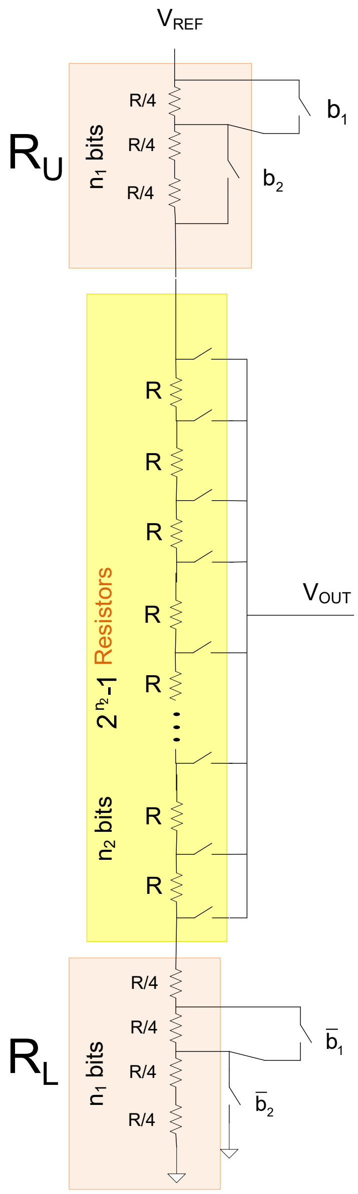
EE 435

Lecture 34

Switches
Current Steering DACs

Review from Last Lecture

Basic R-String DAC

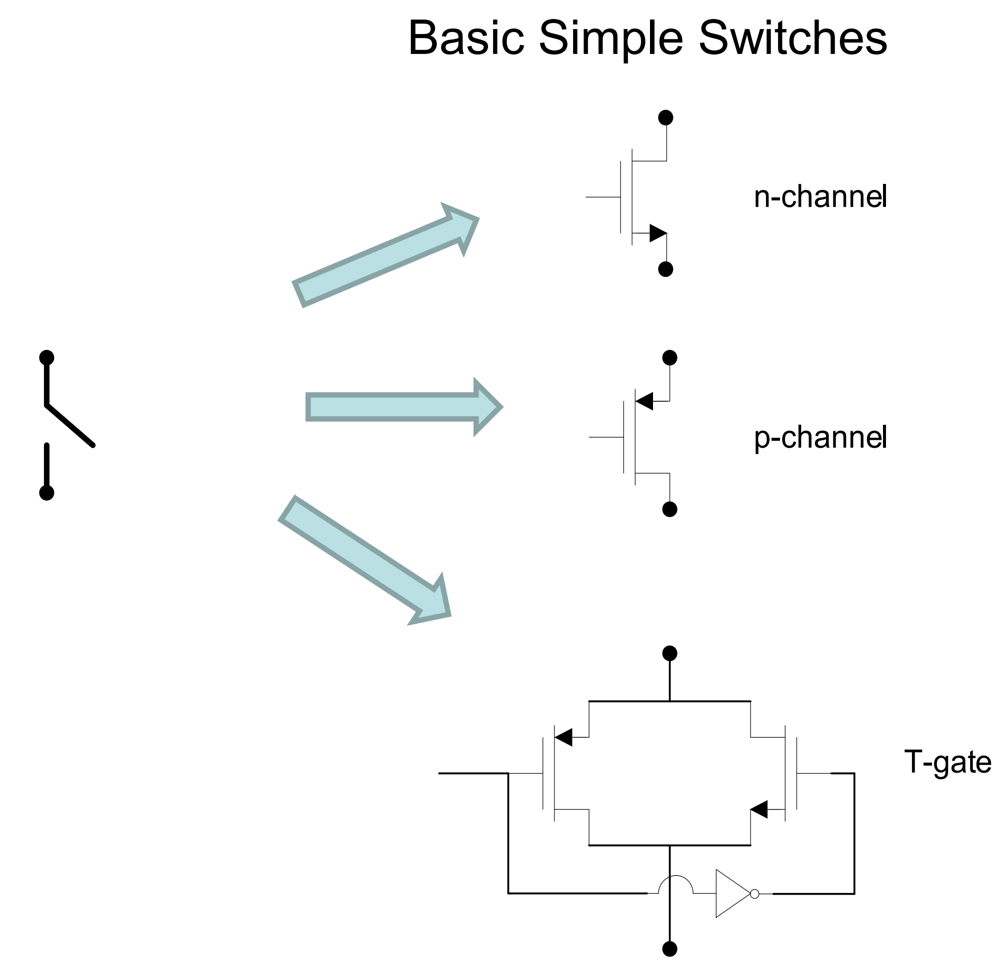


For all b_1 and b_2, $R_U+R_L=R$

- Another Segmented DAC structure
- Can be viewed as a "dither" DAC
- Often n_1 is much smaller than n_2
- Dither can be used in other applications as well

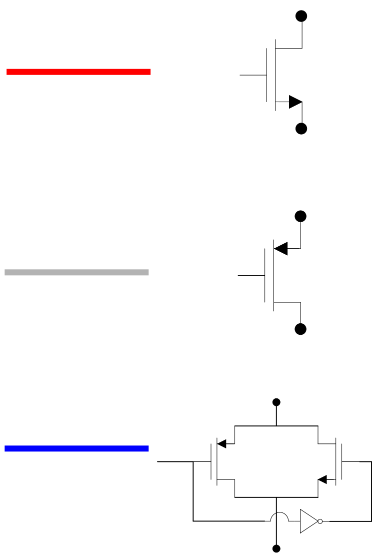
Switches used extensively in data converters !

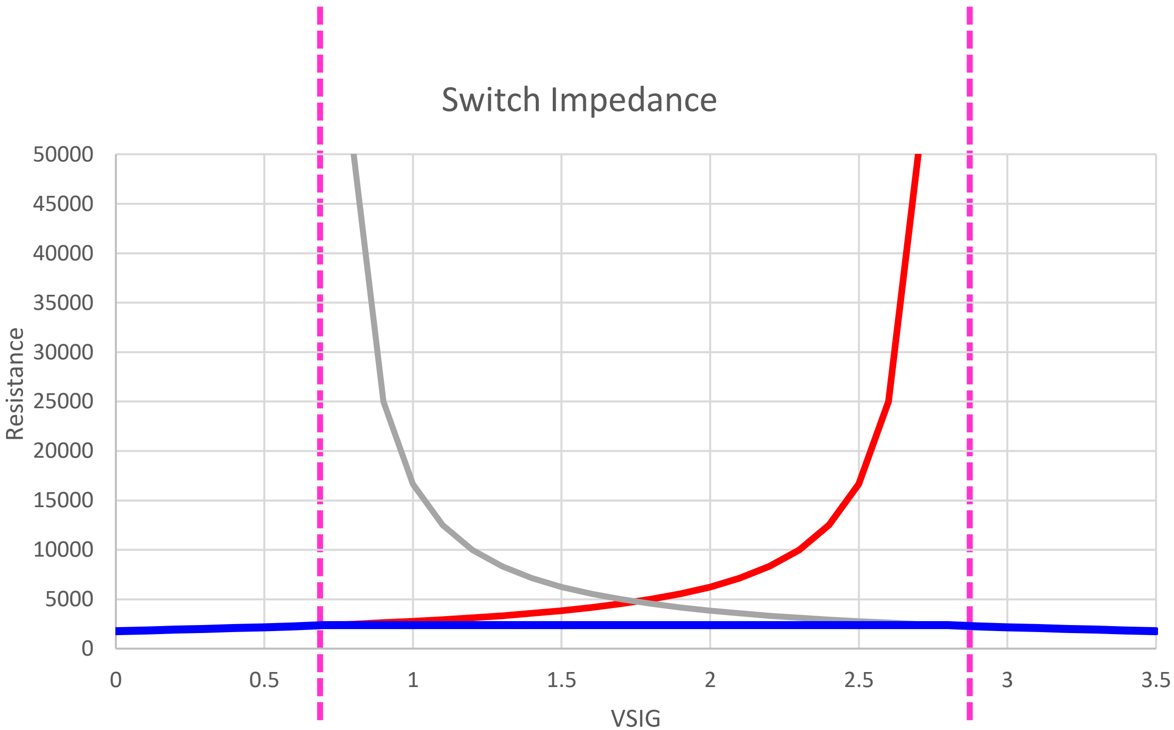
Switch Implementation Issues



Switch Implementation Issues

V_{THn}=0.7
V_{THp}=-0.7
W_p=3W_n
L_p=L_n
V_{DD}=3.5V





V_{SIG}: Voltage on switch when ON

Switch Implementation Issues

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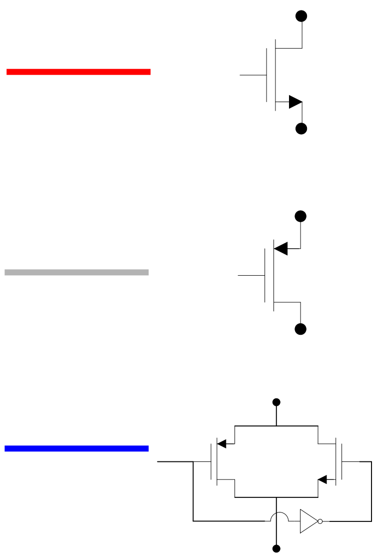

