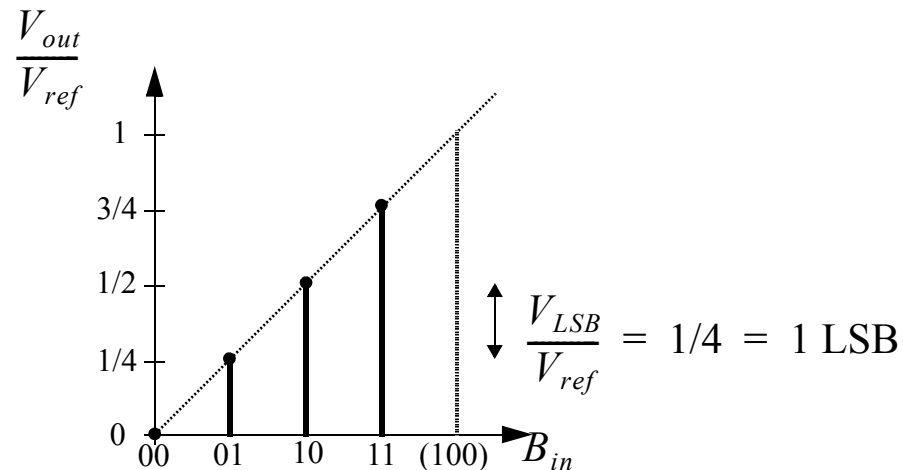
$$V_{out} = V_{ref}(b_1 2^{-1} + b_2 2^{-2} + \dots + b_N 2^{-N}) \quad (2)$$

- **Define** V_{LSB} to be LSB signal change, $V_{LSB} \equiv V_{ref}/2^N$

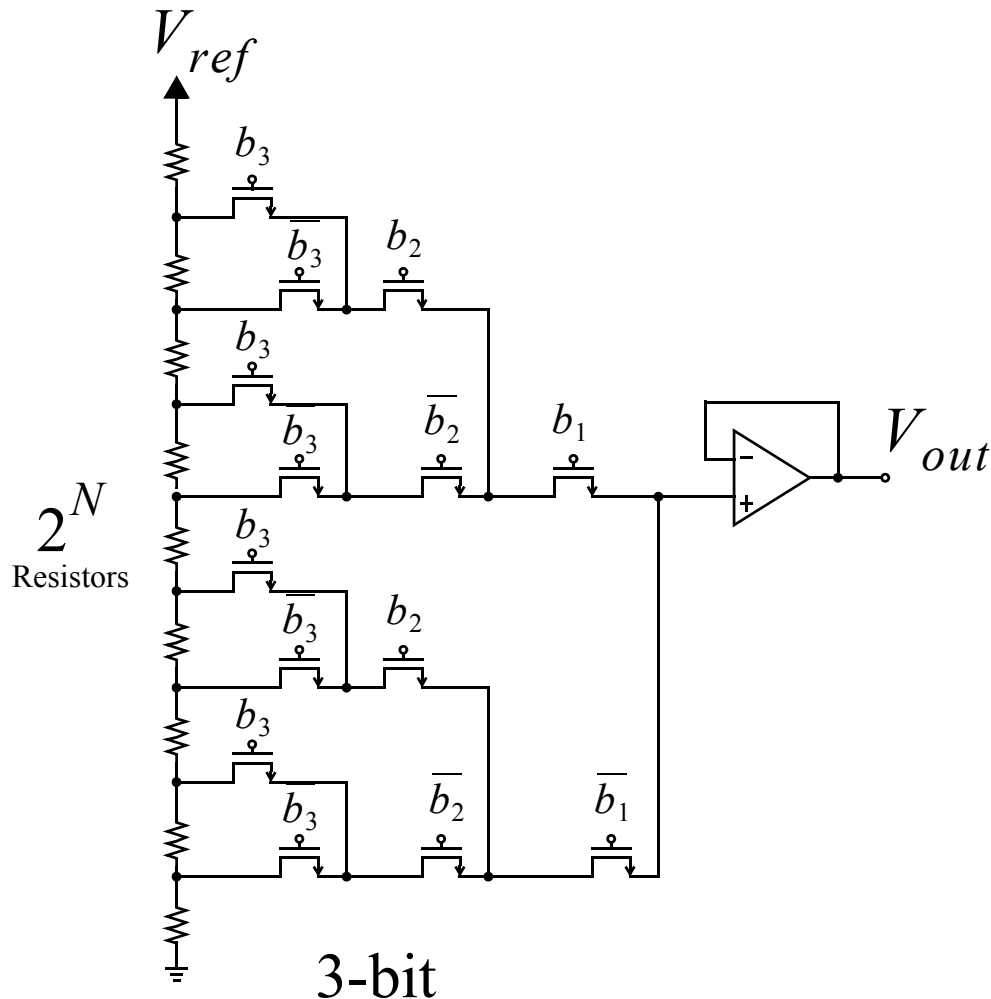


D/A Converter Basics

- For errors, define “units” of LSB $1 \text{ LSB} = 1/2^N$
- A *multiplying* D/A allows V_{ref} to be a *varying input* — V_{out} proportional to multiplication of V_{ref} and B_{in} .
- For *ideal* D/A, output signal is a *well defined value* — no quantization error!



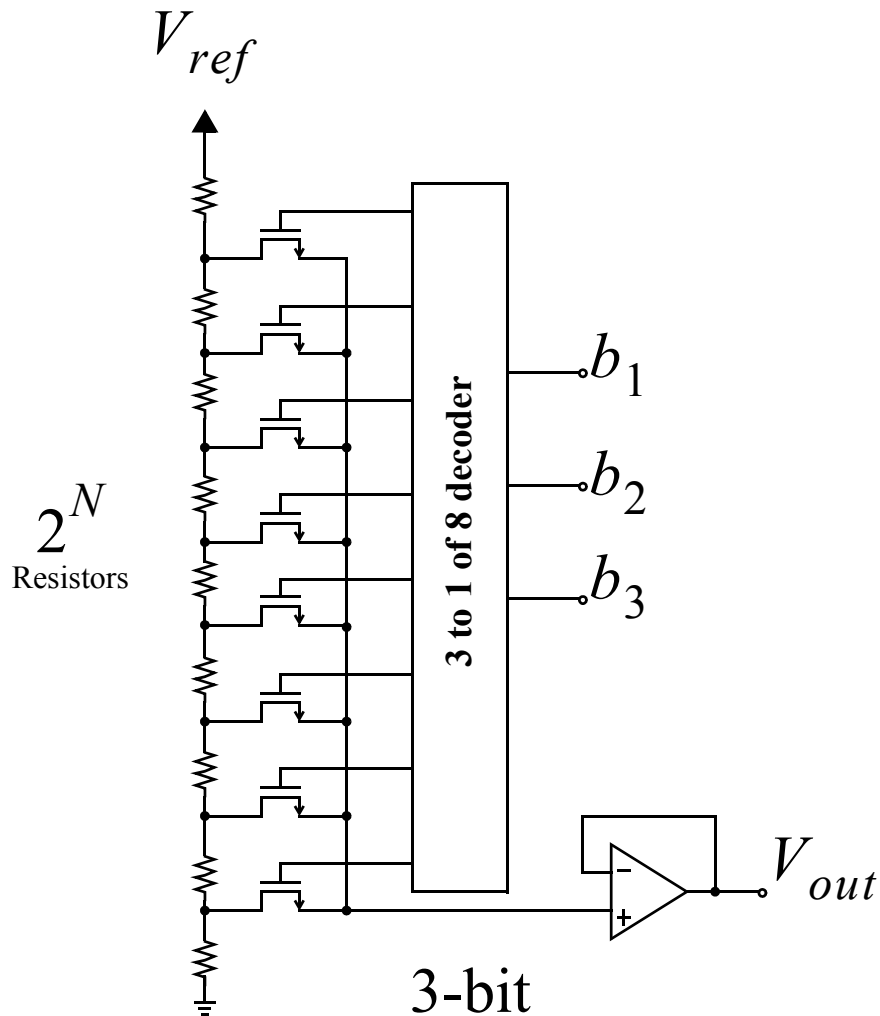
D/A Resistor-String (Hamadé, JSSC, Dec. 1978)



