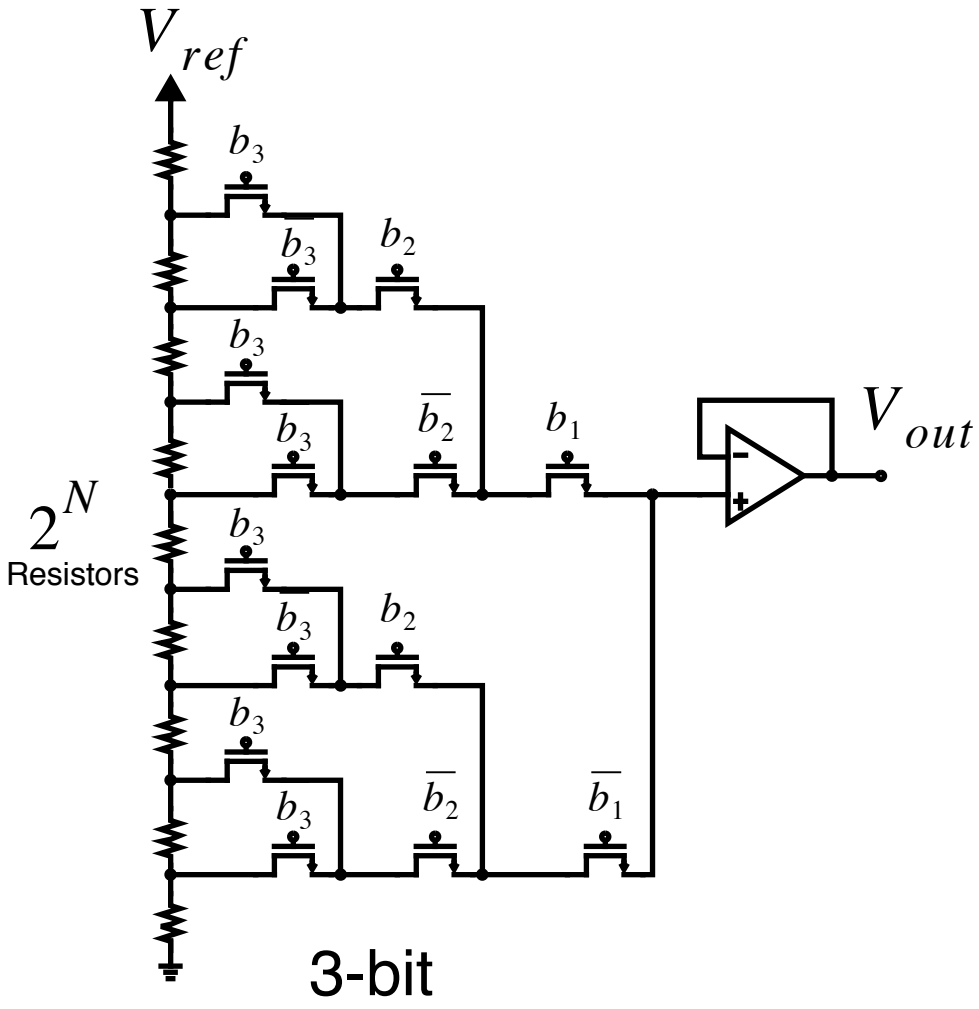
Nyquist-Rate D/A Converters

Reference: Chapter 12 of the text "Analog Integrated Circuit Design" by David Johns and Ken Martin

Chapter 16 of the 2nd Edition of the text by Tony Chan Carusone, David Johns, and Ken Martin

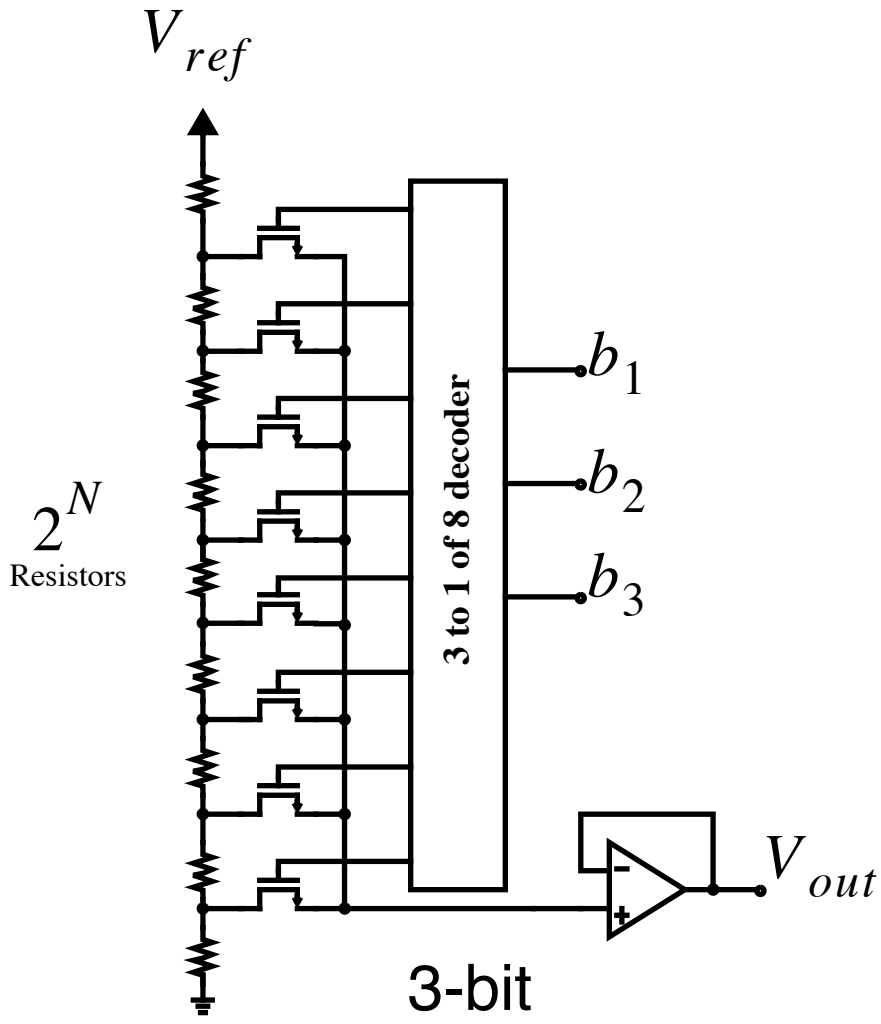
The material of this presentation is courtesy of Dr. Ken Martin.