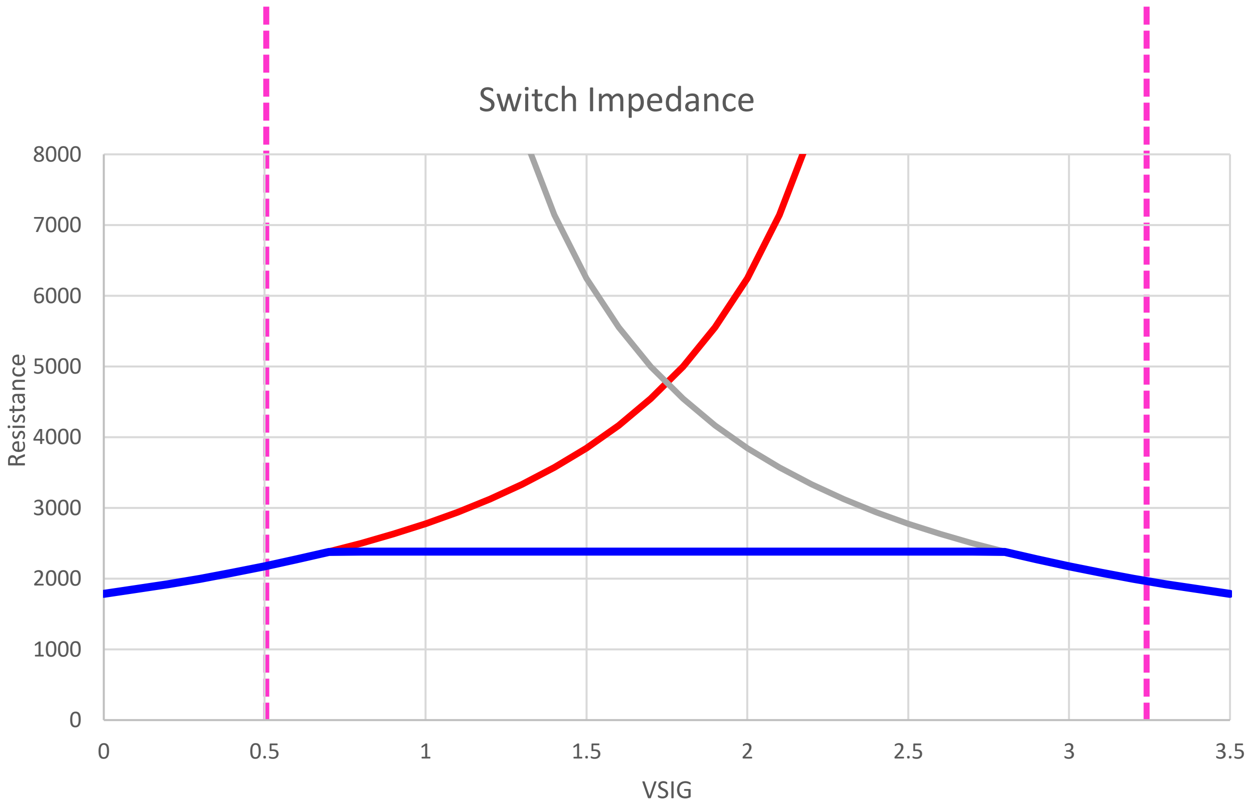

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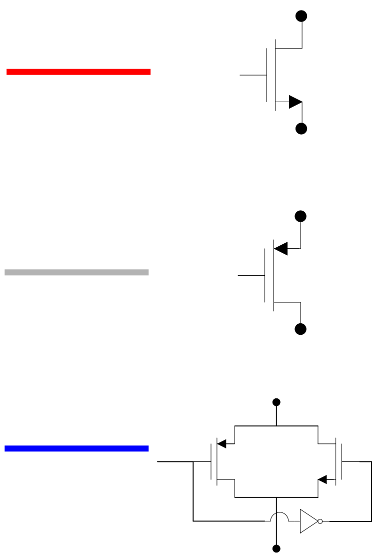
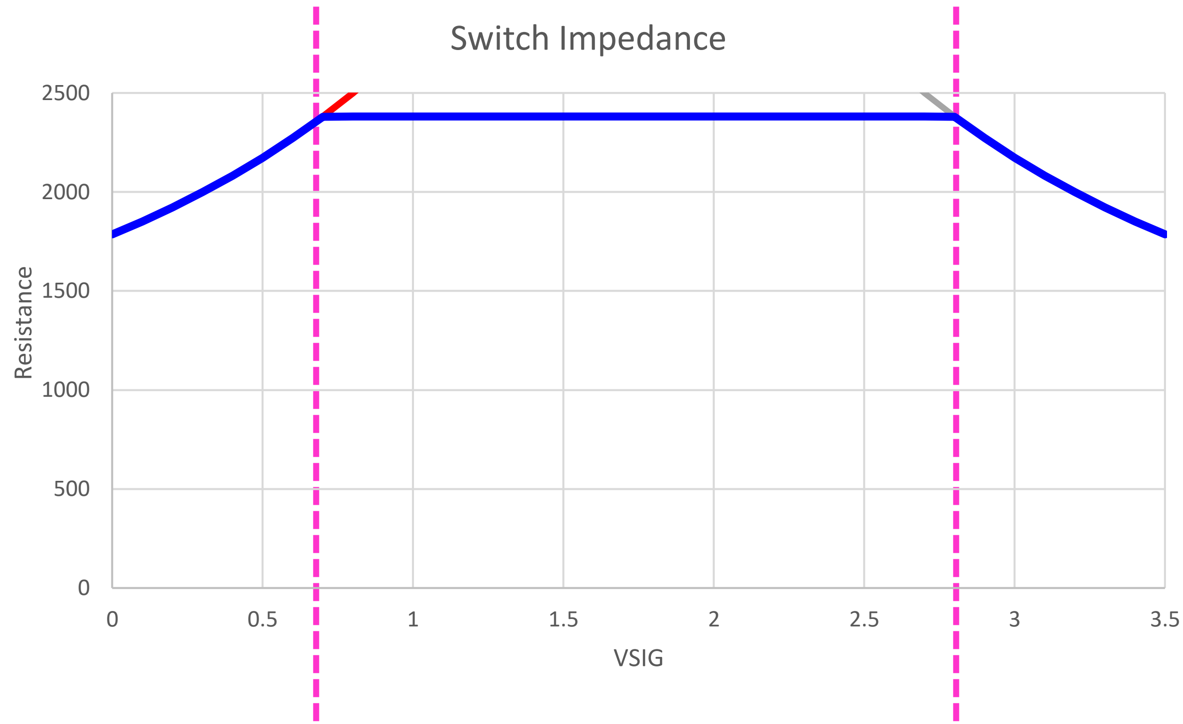


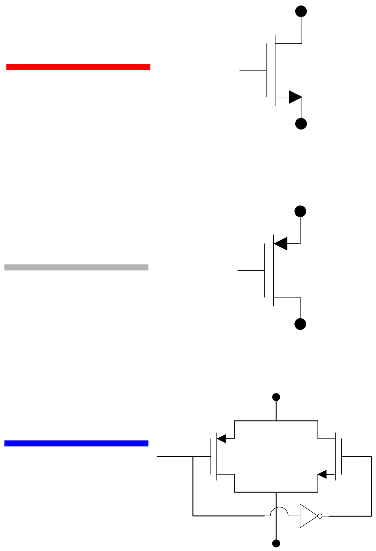


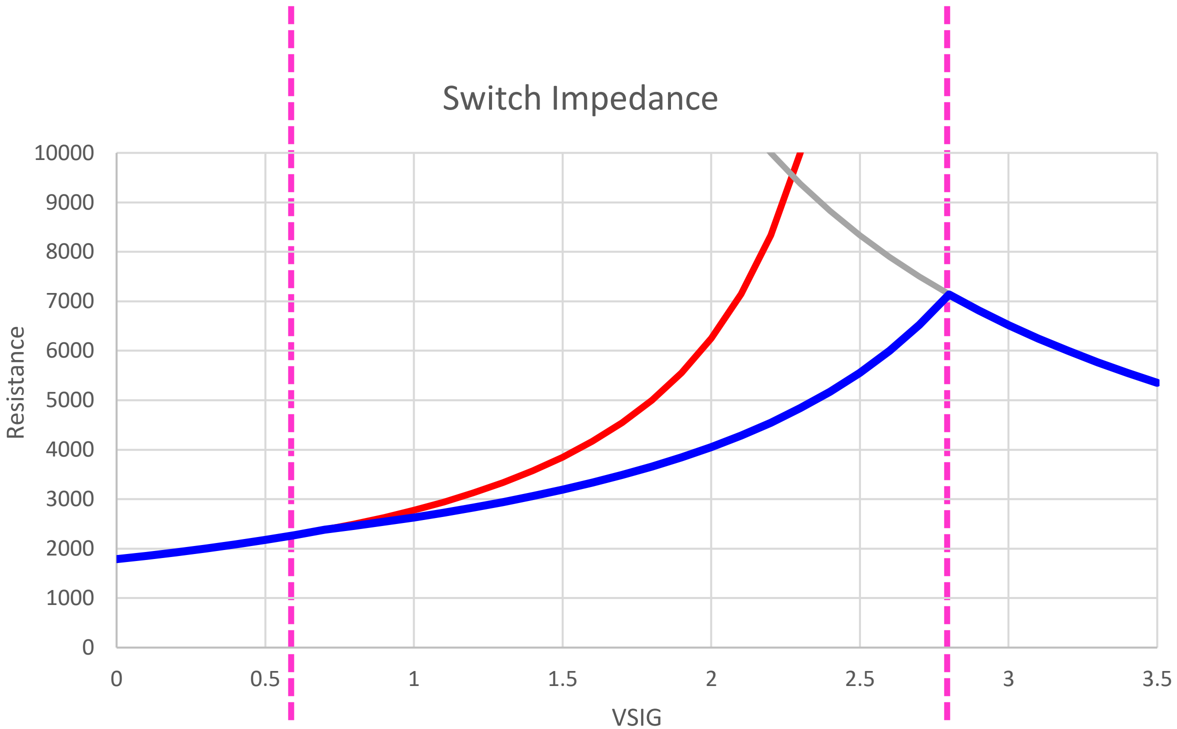
Transmission Gate Impedance Can be Reasonably constant