- Guaranteed monotonic
- Integrated with better than 10-bits absolute accuracy.
- Delay through the switch network major speed limitation
- Resistors might be realized using polysilicon
- If n-channel only used, can be laid out small
- Requires 2^N resistors



D/A Resistor-String — Digital Decoding

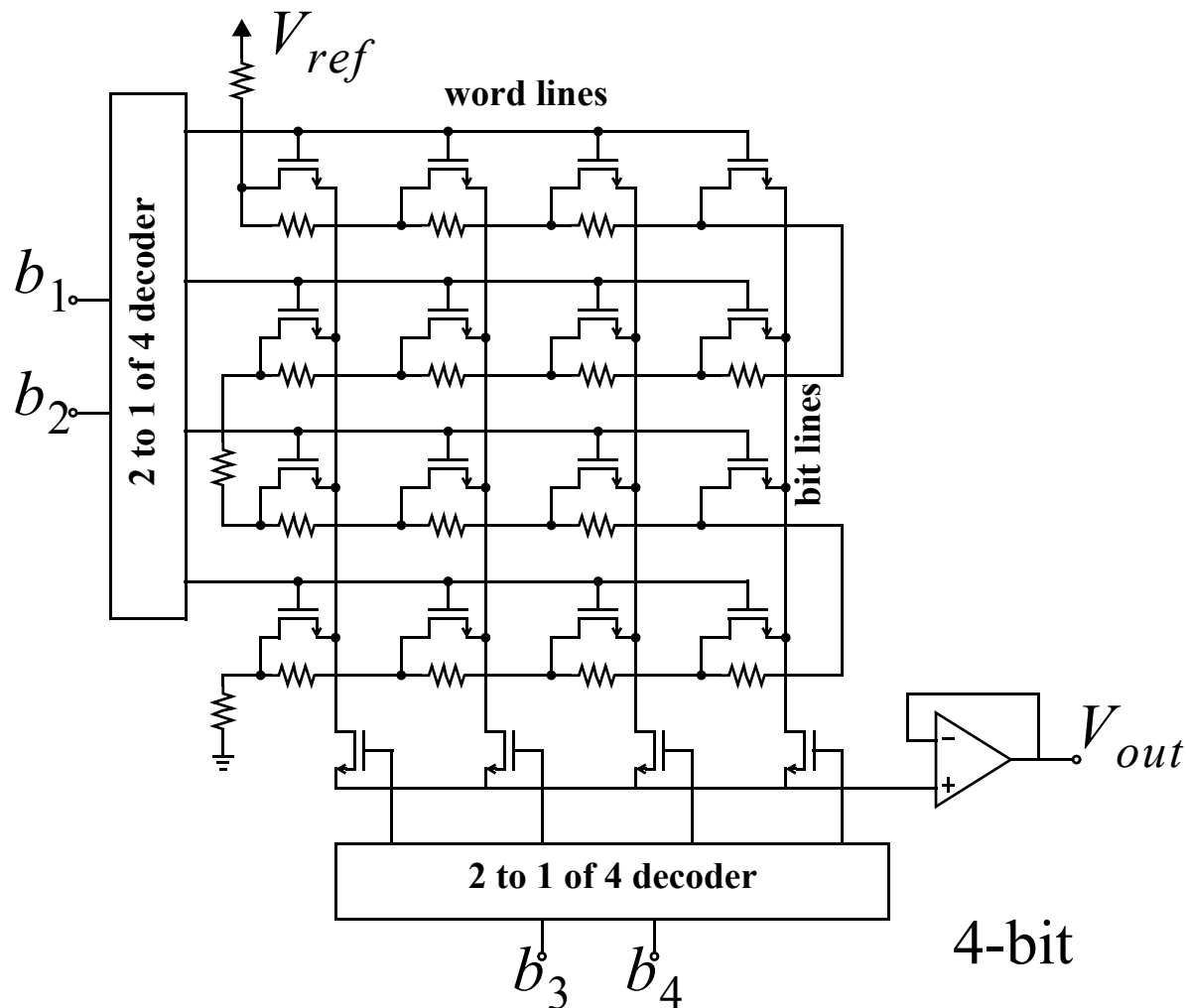


- Higher speed implementation (less resistance thru transistors)
- Large cap load on buffer input
- Can pipeline digital decoding for faster speed
- Requires 2^N resistors



Folded-resistor-string D/A

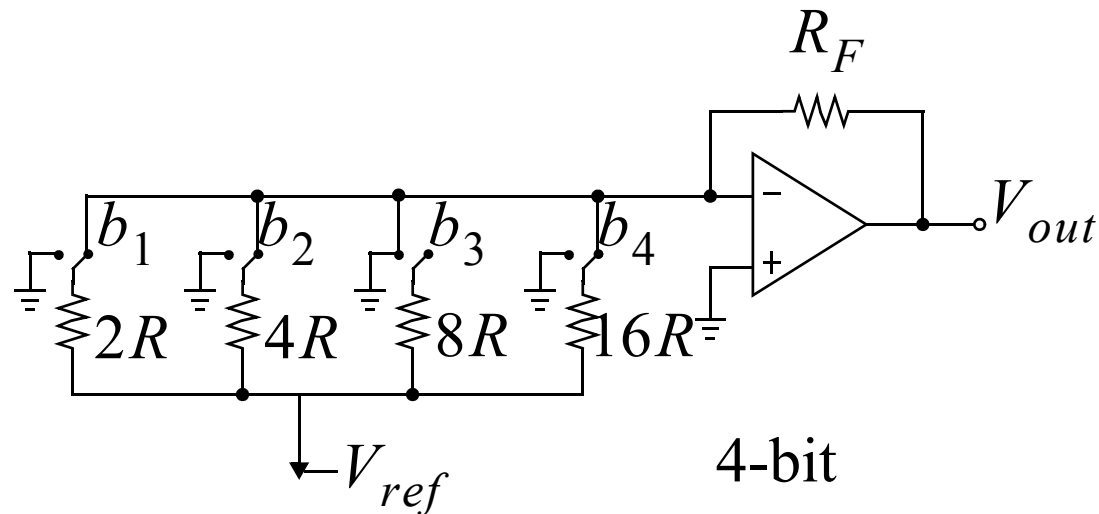
- (Abrial, JSSC, Dec. 1988)



- Less capacitance load over the single bus approach
- Requires 2^N resistors



Binary-Weighted Resistor D/A's.

