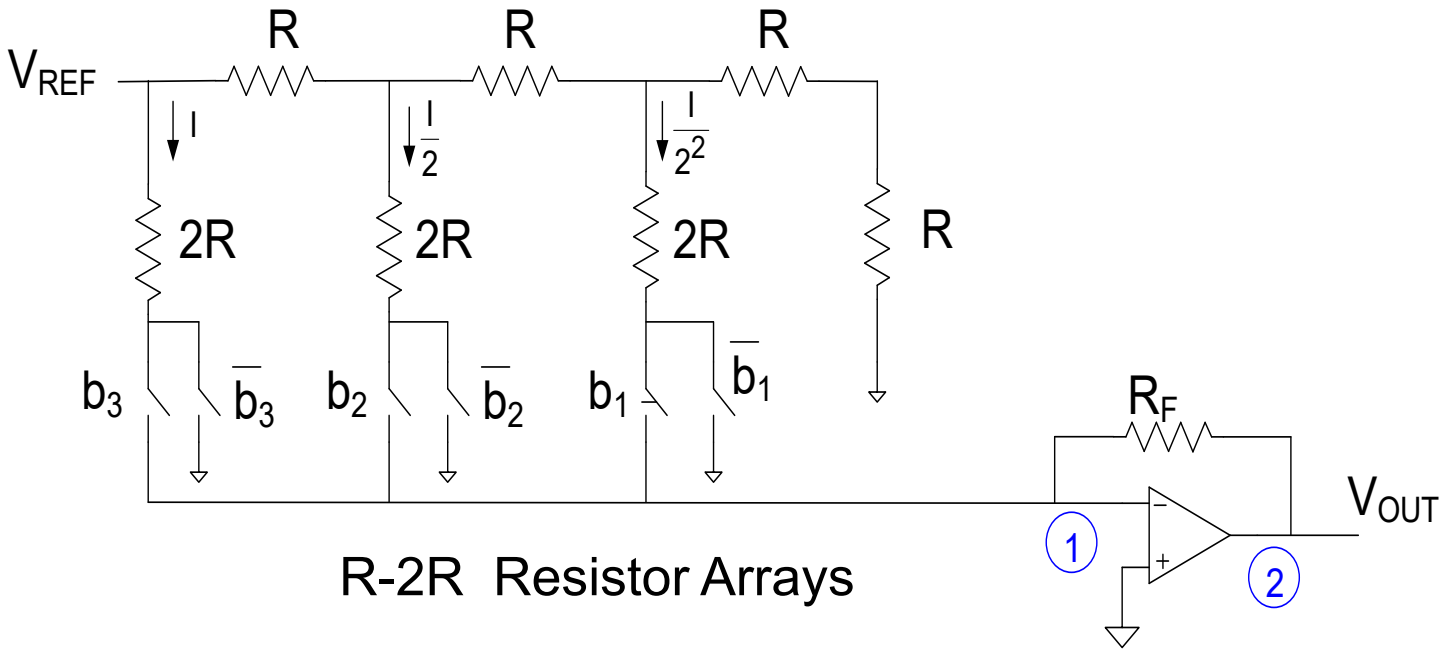
EE 435

Lecture 36

Current Steering DACs
Dynamic Current Source Matching
Charge Redistribution DACs

Review from Last Lecture

Current Steering DACs



R-2R Resistor Arrays

Eliminates need for decoder

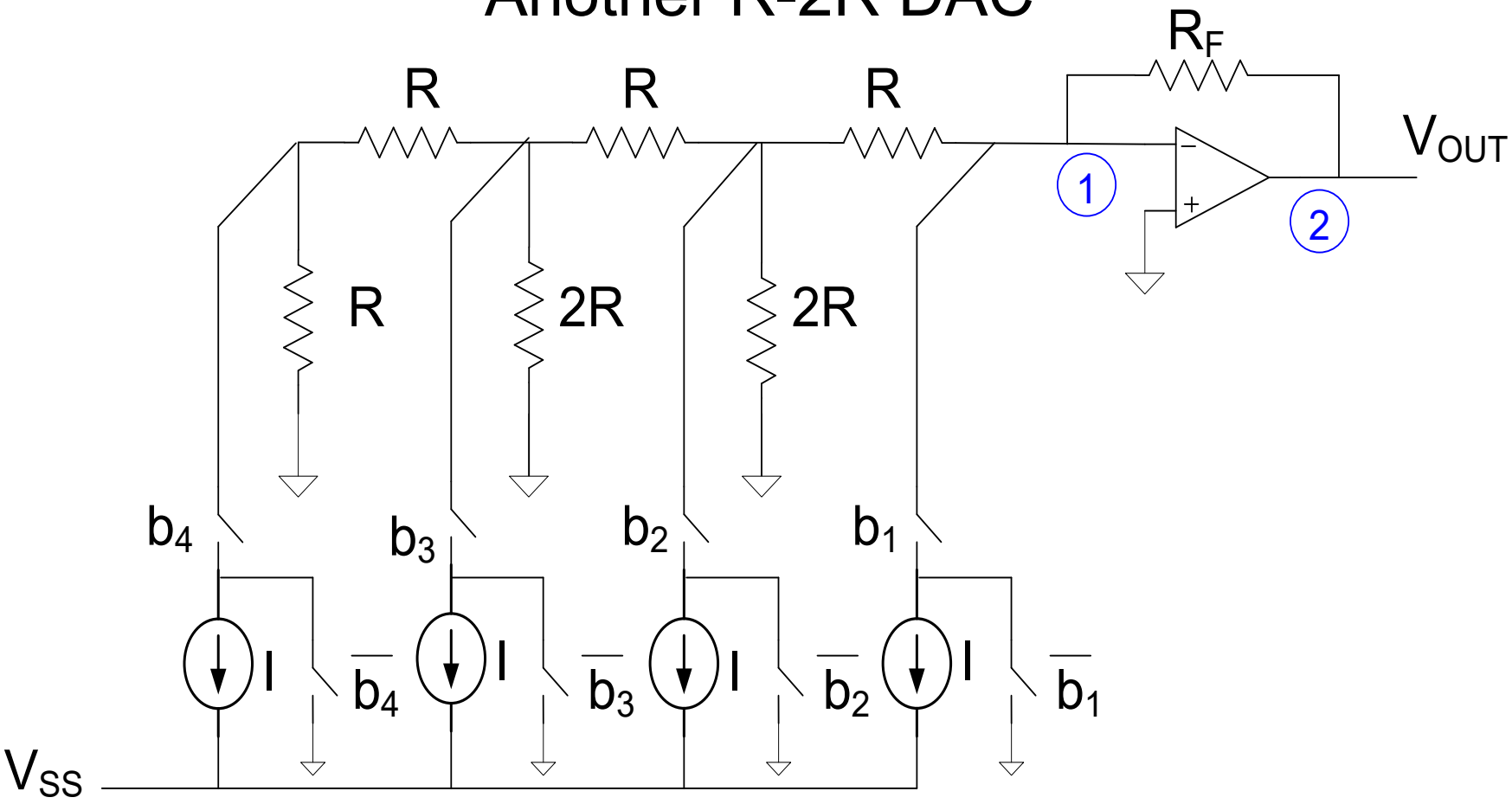
Node voltages ideally stay constant for any input code

Highly sensitive to nonlinearities in switches

How should switches be sized?

Review from Last Lecture

Another R-2R DAC



Clocks must be nonoverlapping

Does this offer any benefits over previous approach ?

Offers some compensation for capacitances on current sources

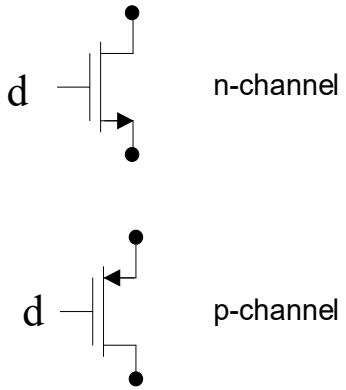
Are there other terminations for the current sources? e.g. Dual R-2R?

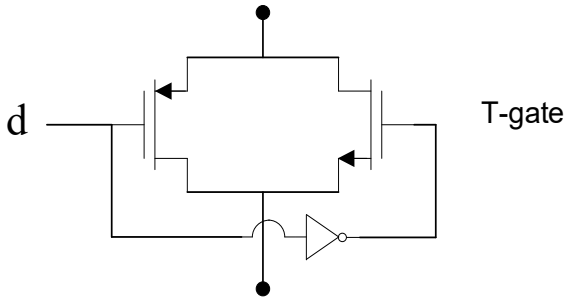
Review from Last Lecture

Switches used extensively in data converters !

Switch Implementation Issues

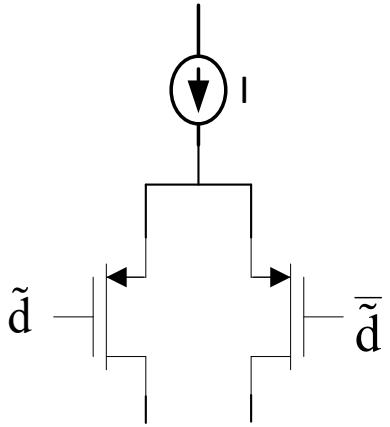
Basic Simple Switches





Transistors switch between deep cutoff and deep triode

Basic Current Steering

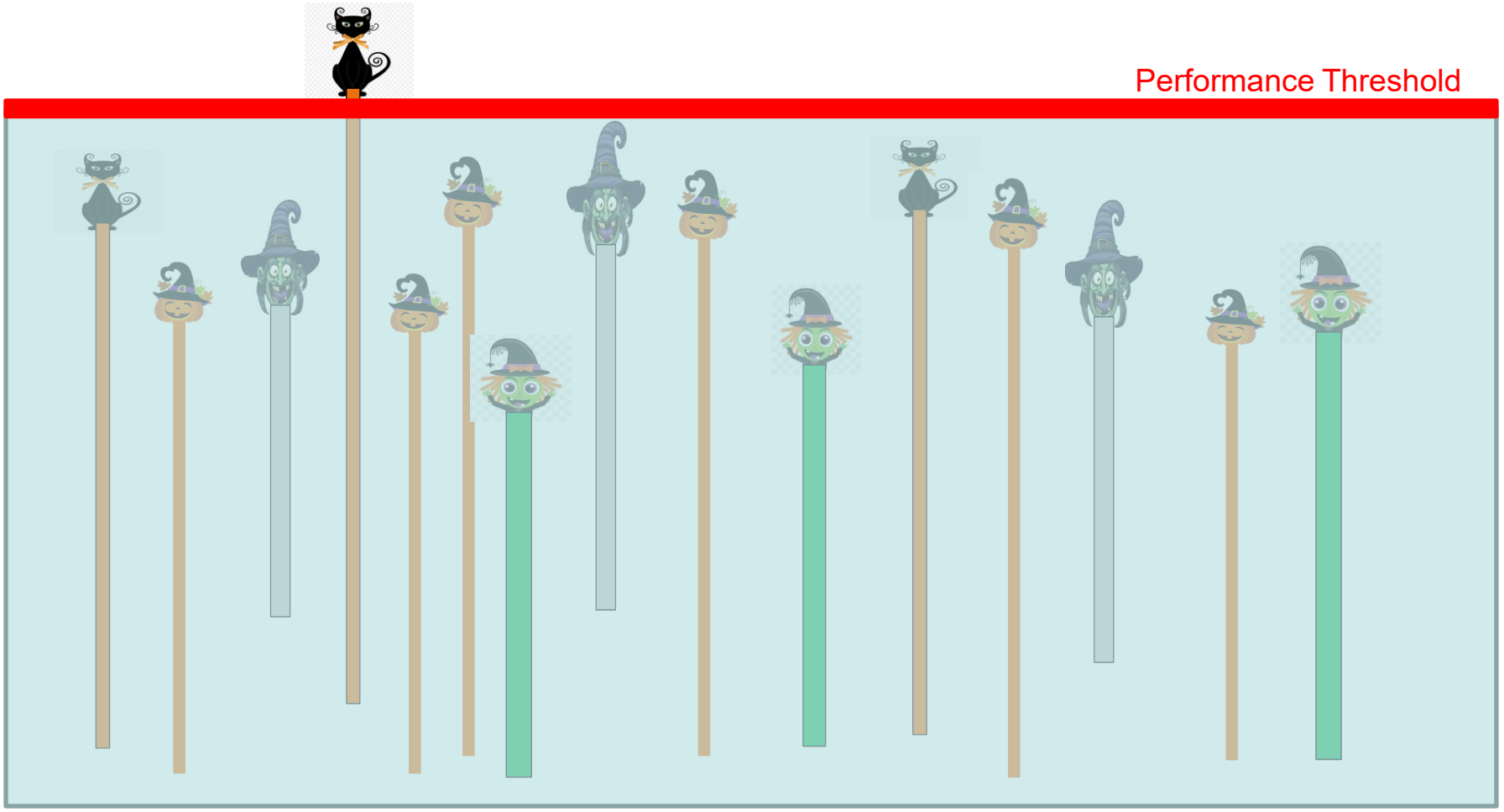


- Transistors avoid triode region and deep cutoff
- Reduced Boolean Input Levels

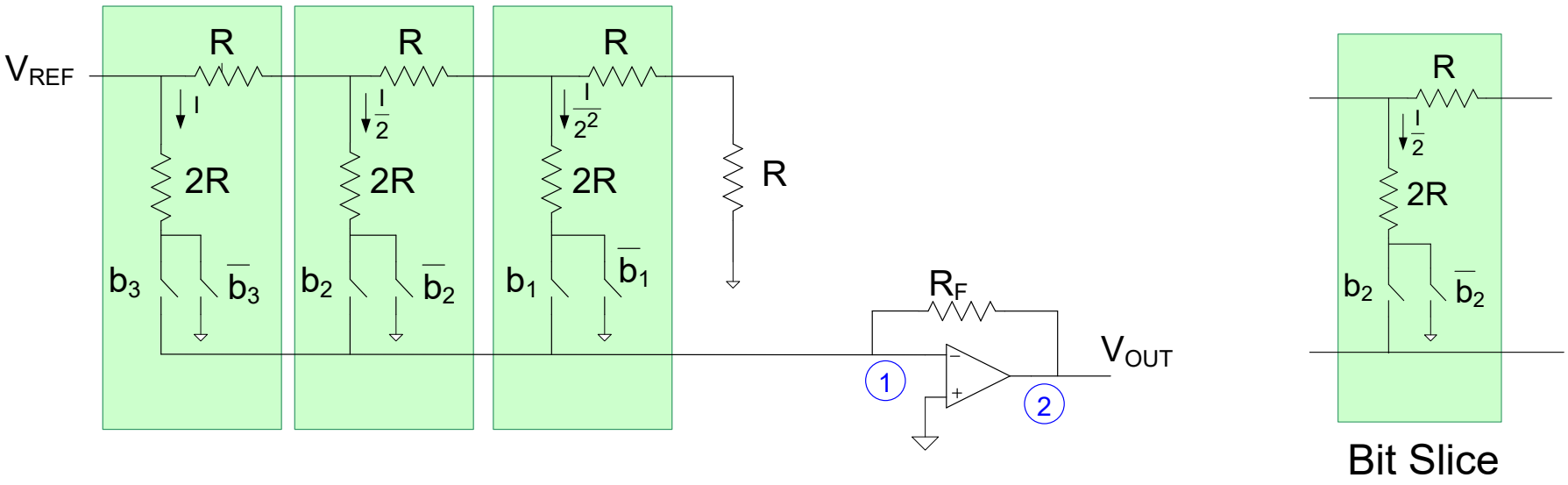
Data Converter Design Strategies

Remember:

Need to keep nonideal effects below an acceptable performance threshold



R-2R DACs



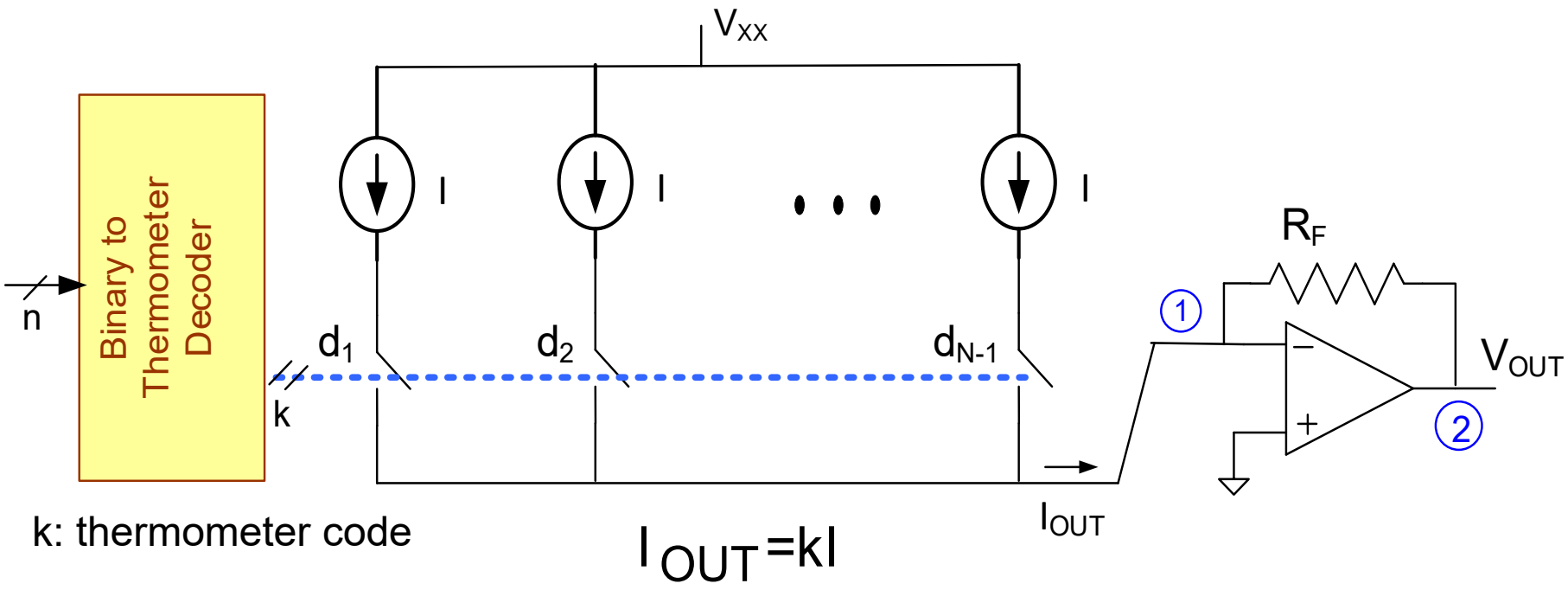
Key characteristic of R-2R Structures

- Area increases linearly with number of bits of resolution
- Binary to thermometer/bubble converter eliminated
- Simple unary cell can be used for R elements
- Common-centroid layout manageable ??

