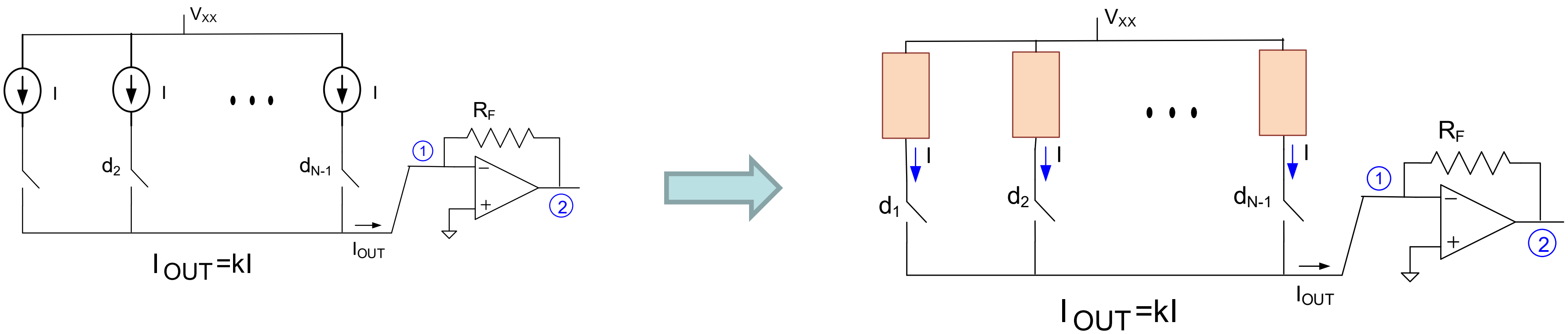
EE 435

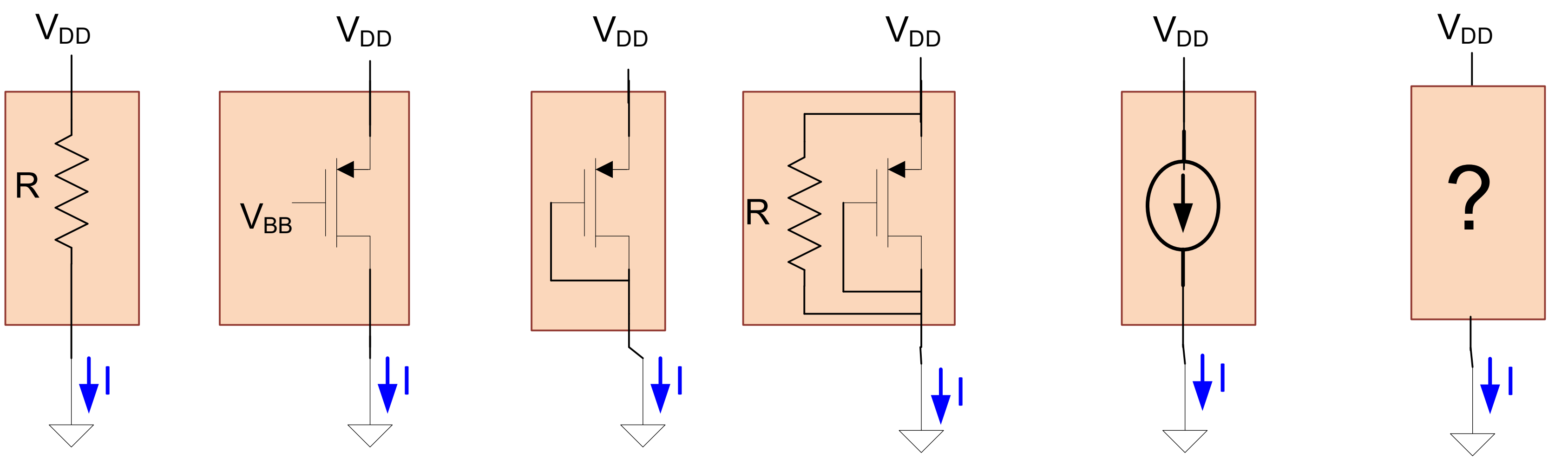
Lecture 34

Current Steering DACs

Current Steering DACs

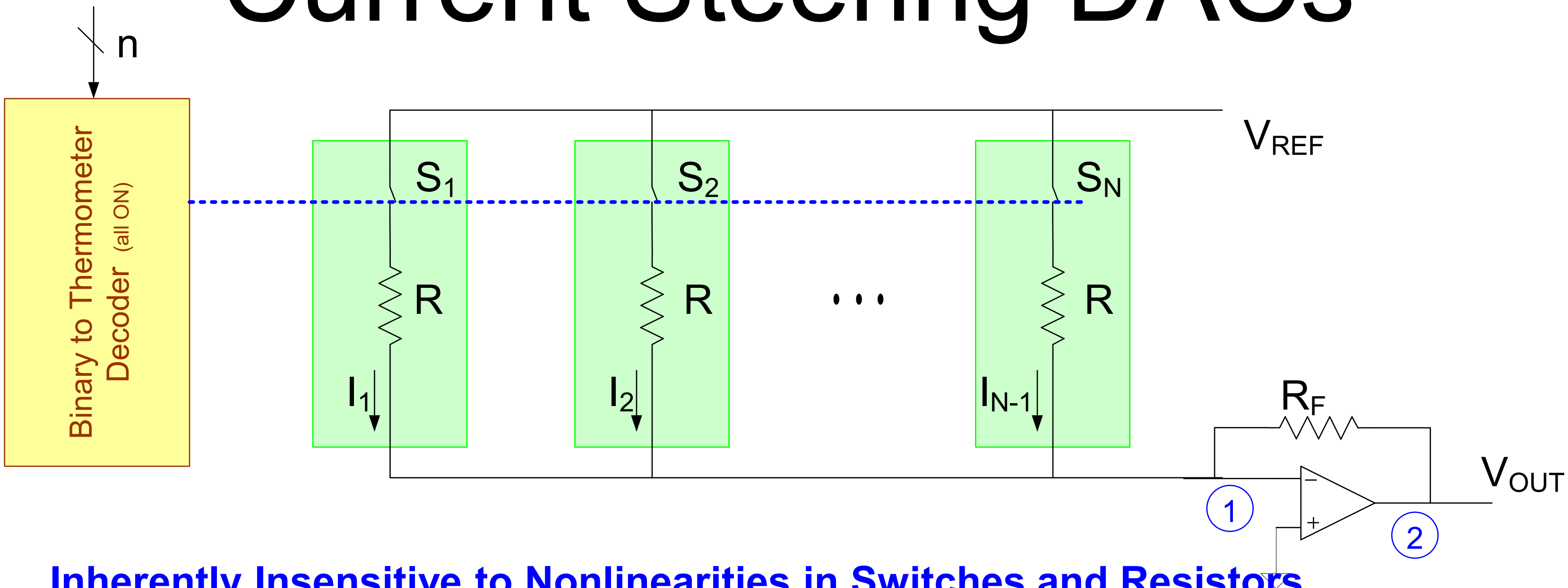


What is important is the current generated, not whether it comes from a “current source”



Many potential current generator blocks, just require that all be ideally identical

Current Steering DACs



Inherently Insensitive to Nonlinearities in Switches and Resistors

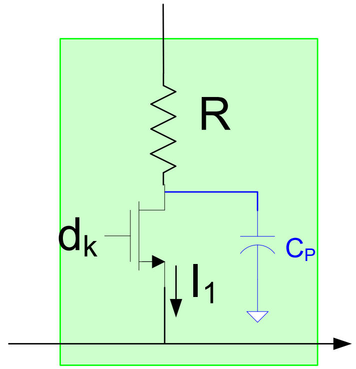
- Termed “top plate switching”
- Thermometer coding
- Excellent DNL properties
- INL may be poor, typically near mid range
- INL is a random variable with variance approximately proportional to area
- Area gets large for good yield with large n

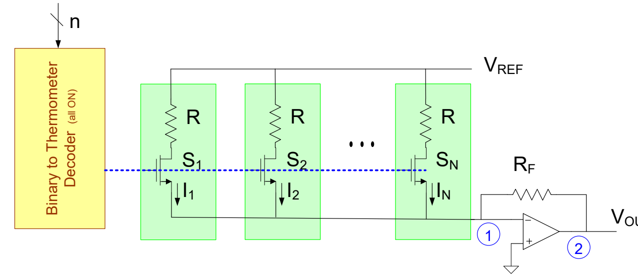
$$\sigma = \frac{A_{PEL}}{\sqrt{A}}$$

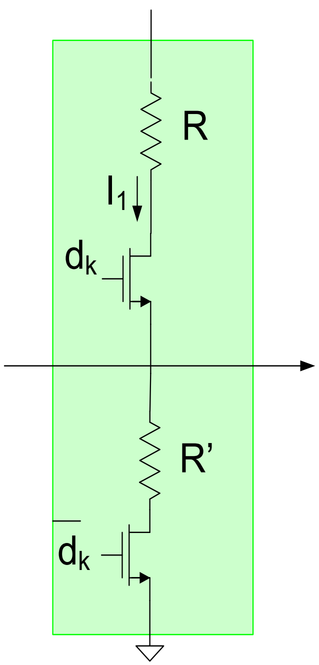
- Each additional bit of resolution requires a factor of 2 increase in area if same sized resistors are used
- Each additional bit of resolution requires another factor of 4 increase in area to maintain the same yield