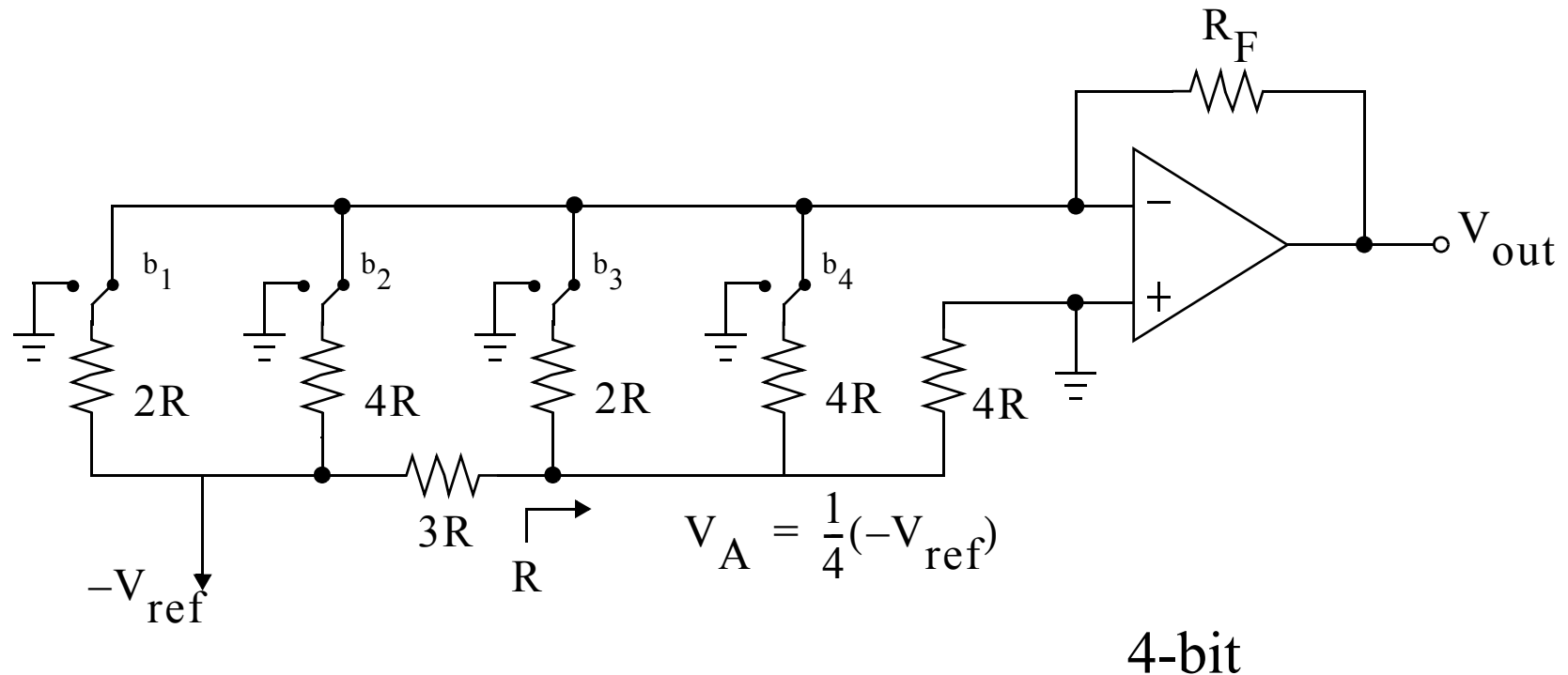


$$V_{out} = -R_F V_{ref} \left(-\frac{b_1}{2R} - \frac{b_2}{4R} - \frac{b_3}{8R} - \dots \right) \quad (3)$$

- Only N resistors
- Resistor and current ratios are on the order of 2^N
- No guarantee of monotonicity.
- Prone to glitches (more later).



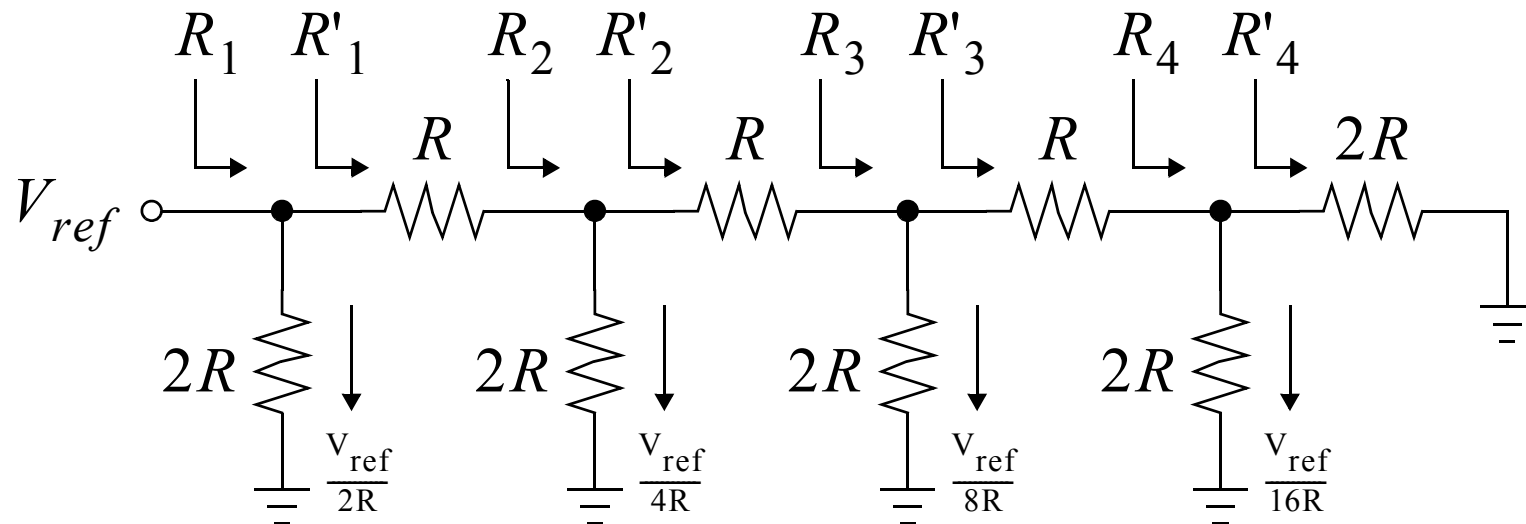
Reduced Spread Binary Resistor D/A



- Reduced resistor spread
- Keep repeating this procedure \longrightarrow R-2R ladder