Key challenges of R-2R Structures

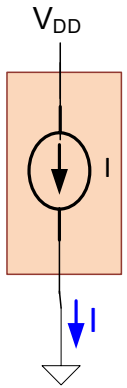
- Switches directly affect R-2R values and ratios
- Voltage on internal nodes must settle for some structures
- If unary cell used, area not optimally allocated for matching

Current Steering DAC



k: thermometer code

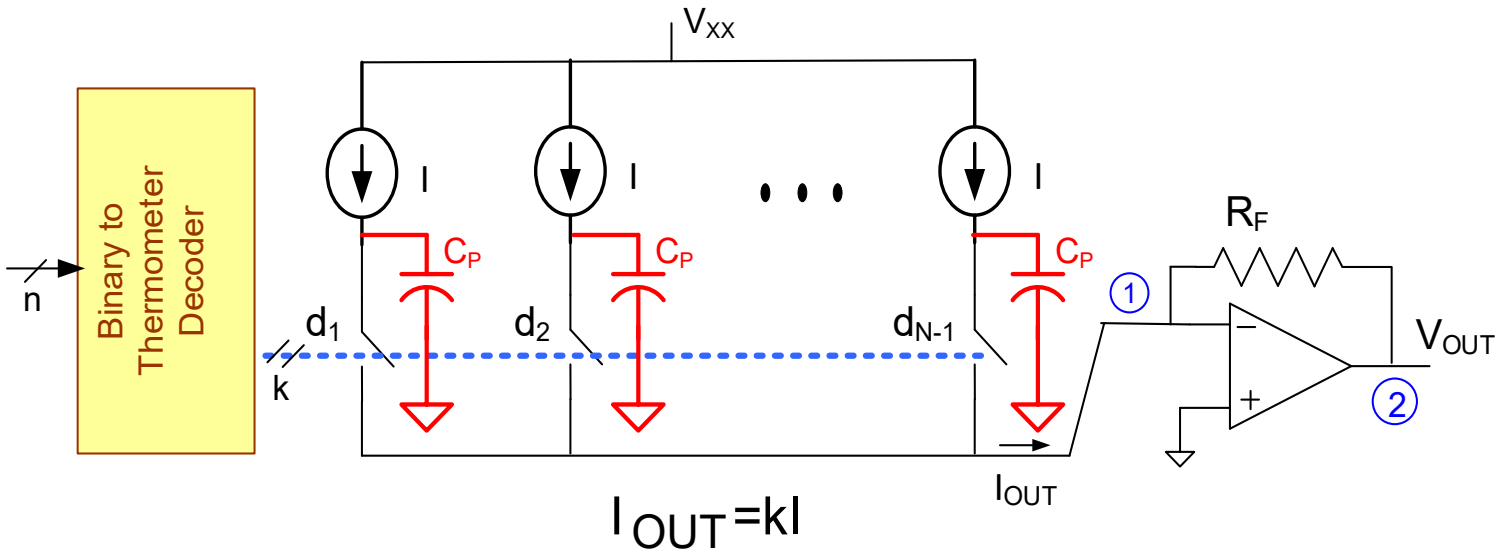
$I_{OUT}=kI$



Switch impedance of little concern if current sources ideal

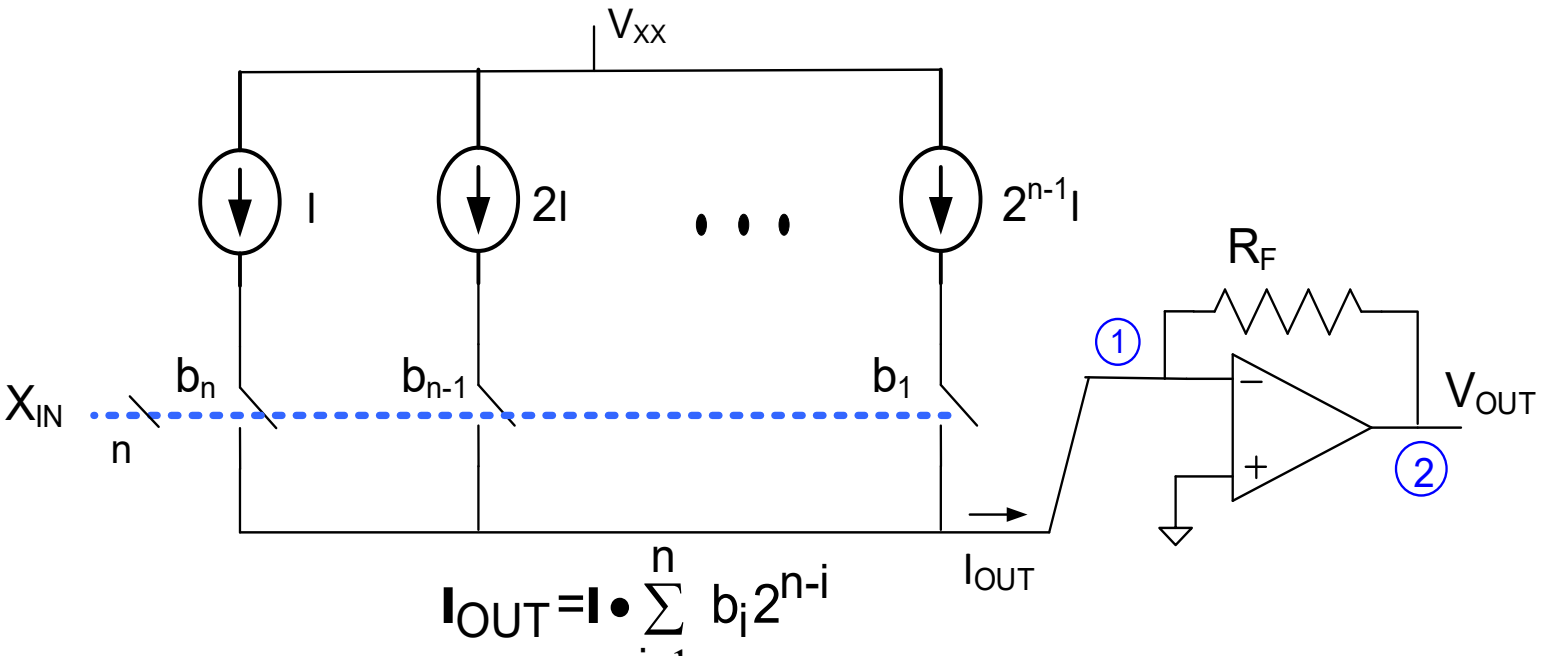
Just requires matching of current sources

Current Steering DAC



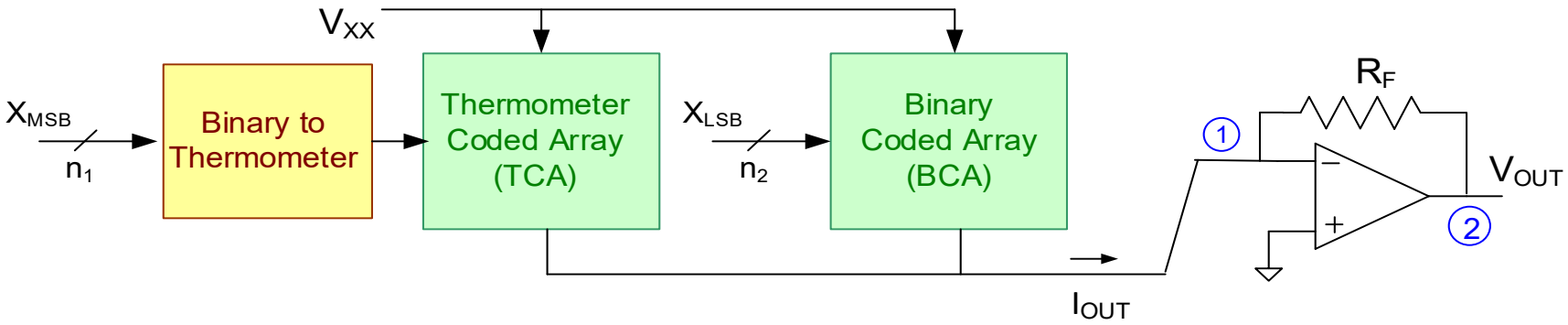
Critical parasitic capacitors in current-steering DAC

Current Steering DAC



- Binary to thermometer decoder eliminated
- Current sources bundled unary cells
- Bundles large for large n

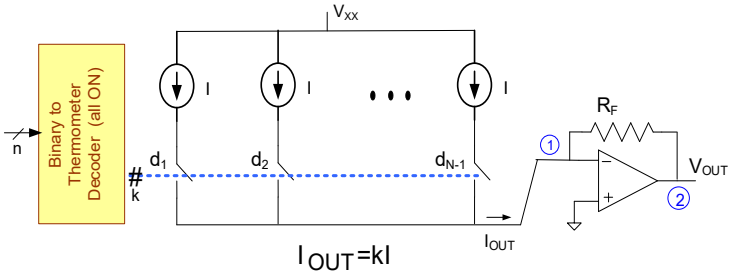
Current Steering DAC

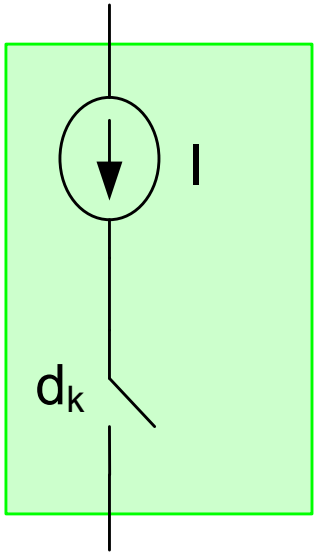


Segmented Structure

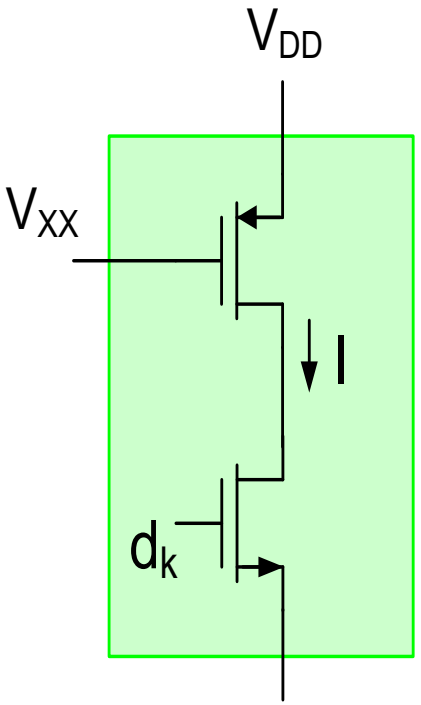
- Exploits benefits of both thermometer and binary coded structures
- Common-centroid layout likely only necessary on TCA
- Dramatic reduction in complexity of decoder possible

Current Steering DAC





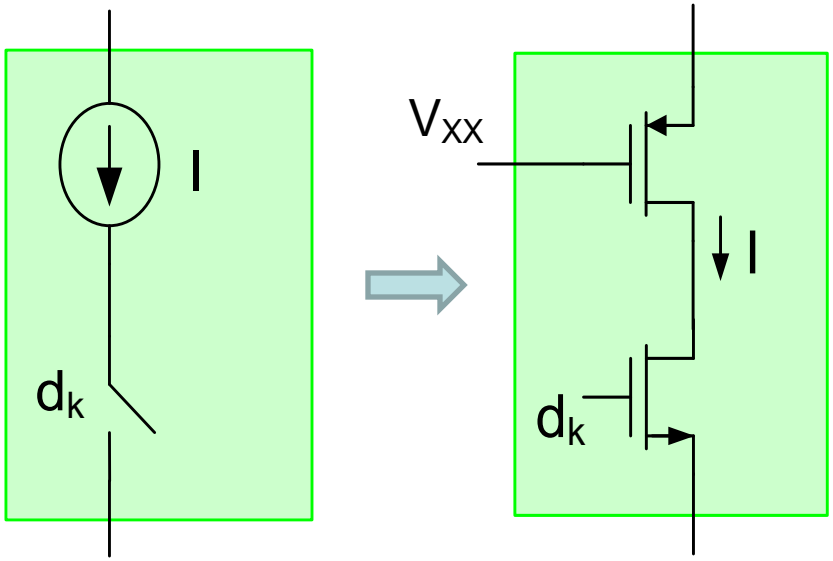
popular current source

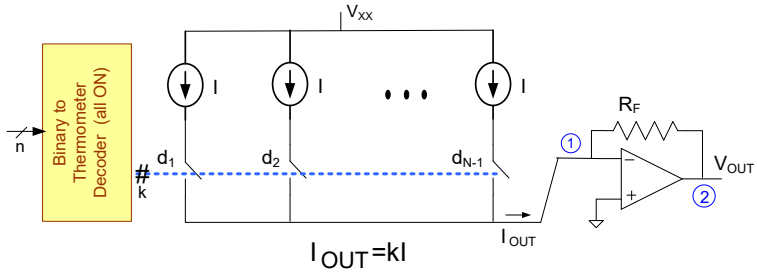


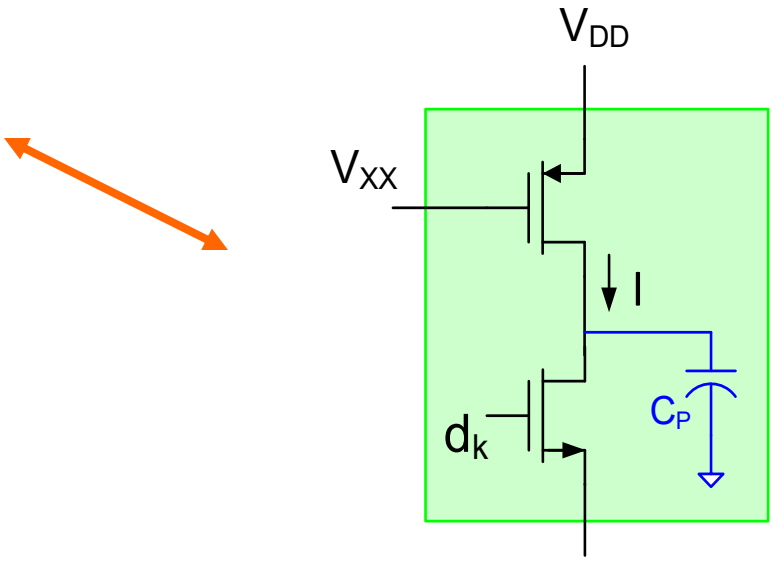
Is linearity or output impedance of current source of concern?

Not if individual slices are matched !

Current Steering DAC

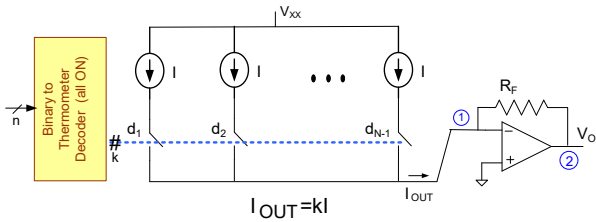


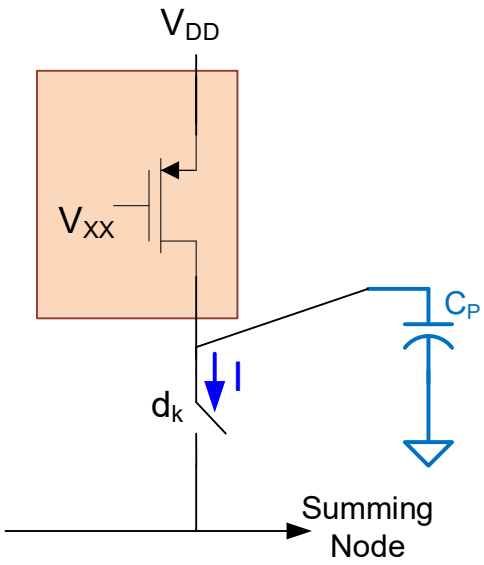


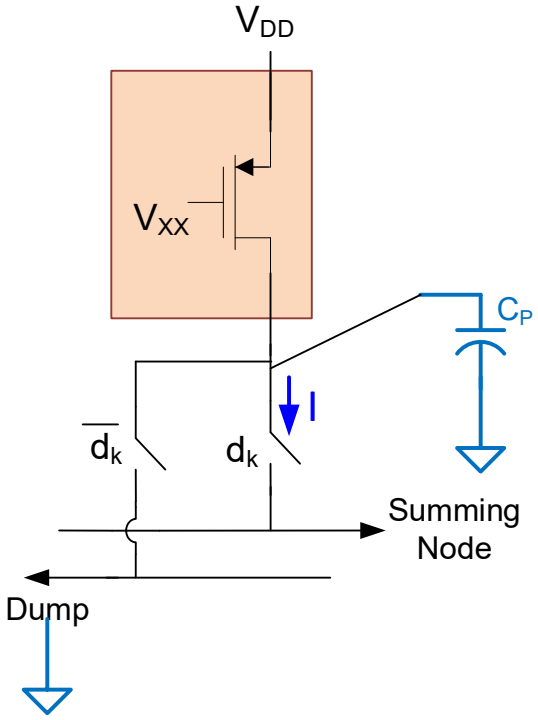


Parasitic capacitance on output of current source problematic

Current Steering DAC

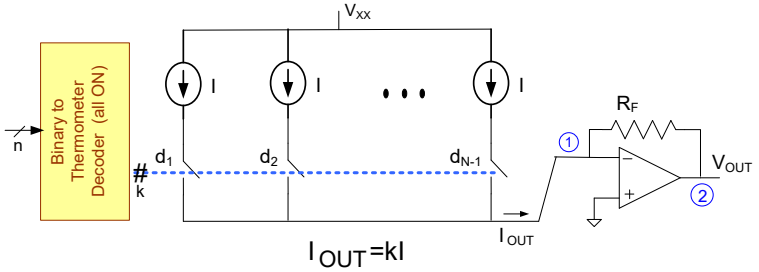


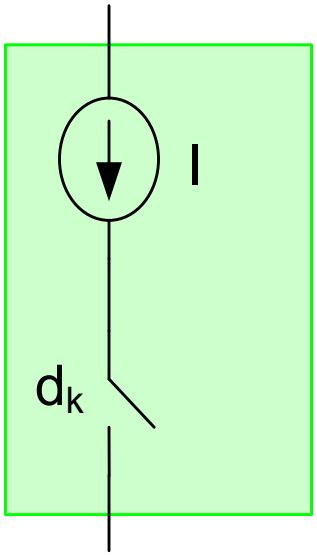




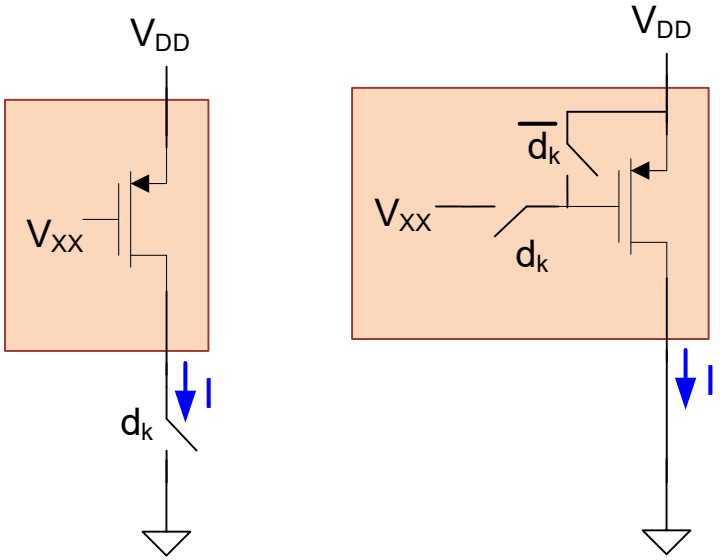
Reducing Effects of Parasitic capacitance on output of current source