Review from Last Lecture

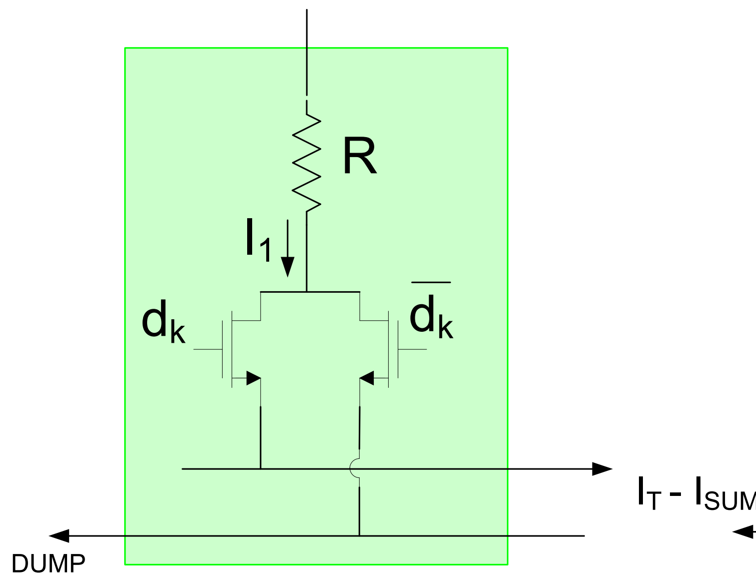
Current Steering DACs



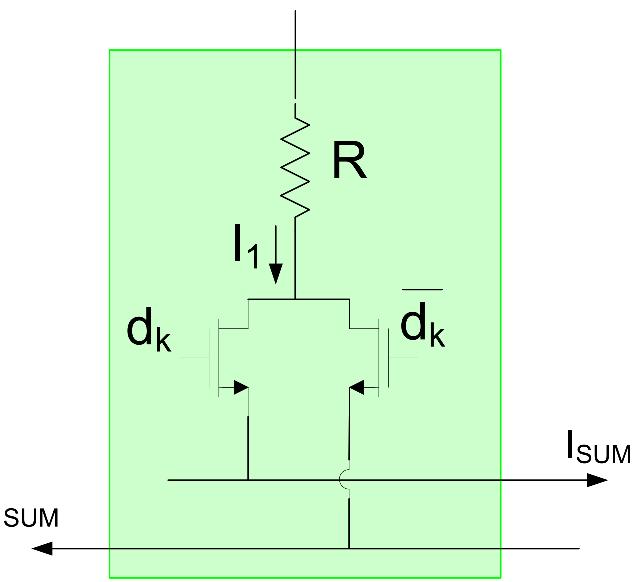




β Compensation



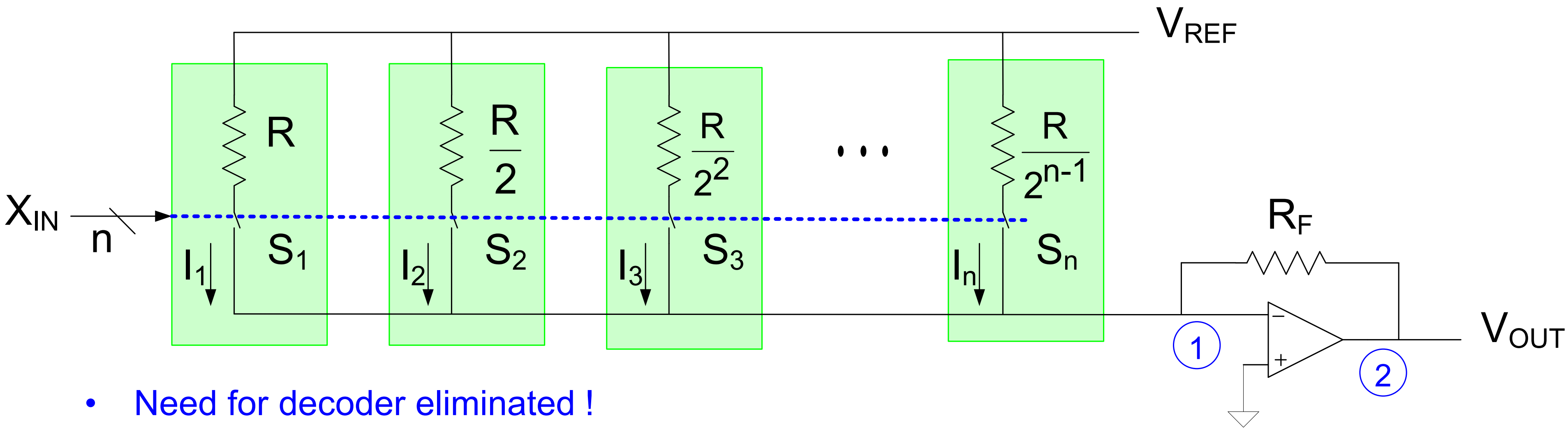
C_P Compensation



Differential Output

Current Steering DACs

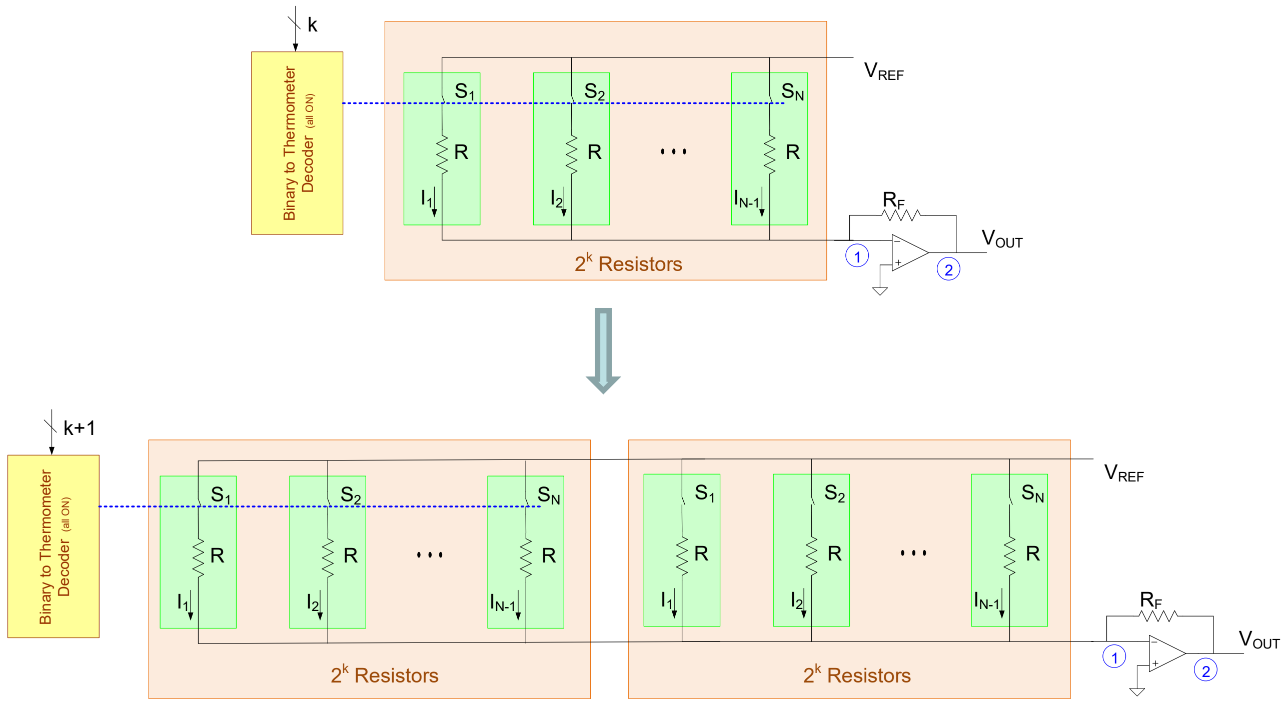
Binary-Weighted Resistor Arrays



- Need for decoder eliminated !
- DNL may be a major problem
- INL performance about same as thermometer coded if same unit resistors used
- Sizing and layout of switches is critical
- Unary resistor arrays usually used with common-centroid layout(at least for MSB)
- Ratio matching strongly dependent upon area (if common-centroid used to eliminate gradients)
- INL is a random variable with variance approximately proportional to $\sigma = \frac{A_{PEL}}{\sqrt{A}}$
- Area gets large for good yield with large n

Observe thermometer coding and binary weighted both offer some major advantages and some major limitations

Current Steering DACs



INL may be poor, typically near mid range

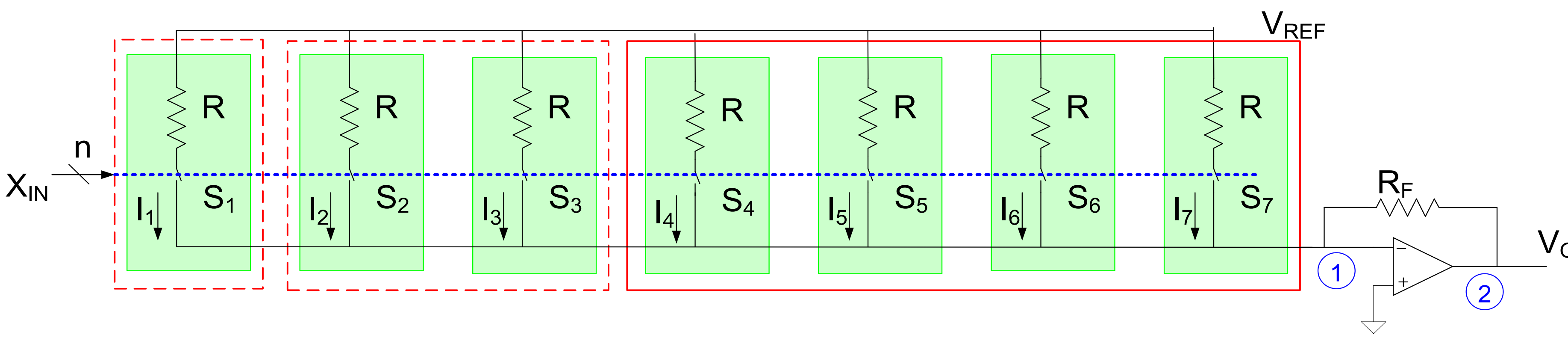
approximately $\sigma = \frac{A_{PEL}}{\sqrt{A}}$

Consider a k-bit structure that has an acceptable (and desired) yield of Y

Can a k+1 bit structure be easily implemented by simply making 2 copies of the resistor array and adding one bit to the decoder?

The one-afternoon design ?

Current Steering DACs

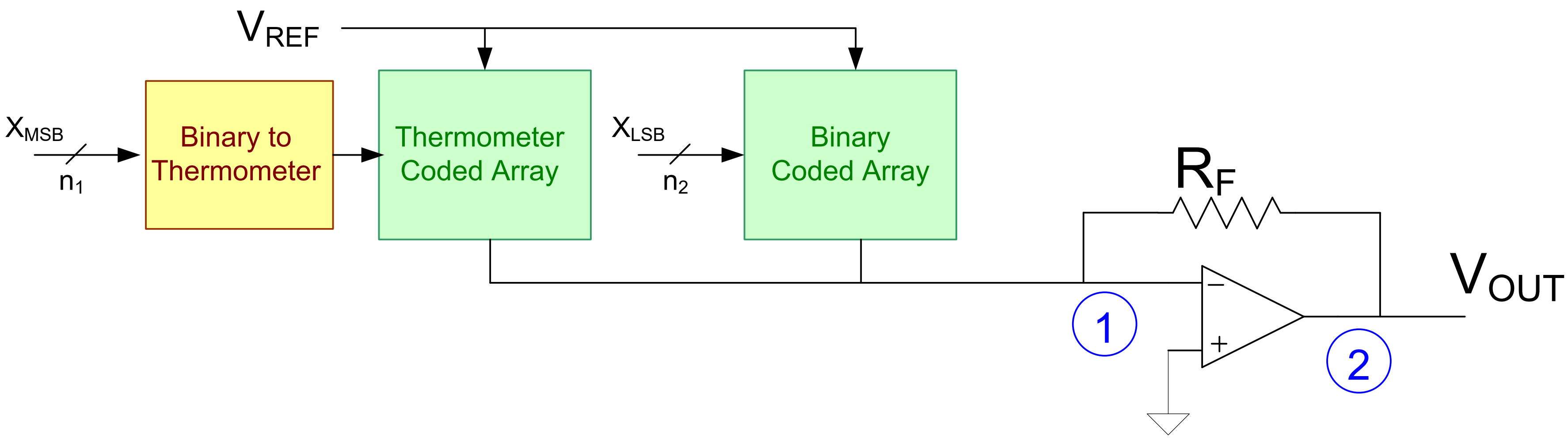


Binary-Weighted Resistor Arrays

Actual layout of resistors is very important

As stated earlier, bundled unary cells are almost always used

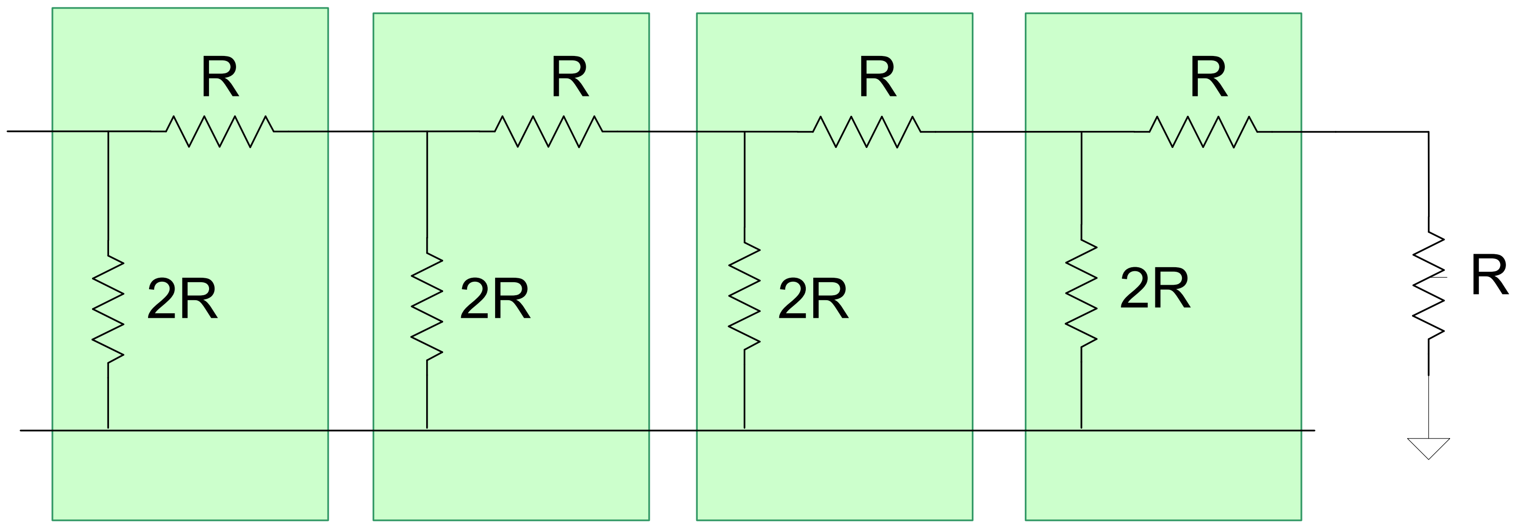
Current Steering DACs



Segmented Resistor Arrays

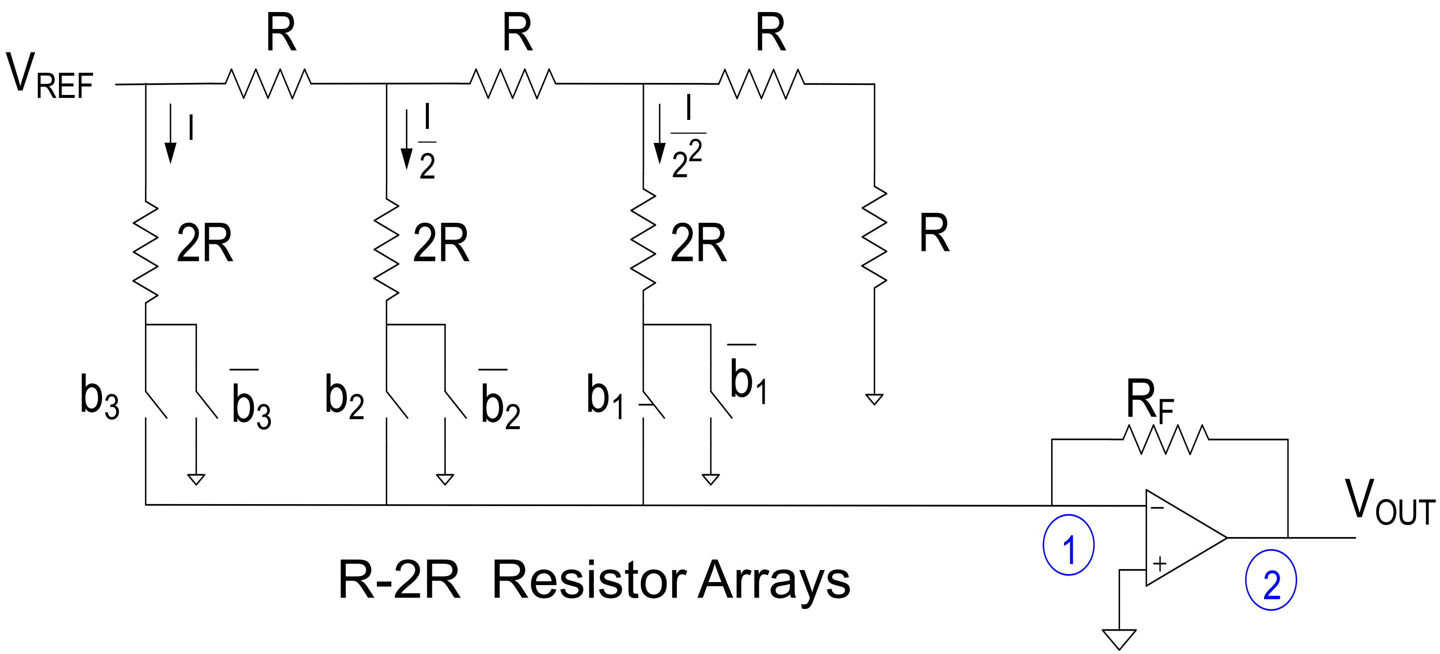
- Combines two types of architectures
- Inherits advantages of both thermometer and binary approach
- Minimizes limitations of both thermometer and binary approach