R-2R Based D/A Converters



$$\begin{aligned}
 R'_4 &= 2R \\
 R_4 &= 2R \parallel 2R = R \\
 R'_3 &= R + R_4 = 2R \\
 R_3 &= 2R \parallel R'_3 = R
 \end{aligned}$$

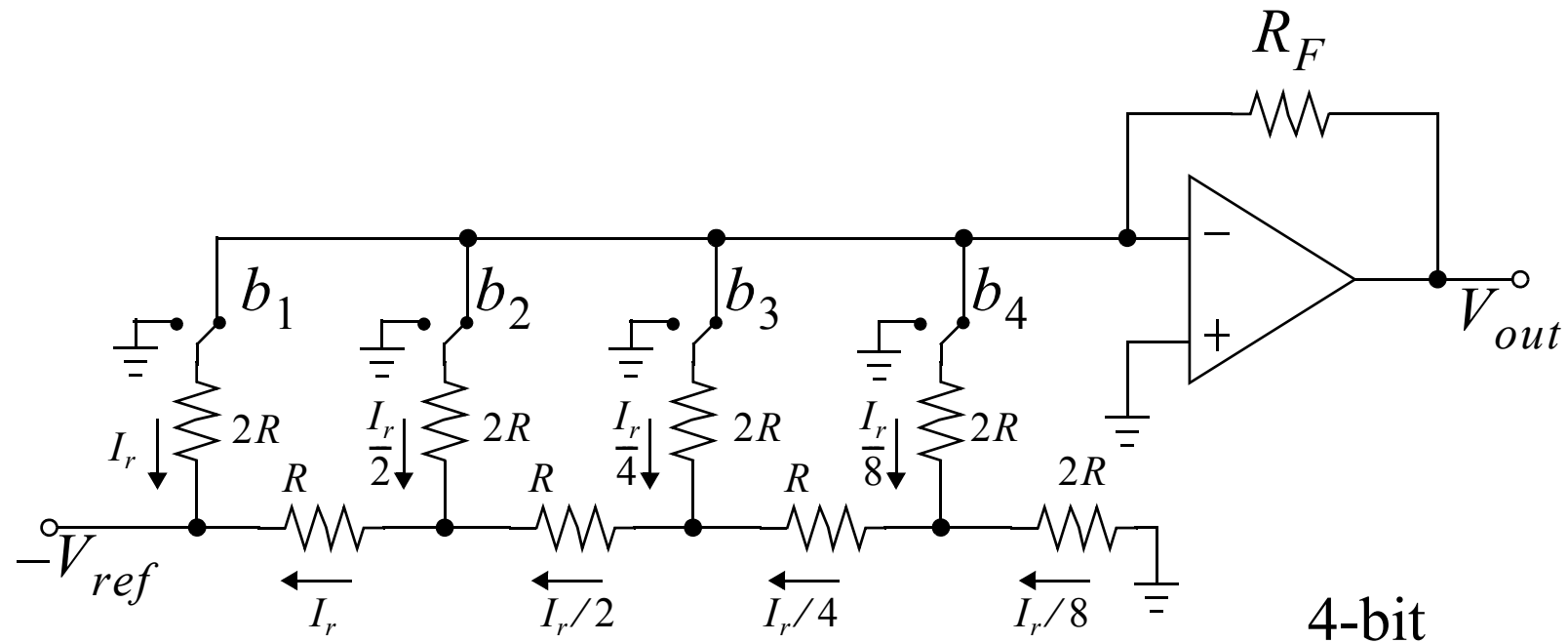
(4)

- Small size, good matching (only R and 2R)



R-2R Based Resistor Ladders

- Example D/A converter

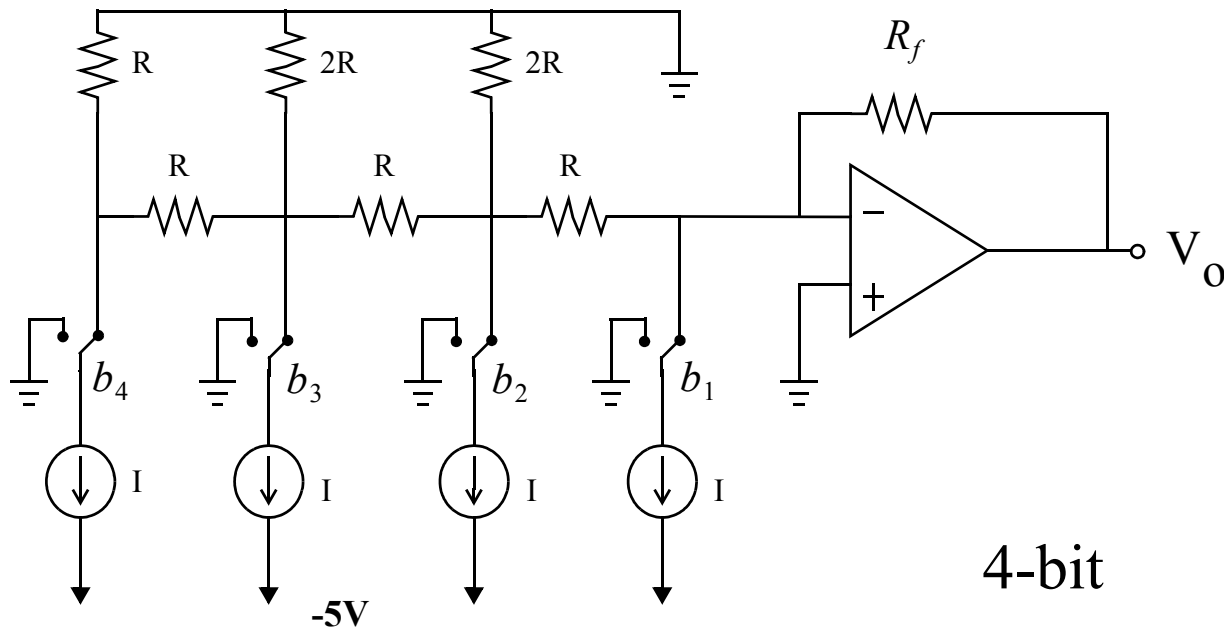


- Currents through the switches are scaled
- Should scale switch sizes for good accuracy
- No node voltage changes except for output \rightarrow fast