Current Steering DAC





Alternative current source cells

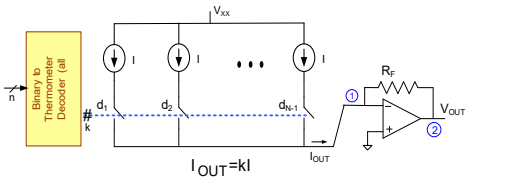


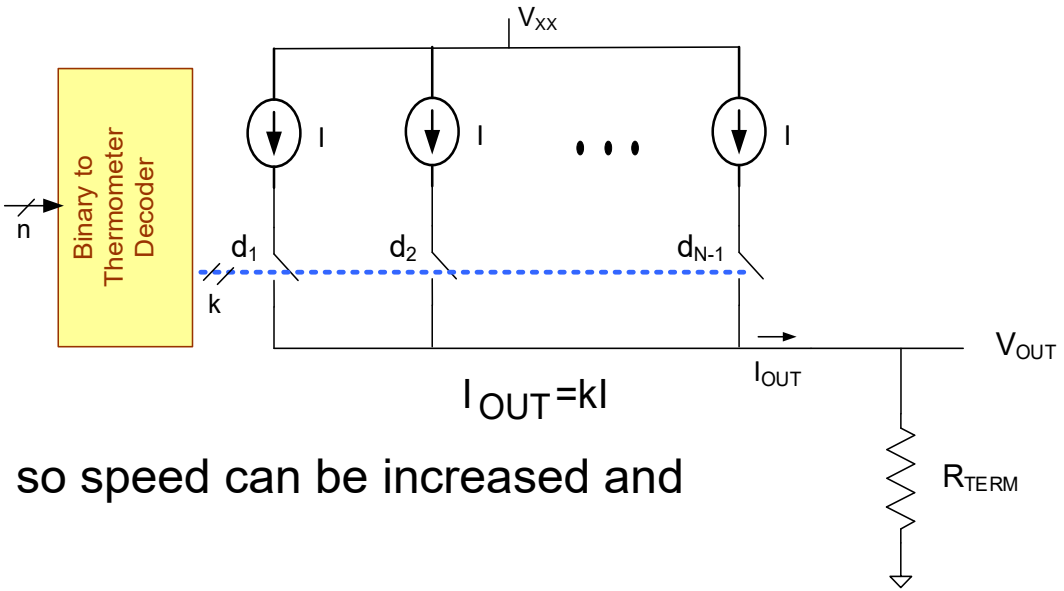
Which is better?

Effects of parasitic diffusion capacitance?

Effects of gate capacitance?

Current Steering DAC





Op Amp can be eliminated so speed can be increased and power reduced

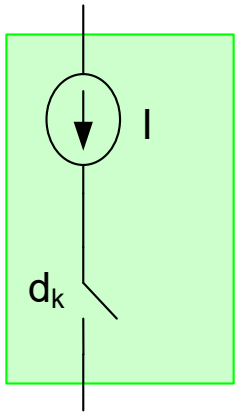
R_{TERM} often 50Ω or 100Ω

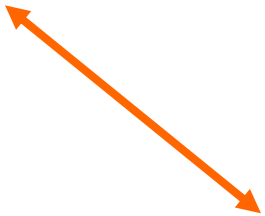
R_{TERM} can be internal or external

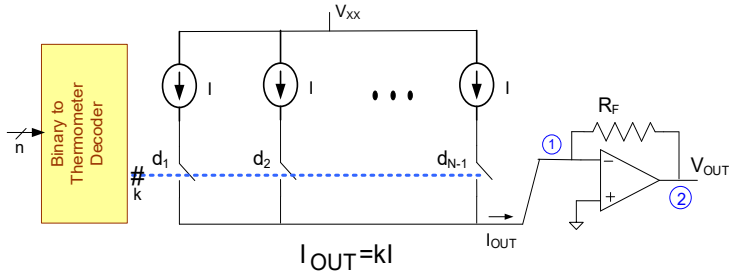
Switch impedance now of concern

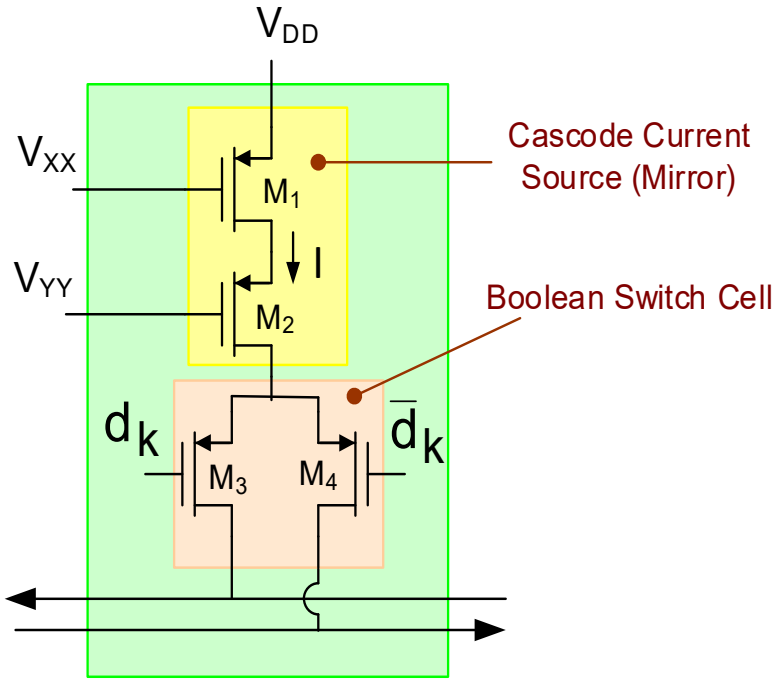
Output impedance of current sources now of concern

Current Steering DAC





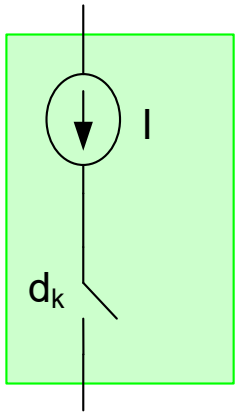


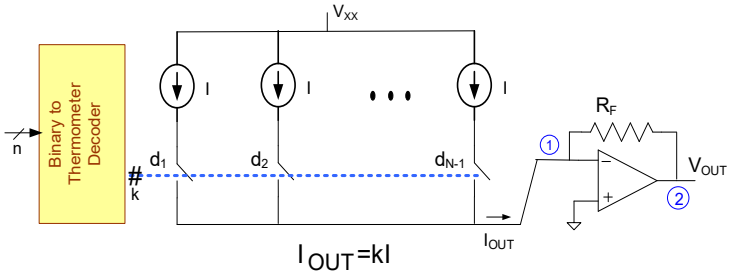


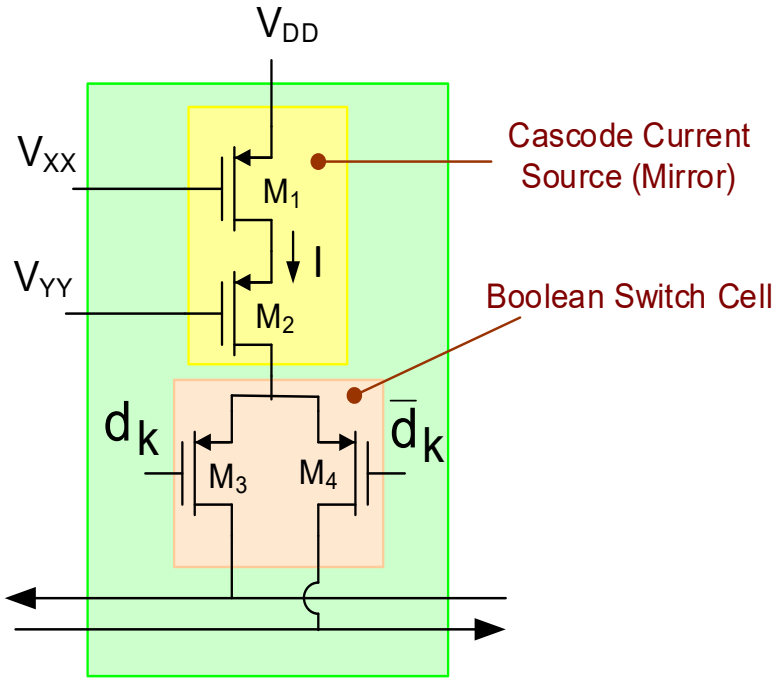
Cascoding reduces output conductance of current source

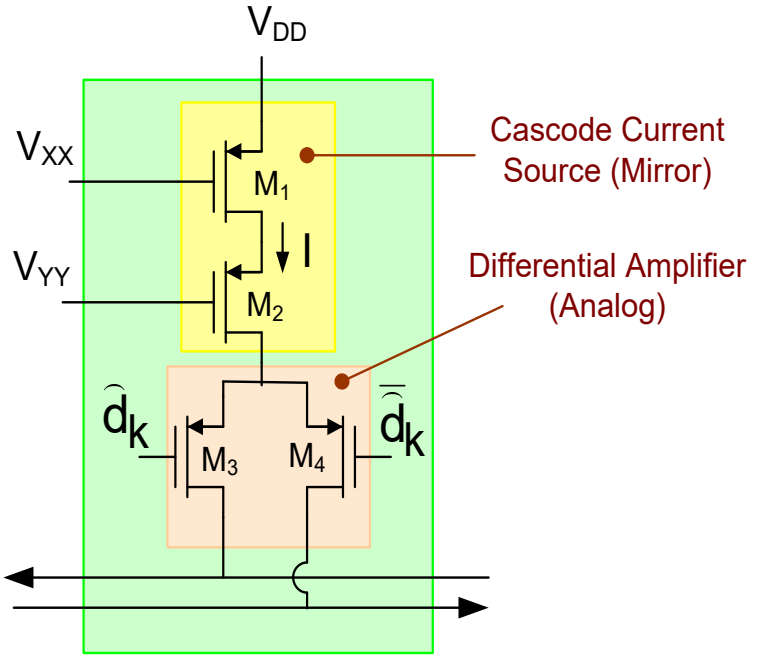
No power penalty, slight reduction in overhead

Current Steering DAC



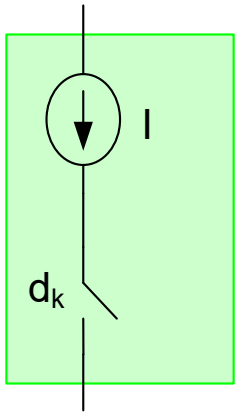


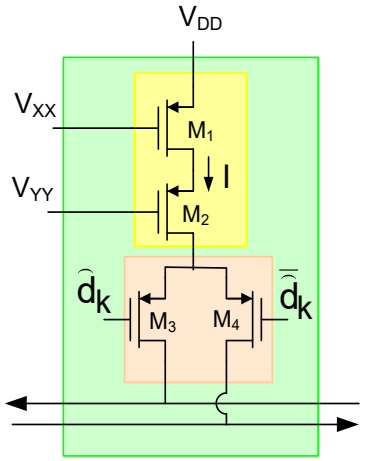


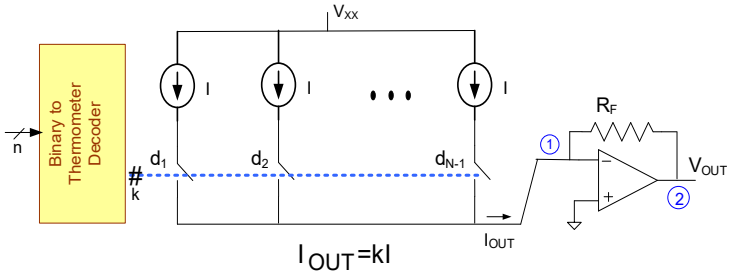


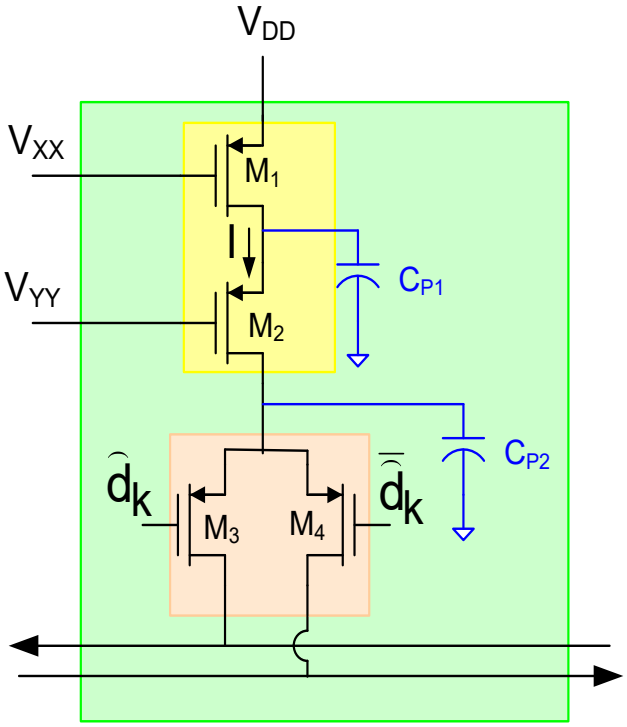
Steer rather than switch current
Reduced swing on control signals