R-2R Resistor Arrays



- 4 bit-slices shown
- Can be extended to arbitrary number of bit slices
- Conceptually, area goes up linearly with number of bit slices

Current Steering DACs



R-2R Resistor Arrays

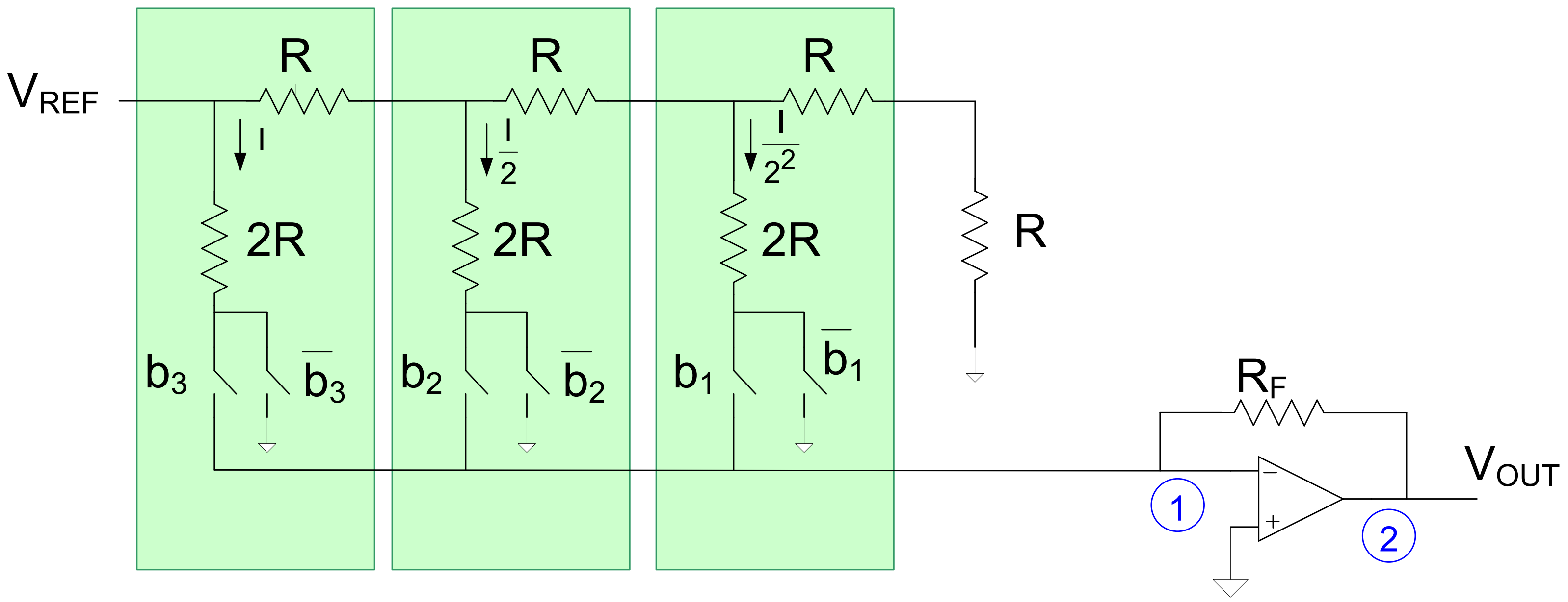
Eliminates need for decoder

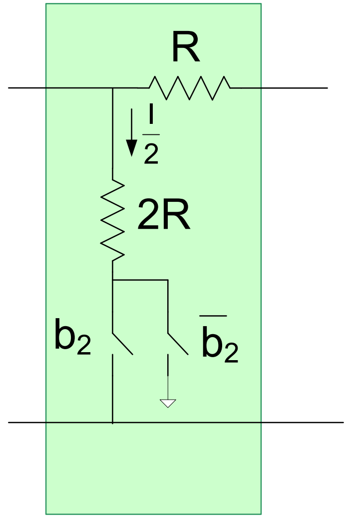
Node voltages ideally stay constant for any input code

Highly sensitive to nonlinearities in switches

How should switches be sized?

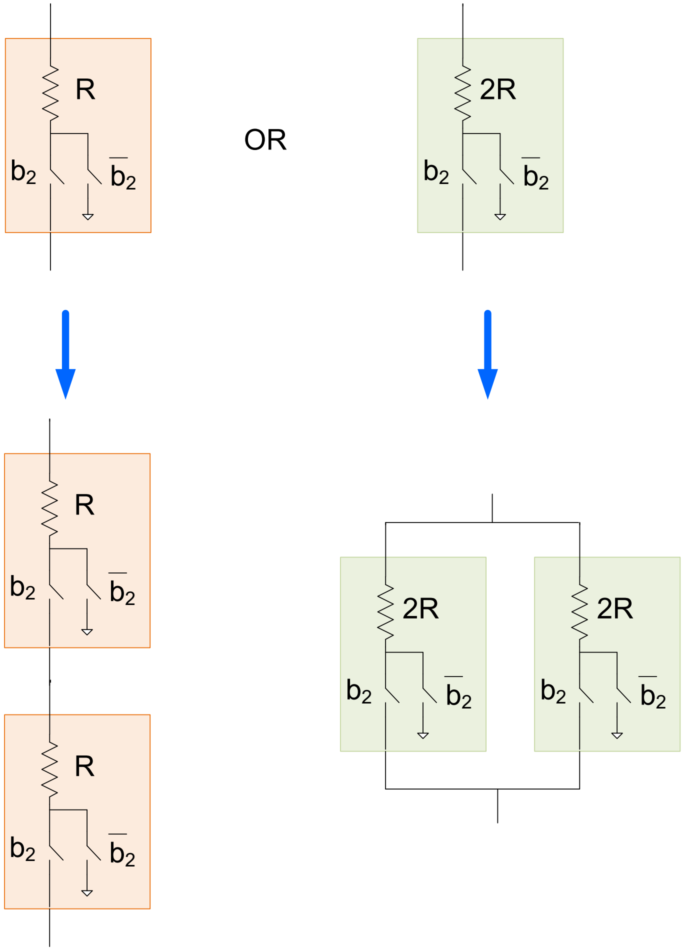
Current Steering DACs





R-2R Resistor Arrays

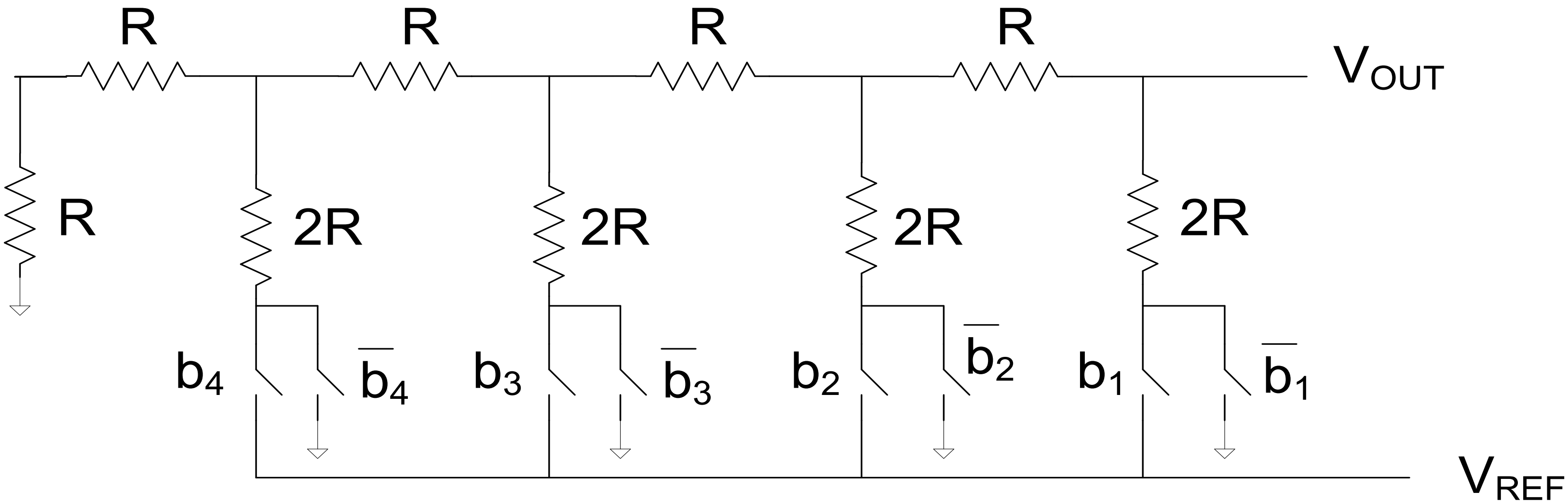
R-2R Implementation



- Unit cell widely used
- Switch included in cell even if not switched!
- Code dependence of switch impedance of concern

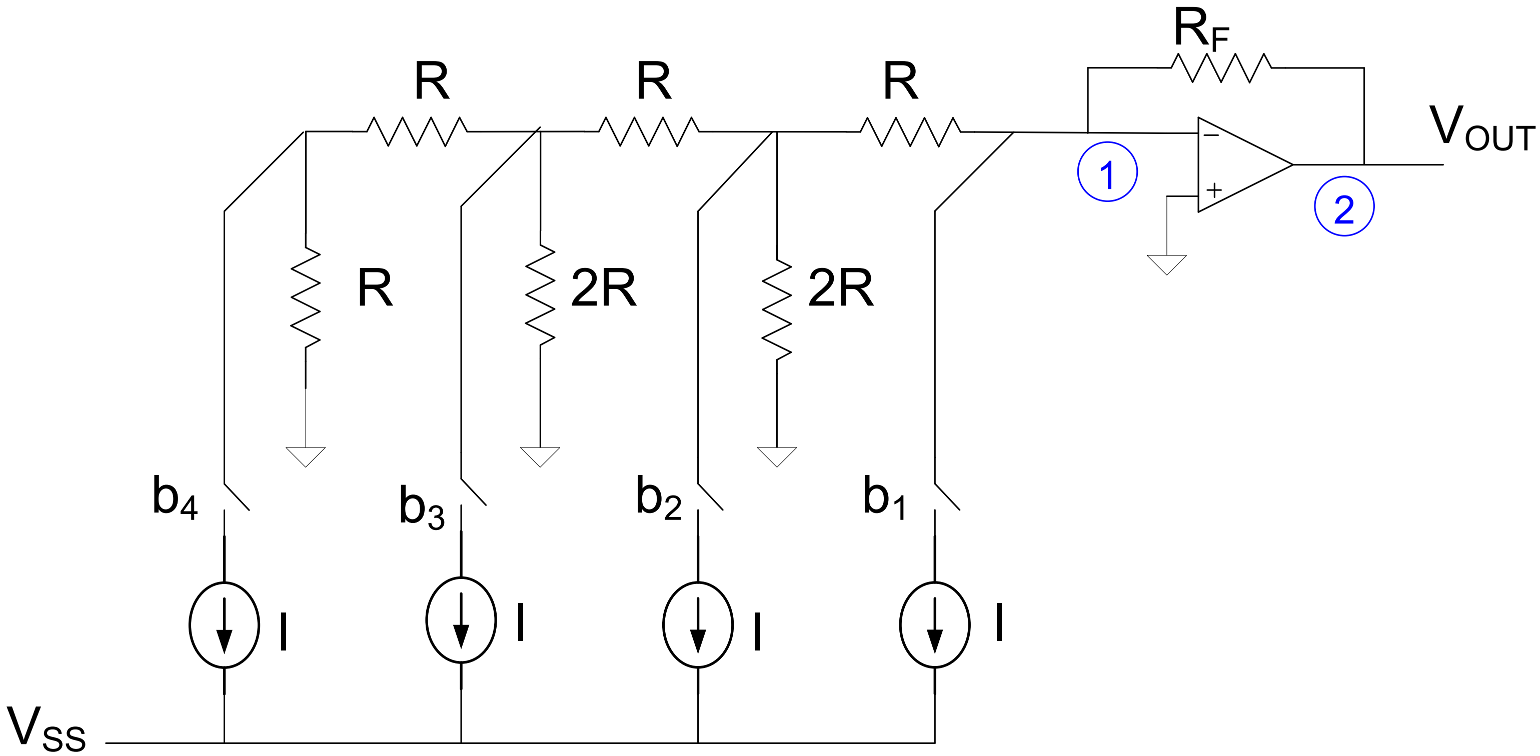
How can switch impedances be matched?