R-2R Based Resistor Ladders

- Slower circuit having *equal* current through switches

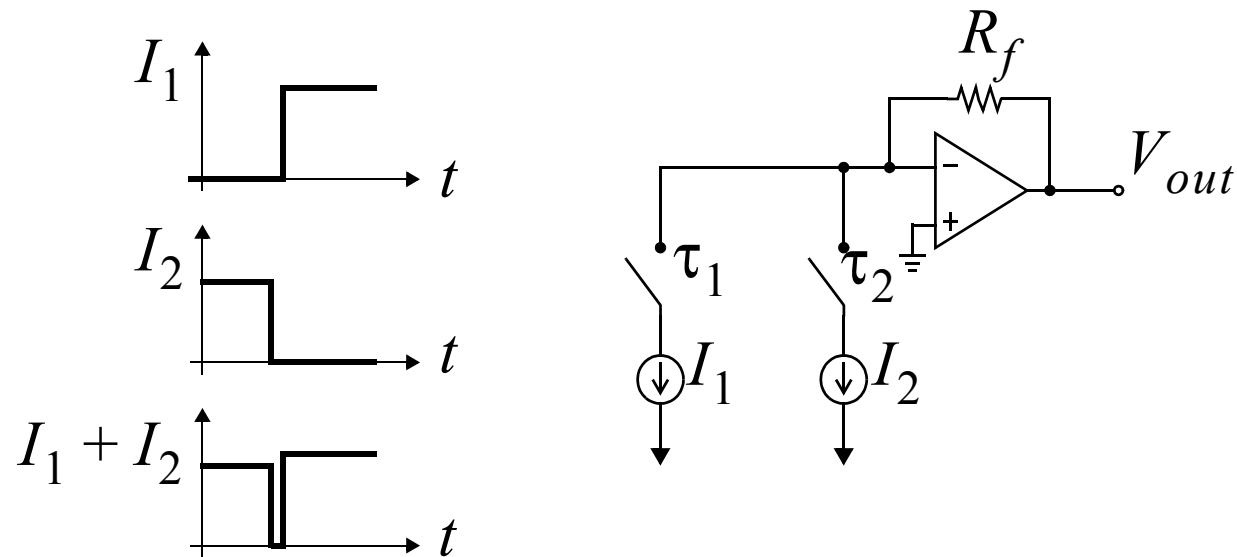


- Node voltages change — slower circuit
- No need to scale switch sizes (smaller size)



Glitches

- Different delays for switching the different currents
- MSB change often worst case

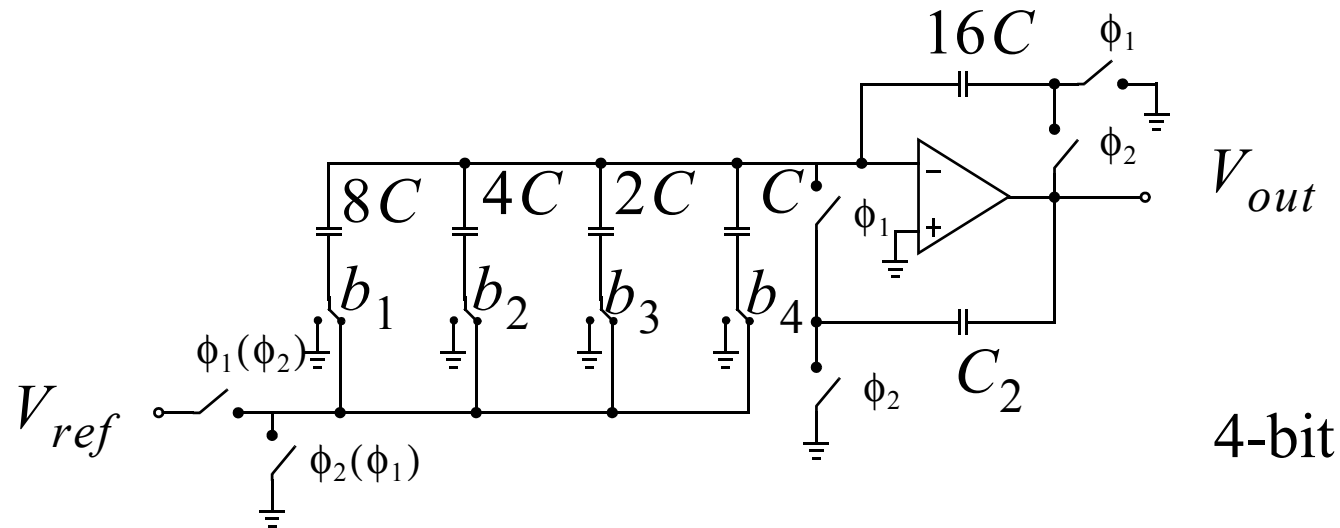


- Glitches can be minimized by limiting the bandwidth but that slows down circuit
- Use thermometer code to reduce glitches



Charge-Redistribution SC D/A's

- Programmable SC gain amplifier.

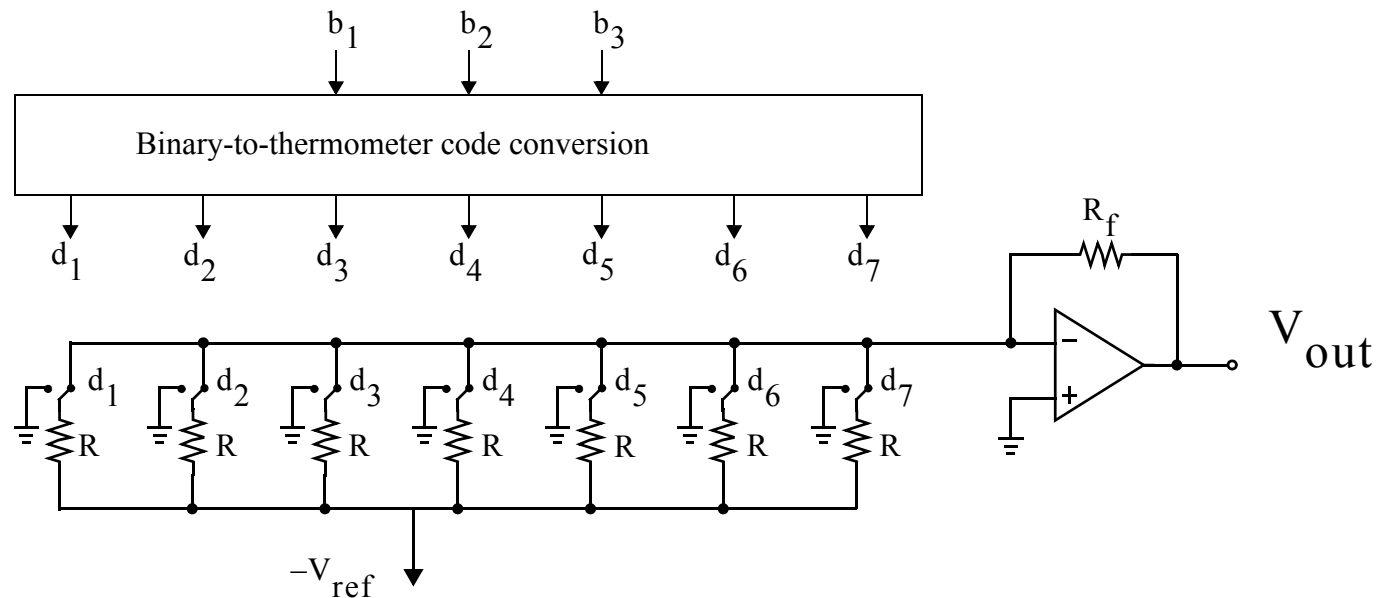


- Sign bit realized by interchanging input phases
- Carefully clock-waveforms required to minimize voltage dependency of clock-feed-through.
- Digital codes should be changed when input side of capacitors are connected to ground. Requires extra digital complexity.