Resistor-String D/A (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

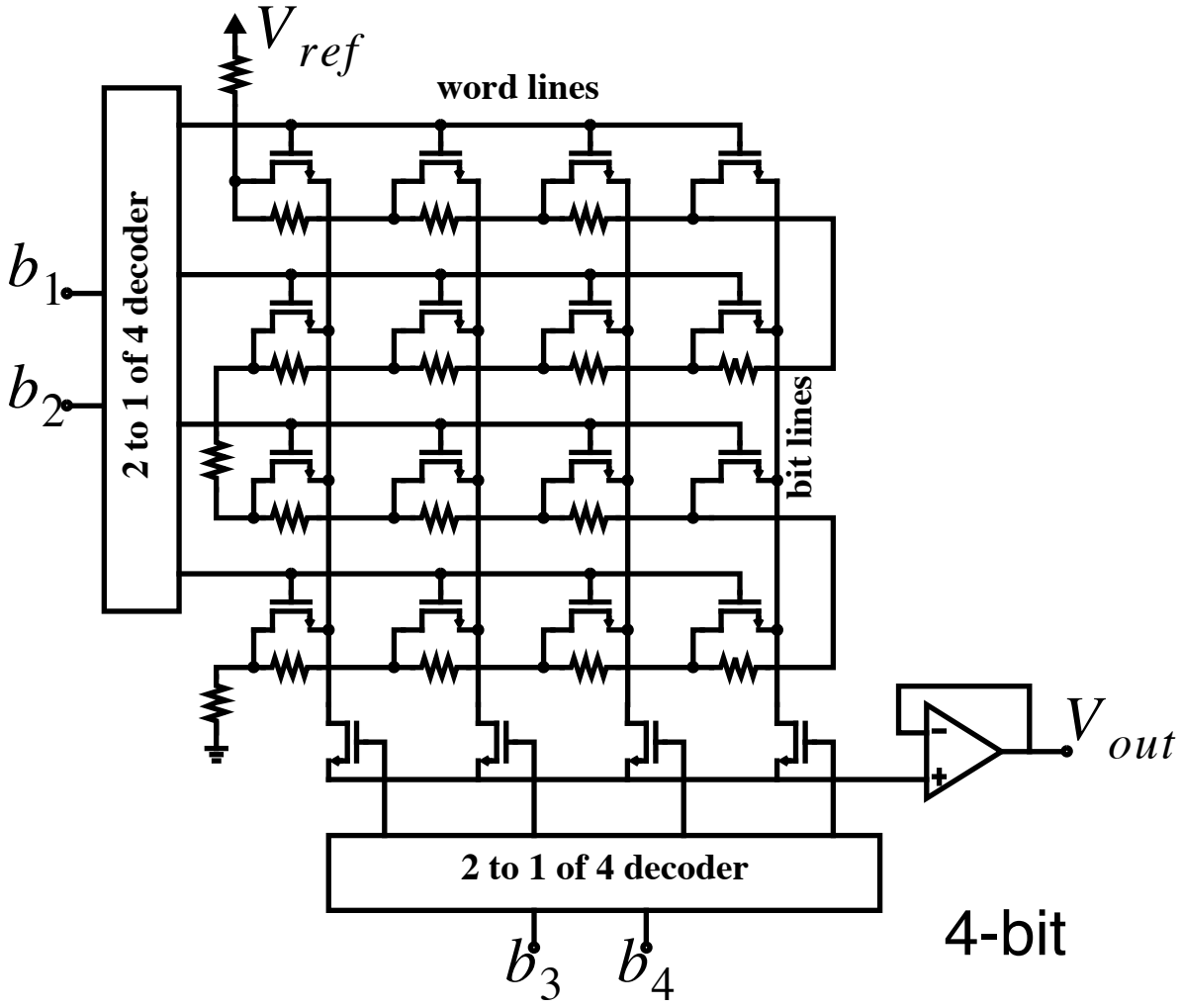
D/A Resistor-String — Digital Decoding



- Higher speed implementation (less resistance thru transistors)
- Large cap load on buffer input
- Requires 2^N resistors

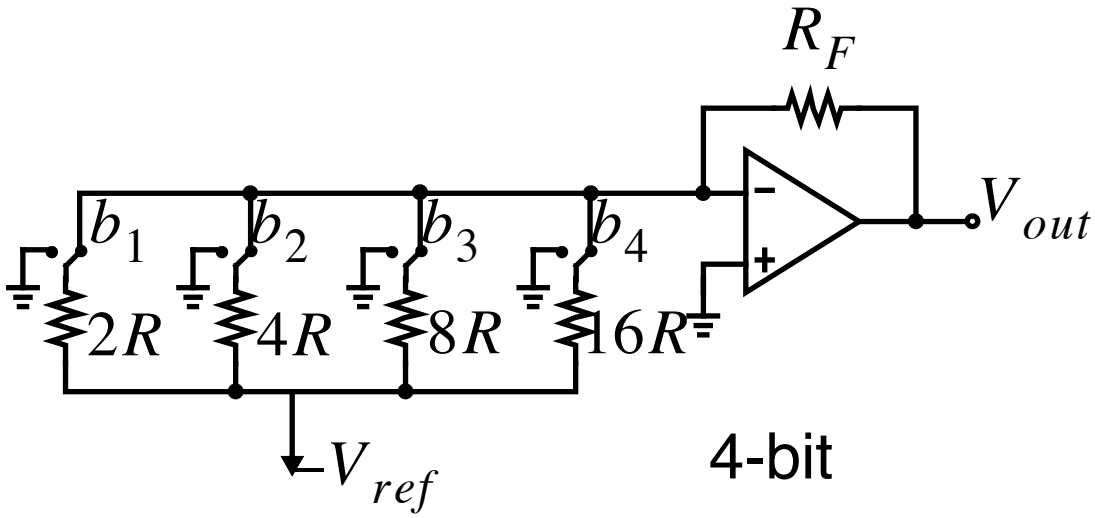
Folded-resistor-string D/A

- (Abrial, JSSC, Dec. 1988)