Current Steering DAC

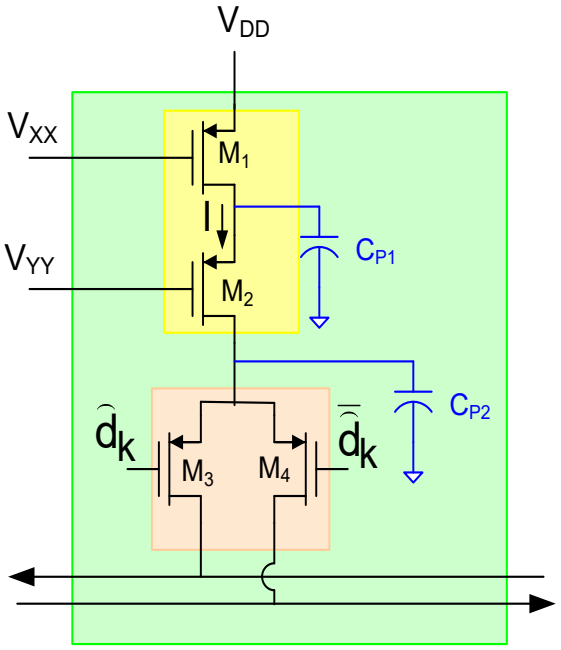


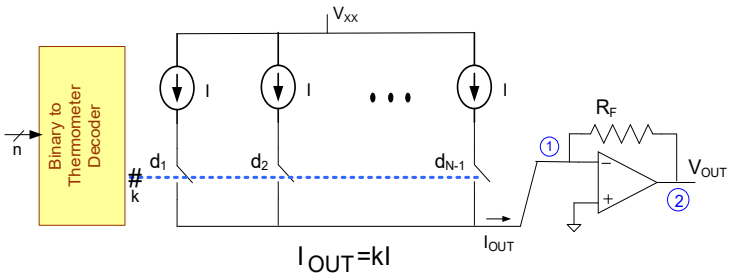


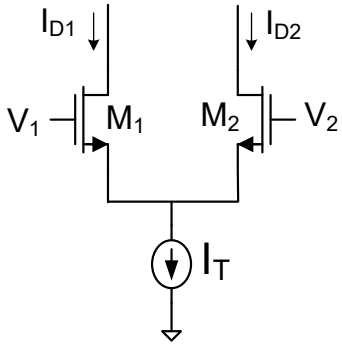


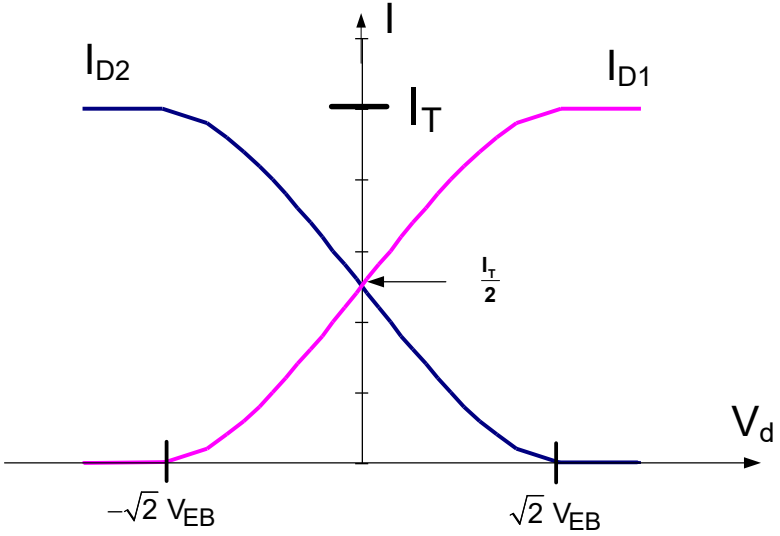


Current Steering DAC



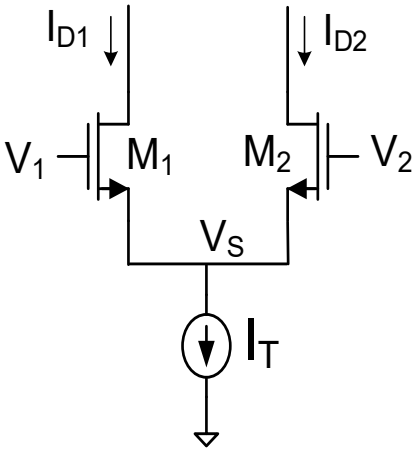


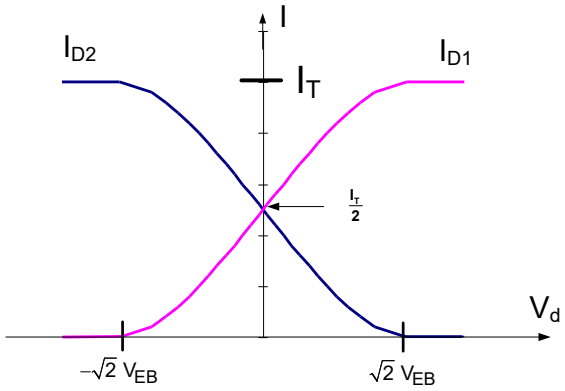




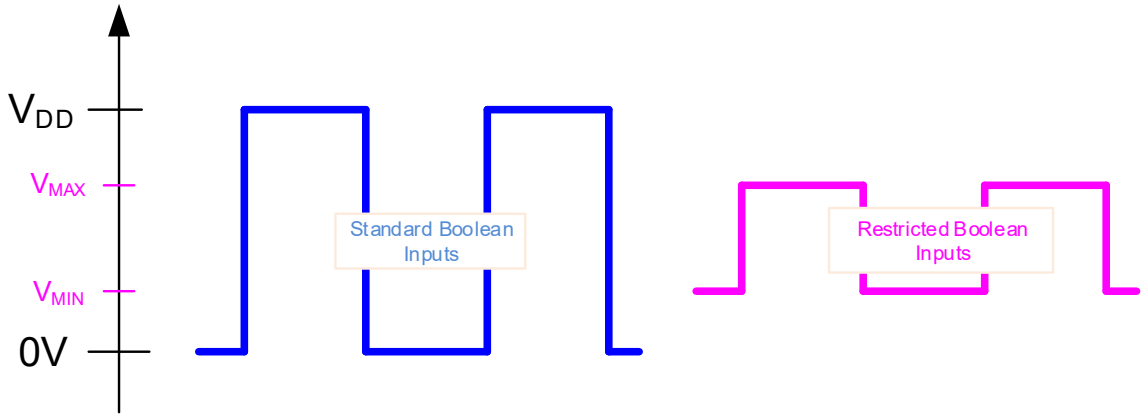
- Need only signal swing of $2\sqrt{2}V_{EB}$ to steer currents (so can reduce turn-on and turn-off times)
- Steering also results in cascoding with M_3 and M_4 thus increasing output impedance of current source (so can probably eliminate M_2)

Current Steering DAC

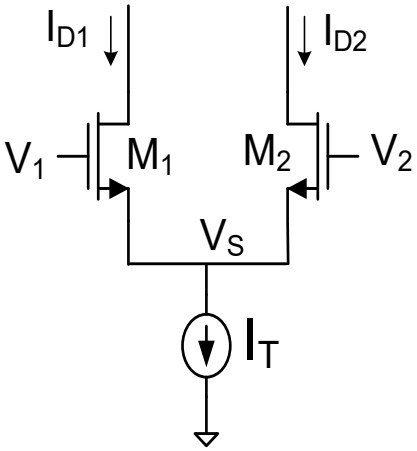


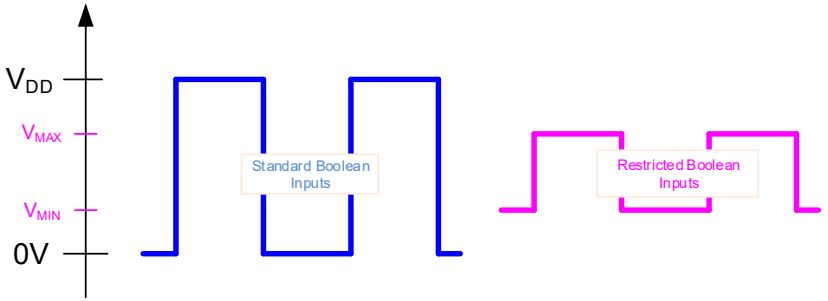


Reduced Signal Swing on V_S Node with Current Steering

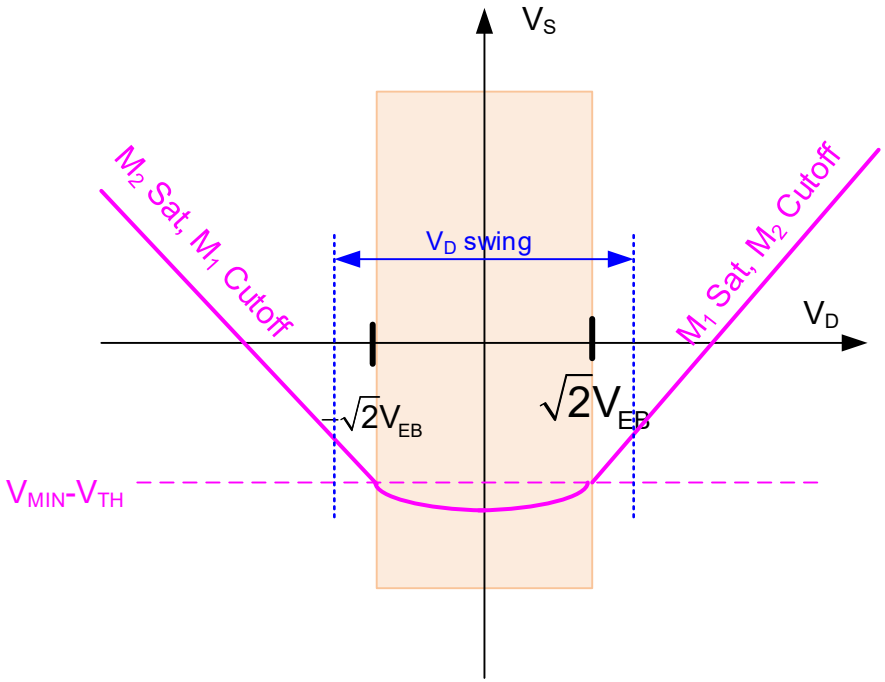


Current Steering DAC

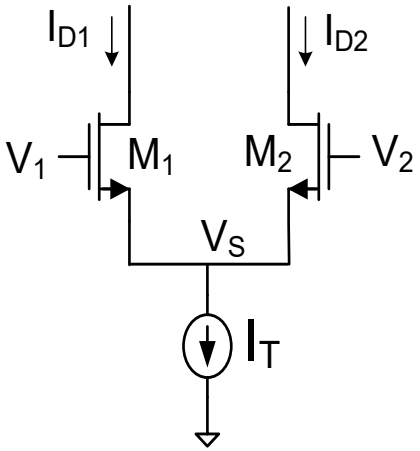


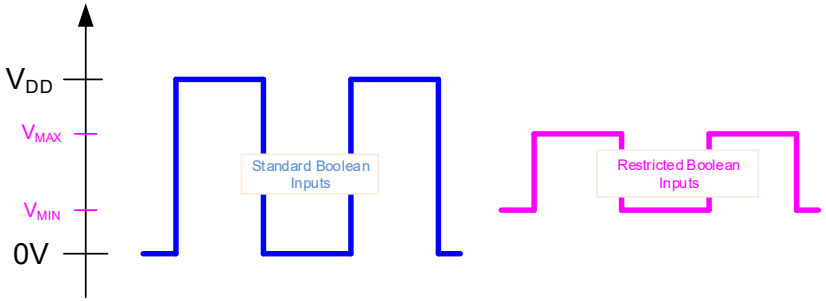


Reduced Signal Swing on V_S Node with Current Steering



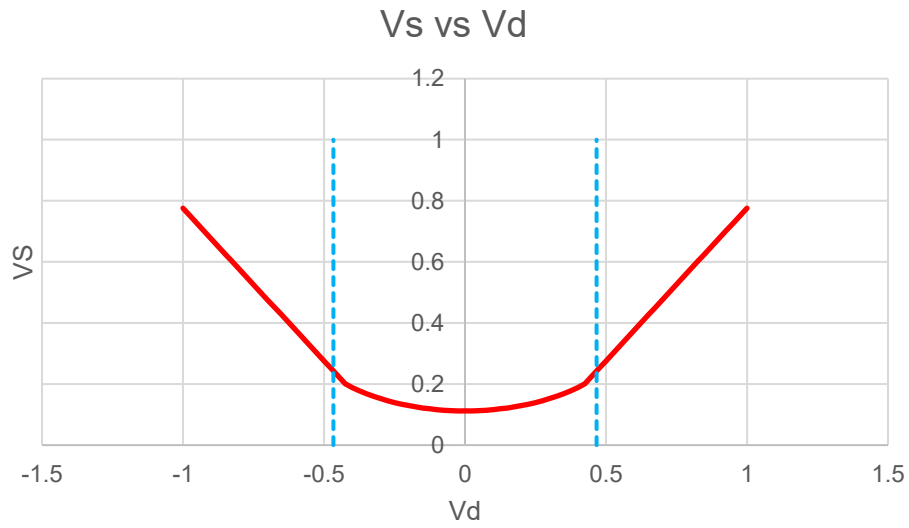
Current Steering DAC





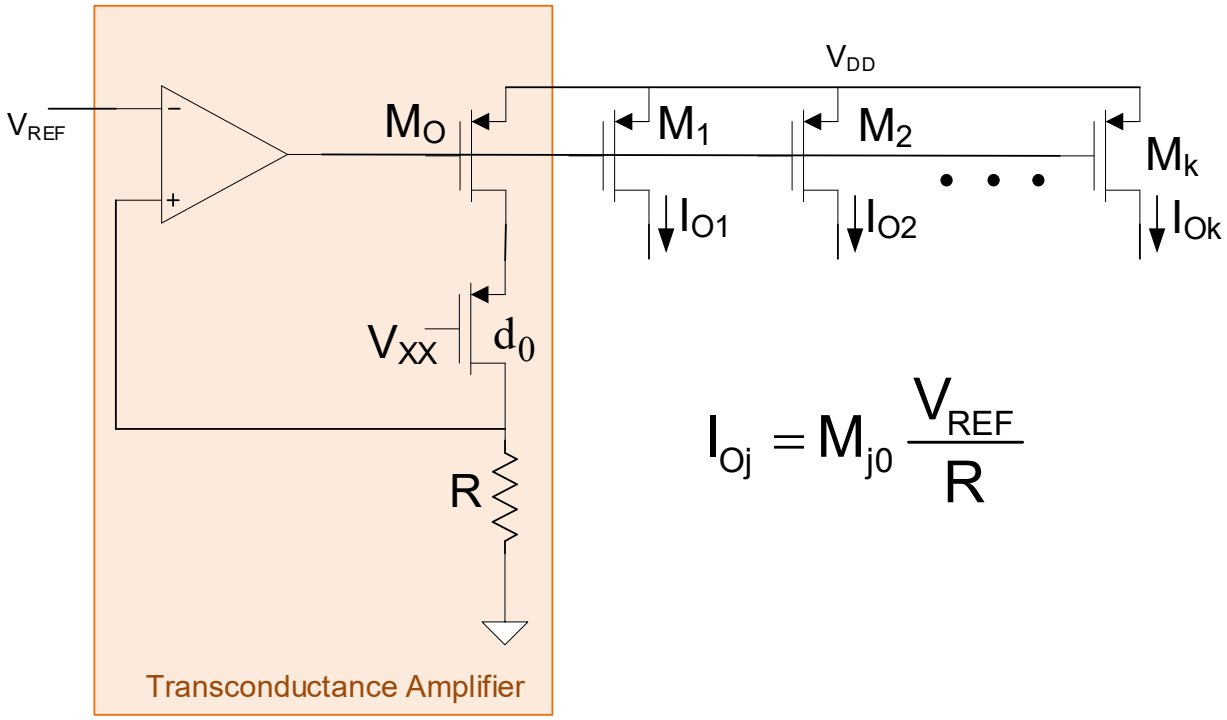
Reduced Signal Swing on V_S Node with Current Steering

Simulation Results: V_{TH}=0.4V, V_{MIN}=0.6V, V_{MAX}=1.07V,V_{EB}=0.3V,γ=1.1



V_S swing about 100mV

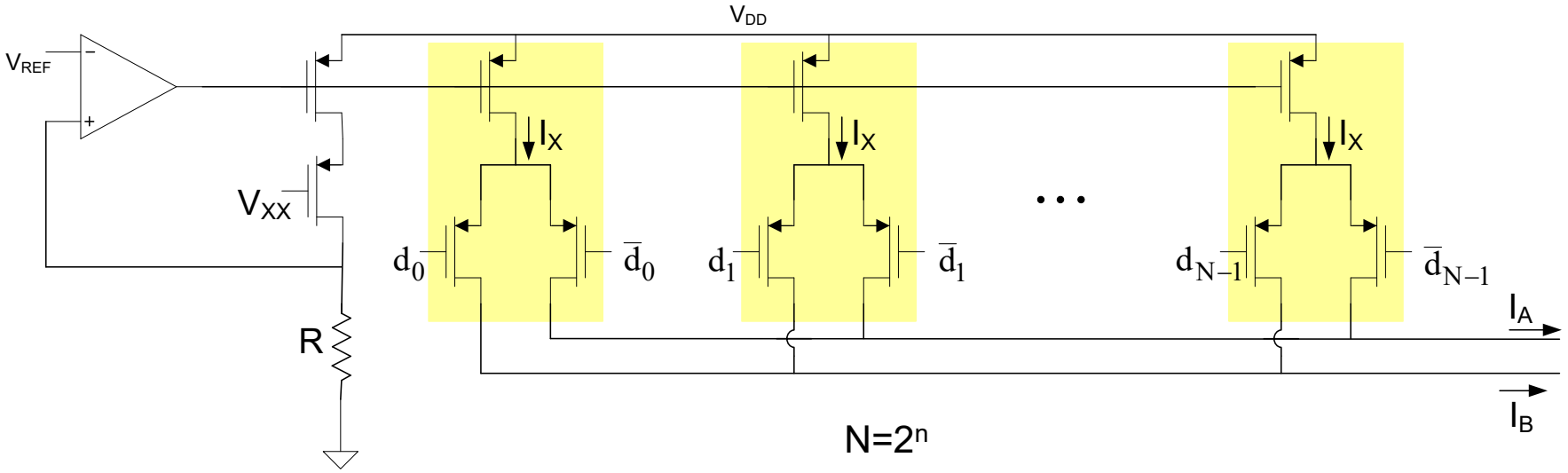
Multiple-output Transconductance Amplifier



$$I_{Oj} = M_{j0} \frac{V_{REF}}{R}$$

- Good linearity
- Each additional output requires only one additional transistor
- Relevant if MDAC output desired
- Cascoding of output devices useful if driving resistive load

Current Steering DAC with Supply Independent Biasing



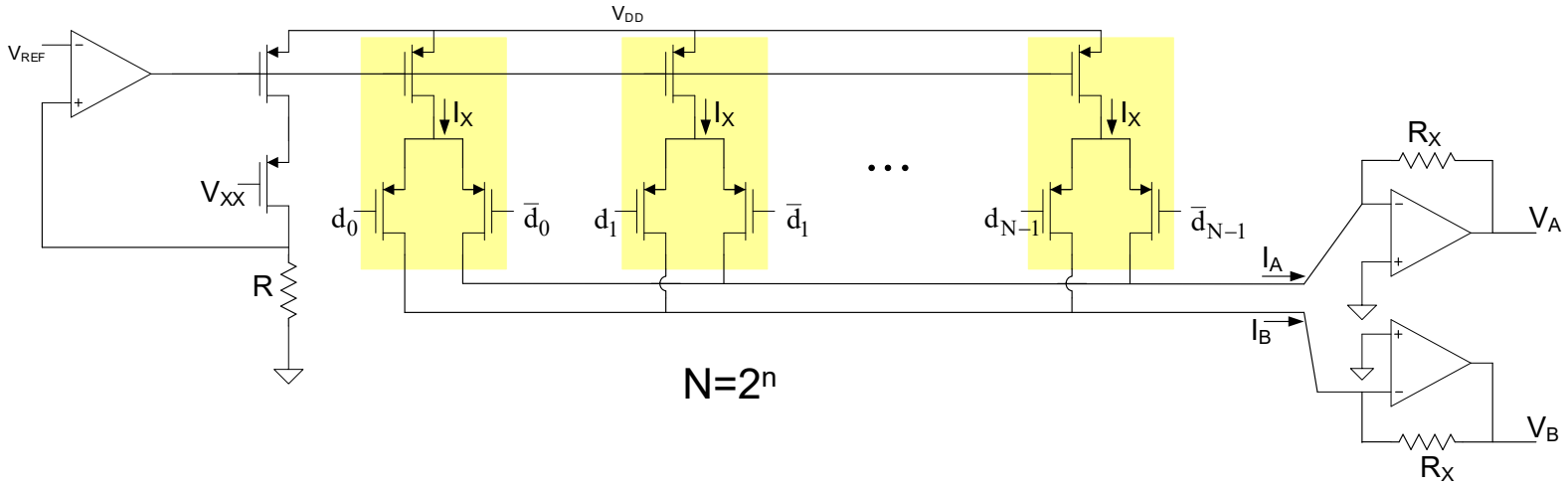
If transistors on top row are all matched, $I_X = V_{REF}/R$