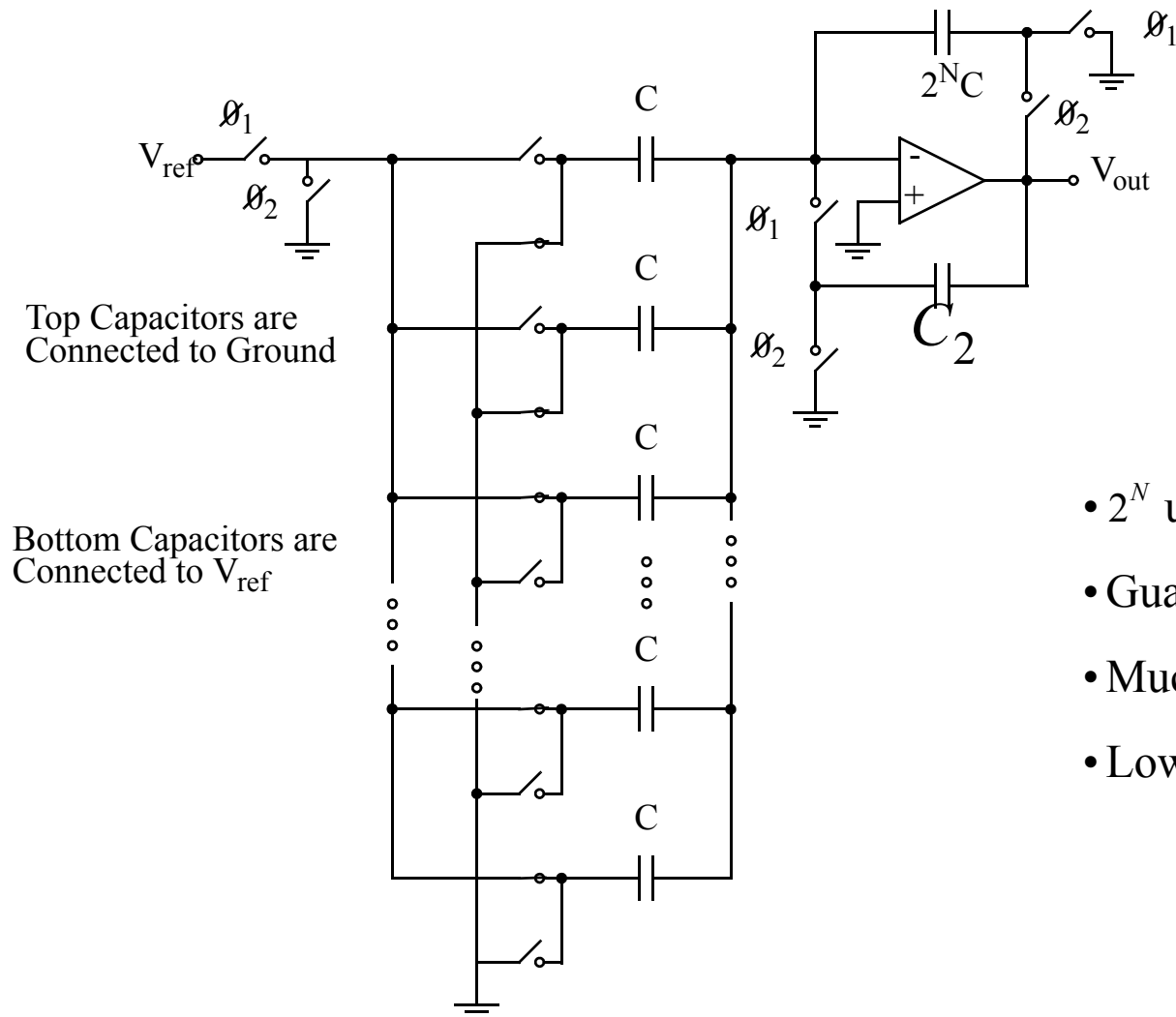


Thermometer D/A Converters

Decimal	Binary			Thermometer Code						
	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



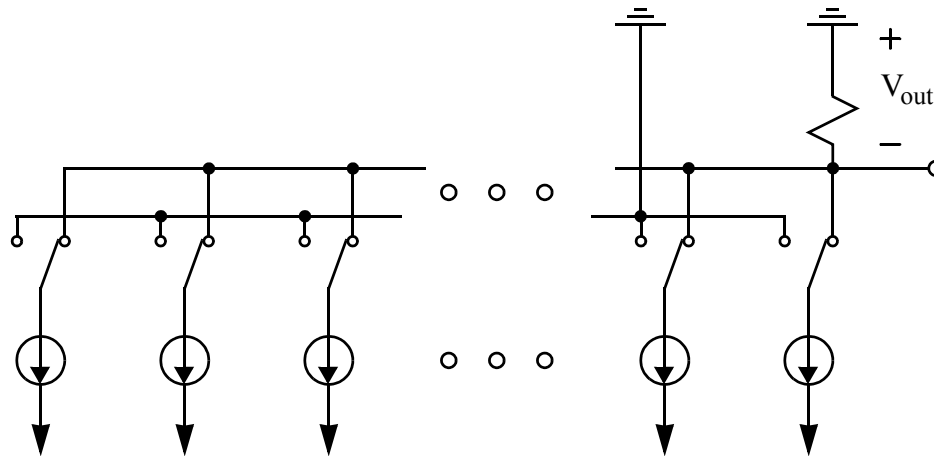
Thermometer Code D/A Converter



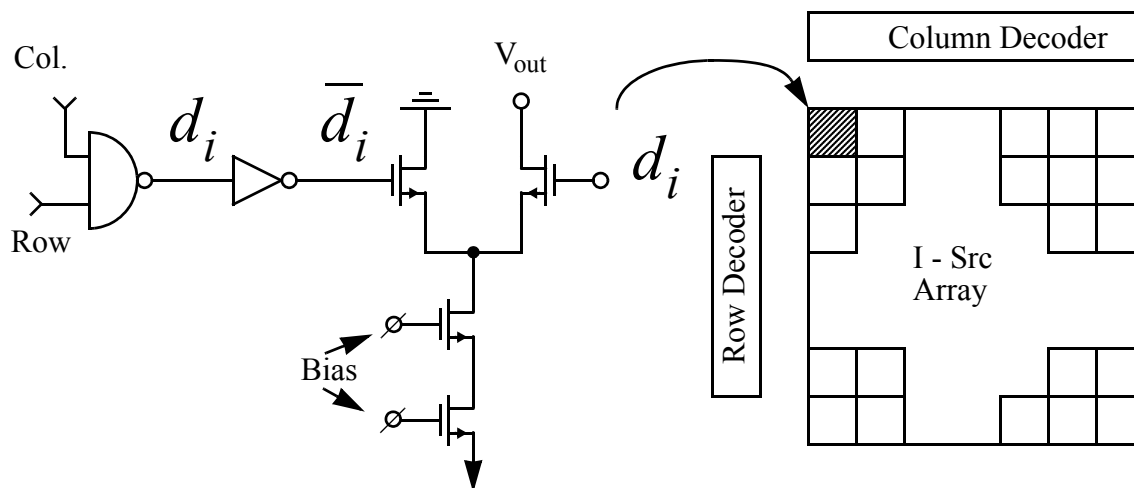
- 2^N unit sized caps
- Guaranteed monotonic
- Much lower glitching
- Low DNL