Switch Implementation Issues

Equal-Sized Switches

V_{THn}=0.7
V_{THp}=-0.7
W_p=W_n
L_p=L_n
V_{DD}=3.5V

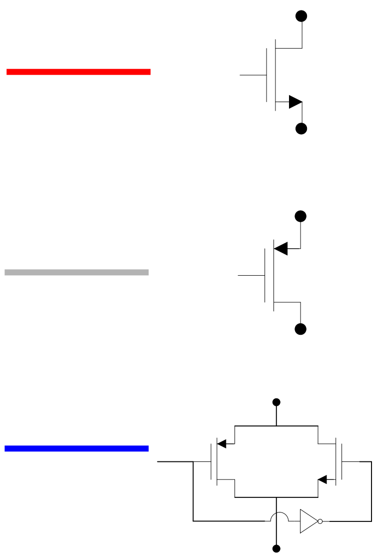


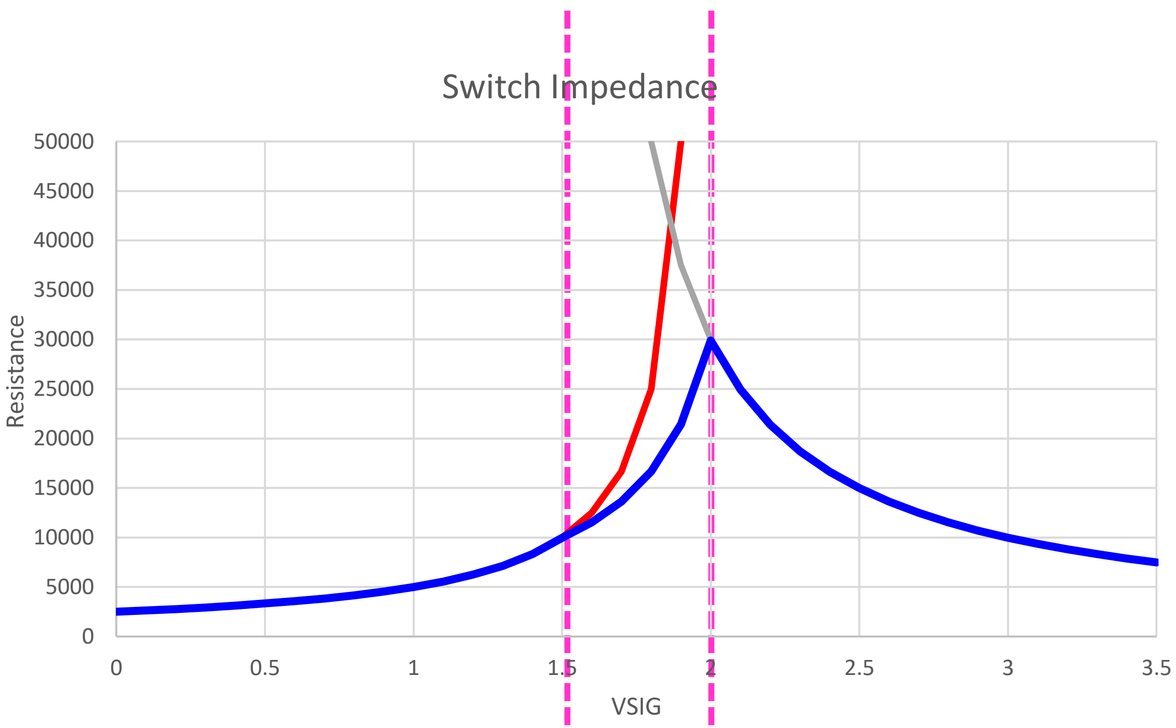


Switch Implementation Issues

Equal-Sized Switches
High Threshold Voltages

V_{THn}=1.50
V_{THp}=-1.5
W_p=W_n
L_p=L_n
V_{DD}=3.5V



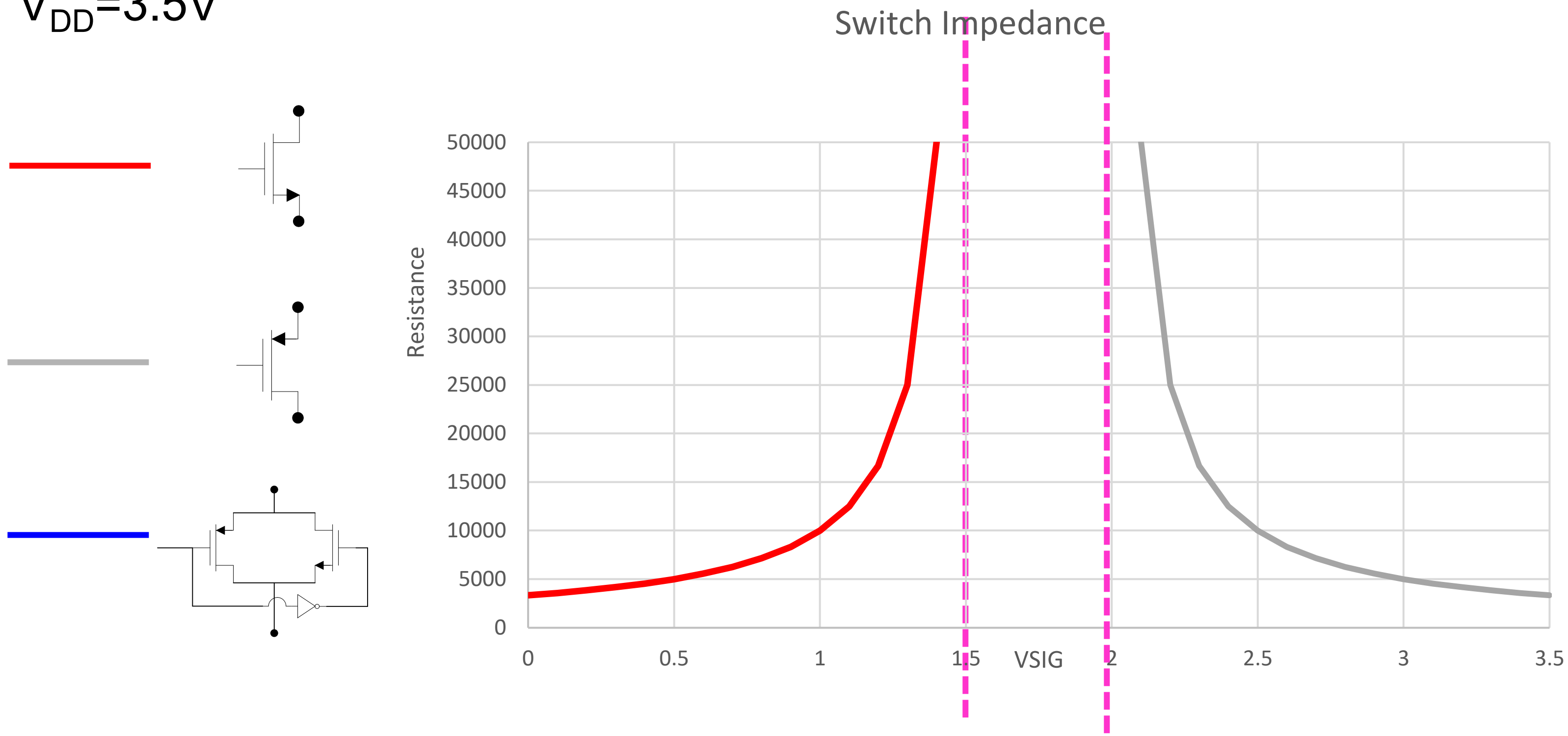


Even Transmission Gate Does Not Perform Well

Switch Implementation Issues

V_{THn}=2.0
V_{THp}=-2.0
W_p=3W_n
L_p=L_n
V_{DD}=3.5V

Tough unlikely, this is what would happen if very high threshold devices were used



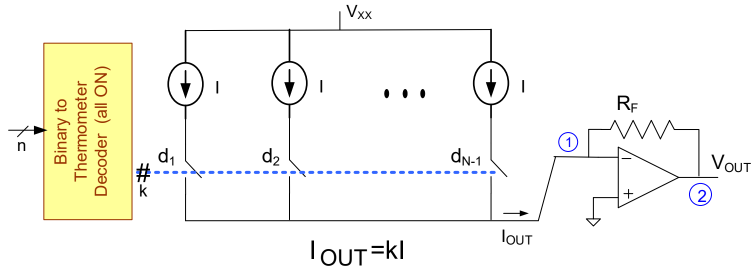
Gap where neither switch is working

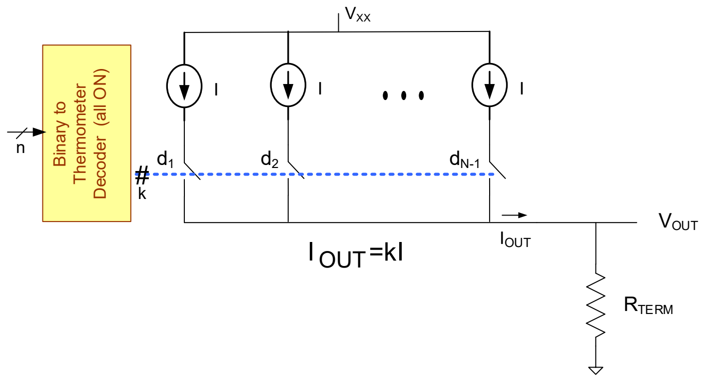
Current Steering DACs

Current will be "steered" to a resistive load (on chip)

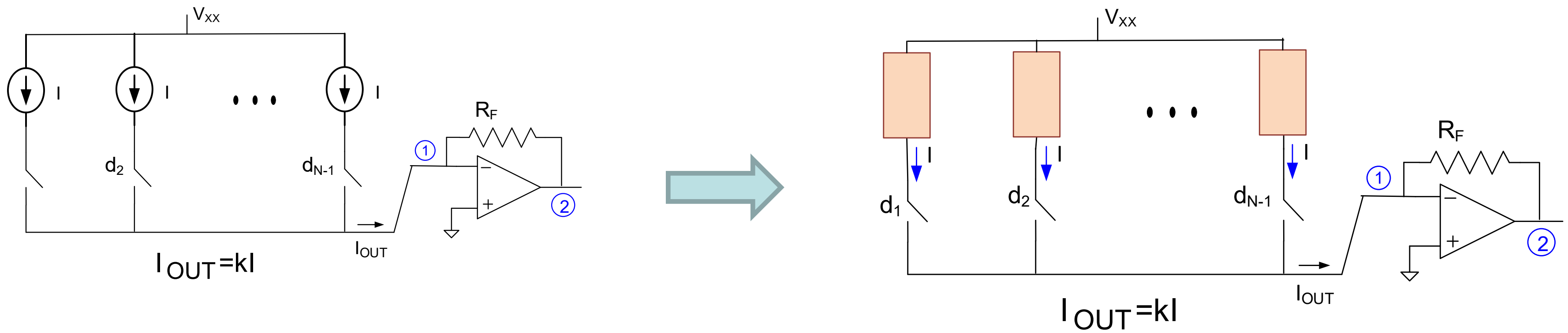
Output could be a current (user supplies load)