Thermometer coded structure (requires binary to thermometer decoder)

$$I_A = \left(\frac{V_{REF}}{R}\right)\sum_{i=0}^{N-1} d_i$$

Provides Differential Output Currents

Current Steering DAC with Supply Independent Biasing

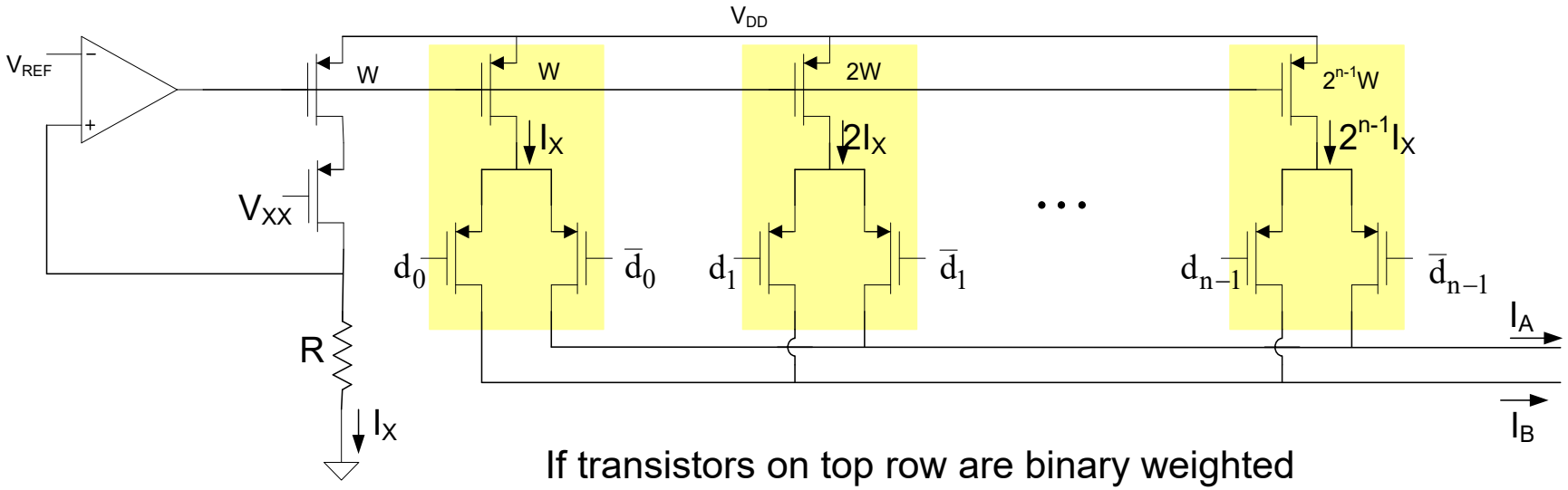


If transistors on top row are all matched, $I_X = V_{REF}/R$

$$V_A = \left(-V_{REF} \frac{R_A}{R} \right) \sum_{i=0}^{N-1} d_i$$

Provides Differential Output Voltages

Current Current Steering DAC with Supply Independent Biasing



If transistors on top row are binary weighted

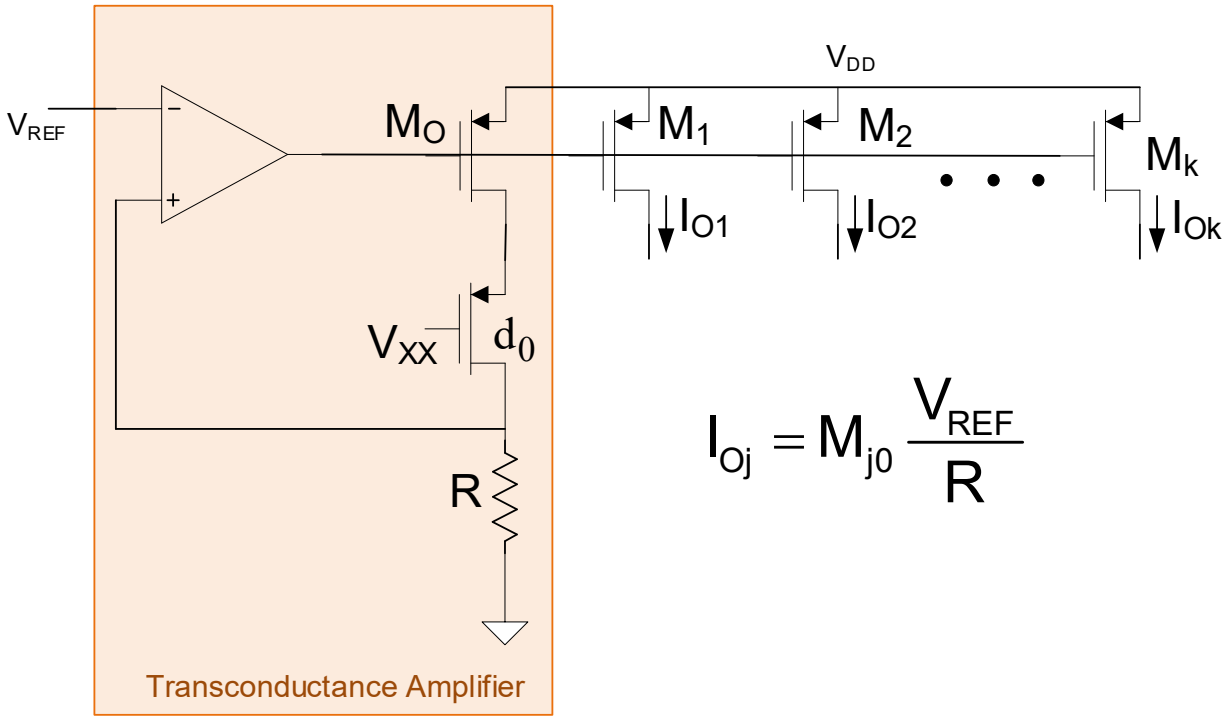
$$I_A = \left(\frac{V_{REF}}{R}\right)\sum_{i=0}^{n-1} d_i 2^i$$

Provides Differential Output Currents

Usually use bundled unary cells
Can use current steering rather than current switching

(switched LSB:MSB notation)

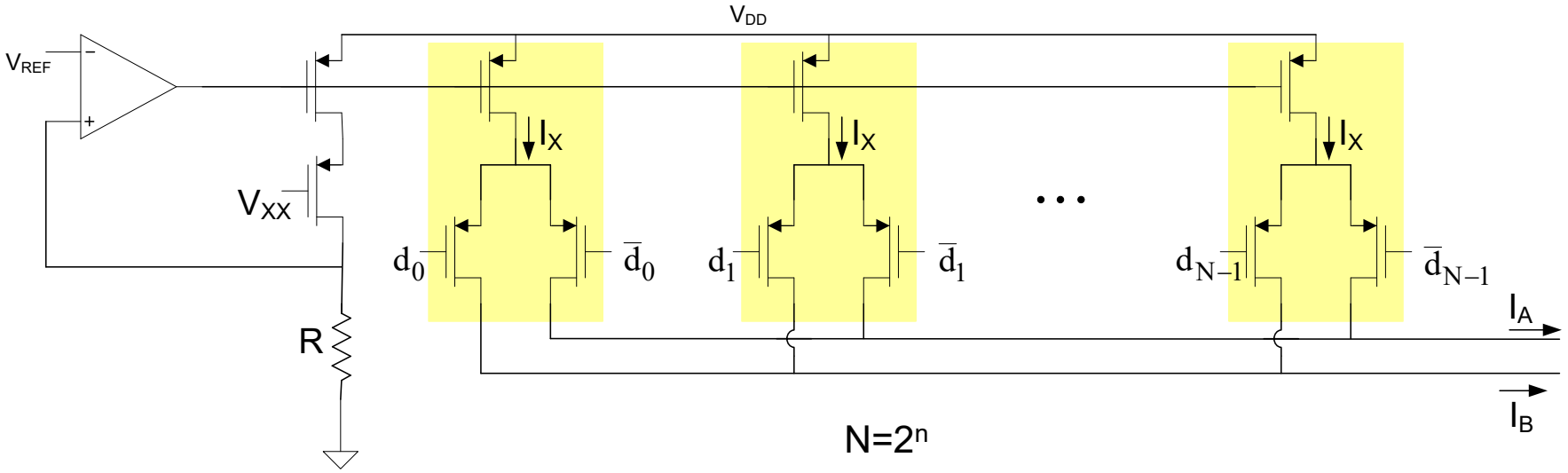
Multiple-output Transconductance Amplifier



$$I_{Oj} = M_{j0} \frac{V_{REF}}{R}$$

- Good linearity
- Each additional output requires only one additional transistor
- Relevant if MDAC output desired
- Cascoding of output devices useful if driving resistive load

Current Steering DAC with Supply Independent Biasing



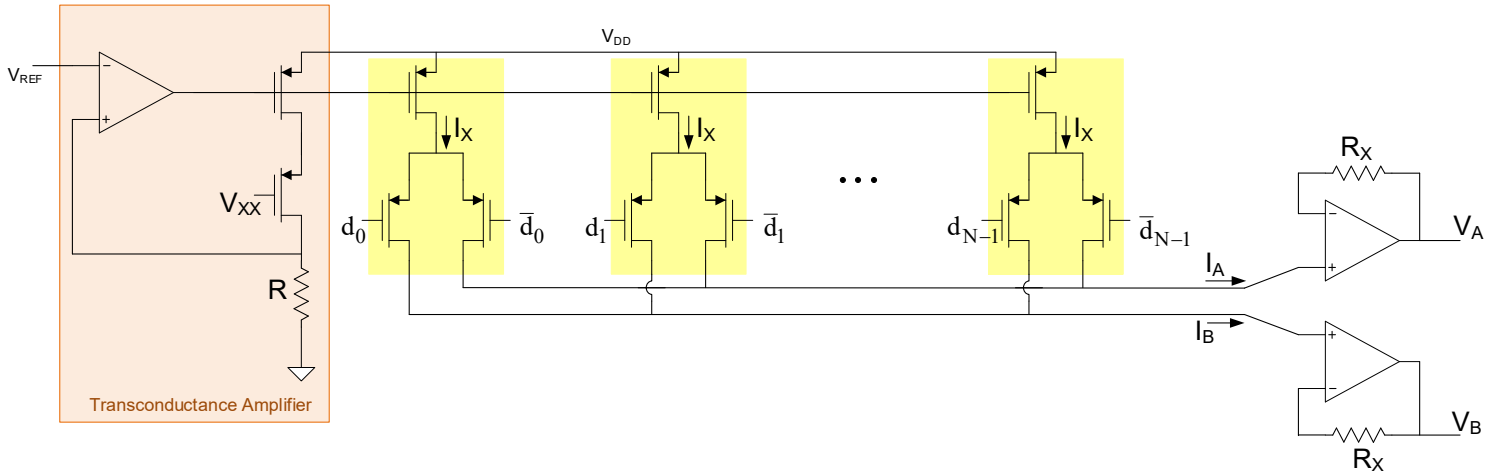
If transistors on top row are all matched, $I_X = V_{REF}/R$

Thermometer coded structure (requires binary to thermometer decoder)

$$I_A = \left(\frac{V_{REF}}{R}\right)\sum_{i=0}^{N-1} d_i$$

Provides Differential Output Currents

Current Steering DAC with Supply Independent Biasing



$N=2^n$

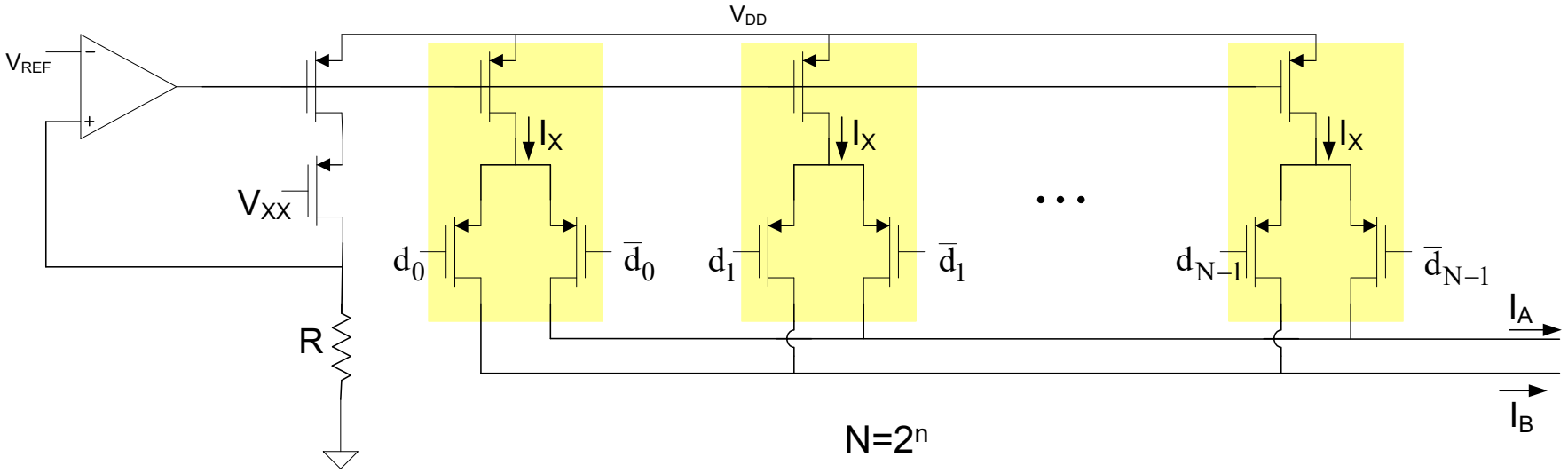
If transistors on top row are all matched, $I_X=V_{REF}/R$

Thermometer coded structure (requires binary to thermometer decoder)

$$I_A = \left(\frac{V_{REF}}{R}\right)\sum_{i=0}^{N-1} d_i$$

Provides Differential Output Currents

Current Steering DAC with Supply Independent Biasing



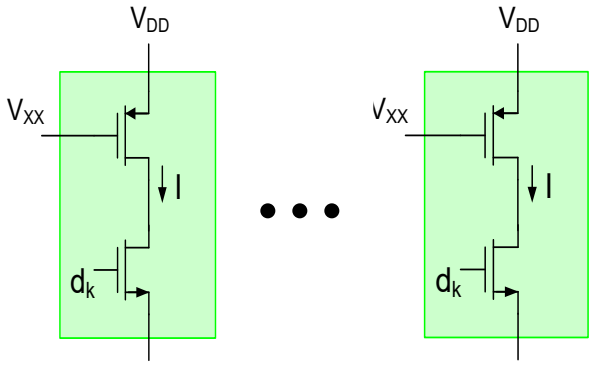
If transistors on top row are all matched, $I_X = V_{REF}/R$

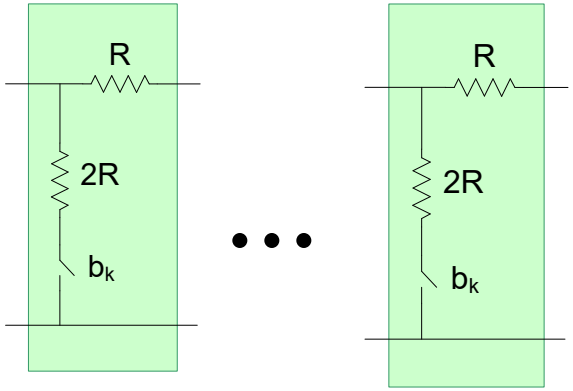
$$I_A = \left(\frac{V_{REF}}{R}\right)\sum_{i=0}^{N-1} d_i$$

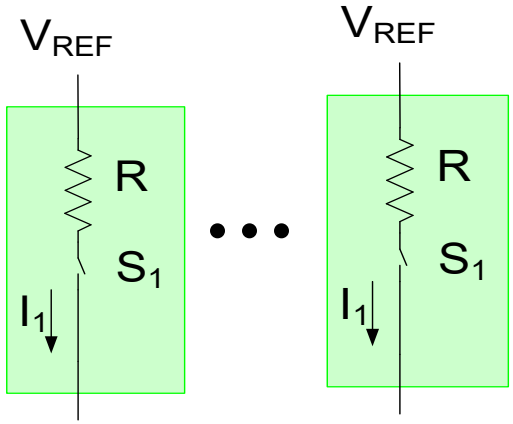
Provides Differential Output Currents

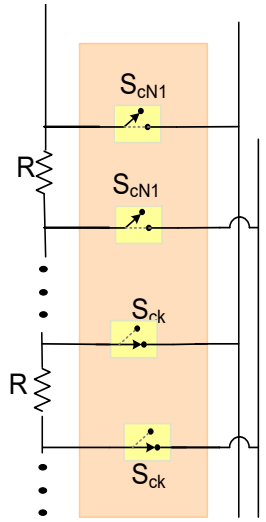
Usually use bundled unary cells
Can use current steering rather than current switching
(have switched LSB:MSB notation)

Matching is Critical in all DAC Considered



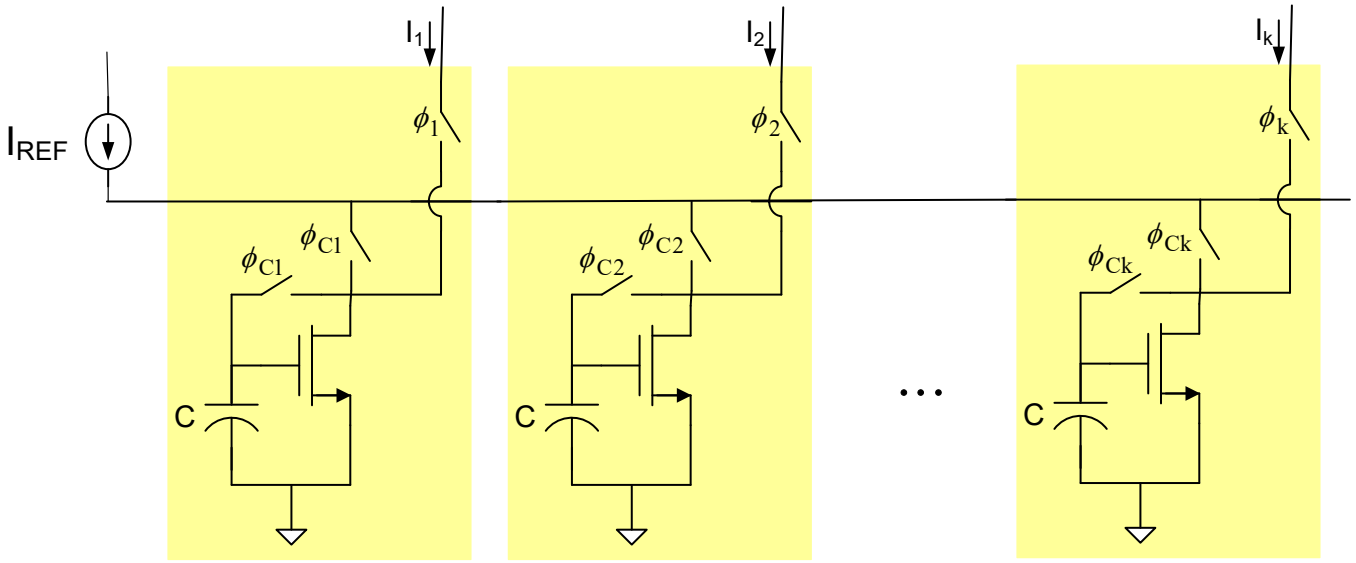






Obtaining adequate matching remains one of the major challenges facing the designer!