Another R-2R DAC



Node voltages change with input code

Another R-2R DAC



Requires matching both current sources and resistors

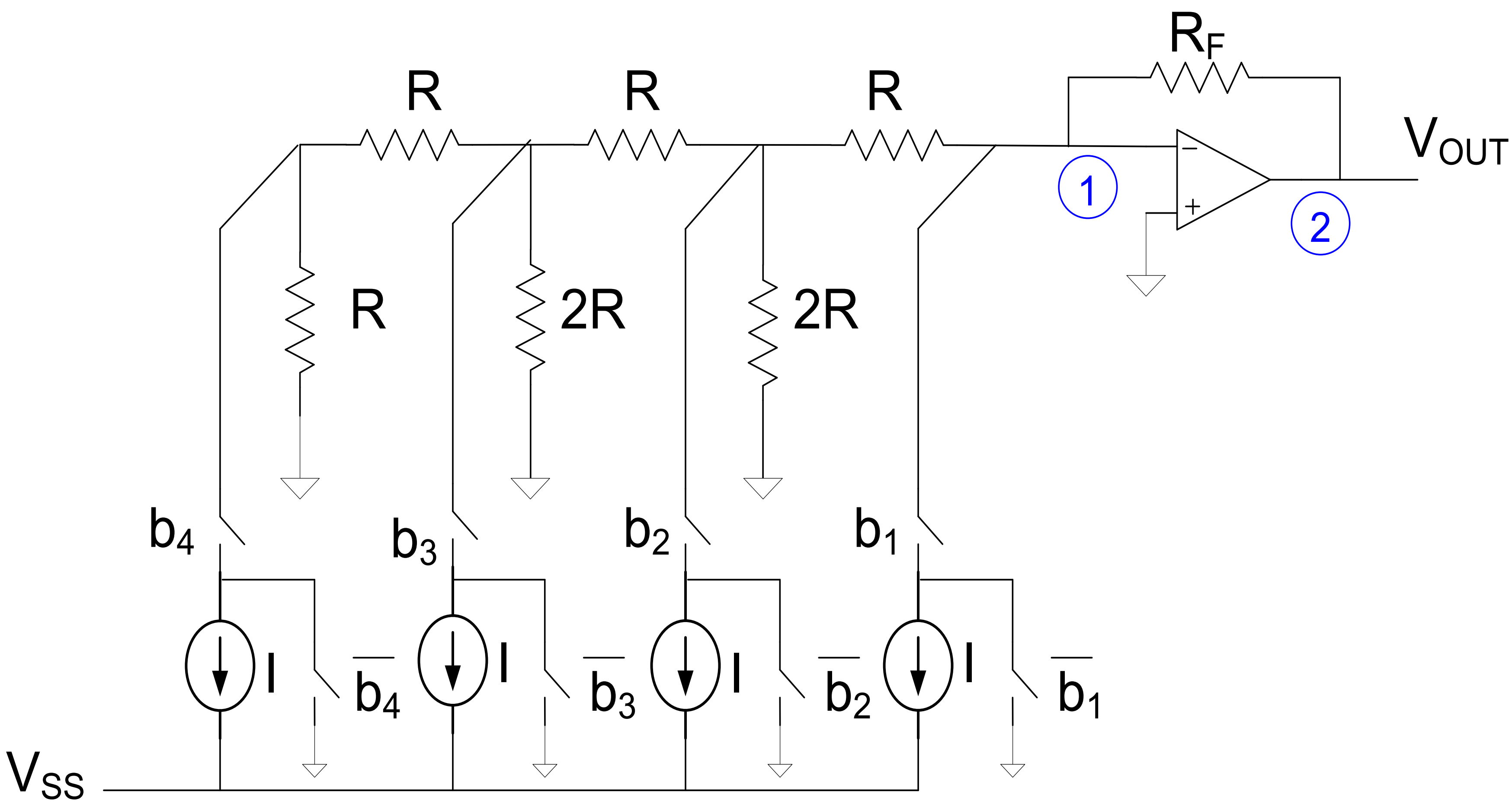
But switch impedance does not affect performance

β is independent of Boolean code

Node voltages in R/2R block must change for any input transitions

Voltages on internal R-2R nodes must settle with input transitions

Another R-2R DAC



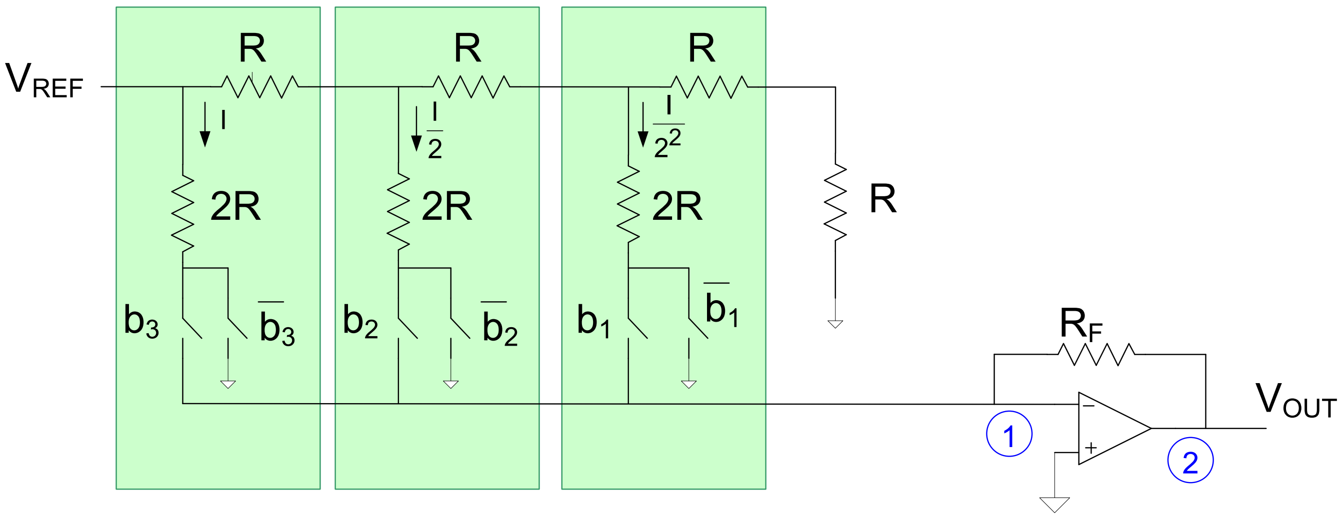
Clocks must be nonoverlapping

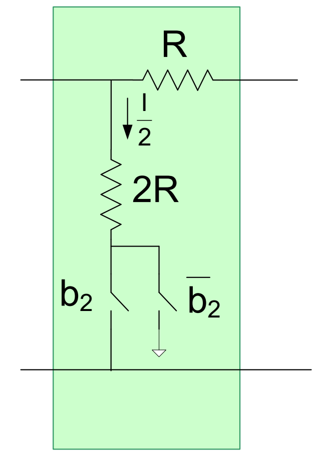
Does this offer any benefits over previous approach ?

Offers some compensation for capacitances on current sources

Are there other terminations for the current sources?

R-2R DACs





Bit Slice

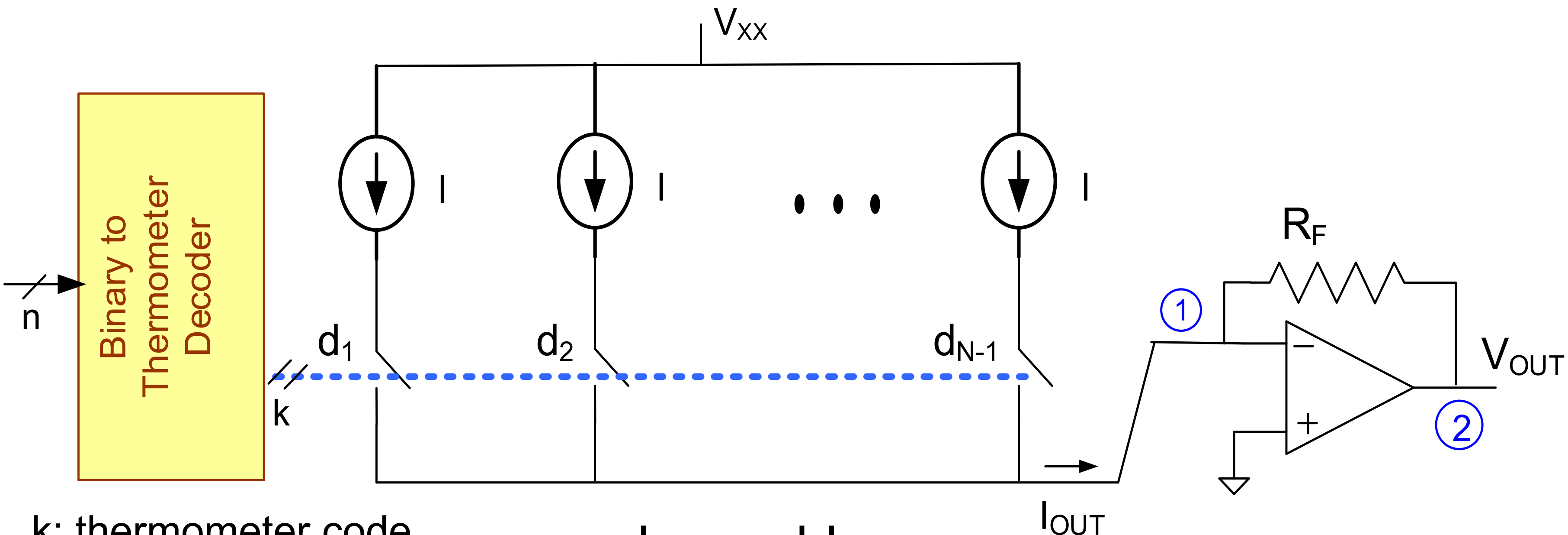
Key characteristic of R-2R Structures

- 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

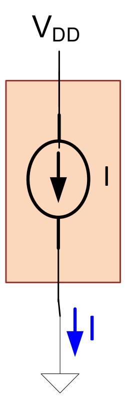
- Switches directly affect R-2R values and ratios
- Voltage on internal nodes must settle for some structures
- If unary cell used, area not optimally allocated for matching

Current Steering DAC



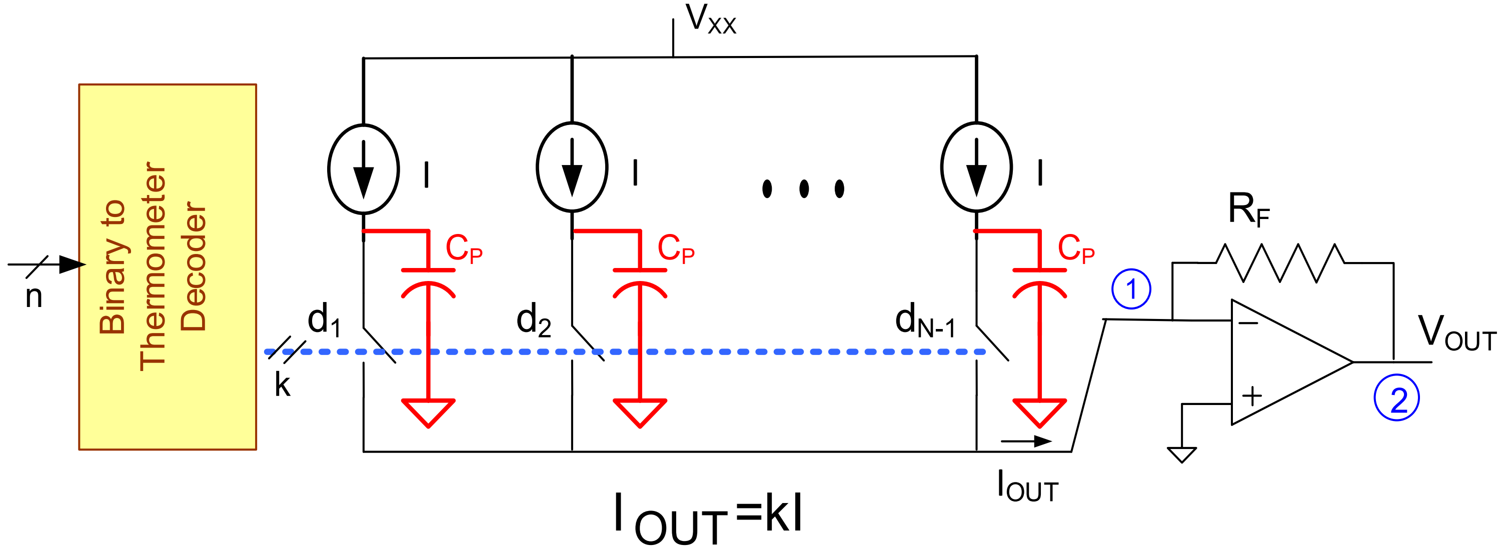
k: thermometer code

$$I_{OUT} = kI$$



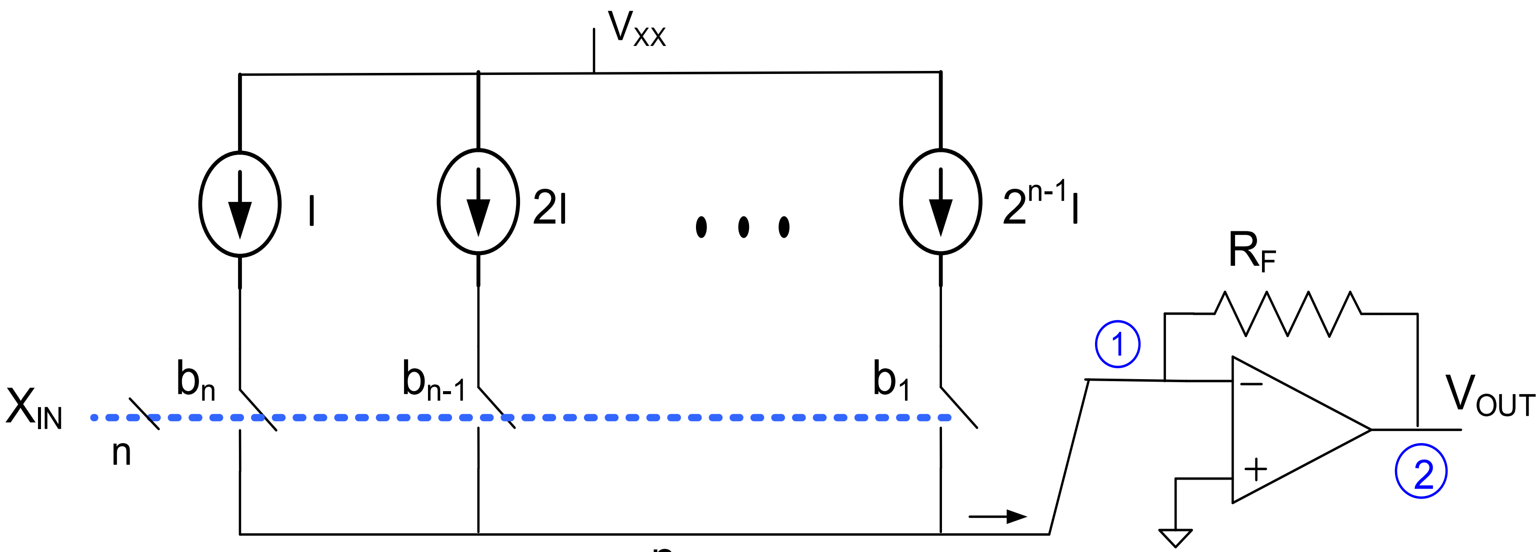
Switch impedance of little concern if current sources ideal