Basic Concept of Current Steering DACs

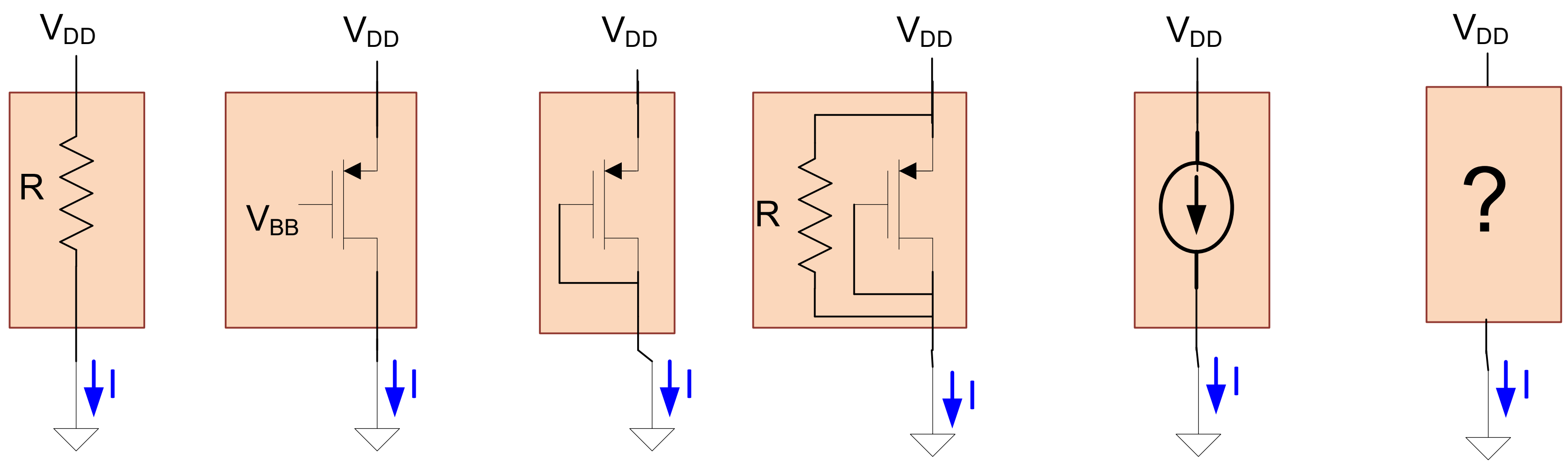




Current Steering DACs

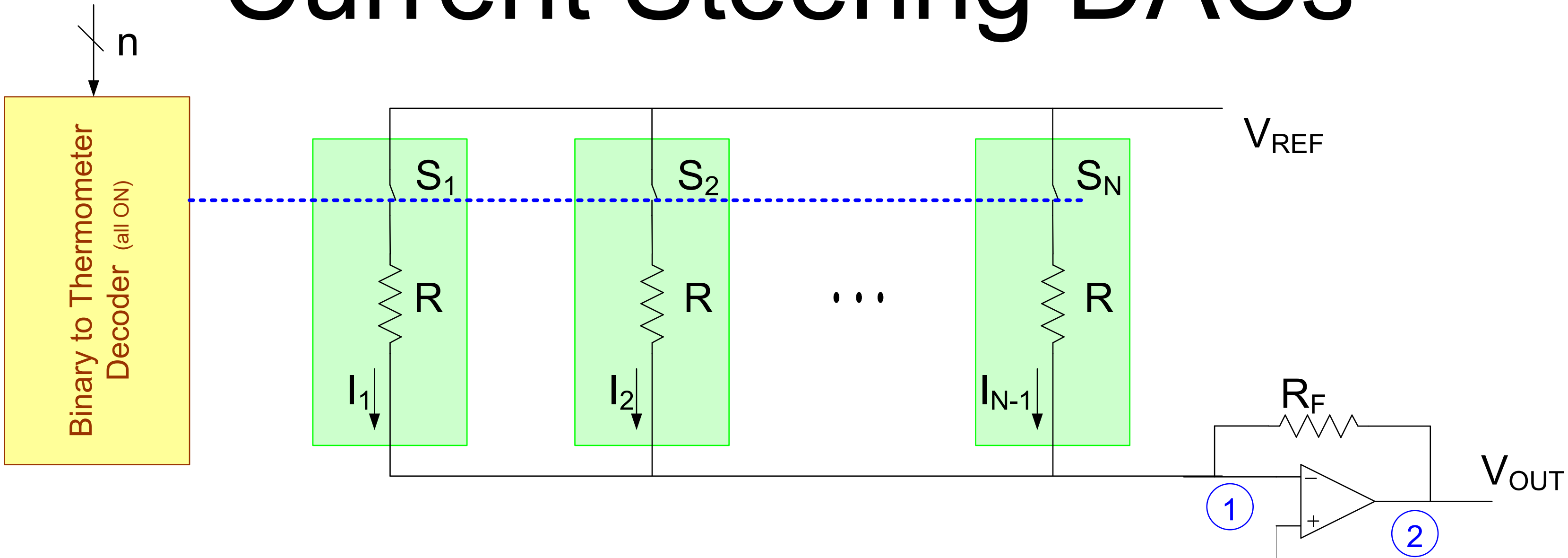


What is important is the current generated, not whether it comes from a "current source"



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

Current Steering DACs



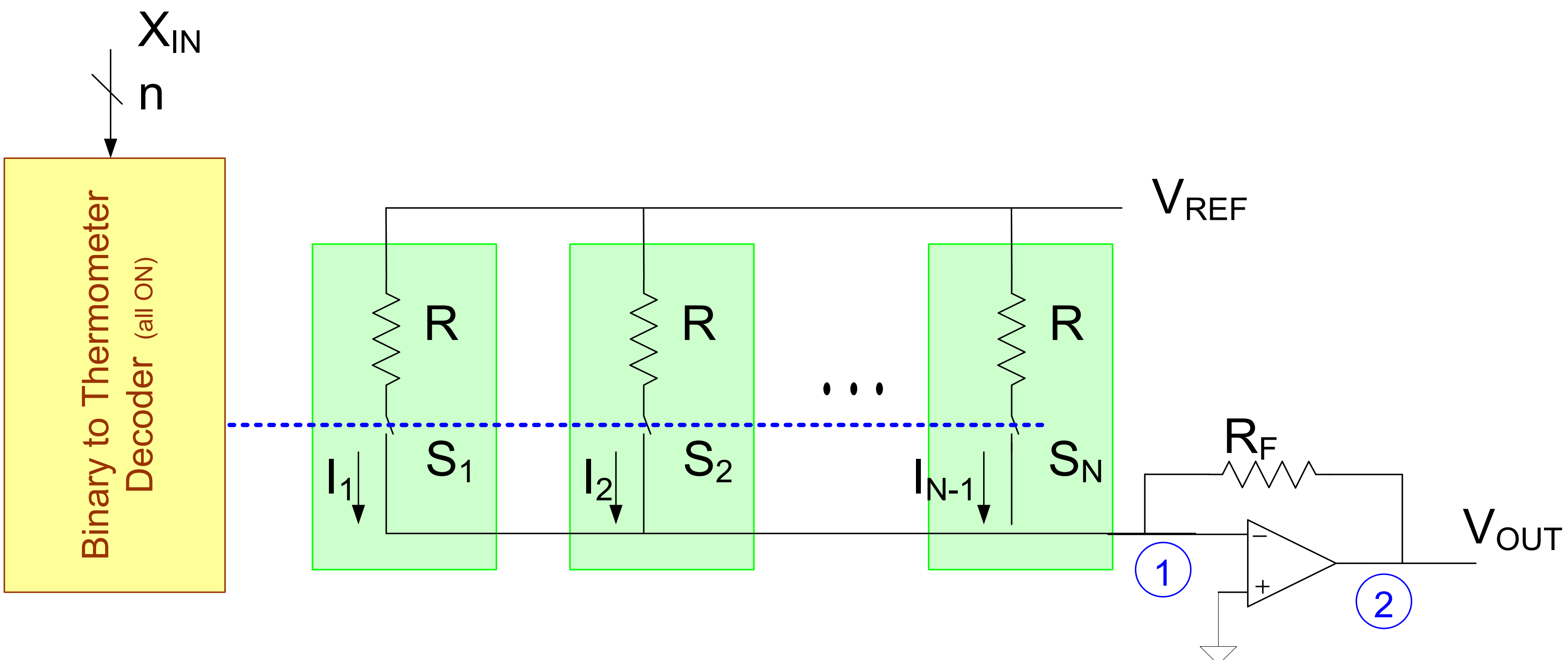
Inherently Insensitive to Nonlinearities in Switches and Resistors

- 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

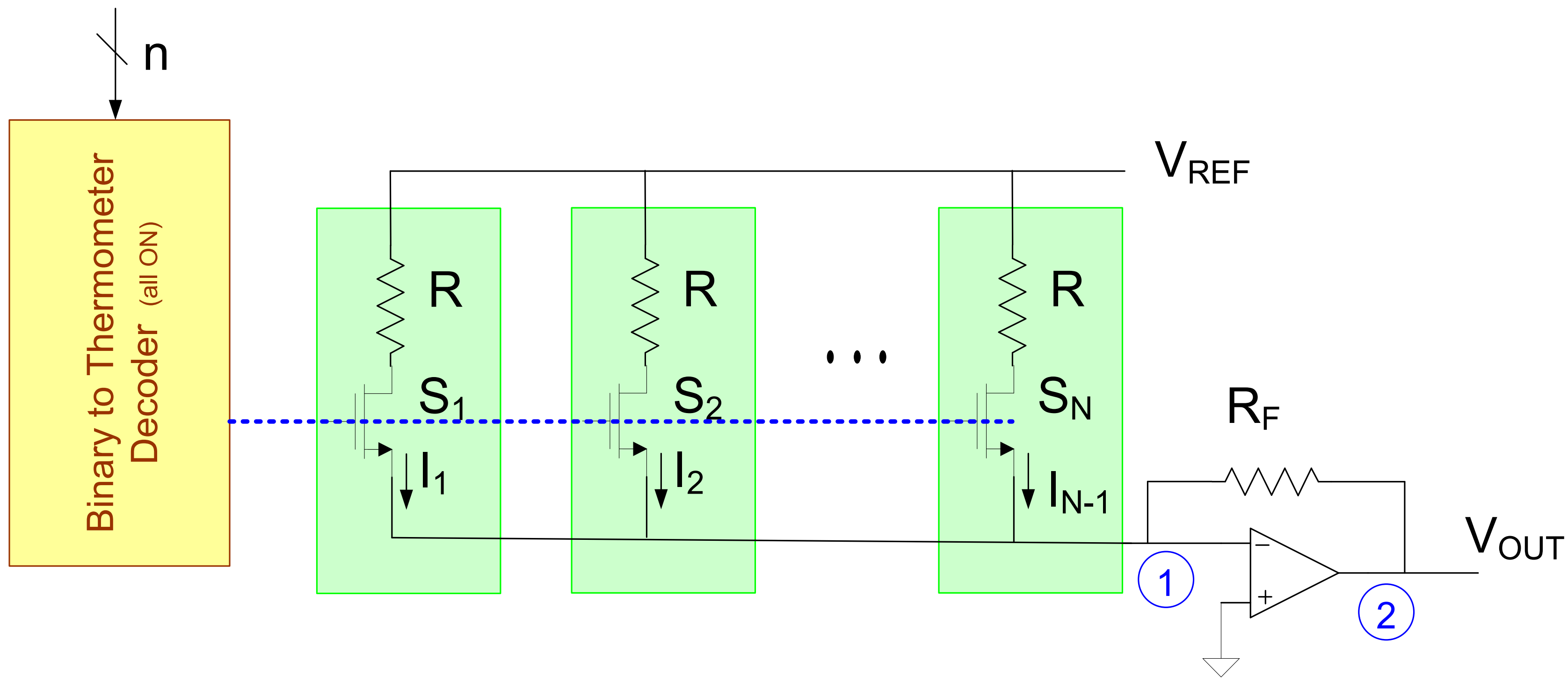
Current Steering DACs



Inherently Insensitive to Nonlinearities in Switches and Resistors
Smaller ON resistance and less phase-shift from clock edges