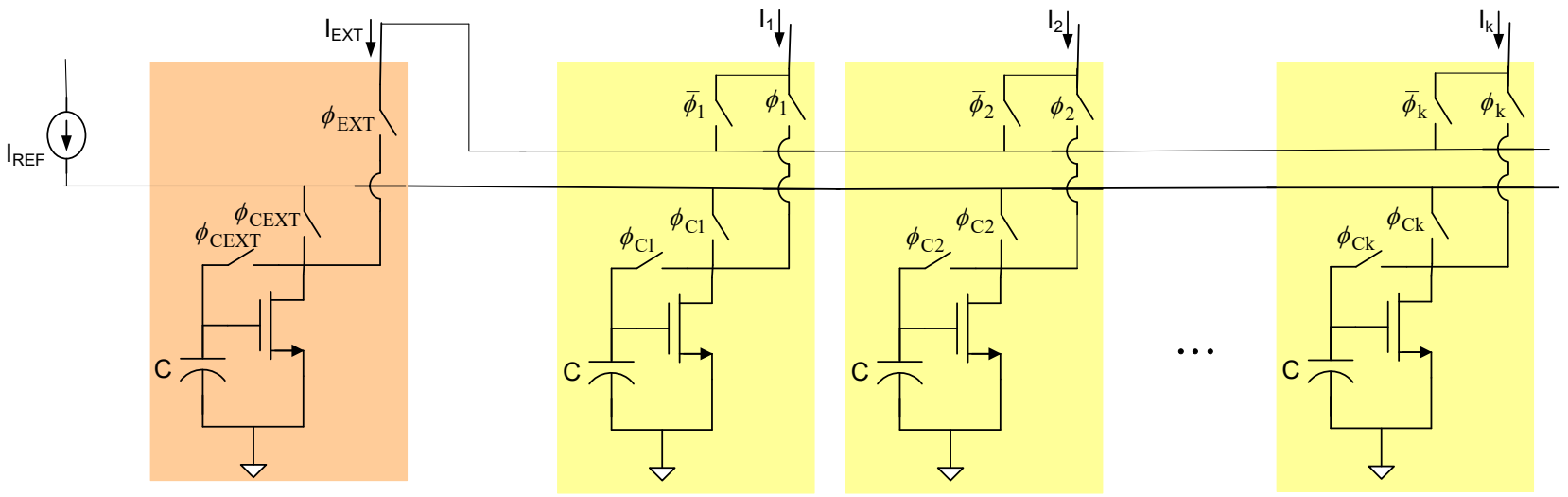
Dynamic Current Source Matching



- $\varphi_1,\ldots\varphi_k\ldots\varphi_n$ distinct from $d_1,\ldots d_n$ (not shown)
- Correct charge is stored on C to make all currents equal to I_{REF}
- Does not require matching of transistors or capacitors
- Requires refreshing to keep charge on C
- Form of self-calibration
- Calibrates current sources one at a time
- Current source unavailable for use while calibrating
- Can be directly used in DACs (thermometer or binary coded)

Often termed “Current Copier” or “Current Replication” circuit

Dynamic Current Source Matching



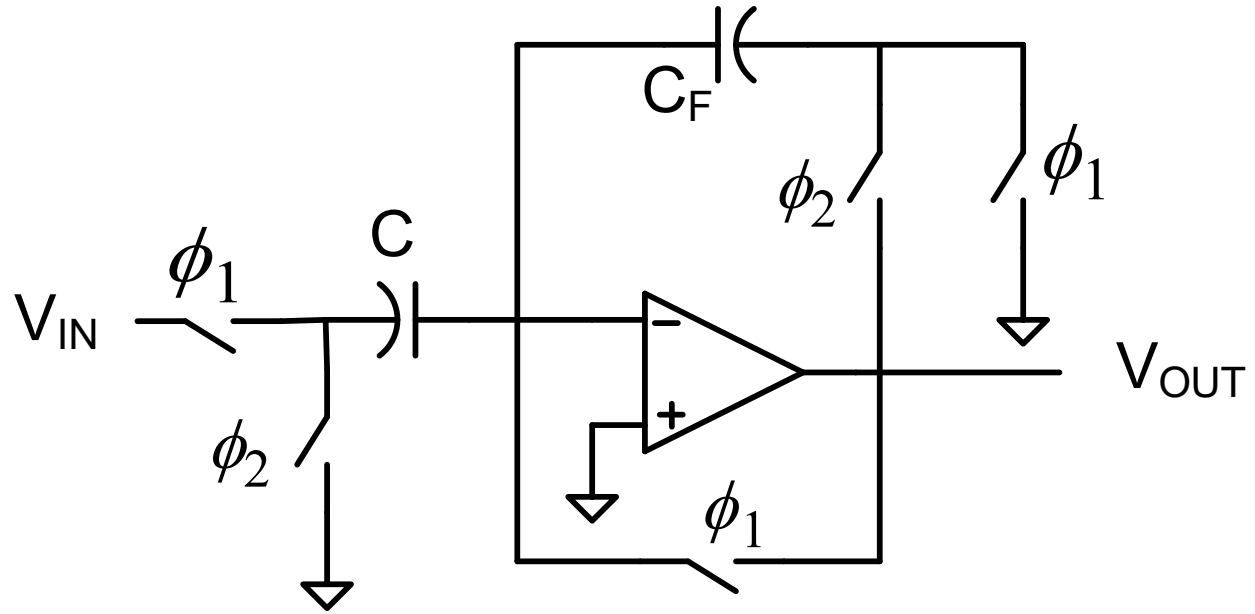
Extra current source can be added to facilitate background calibration

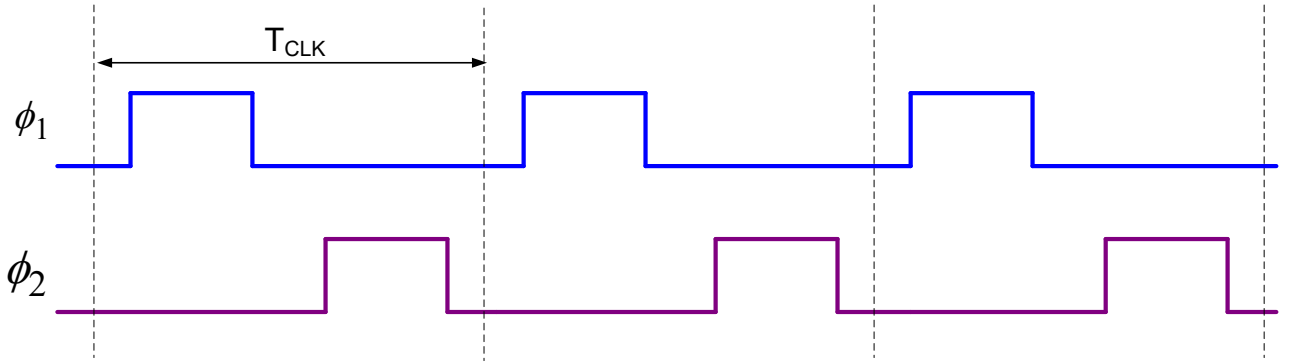
Charge Redistribution DACs

- Previous DACs based upon matching of resistors or transistors
- Switch impedance was of concern in most of the structures
- Capacitor matching can be very good in most processes and area required for a given level of matching may be smaller for capacitors than for resistors or transistors in some processes
- Capacitor linearity is often excellent

Will now focus on building DACs that take advantage of good capacitor matching and linearity

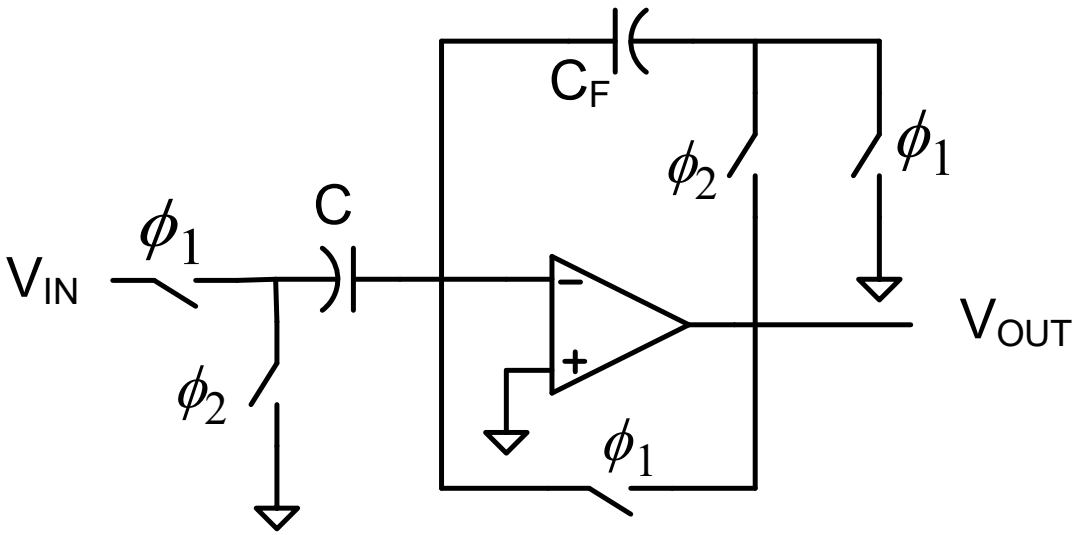
A charge redistribution circuit

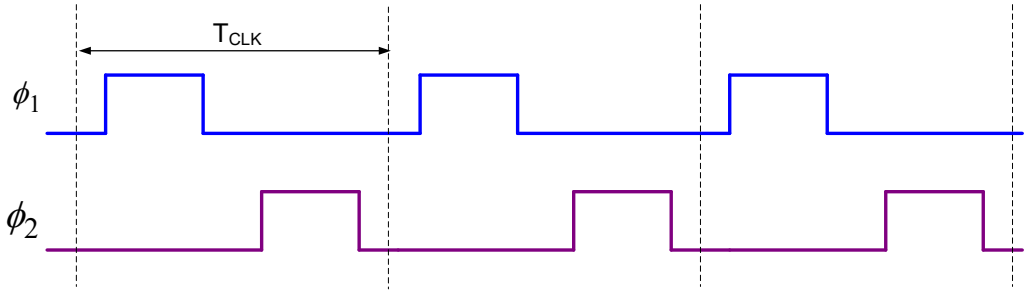




Clocks are complimentary non-overlapping

A charge redistribution circuit





During phase φ_1

$$Q_{\phi 1} = CV_{IN}$$

$$Q_{CF} = 0$$

During phase φ_2

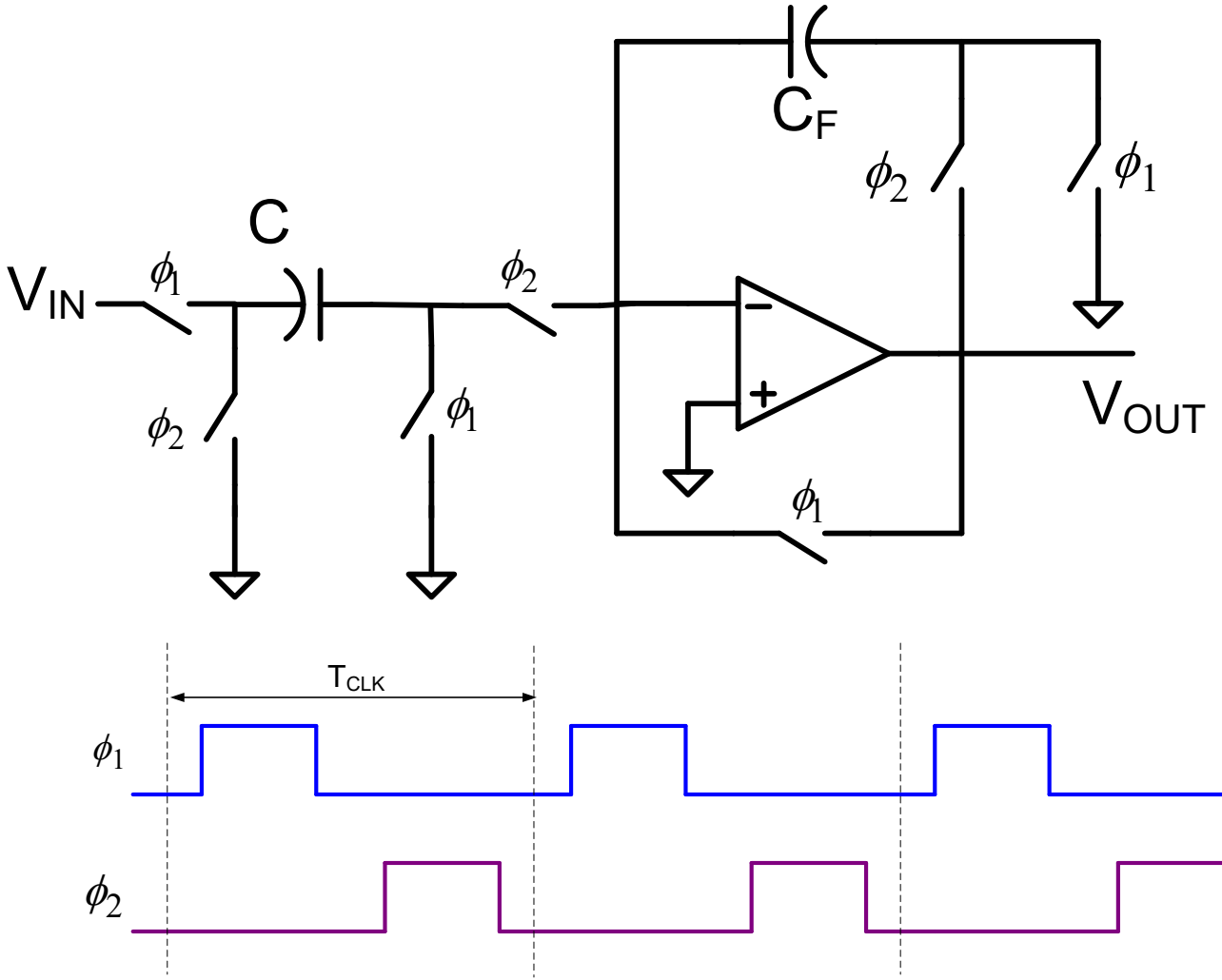
$$\frac{Q_{\phi 1}}{C_F} = V_{OUT}$$

$$\frac{CV_{IN}}{C_F} = V_{OUT}$$

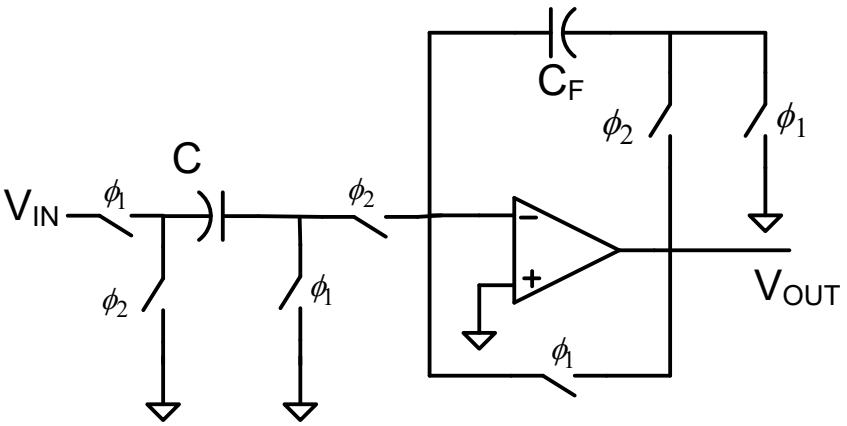
$$\frac{V_{OUT}}{V_{IN}} = \frac{C}{C_F}$$

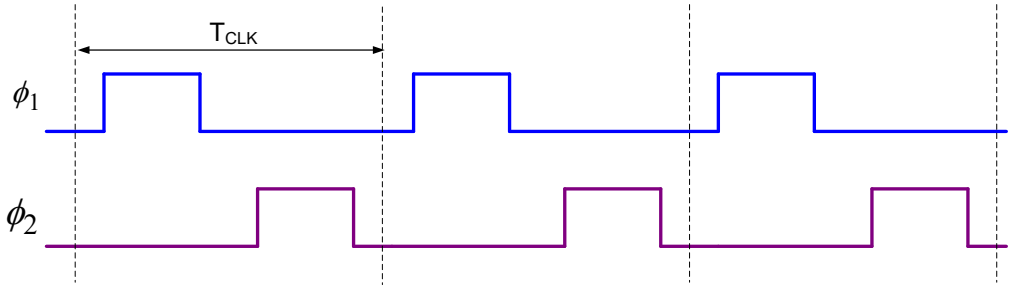
Serves as a noninverting amplifier
Gain can be very accurate
Output valid only during Φ_2