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

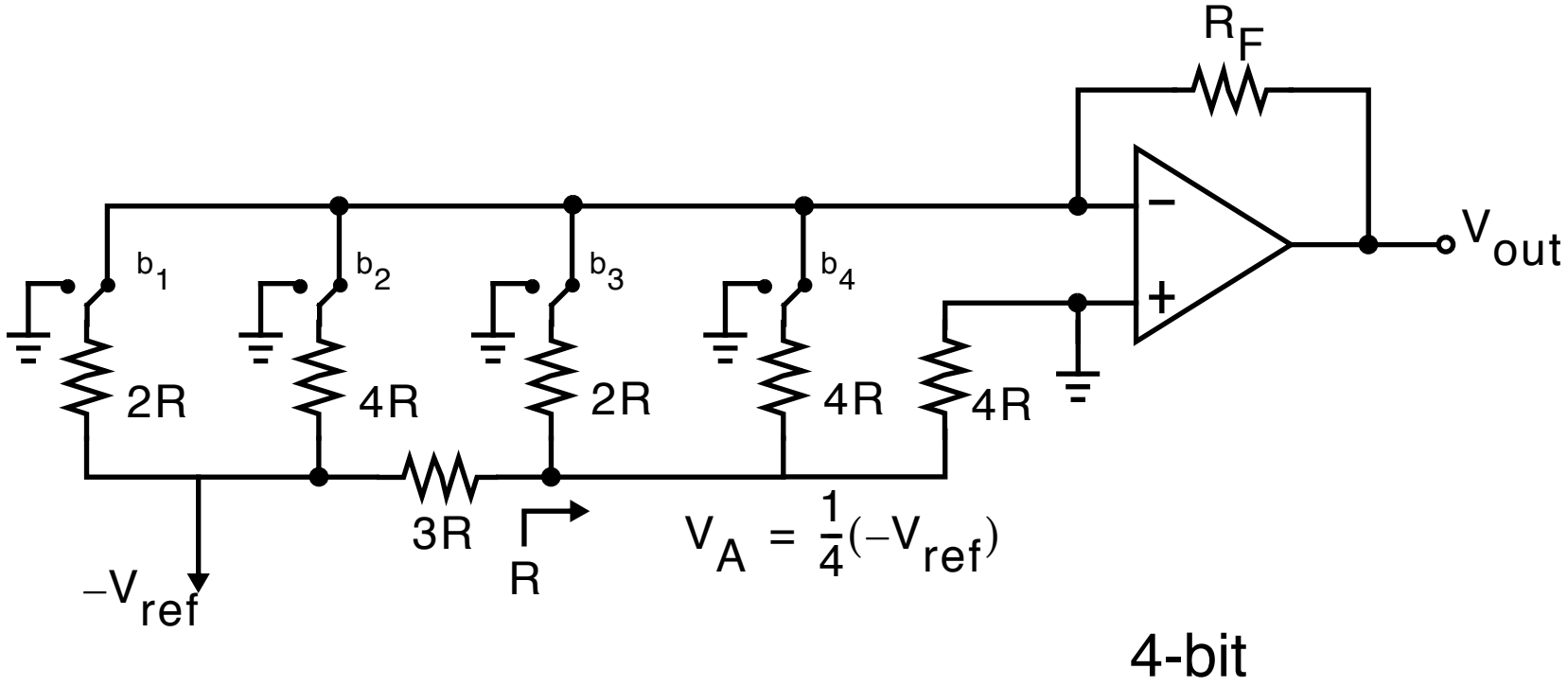
Binary-Weighted Resistor D/A's.



$$V_{\text{out}} = -R_F V_{ref}\left(-\frac{b_1}{2R} - \frac{b_2}{4R} - \frac{b_3}{8R} - \ldots\right) \qquad (1)$$