Current-Mode D/A's

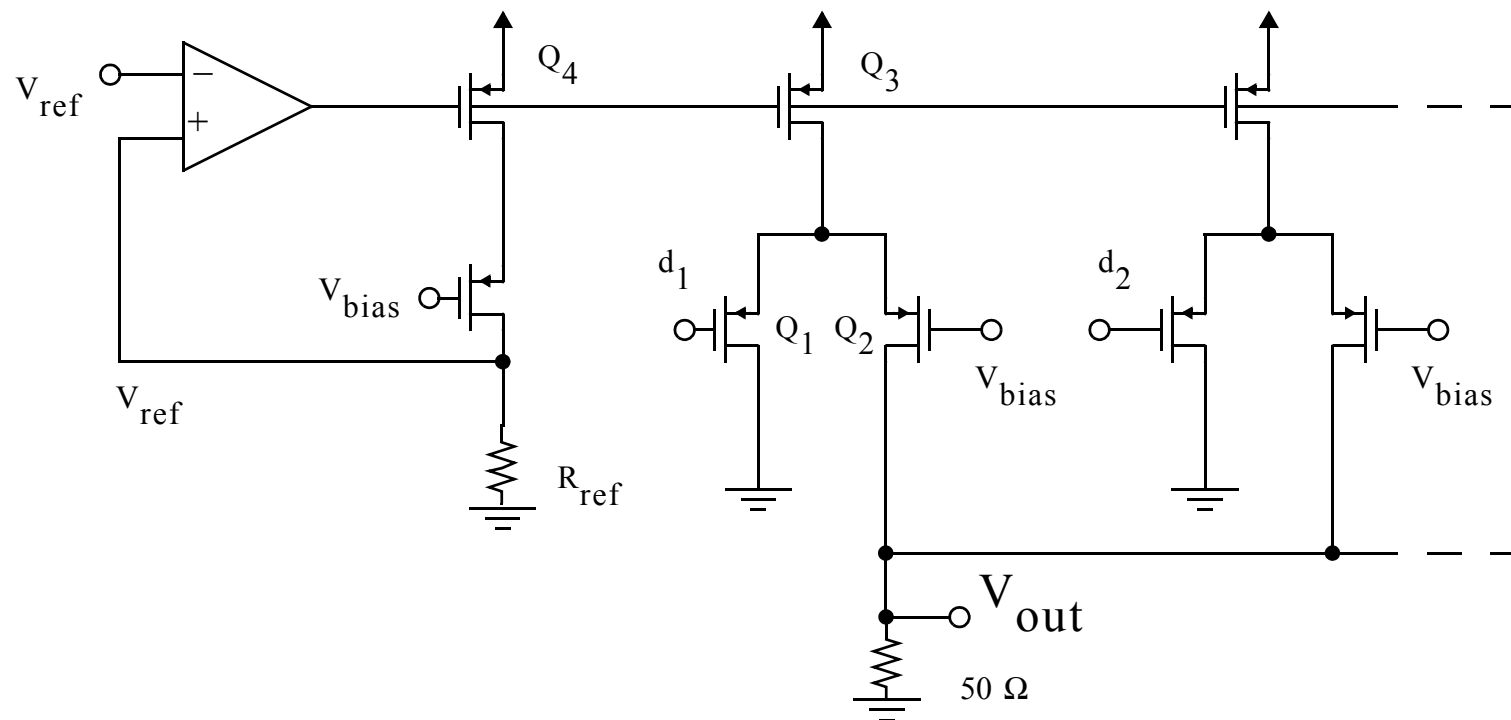


- Thermometer-code
- High-speed, output feeds directly to resistor
- Important that delay to all the switches are equal.
- Overlapped clocks much better than having non-overlapped clocks.



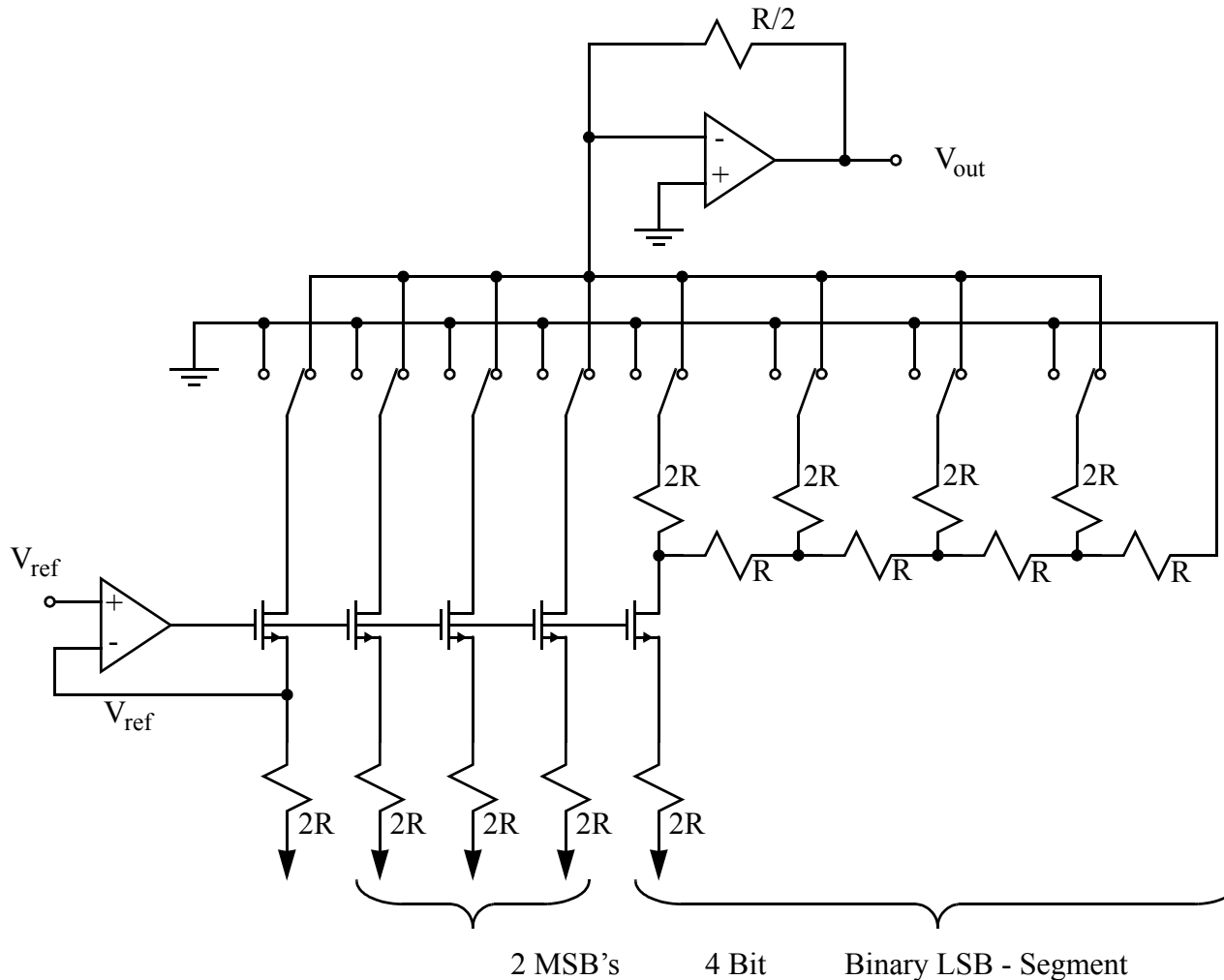
Current-Steered D/A [Colles, 88]