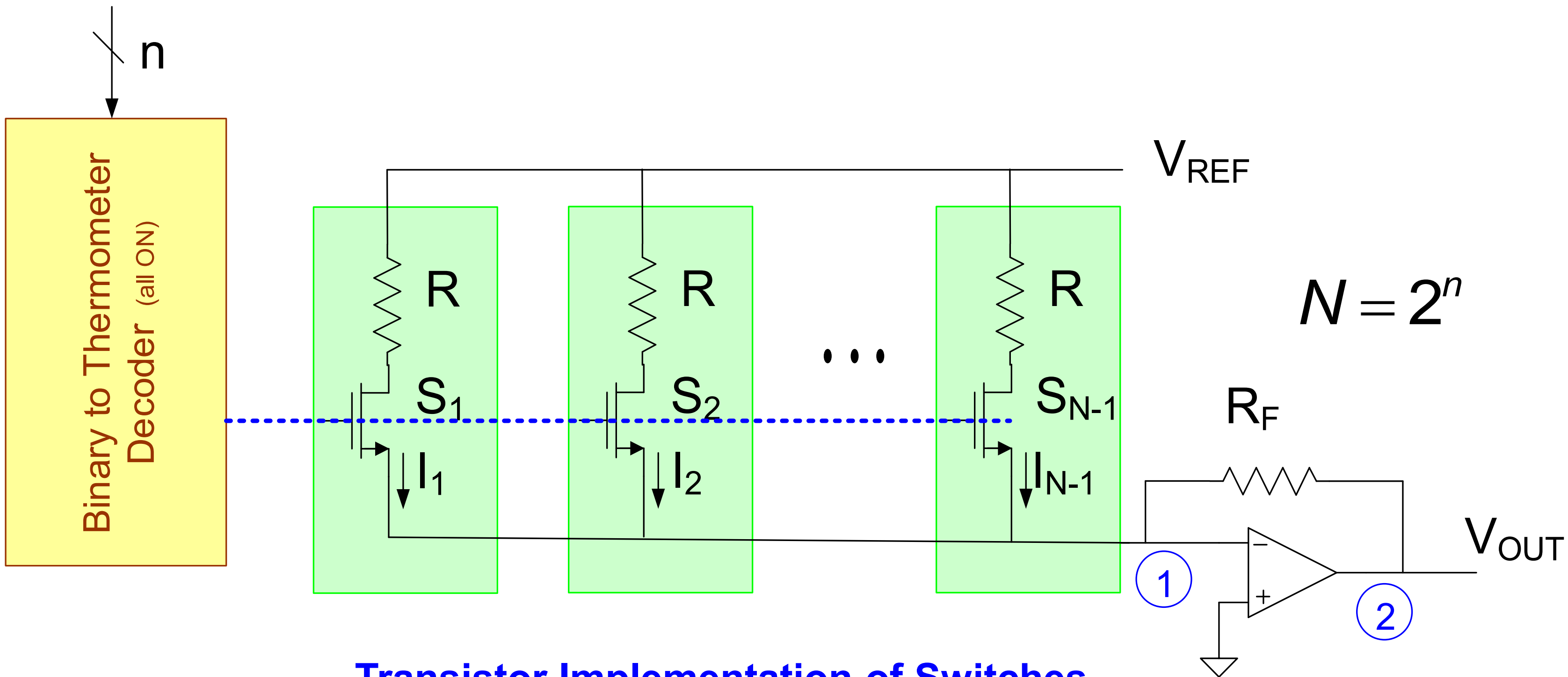
- Termed “bottom plate switching”
- Thermometer coded

Current Steering DACs



Transistor Implementation of Switches

Current Steering DACs



Transistor Implementation of Switches

How should the op amp be compensated?

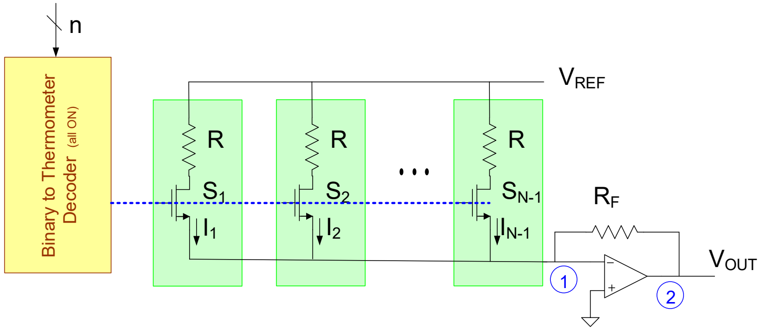
Assume k switches are on $0<k<N-1$

$$\beta = \frac{\frac{R_{CELL}}{k}}{\frac{R_{CELL}}{k}+R_F} = \frac{R_{CELL}}{R_{CELL}+kR_F}$$

If $V_{OUTFS} = V_{REF}$ $R_{CELL} = NR_F$

$$0.5 < \beta \leq 1$$

How should the op amp be compensated?

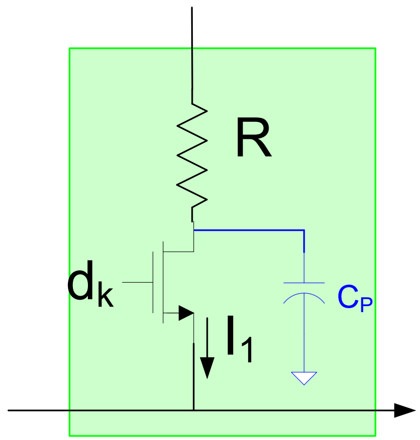


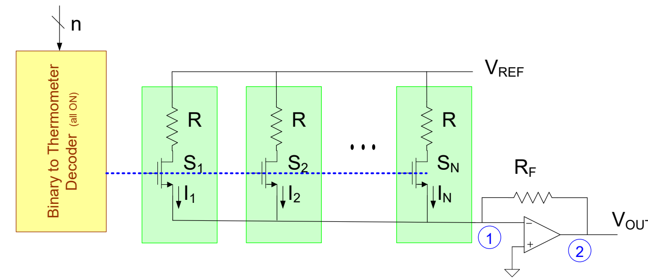
$$\beta = \frac{\frac{R_{CELL}}{k}}{\frac{R_{CELL}}{k}+R_F} = \frac{R_{CELL}}{R_{CELL}+kR_F}$$

$$V_{OUTFS} = V_{REF}$$

$$0.5 < \beta \leq 1$$

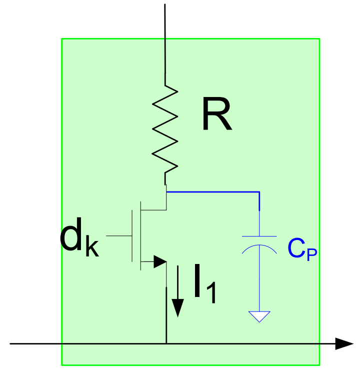
Current Steering DACs

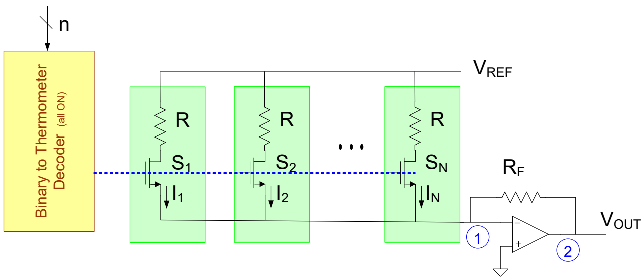


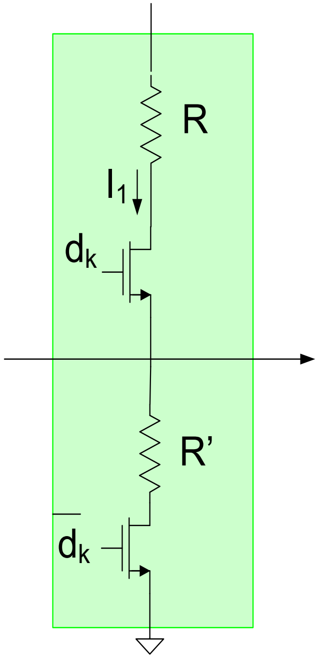


	Problem?
Switch impedance	No
Code-dependent phase margin	Yes
Single-ended output	Yes
C_P	Yes
Thermometer to Binary Decoder	Yes
Op Amp Bandwidth	Yes
Code-dependent switching time	No