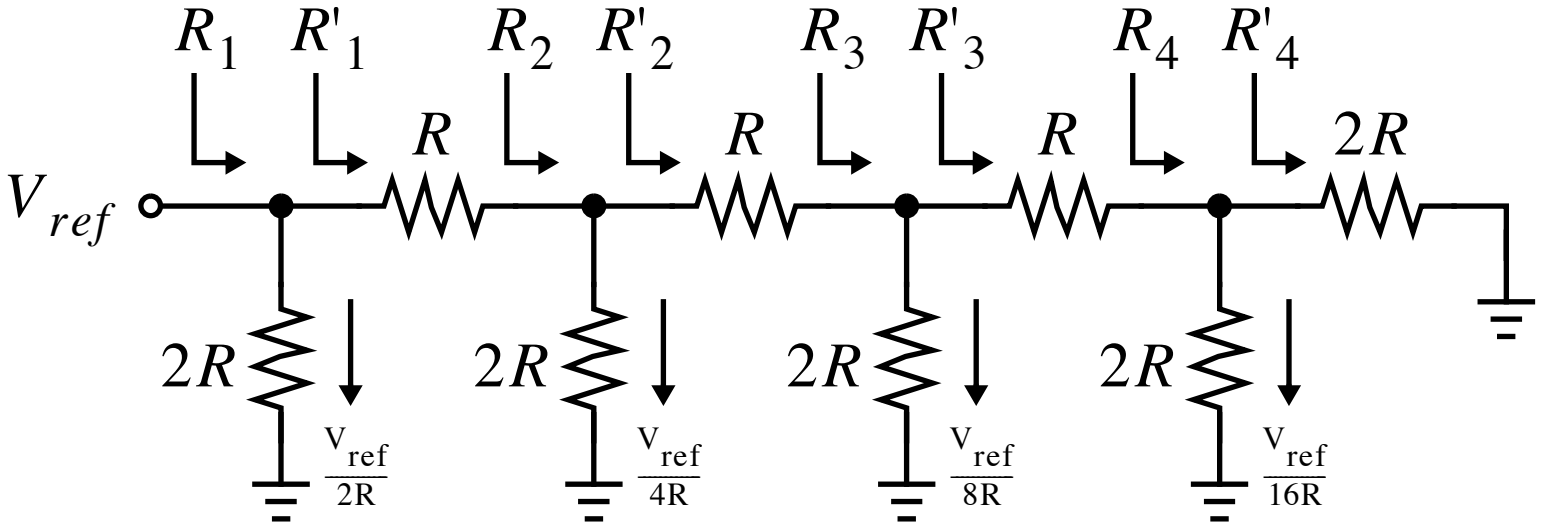
- Only N resistors
- Resistor and current ratios are on the order of 2^N
- Prone to glitches (more later).

Reduced Spread Binary Resistor D/A



- Reduced resistor spread

R-2R Based D/A Converters

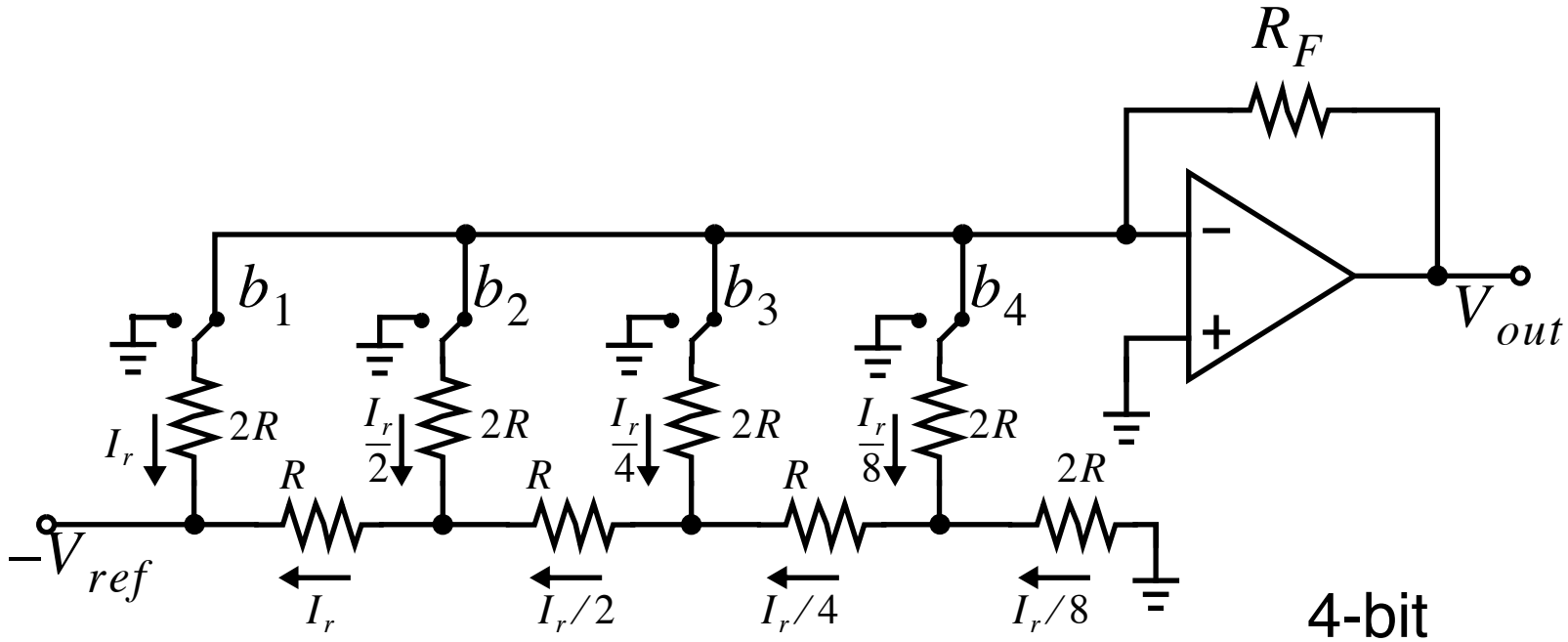


$$
\begin{aligned}
R'_4 &= 2R \\
R_4 &= 2R \,\|\, 2R = R \\
R'_3 &= R + R_4 = 2R \\
R_3 &= 2R \,\|\, R'_3 = R
\end{aligned}
\tag{2}
$$