Current Steering DAC



Critical parasitic capacitors in current-steering DAC

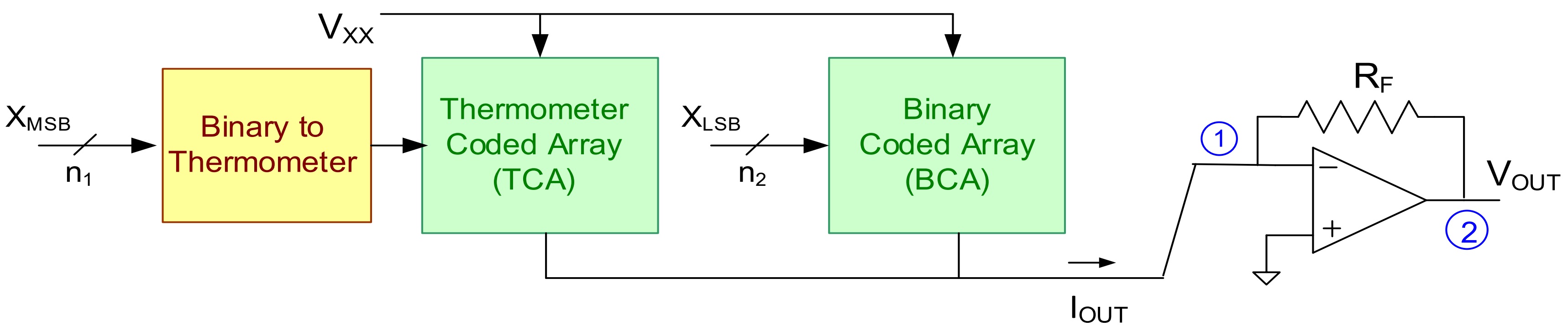
Current Steering DAC



$$\mathbf{I}_{OUT} = \mathbf{I} \bullet \sum_{i=1}^{n} b_i 2^{n-i}$$

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

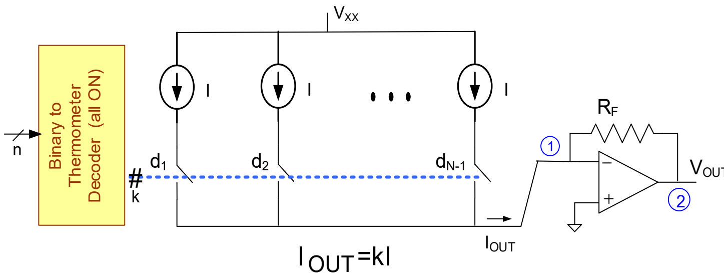
Current Steering DAC

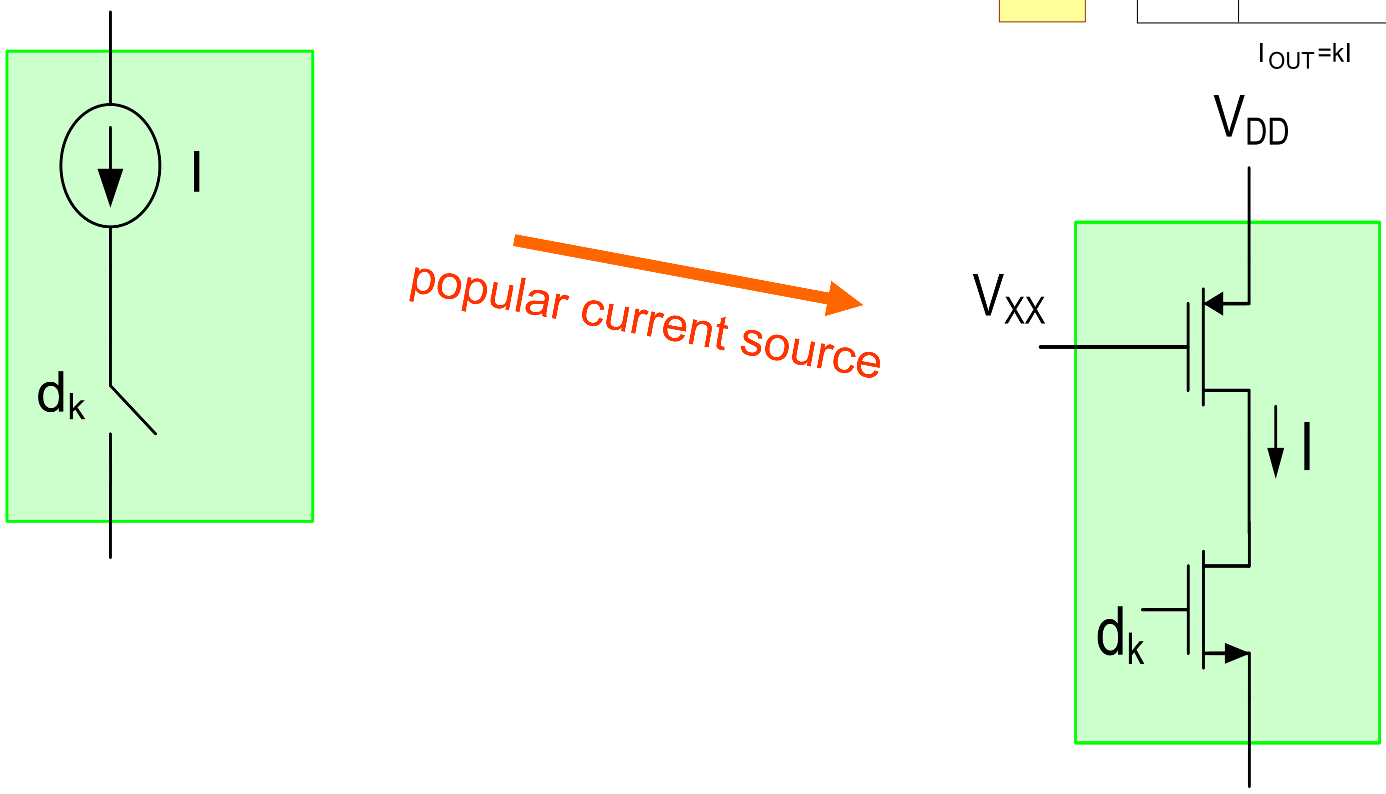


Segmented Structure

- 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

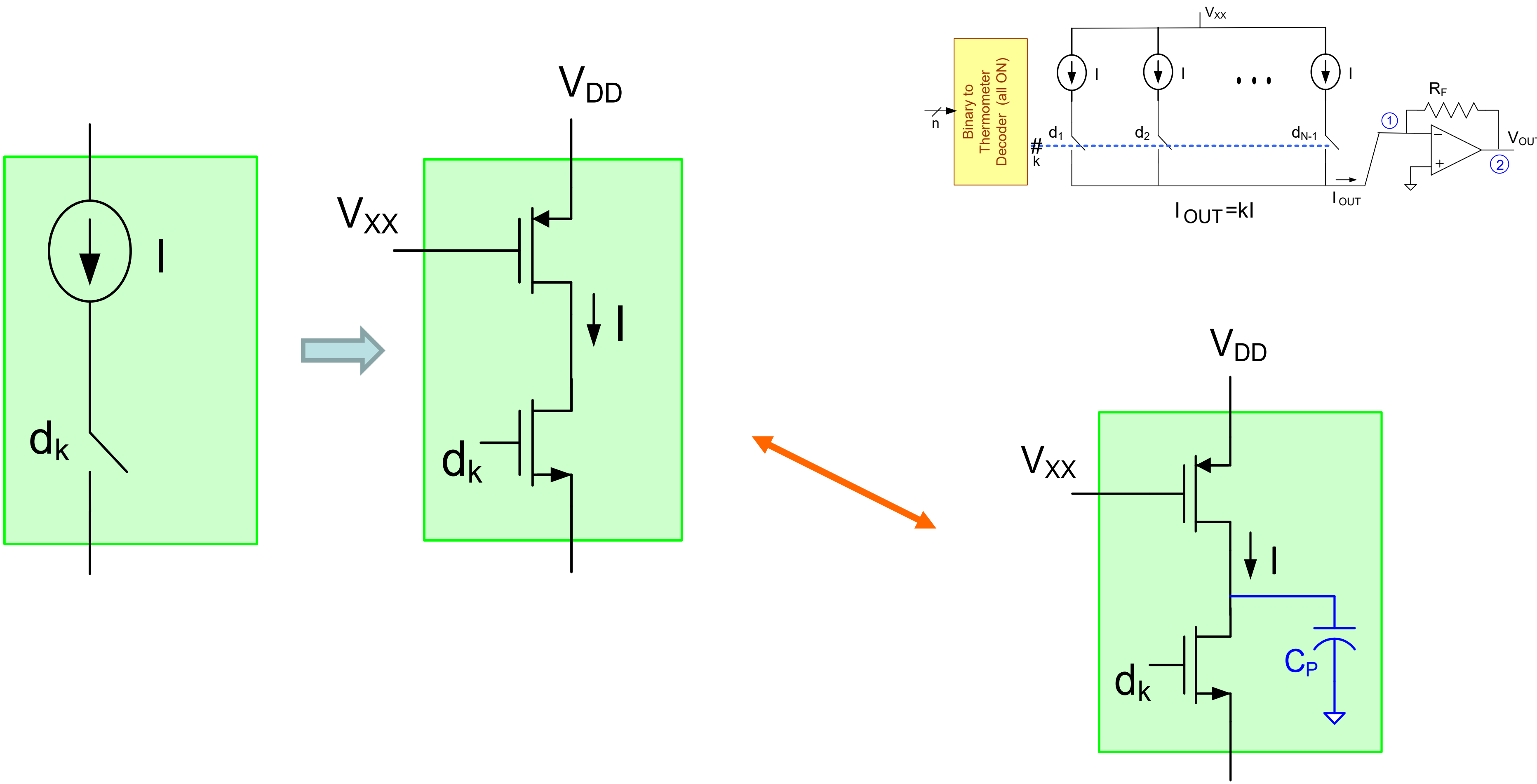




Is linearity or output impedance of current source of concern?

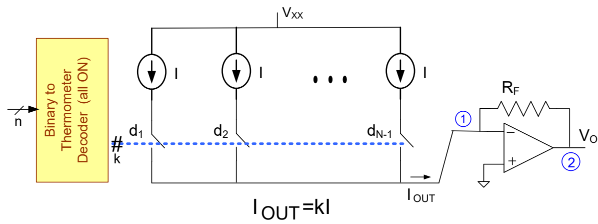
Not if individual slices are matched !