- Operates as cascode current sources.
- For max speed, keep voltage swing at source of Q_1 small (just turned off)
- Switching feed-through from the digital input enhances switching speed.



Segmented D/A

- Schoeff, 79; Saul, 85; Grebene, 84

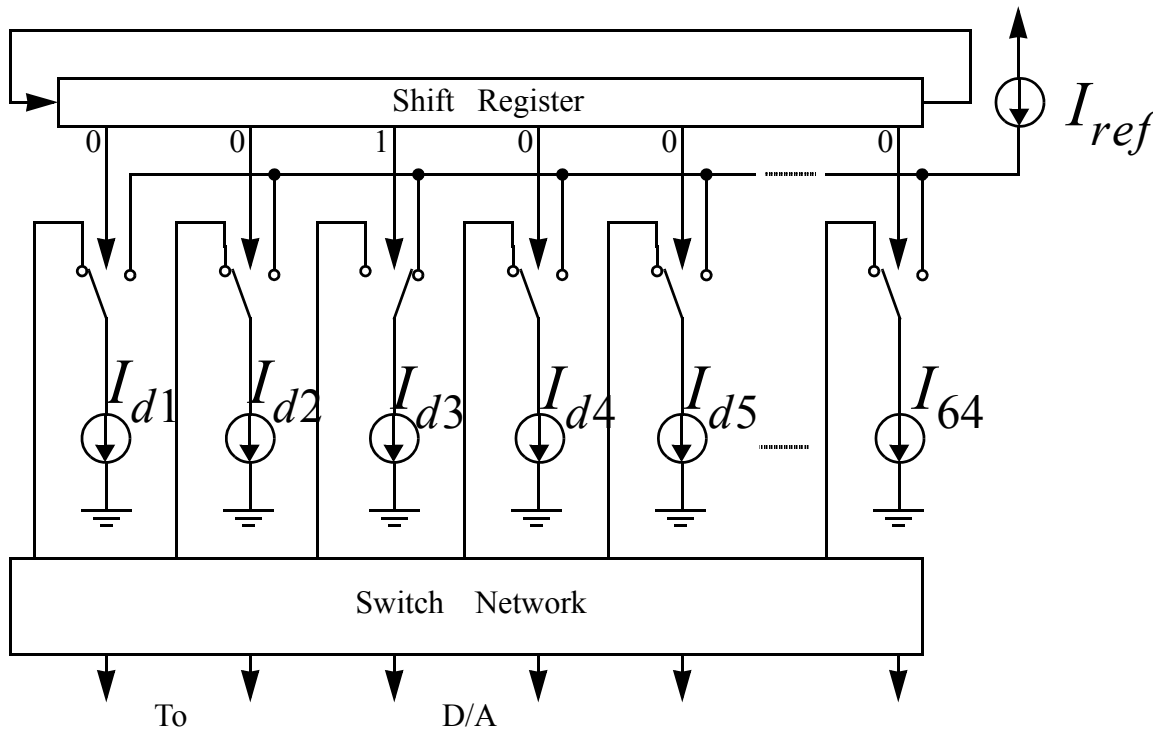


- Combine thermometer and binary
- Accuracy needed for LSB reduced
- Glitches reduced
- Very popular



Dynamically-Matched Current Sources

- Schouwenaar, 88

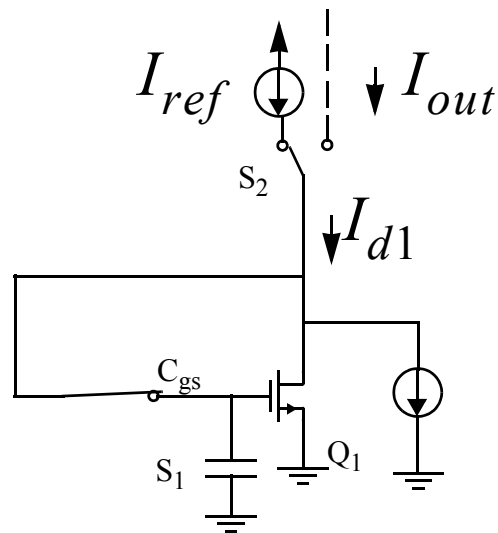


- Each current source is calibrated with a single reference
- 64 used so D/A can continue operating
- Achieved 92 dB SNDR, and 20 mW with 3V.
- Used for audio application

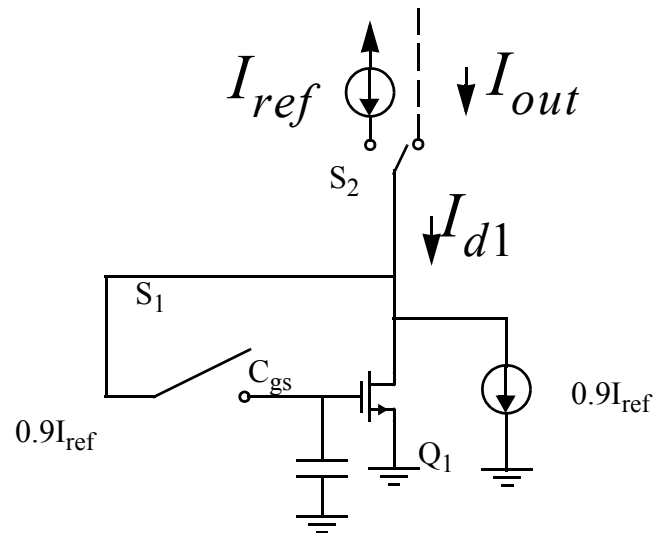
- Dynamic technique with current switching for realizing very well-matched current sources
- Up to 16 bit accuracy



Dynamically-Matched Current Sources



Calibration



Regular Usage

- Current source $0.9I$ added so a low g_m device used (W/L equal to 10/75)
- Re-calibrate before leakage causes 0.5LSB error

- Minimize clock-feedthrough and charge-injection by having capacitance C_{gs} and bias voltage V_{GS} large
- Implies voltage error causes less current deviation.