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

R-2R Based Resistor Ladders

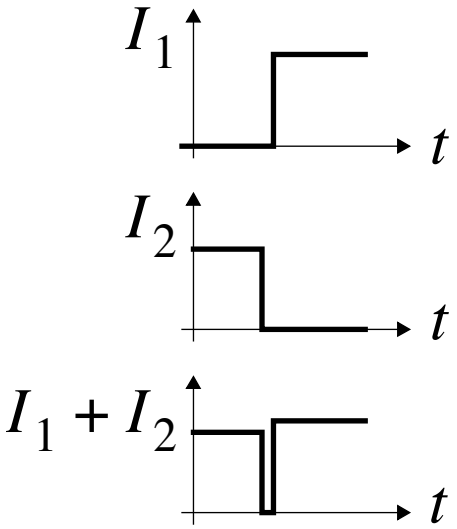
- Example D/A converter

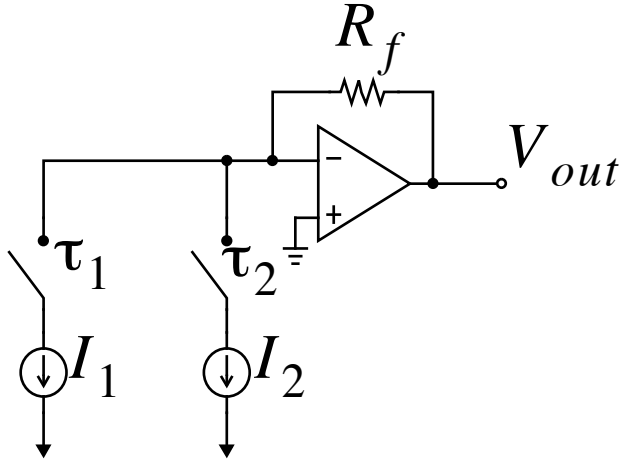


- Currents through the switches are scaled
- Should scale switch sizes for good accuracy
- No node voltage changes except for output —> fast