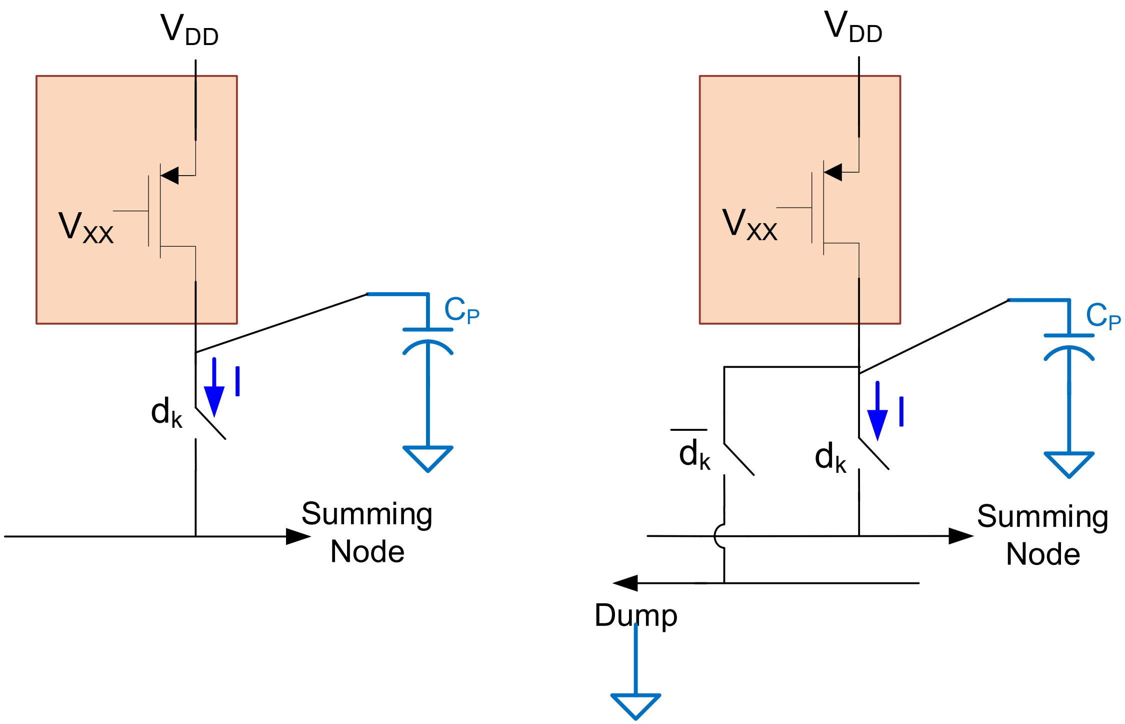
Current Steering DAC



Parasitic capacitance on output of current source problematic

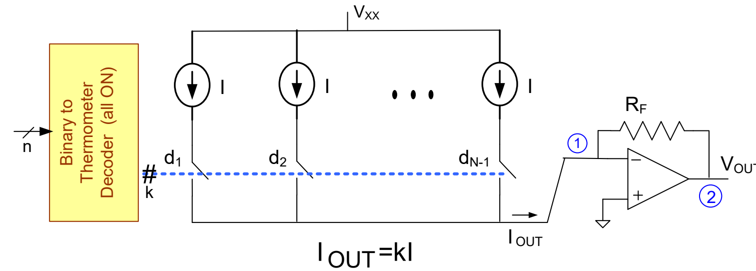
Current Steering DAC

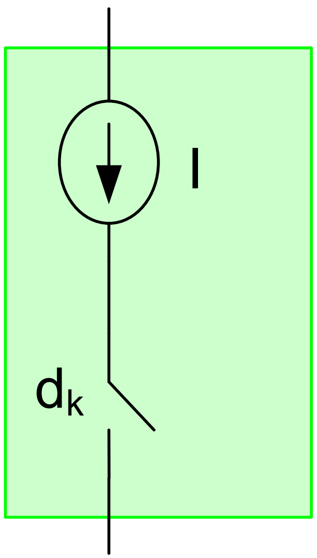




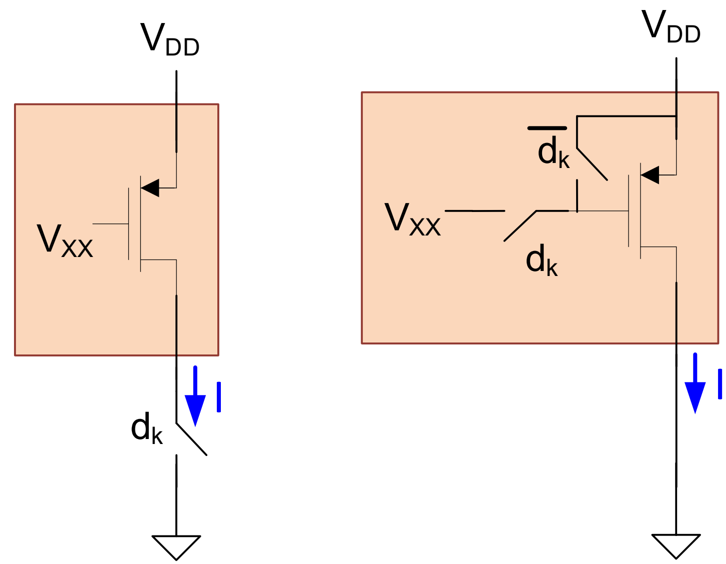
Reducing Effects of Parasitic capacitance on output of current source

Current Steering DAC





Alternative current source cells

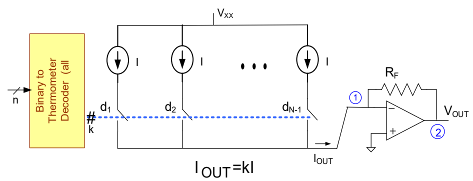


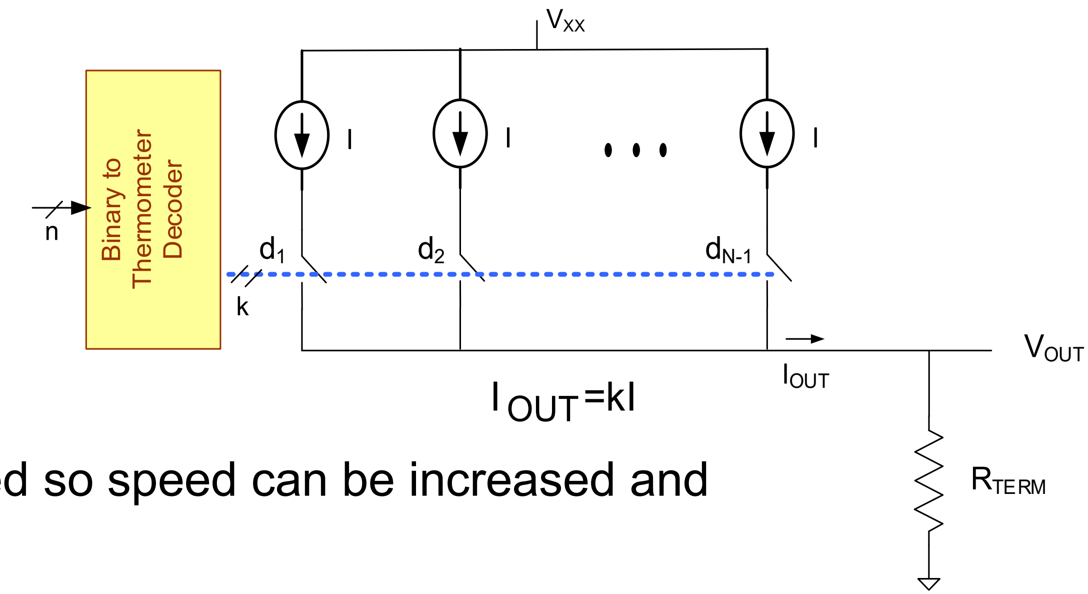
Which is better?