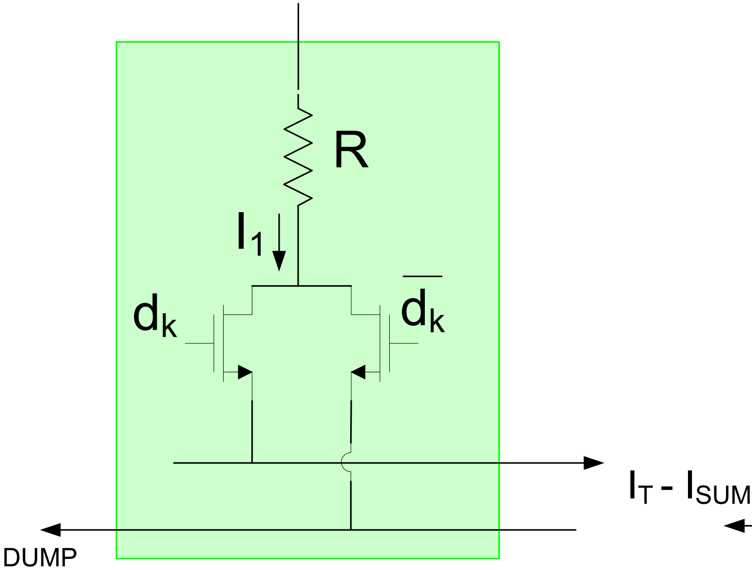
Current Steering DACs



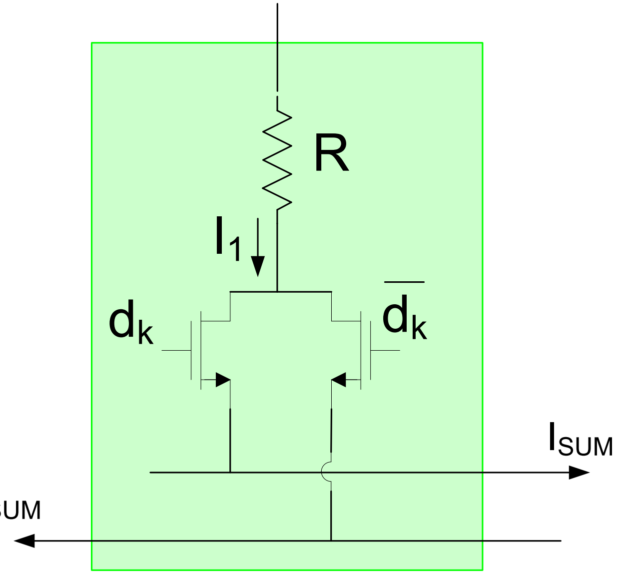




β Compensation



C_P Compensation



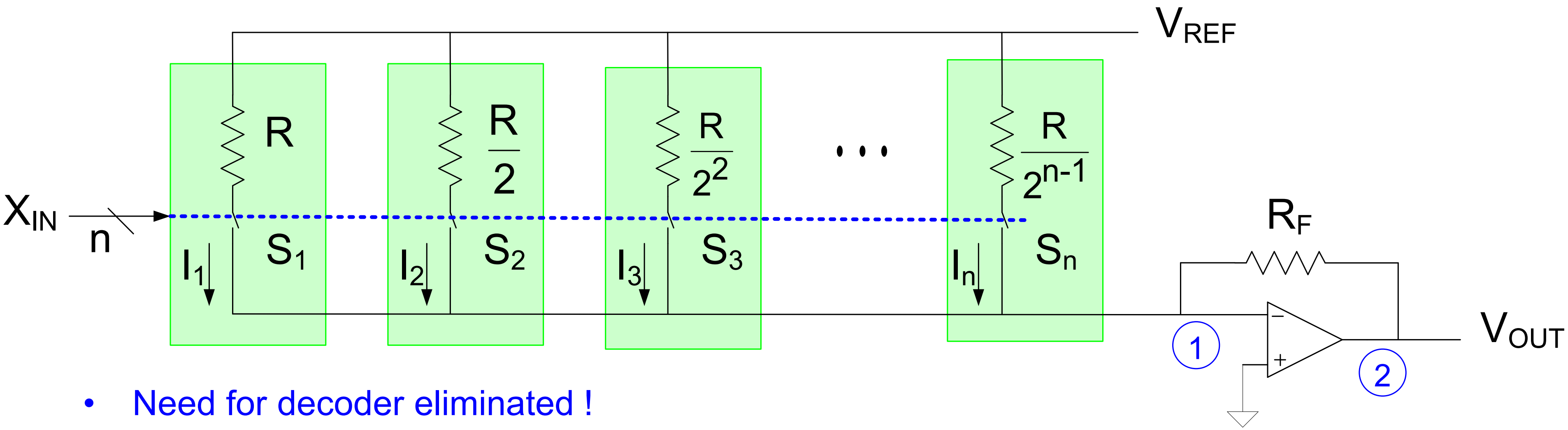
Differential Output

Stay Safe and Stay Healthy !

End of Lecture 34

Current Steering DACs

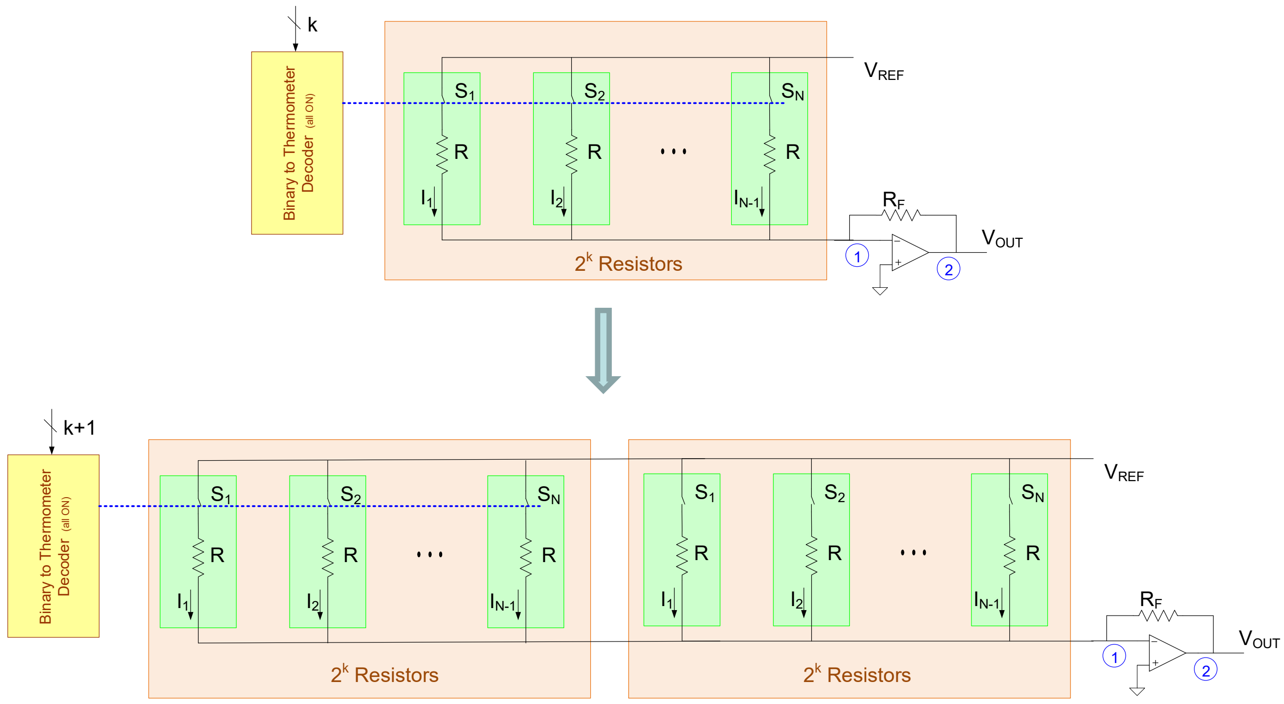
Binary-Weighted Resistor Arrays



- 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

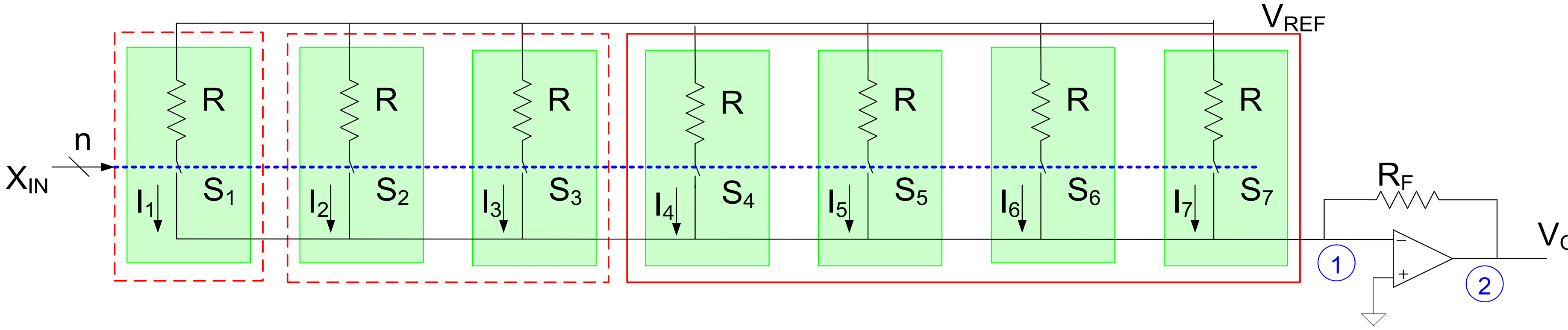
approximately $\sigma = \frac{A_{PEL}}{\sqrt{A}}$