Glitches

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

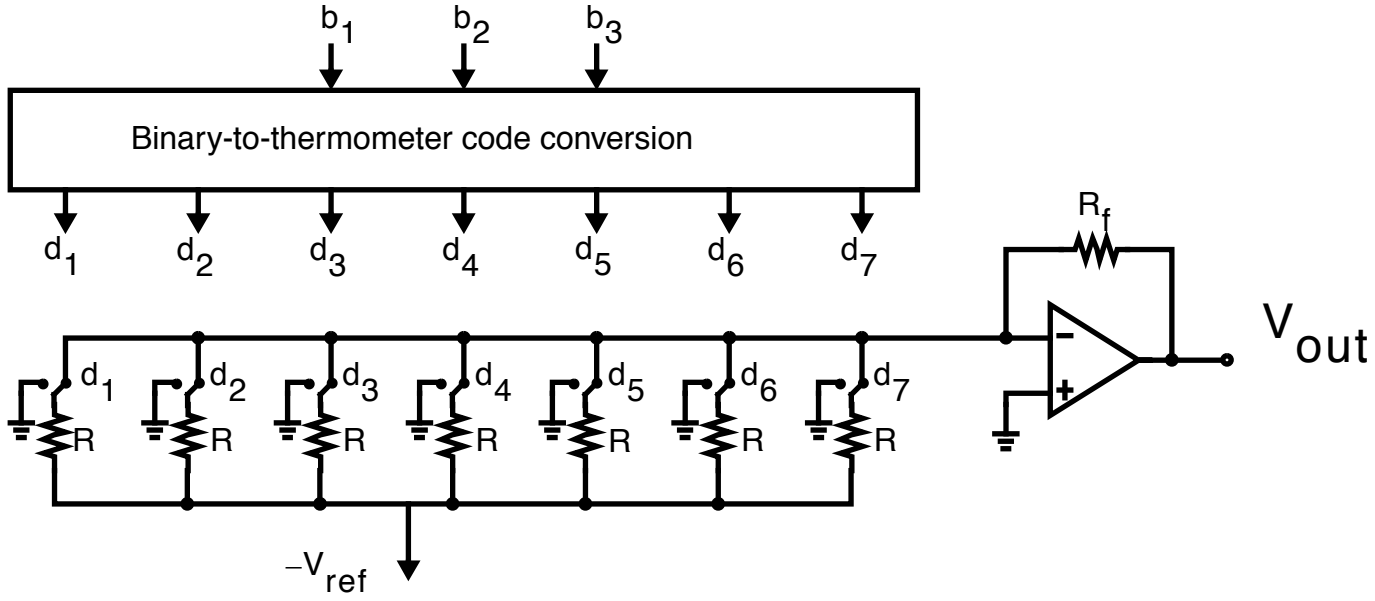




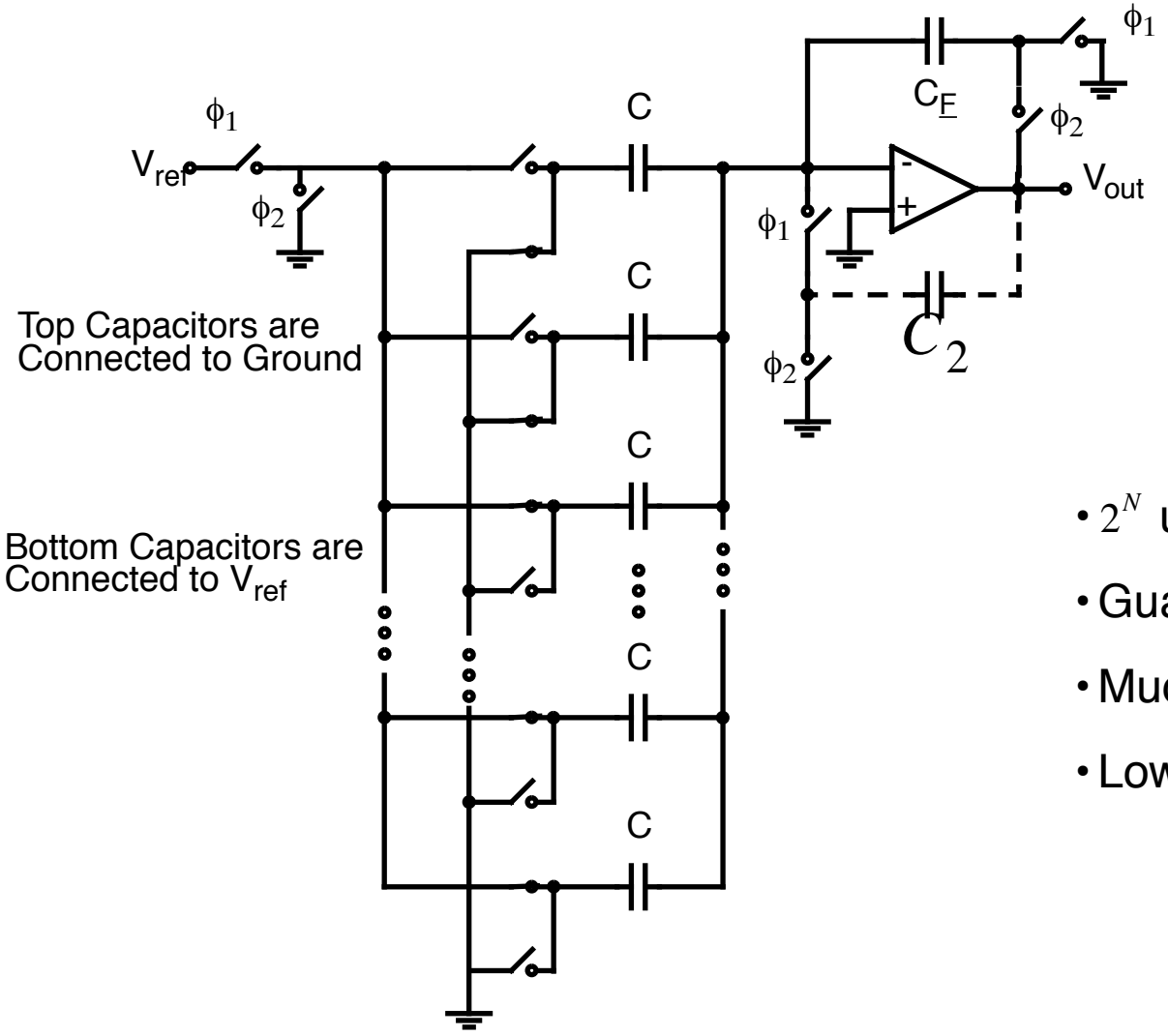
- Glitches can be minimized by limiting the bandwidth but that slows down circuit
- Use thermometer code to reduce glitches