Another charge redistribution circuit



A charge redistribution circuit





During phase φ_1

$$Q_{\phi 1} = CV_{IN}$$

$$Q_{CF} = 0$$

During phase φ_2

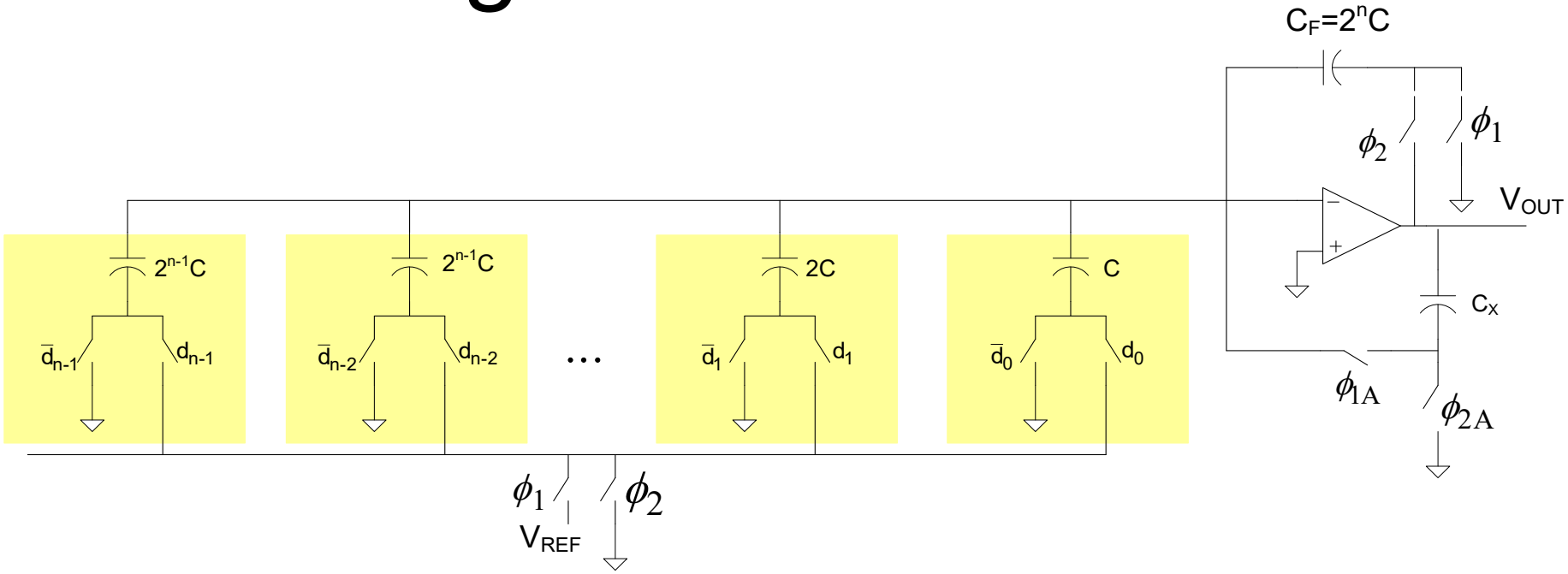
$$\frac{-Q_{\phi 1}}{C_F} = V_{OUT}$$

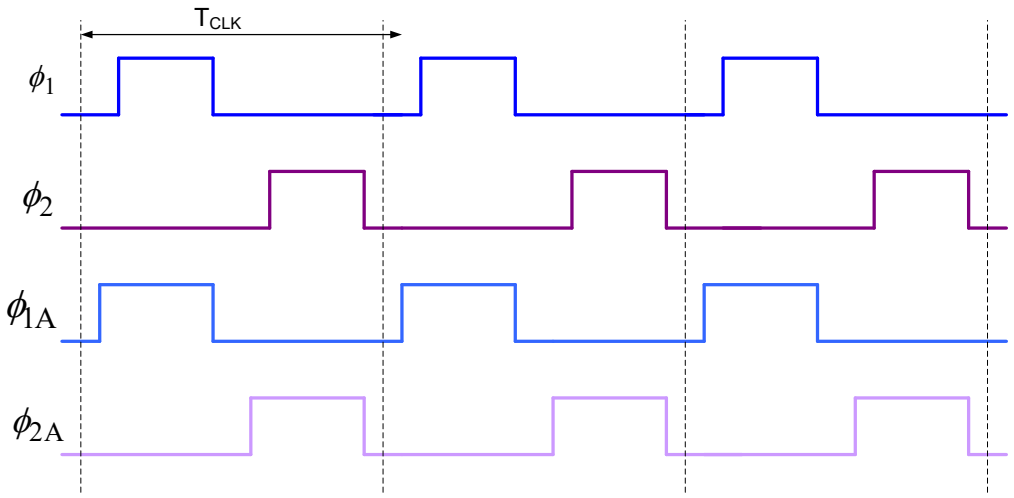
$$\frac{-CV_{IN}}{C_F} = V_{OUT}$$

$$\frac{V_{OUT}}{V_{IN}} = -\frac{C}{C_F}$$

Serves as a inverting amplifier
Gain can be very accurate
Output valid only during Φ_2

A charge redistribution DAC

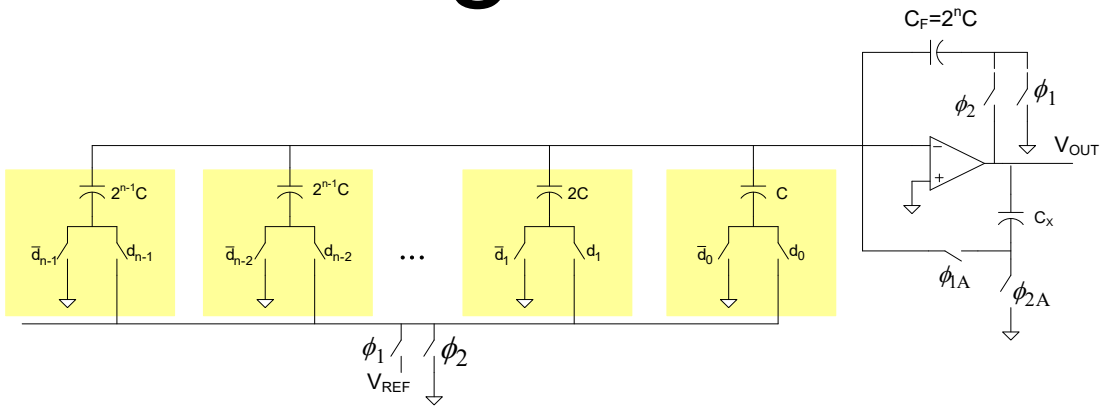


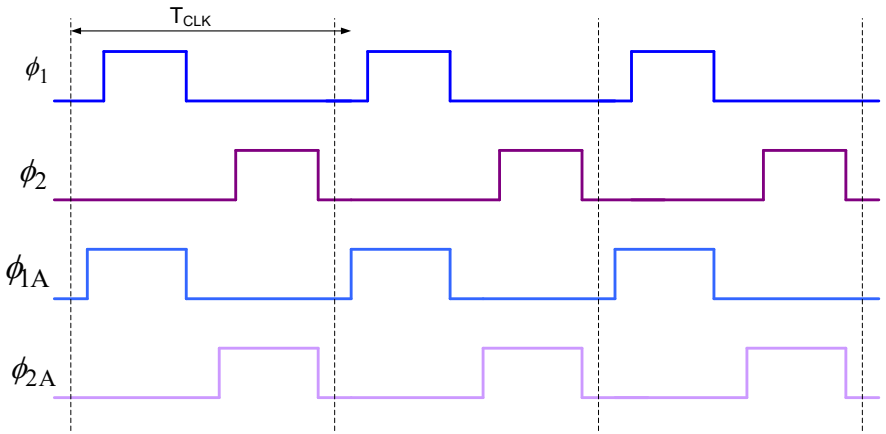


C_X does some good things
(mitigates V_{OS}, 1/f noise and finite gain errors)

Will not consider C_X affects at this time

A charge redistribution DAC





During phase φ_1

$$Q_{\phi 1} = V_{REF} \sum_{i=0}^{n-1} d_i \bullet 2^i C$$

$$Q_{CF} = 0$$

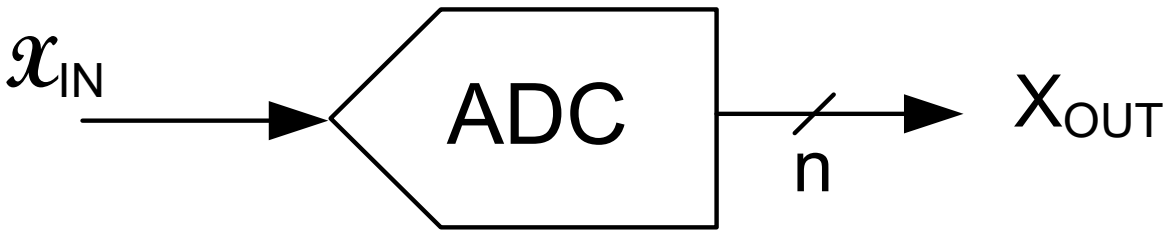
During phase φ_2

$$V_{OUT}(\phi_2) = \frac{1}{C_F} Q_{\phi 1}$$

$$V_{OUT}(\phi_2) = \frac{1}{2^n C} V_{REF} \sum_{i=0}^{n-1} d_i \bullet 2^i C$$

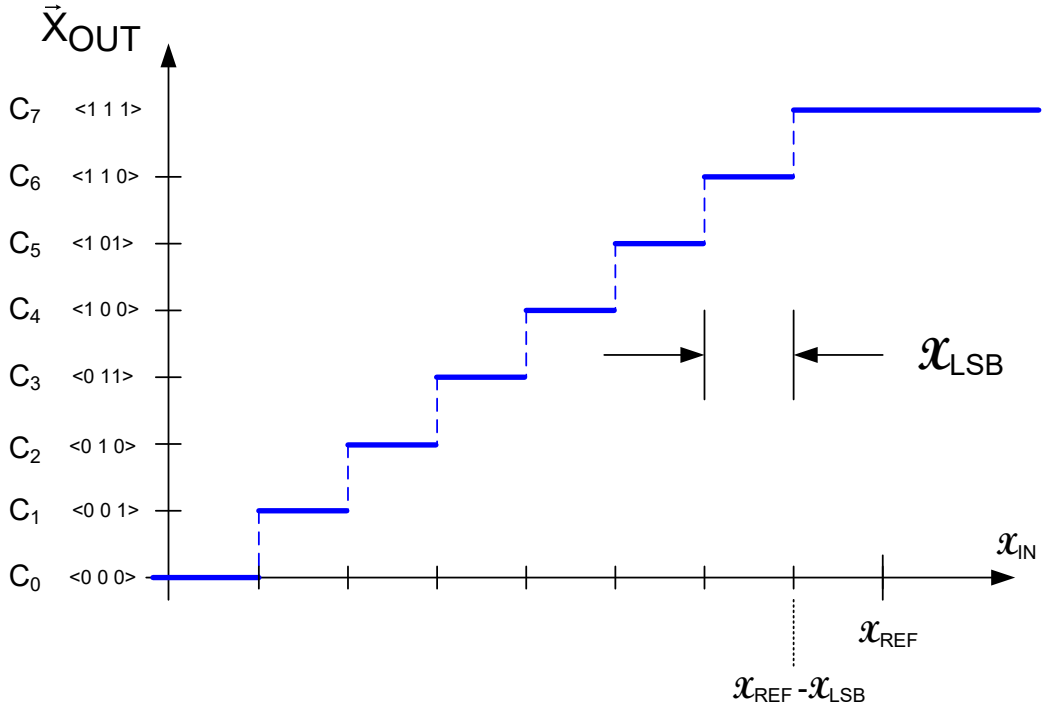
$$V_{OUT}(\phi_2) = V_{REF} \sum_{i=0}^{n-1} \frac{d_i}{2^{n-i}}$$

Analog to Digital Converters



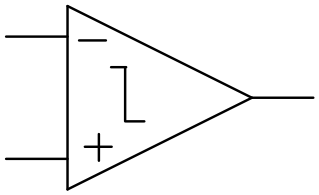
Will now focus on design of ADCs

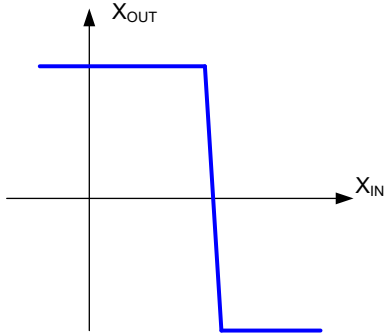
Analog to Digital Converters



Analog to Digital Converters

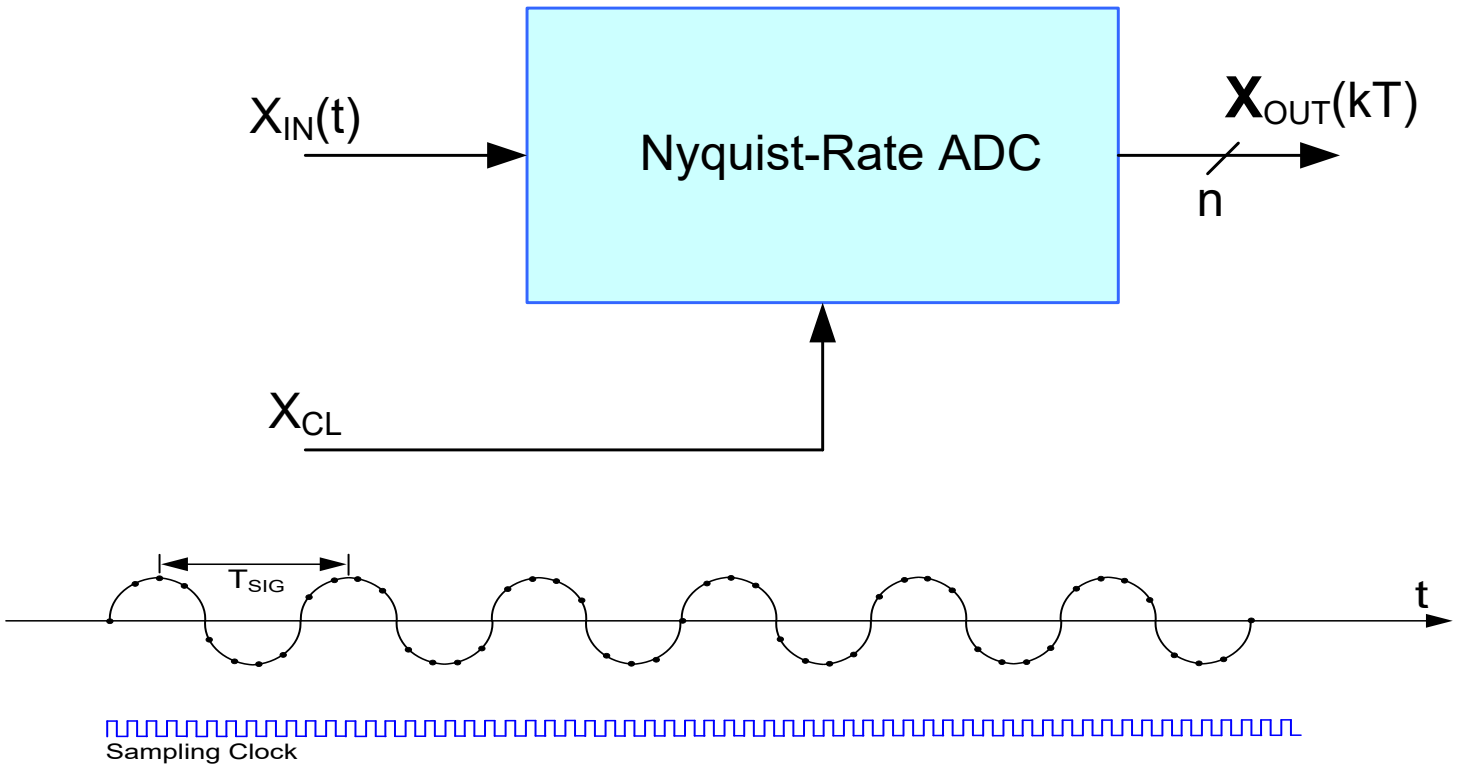
The conversion from analog to digital in most ADCs is done with comparators





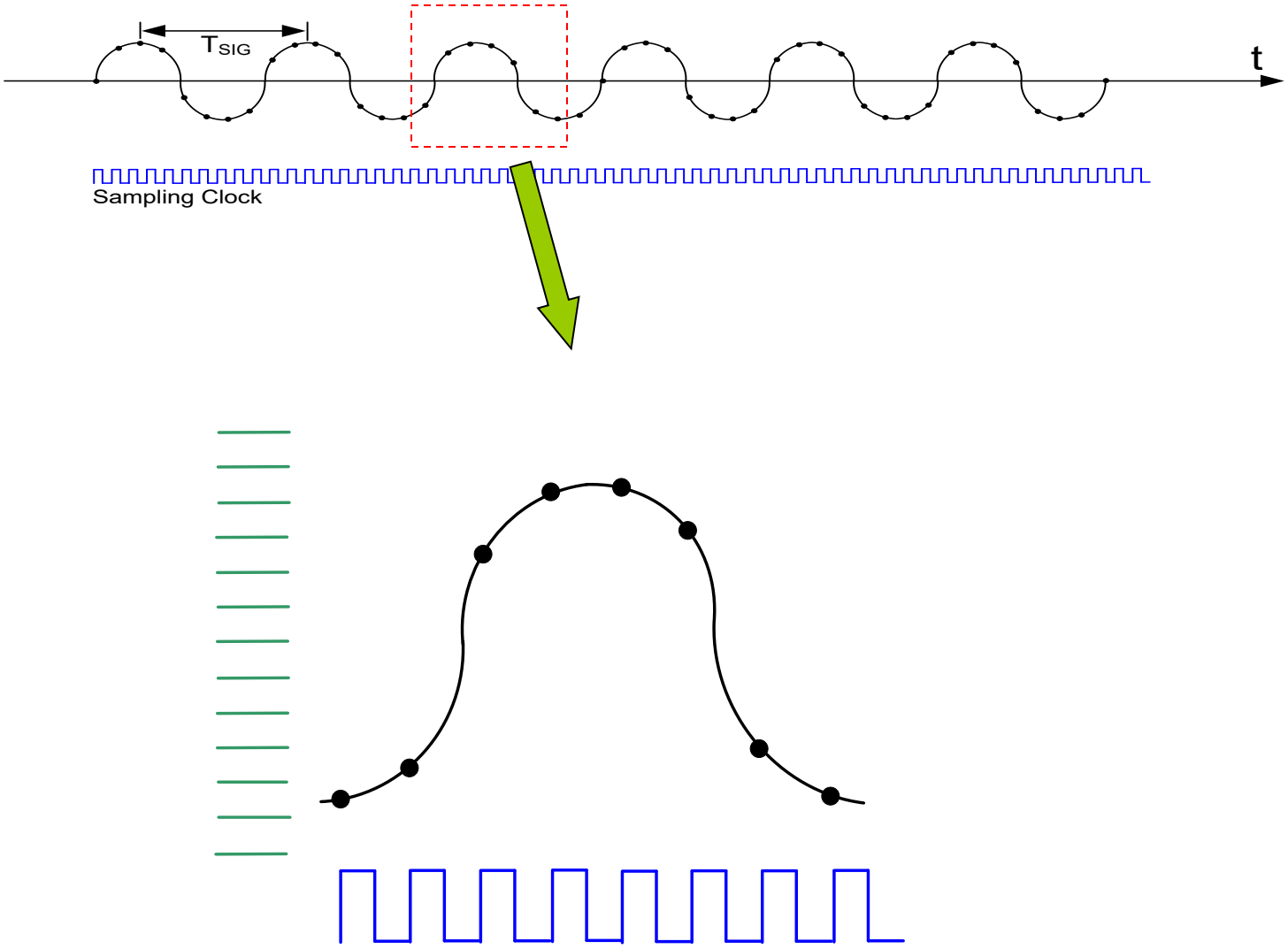
Most ADC design is primarily involved with designing comparators and embedding these into circuits that are robust to nonideal effects