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

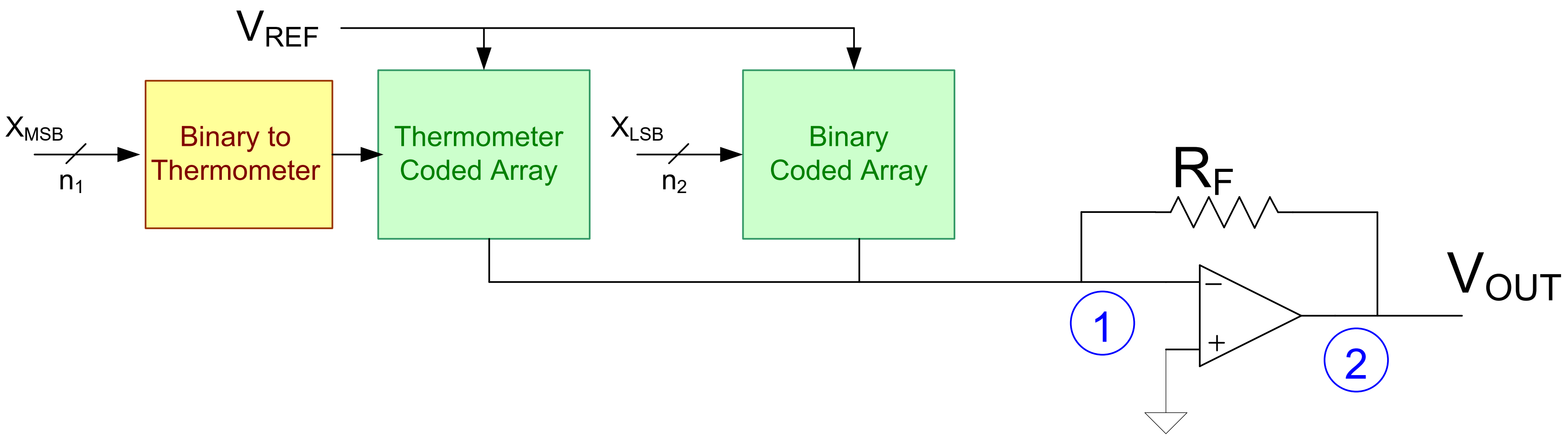


Binary-Weighted Resistor Arrays

Actual layout of resistors is very important

As stated earlier, bundled unary cells are almost always used

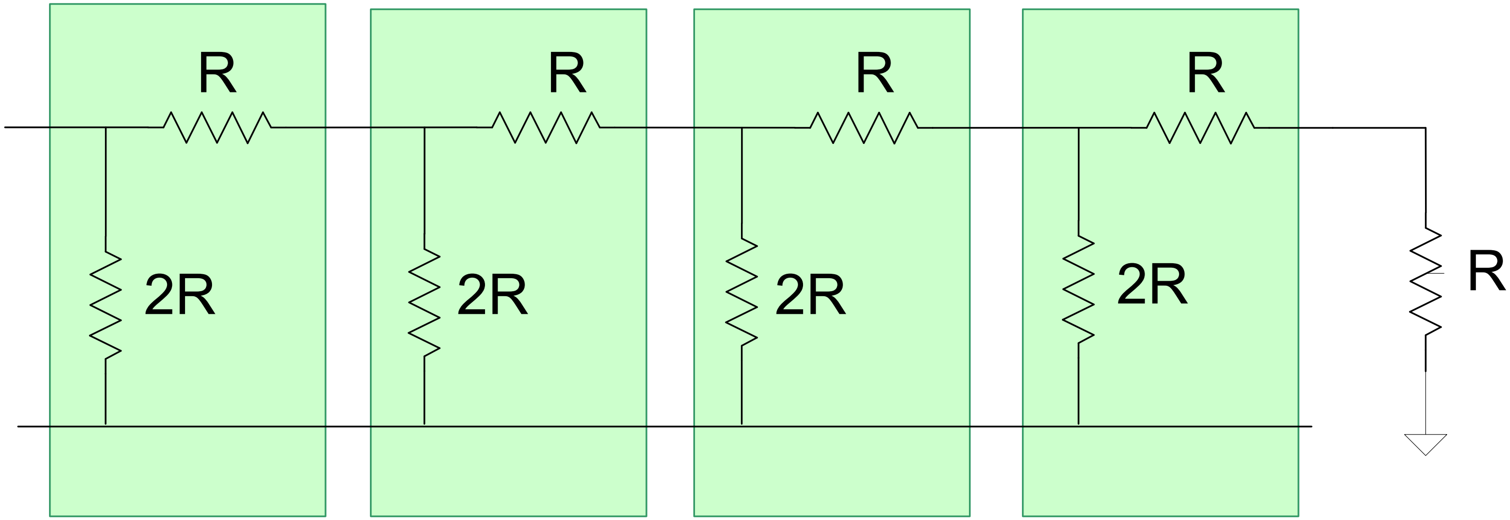
Current Steering DACs



Segmented Resistor Arrays

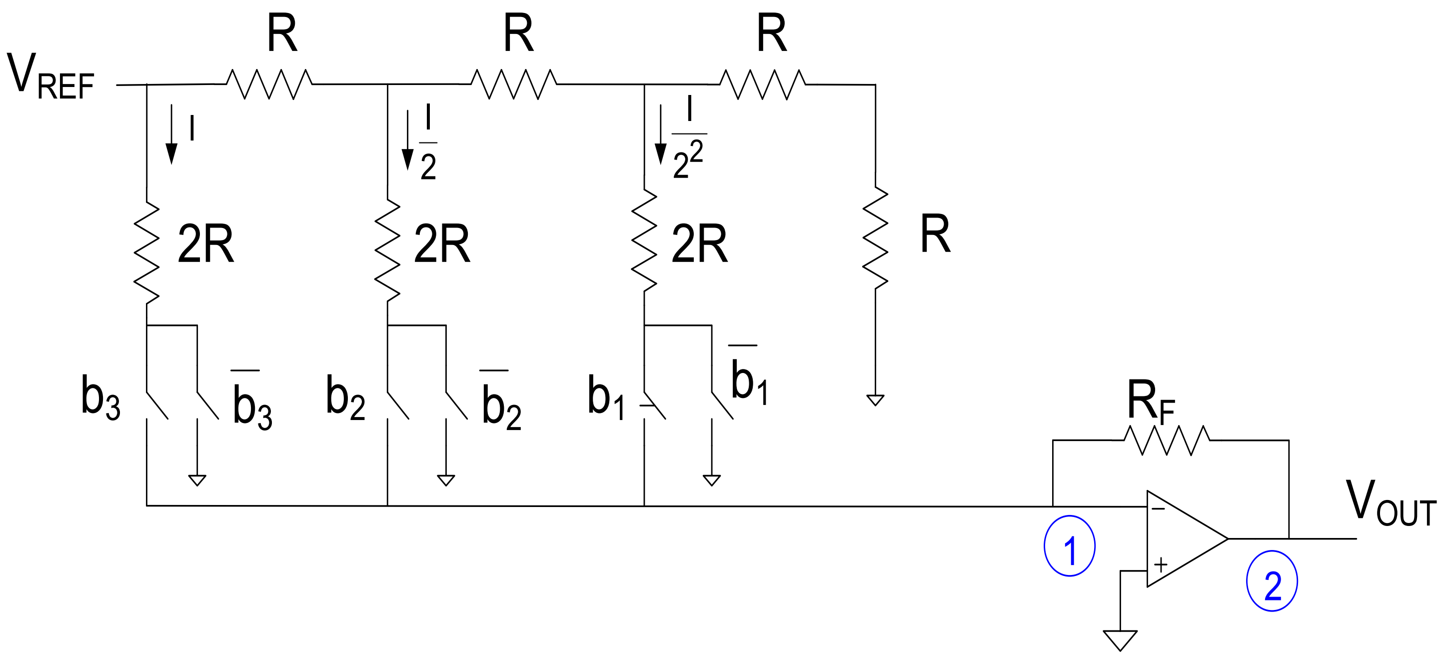
- Combines two types of architectures
- Inherits advantages of both thermometer and binary approach
- Minimizes limitations of both thermometer and binary approach

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



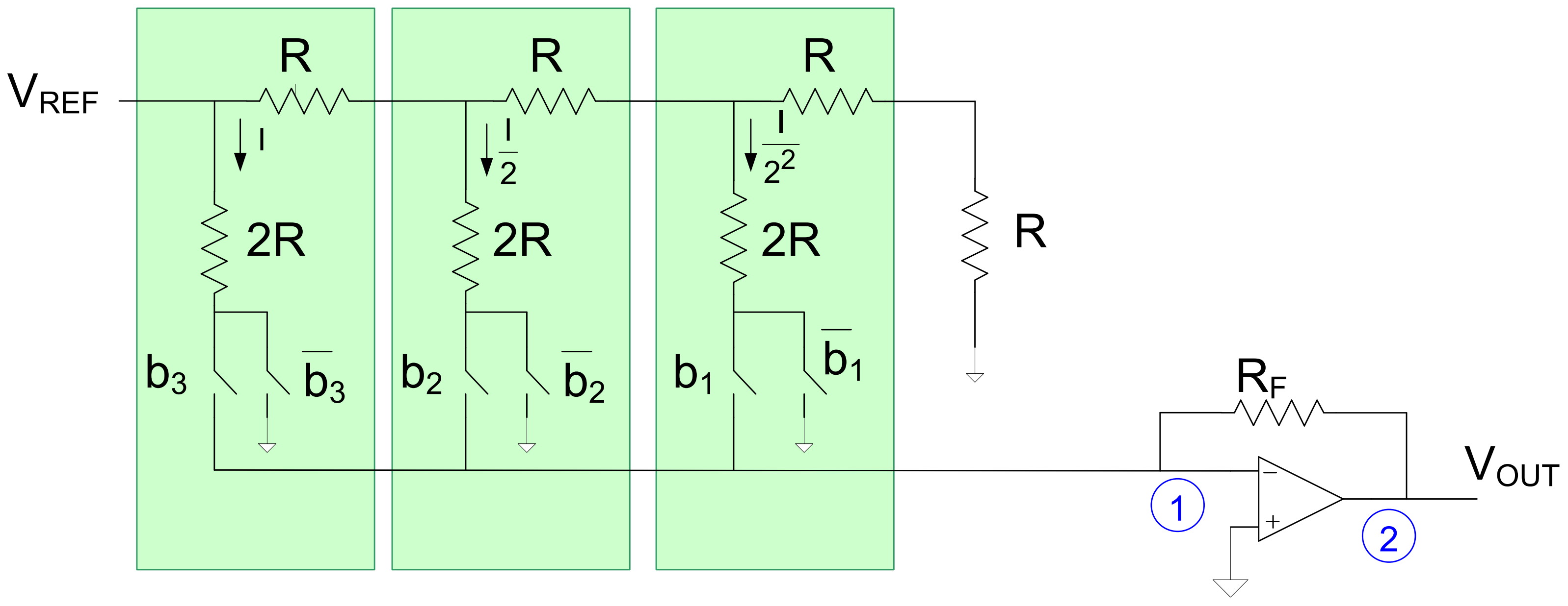
R-2R Resistor Arrays

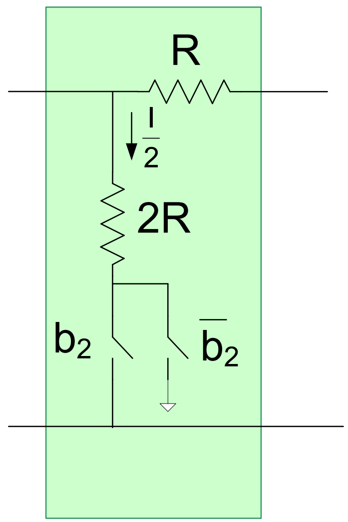
Node voltages ideally stay constant for any input code

Highly sensitive to nonlinearities in switches

How should switches be sized?