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

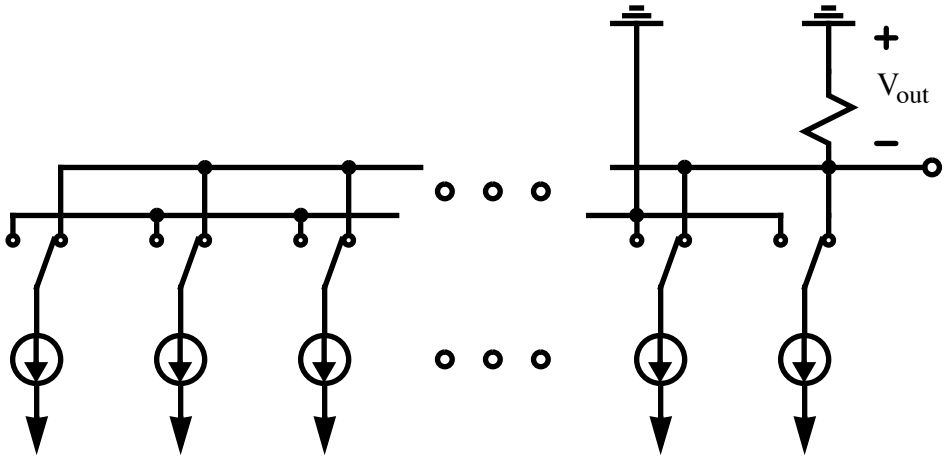


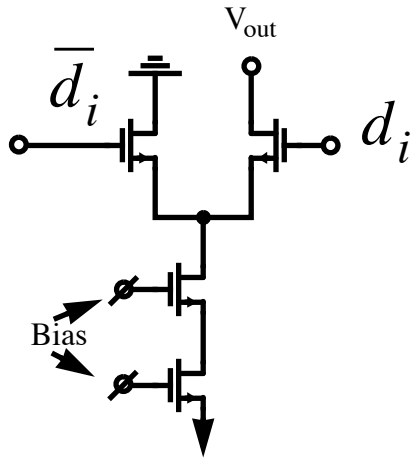
Thermometer Code D/A Converter



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

Current-Mode D/A's

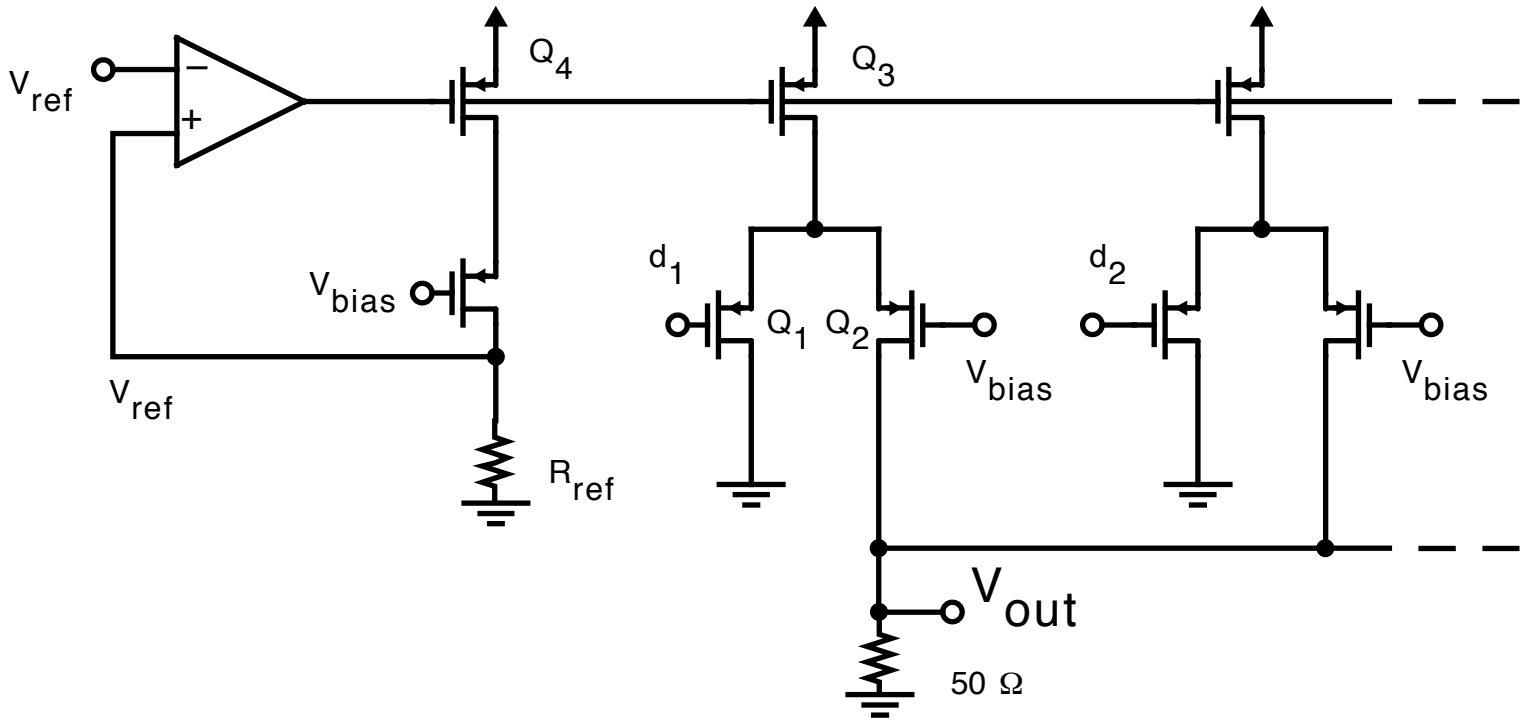




- Thermometer-code
- High-speed, output feeds directly to resistor

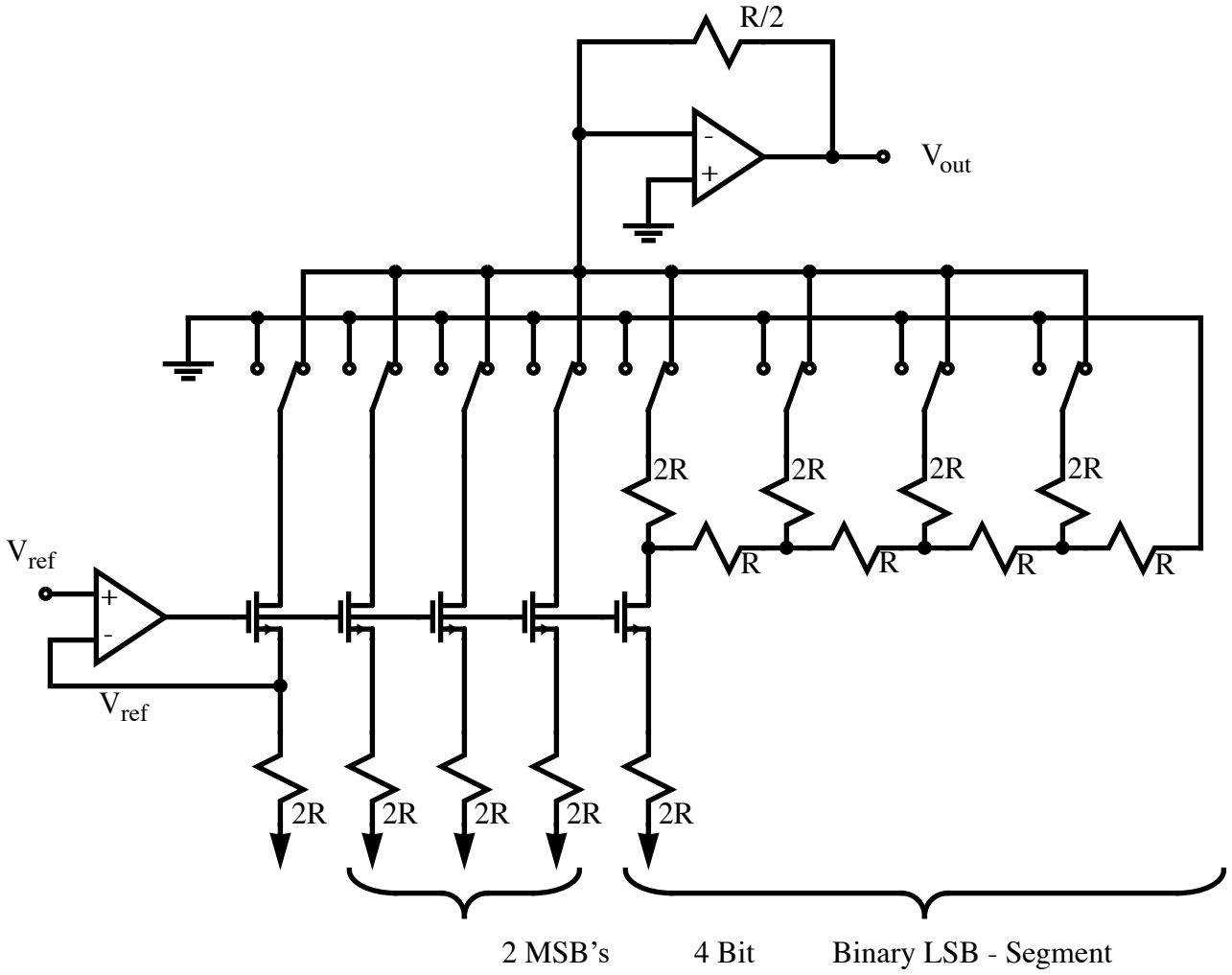
Current-Steered D/A [Colles, 88]

- Operates as cascode current sources.
- Note that although opamp input connections appear to be reversed but they are correct
- For max speed, keep voltage swing at the common connections of the switches small (just turned off).