Nyquist Rate

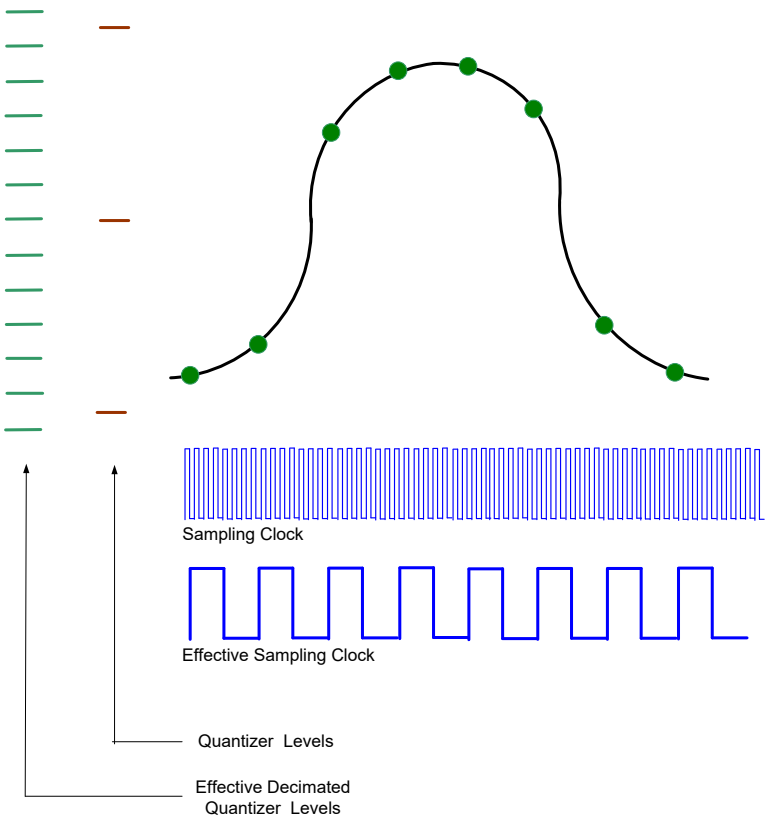


Nyquist Rate Data Converters provide one output for each period of the sampling clock

Nyquist Rate



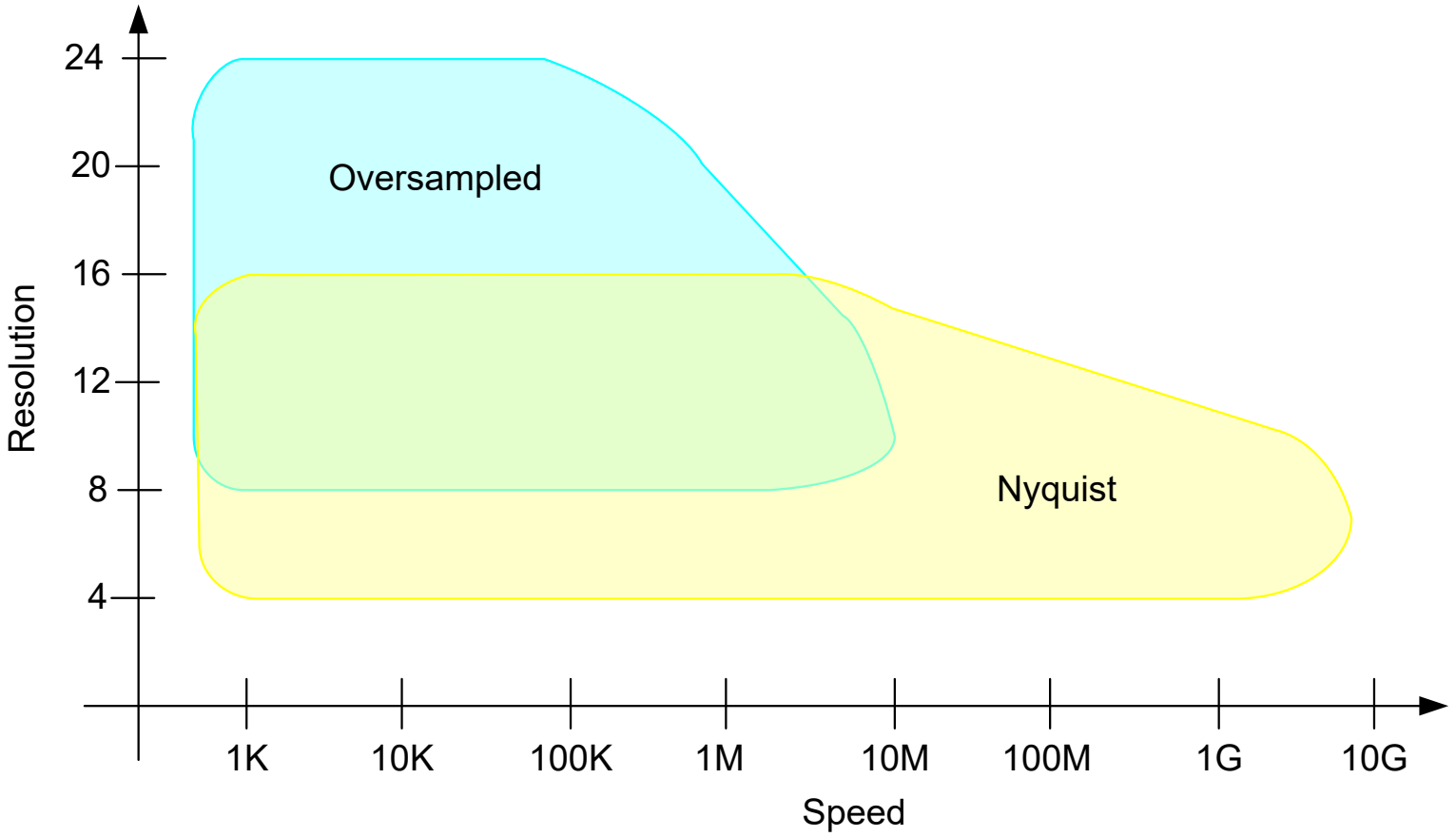
Over-Sampled



Over-Sampled Data Converters require multiple sampling clock periods for each output

Over-sampling ratios of 128:1 or 64:1 are common
Dramatic reduction in quantization noise effects
Limited to relatively low effective conversion rates

Data Converter Type Chart



ADC Types

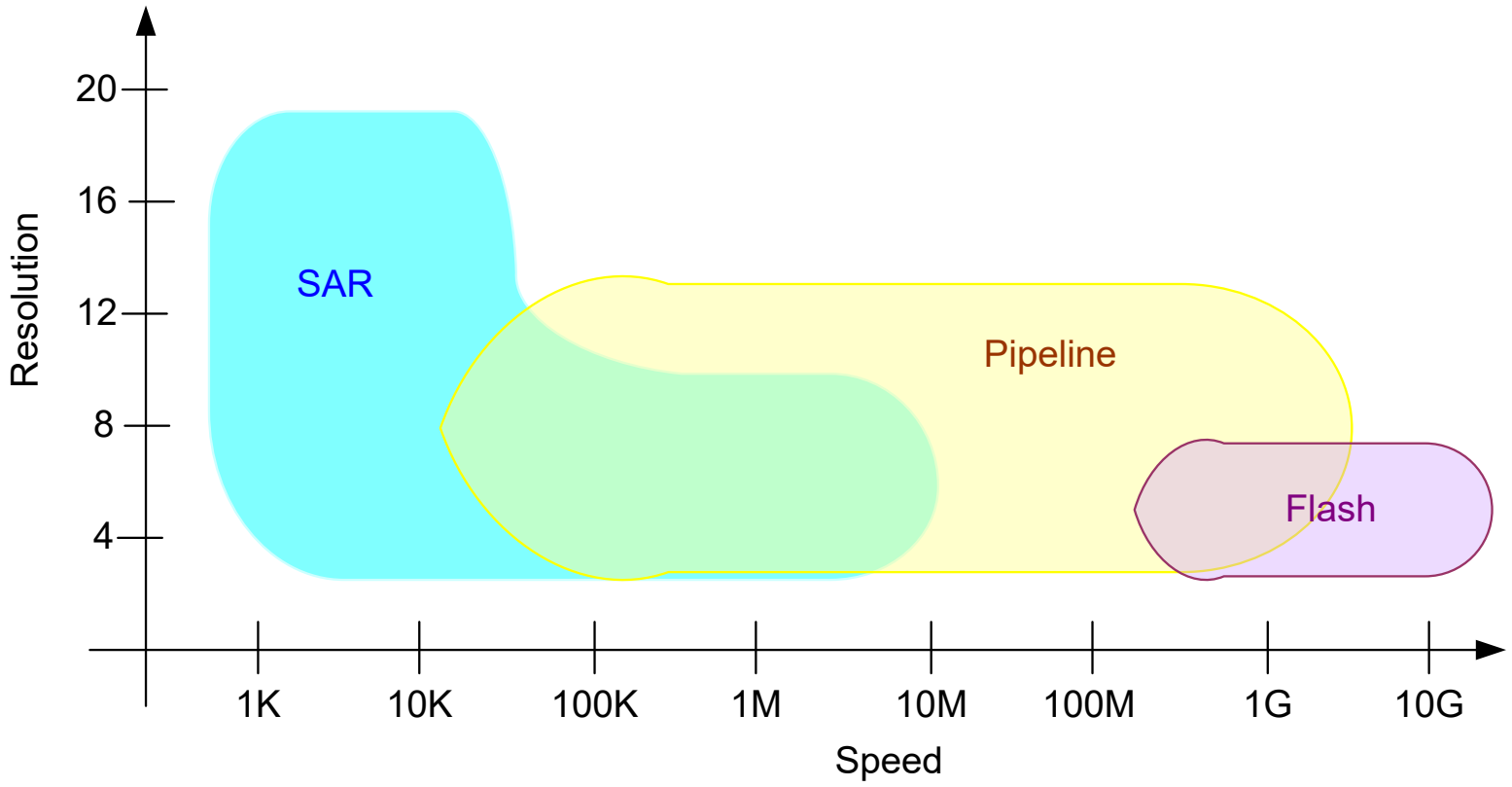
Nyquist Rate

- Flash
- Pipeline
- Two-Step Flash
- Multi-Step Flash
- Cyclic (algorithmic)
- Interpolating
- Successive Approximation
- Folded
- Dual Slope

Over-Sampled

- Single-bit
- Multi-bit
- First-order
- Higher-order
- Continuous-time

Nyqyist Rate Usage Structures



ADC Types

Nyquist Rate

- Flash
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- Cyclic (algorithmic)
- Interpolating
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- Folded
- Dual Slope

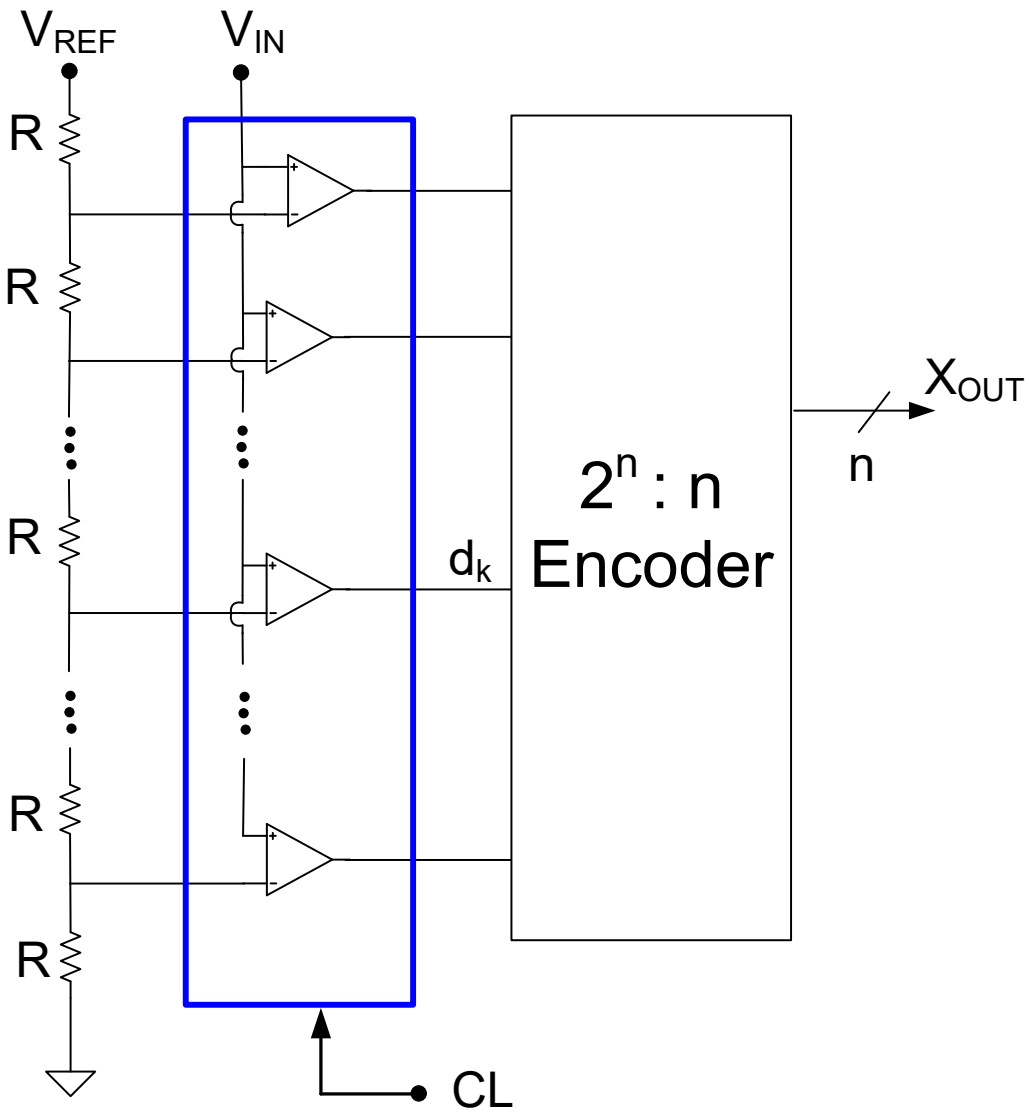
Over-Sampled

- Single-bit
- Multi-bit
- First-order
- Higher-order
- Continuous-time

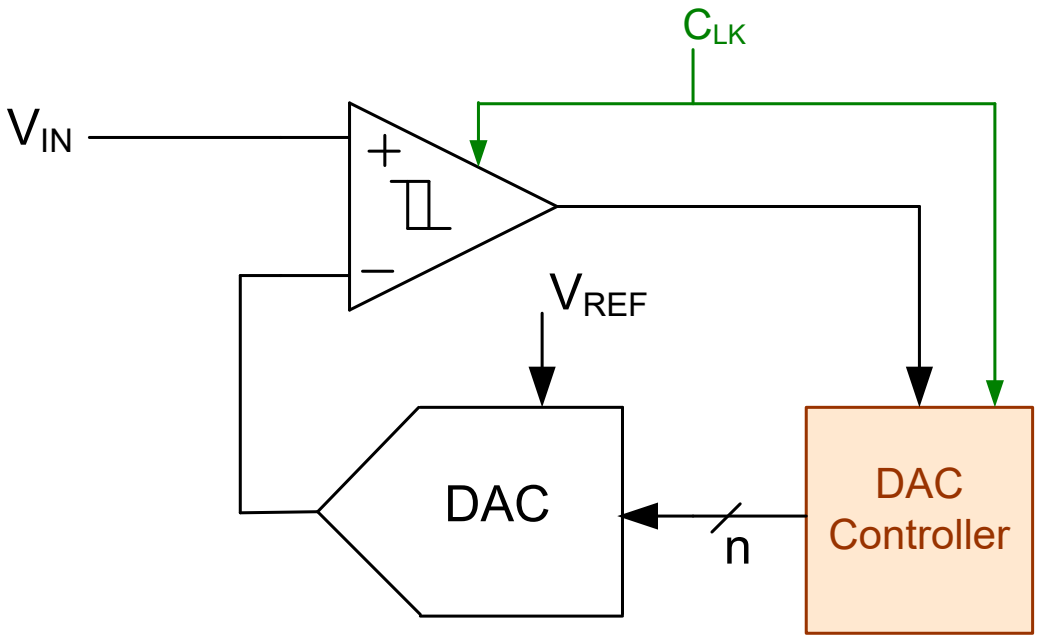
All have comparable conversion rates

Basic approach in all is very similar

Flash ADC



SAR ADC



- DAC Controller may be simply U/D counter
- Binary search controlled by Finite State Machine is faster
- SAR ADC will have no missing codes if DAC is monotone
- Not very fast but can be small

Stay Safe and Stay Healthy !

End of Lecture 36