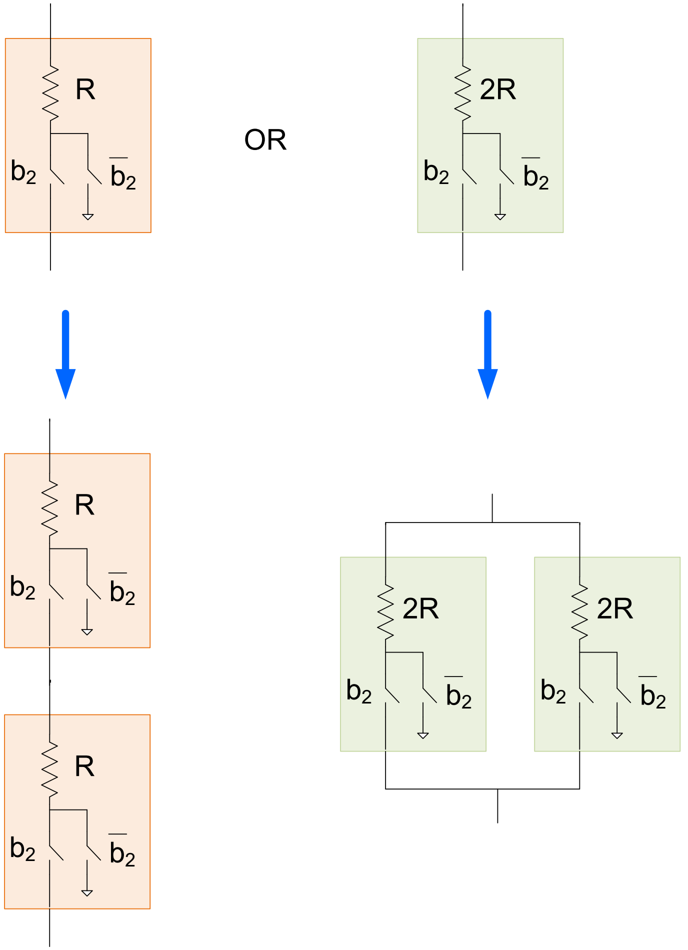
Current Steering DACs





R-2R Resistor Arrays

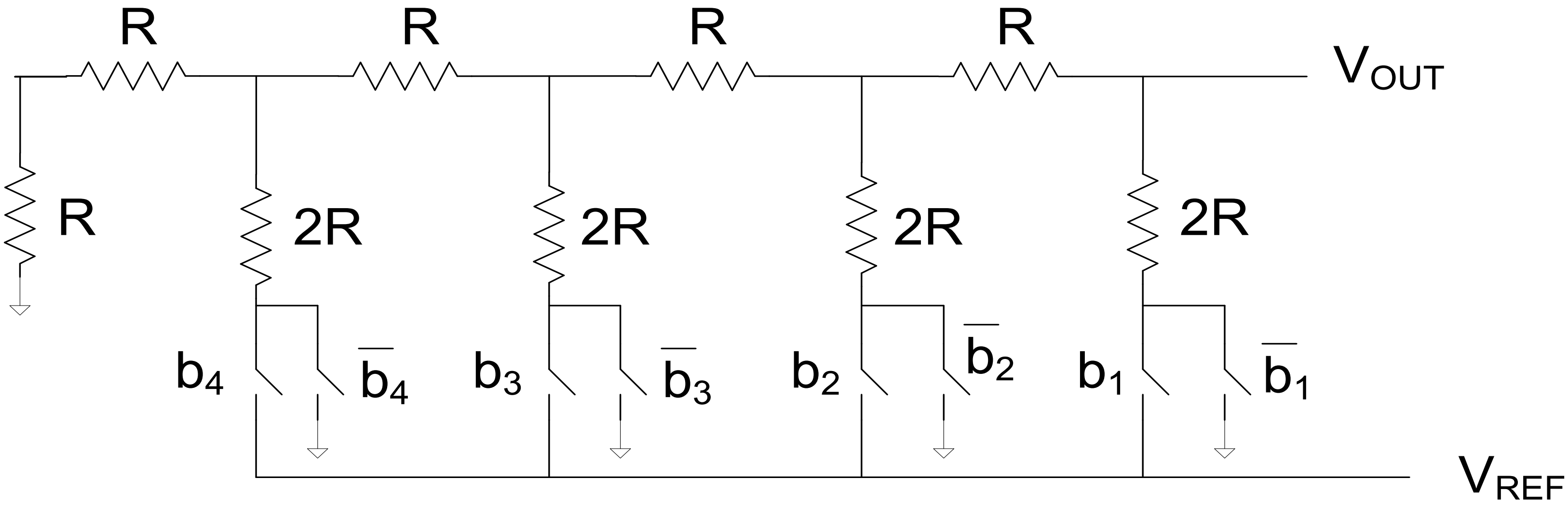
R-2R Implementation



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

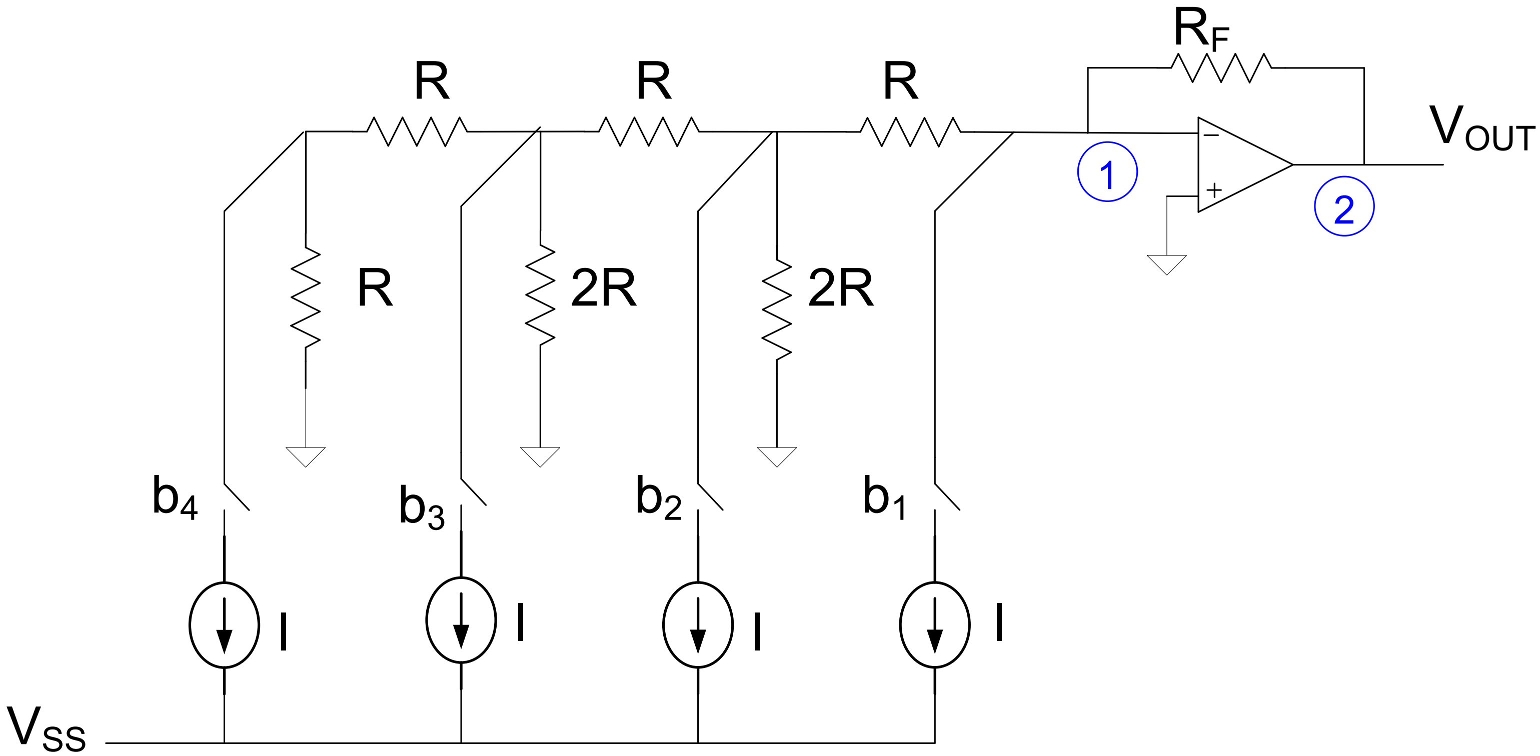
How can switch impedances be matched?

Another R-2R DAC



Node voltages change with input code

Another R-2R DAC



Requires matching both current sources and resistors

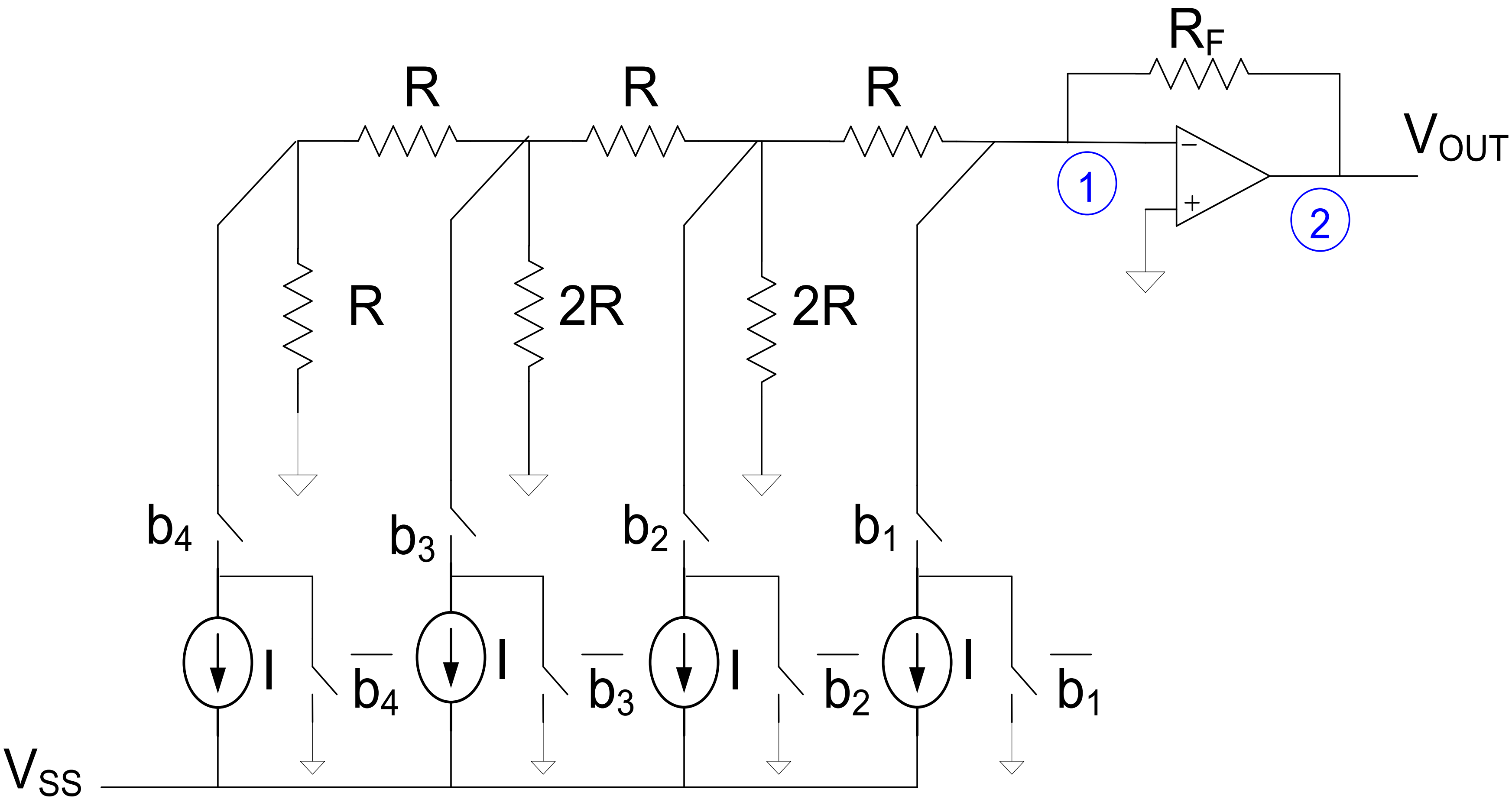
But switch impedance does not affect performance

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?

Stay Safe and Stay Healthy !

End of Lecture 34