Segmented D/A

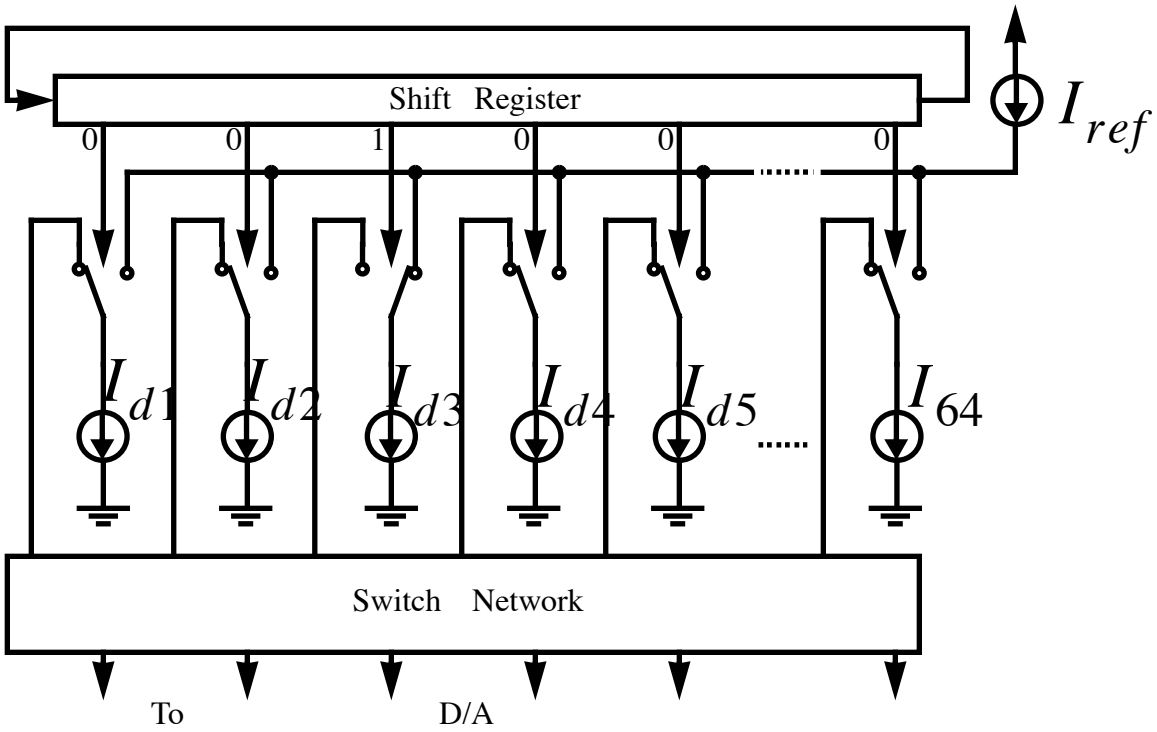
- Schoeff, 79; Saul, 85; Grebene, 84



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

Dynamically-Matched Current Sources

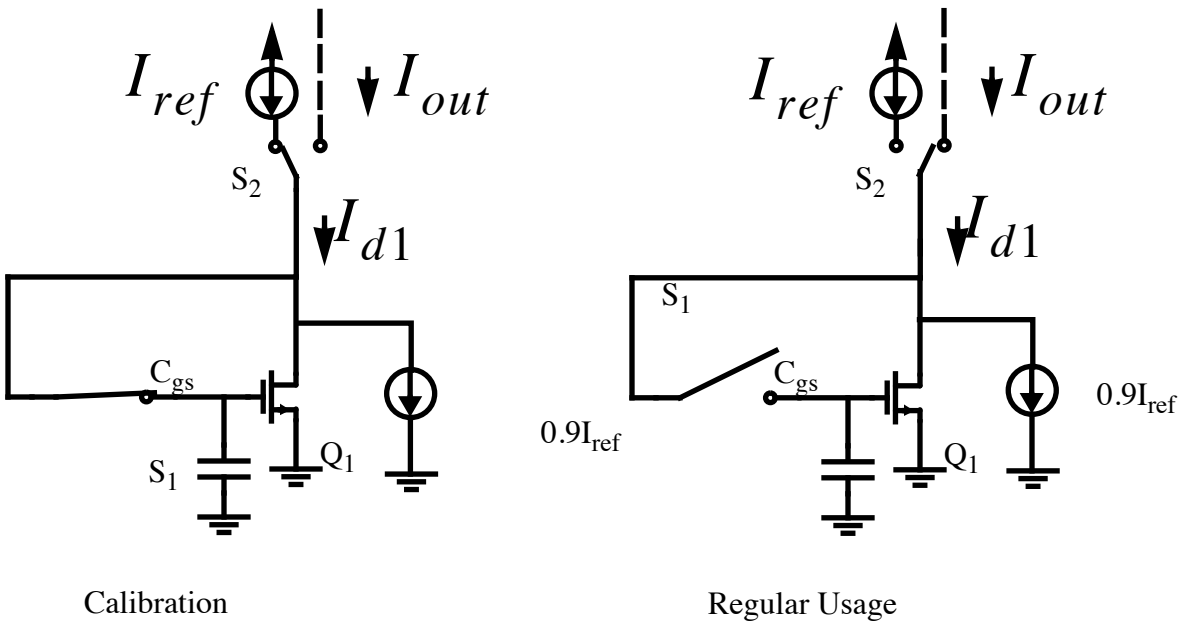
- Schouwenaar, 88



- 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

- 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.