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

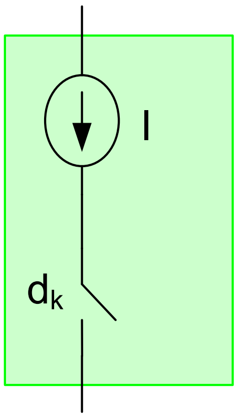
R_{TERM} often 50Ω or 100Ω

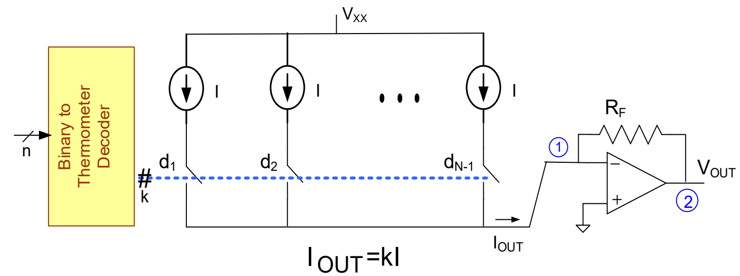
R_{TERM} can be internal or external

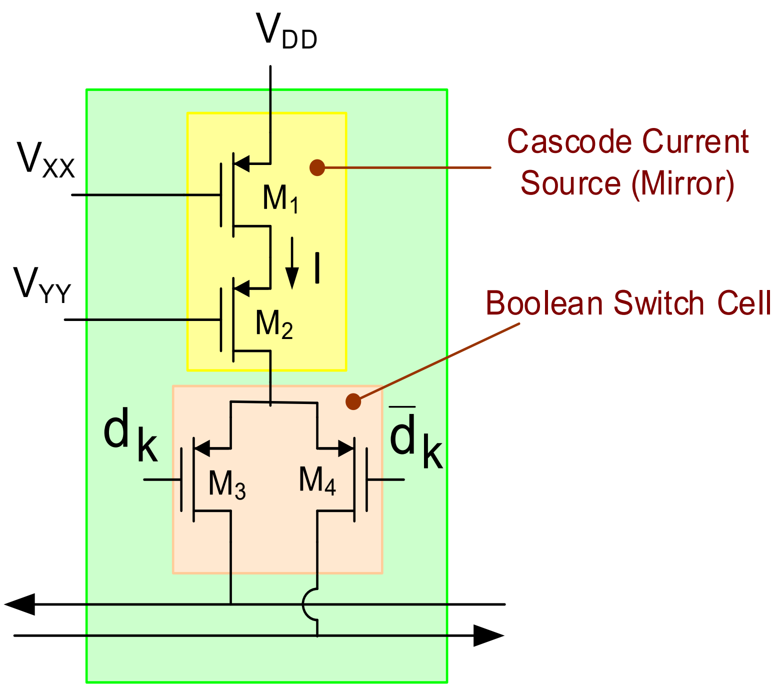
Switch impedance now of concern

Output impedance of current sources now of concern

Current Steering DAC



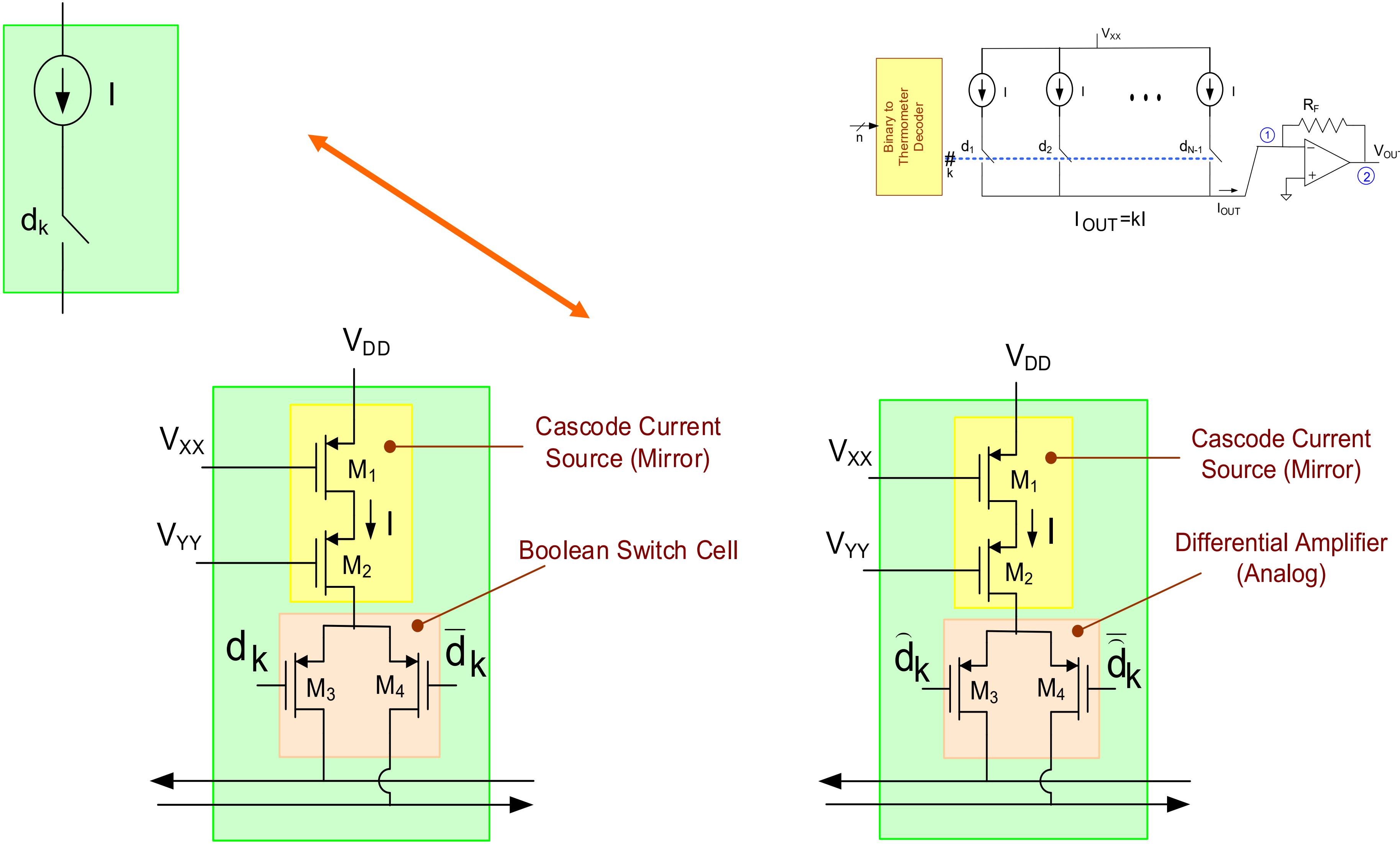




Cascoding reduces output conductance of current source

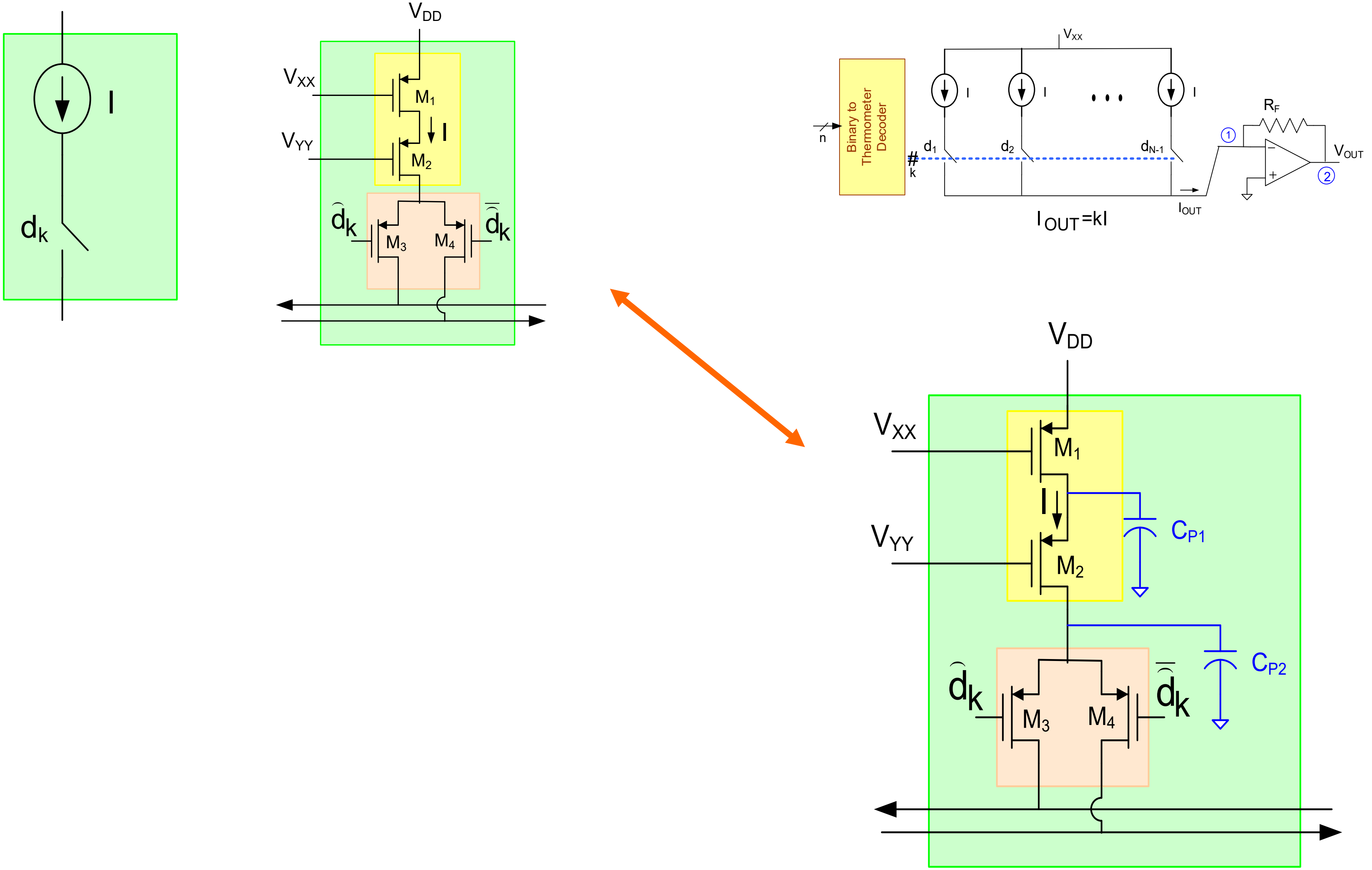
No power penalty, slight reduction in overhead

Current Steering DAC

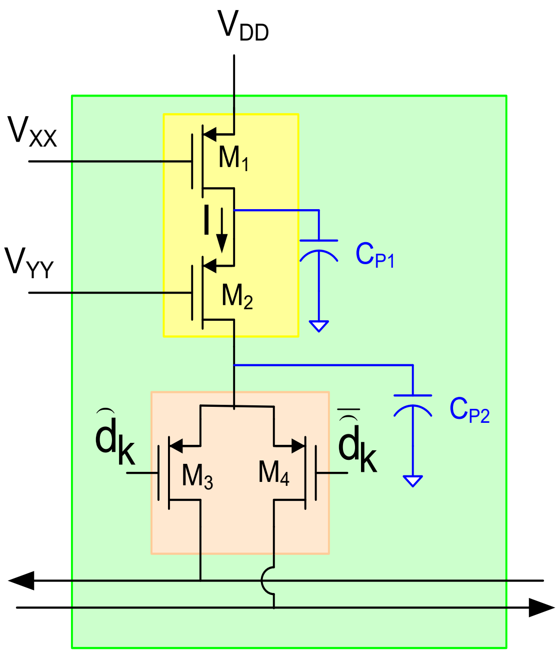


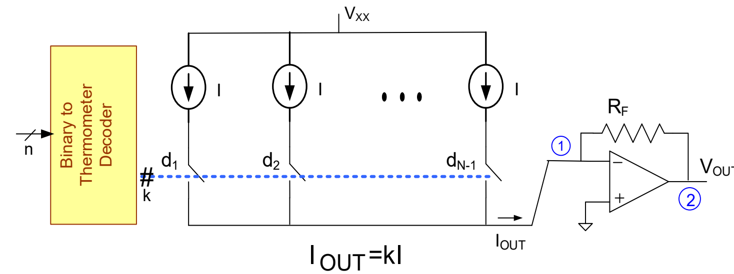
Steer rather than switch current
Reduced swing on control signals

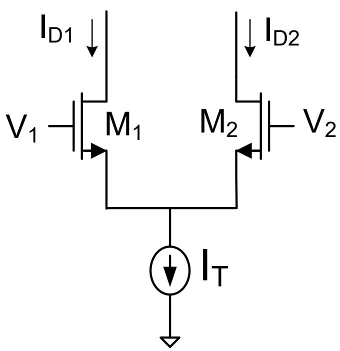
Current Steering DAC

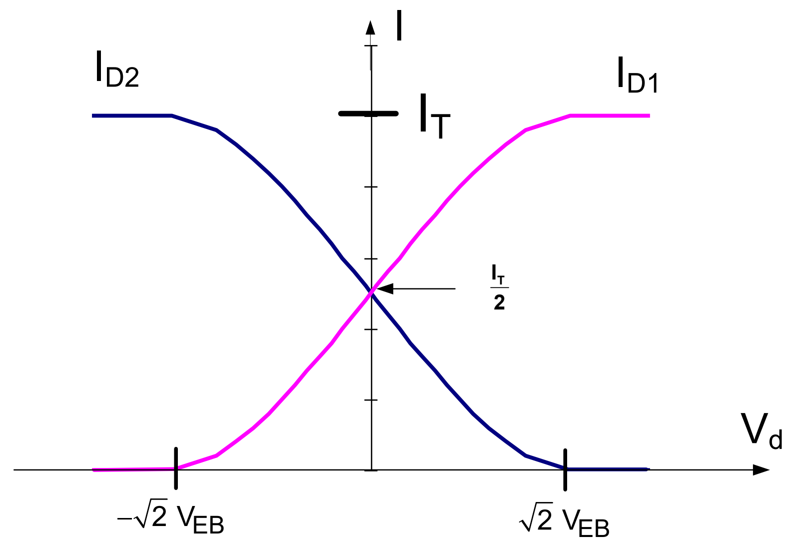


Current Steering DAC



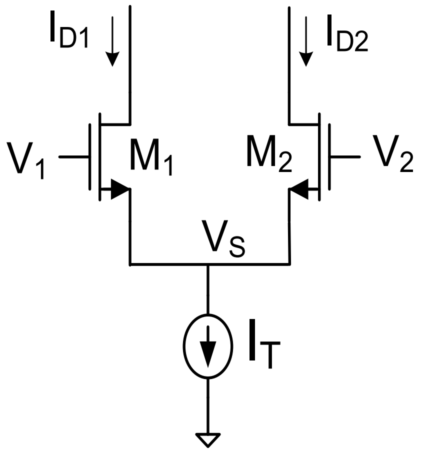


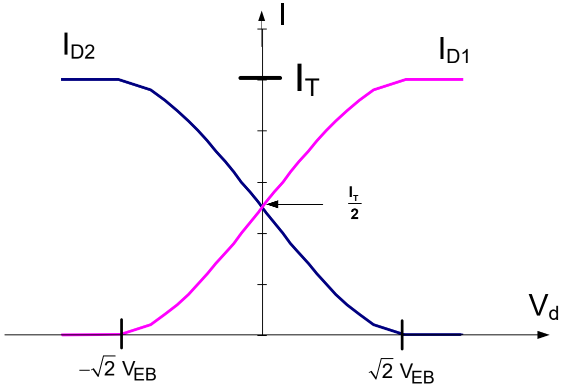




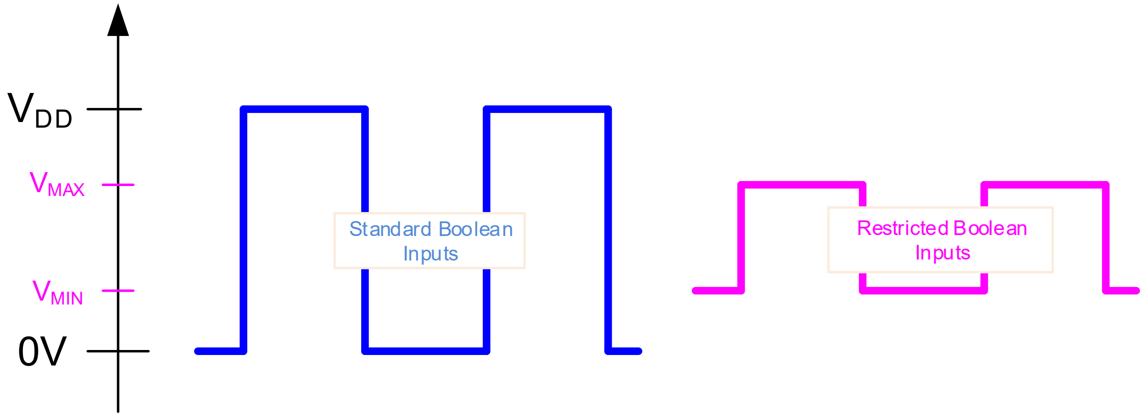
- Need only signal swing of $2\sqrt{2}V_{EB}$ to steer currents (so can reduce turn-on and turn-off times)
- Steering also results in cascoding with M_3 and M_4 thus increasing output impedance of current source (so can probably eliminate M_2)

Current Steering DAC

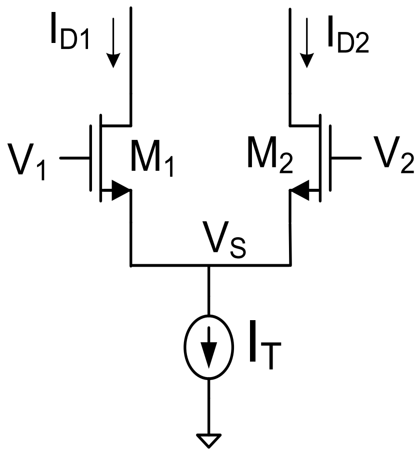


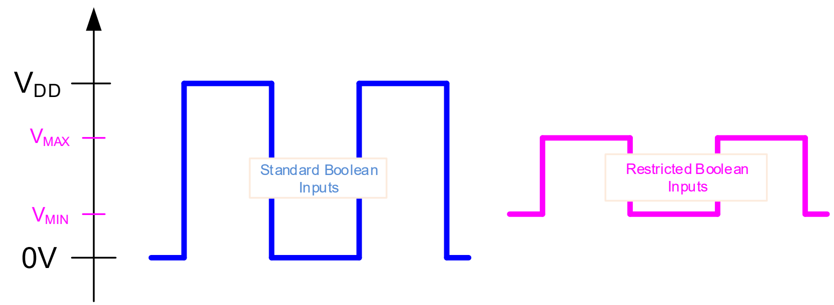


Reduced Signal Swing on V_S Node with Current Steering

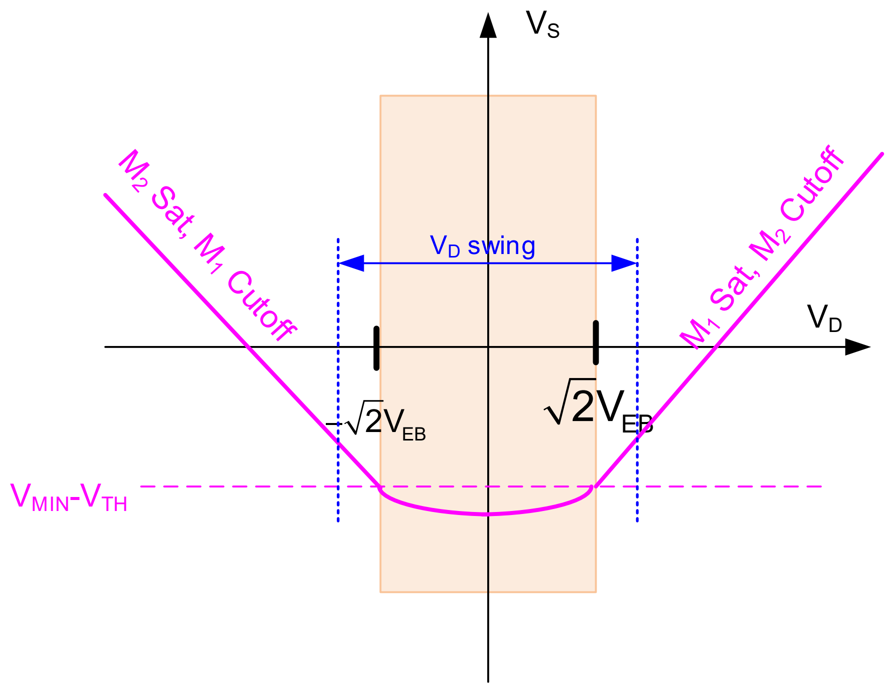


Current Steering DAC

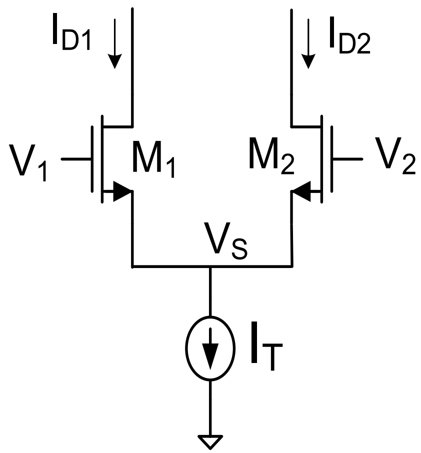


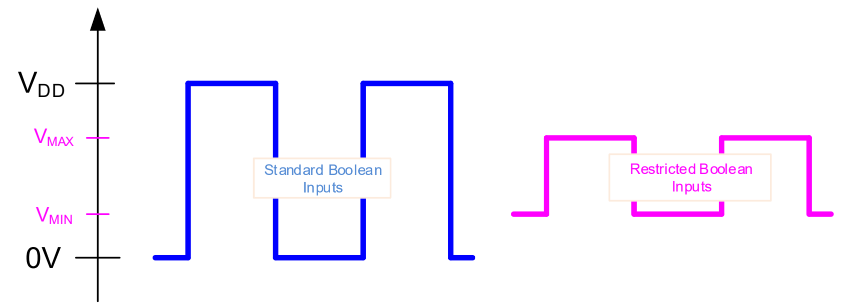


Reduced Signal Swing on V_S Node with Current Steering



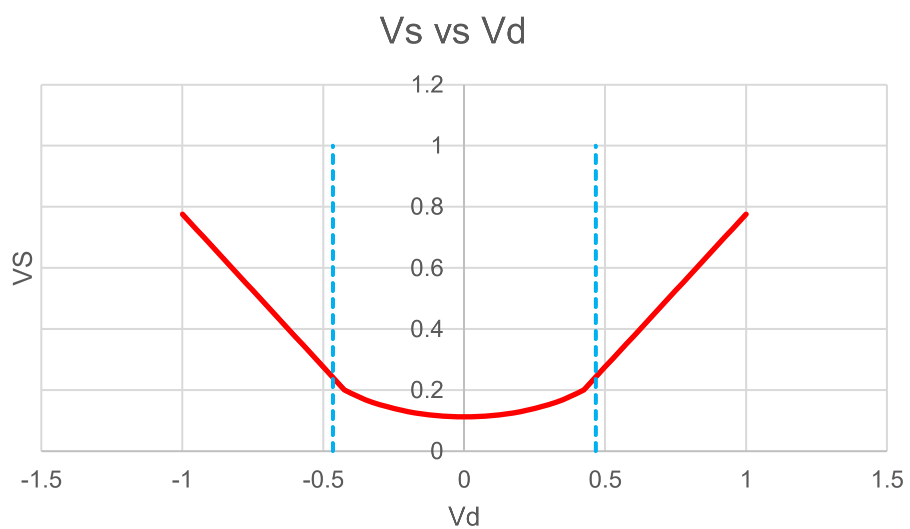
Current Steering DAC





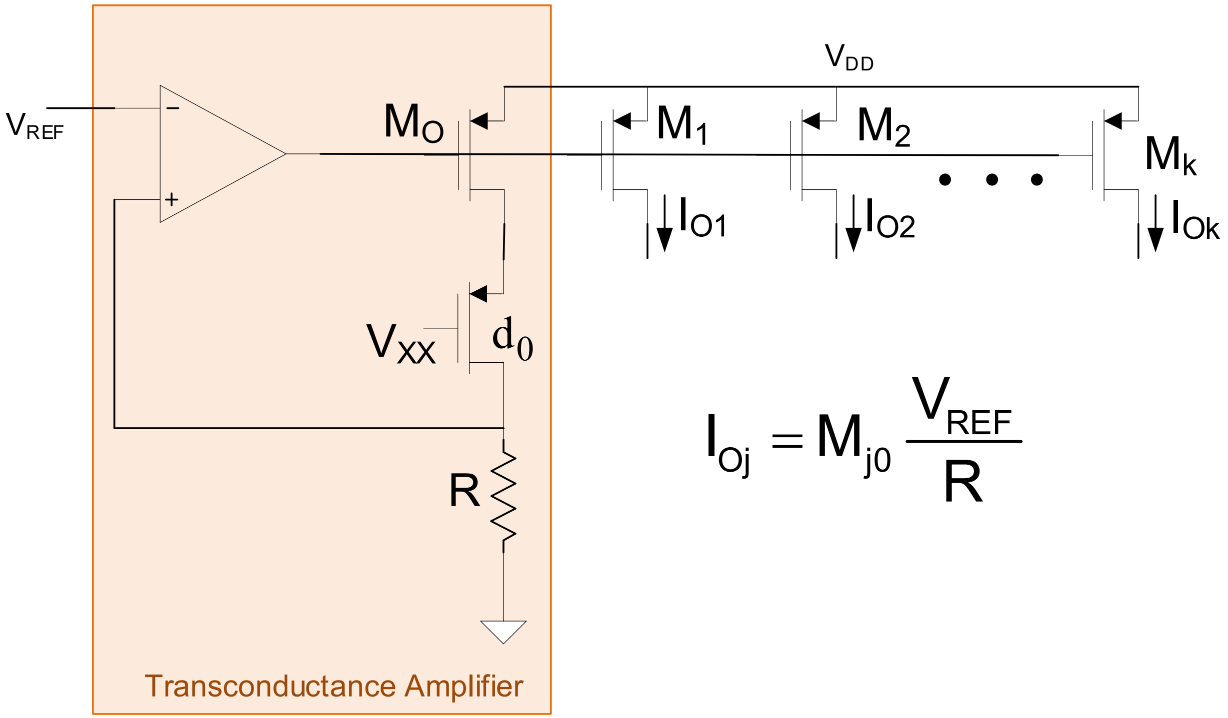
Reduced Signal Swing on V_S Node with Current Steering

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

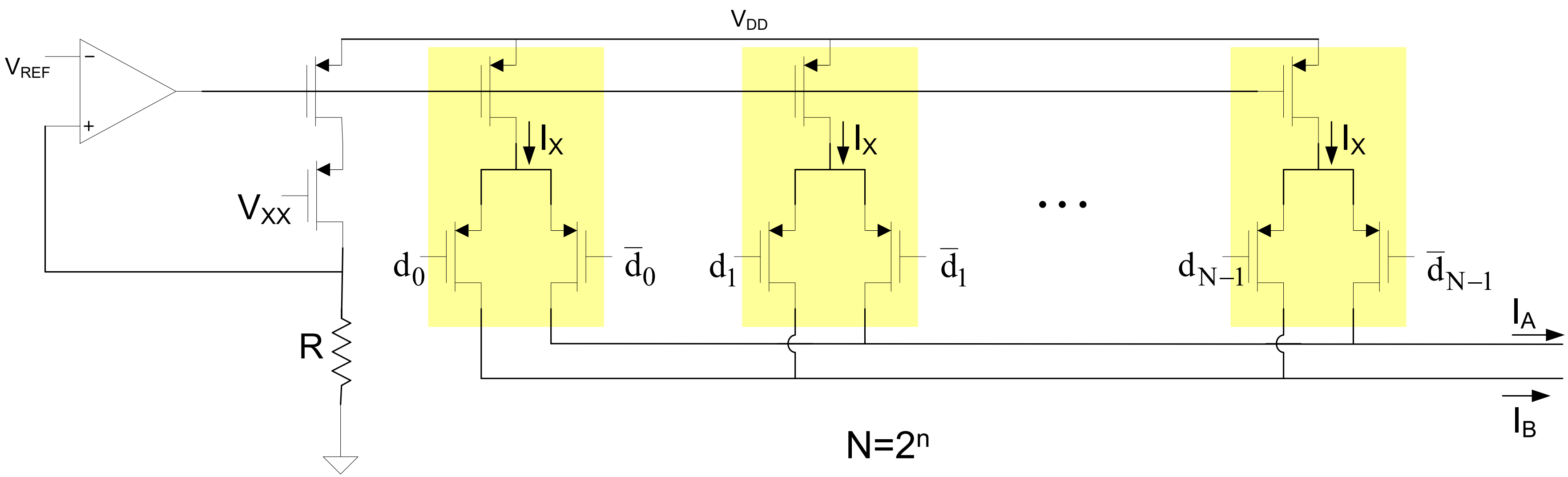
Multiple-output Transconductance Amplifier



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

- 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



$N=2^n$

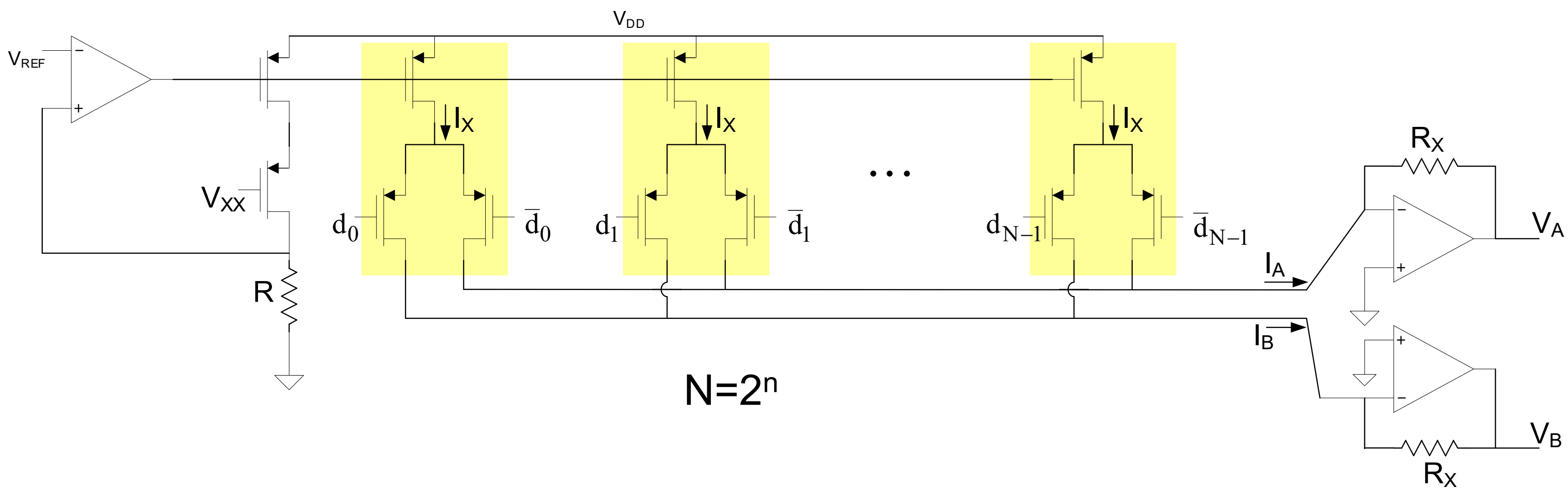
If transistors on top row are all matched, $I_X=V_{REF}/R$

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

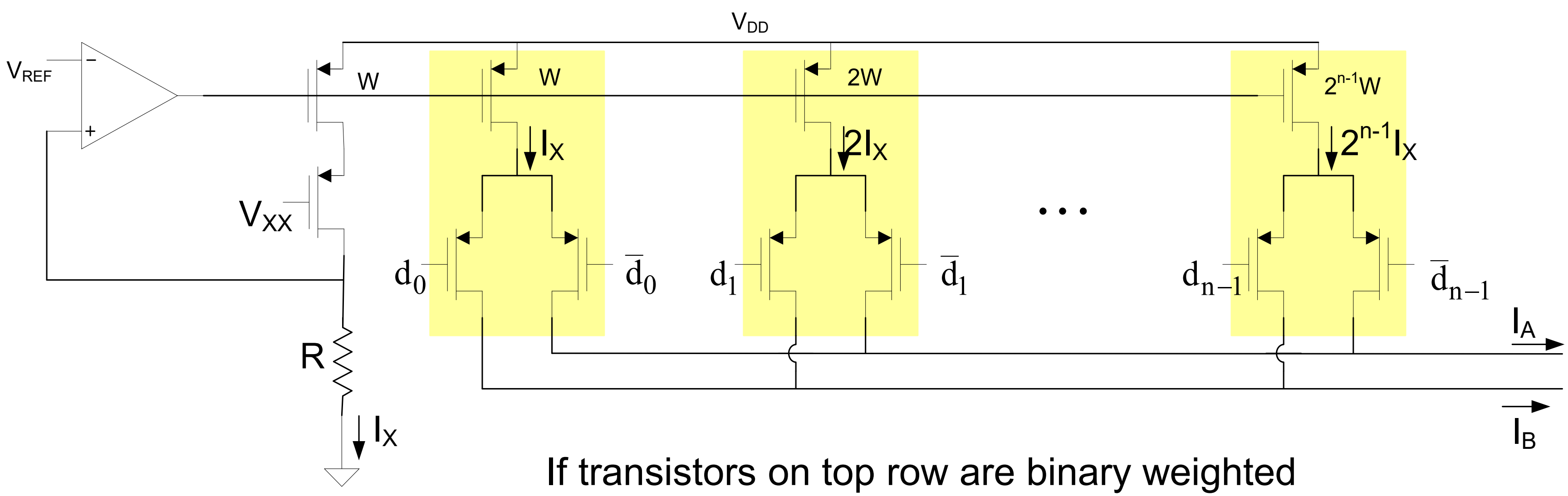


If transistors on top row are all matched, $I_X = V_{REF}/R$

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

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)

Stay Safe and Stay Healthy !

End of Lecture 34