THE JOY OF ANALOG INTEGRATED CIRCUITS

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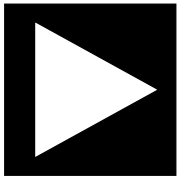
Jan. 9 2013



ANALOG DEVICES

Today's Message

- **Analog IC design taps many areas of expertise: physics, geometry, analysis, algorithms, modeling, ….**

$\Rightarrow$ **Creativity (= Fun) is possible at multiple levels**

Three Examples

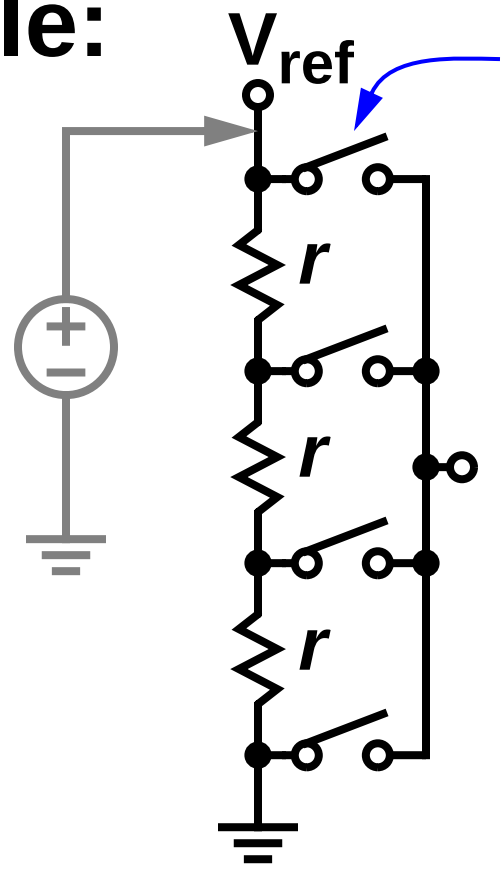
1 Circuit: String DAC Tricks

2 Algorithmic/Signal Processing: $\Delta\Sigma$ DAC

3 Physical: Layout of a current-mode DAC

1. Resistor-String DAC

2-bit example:



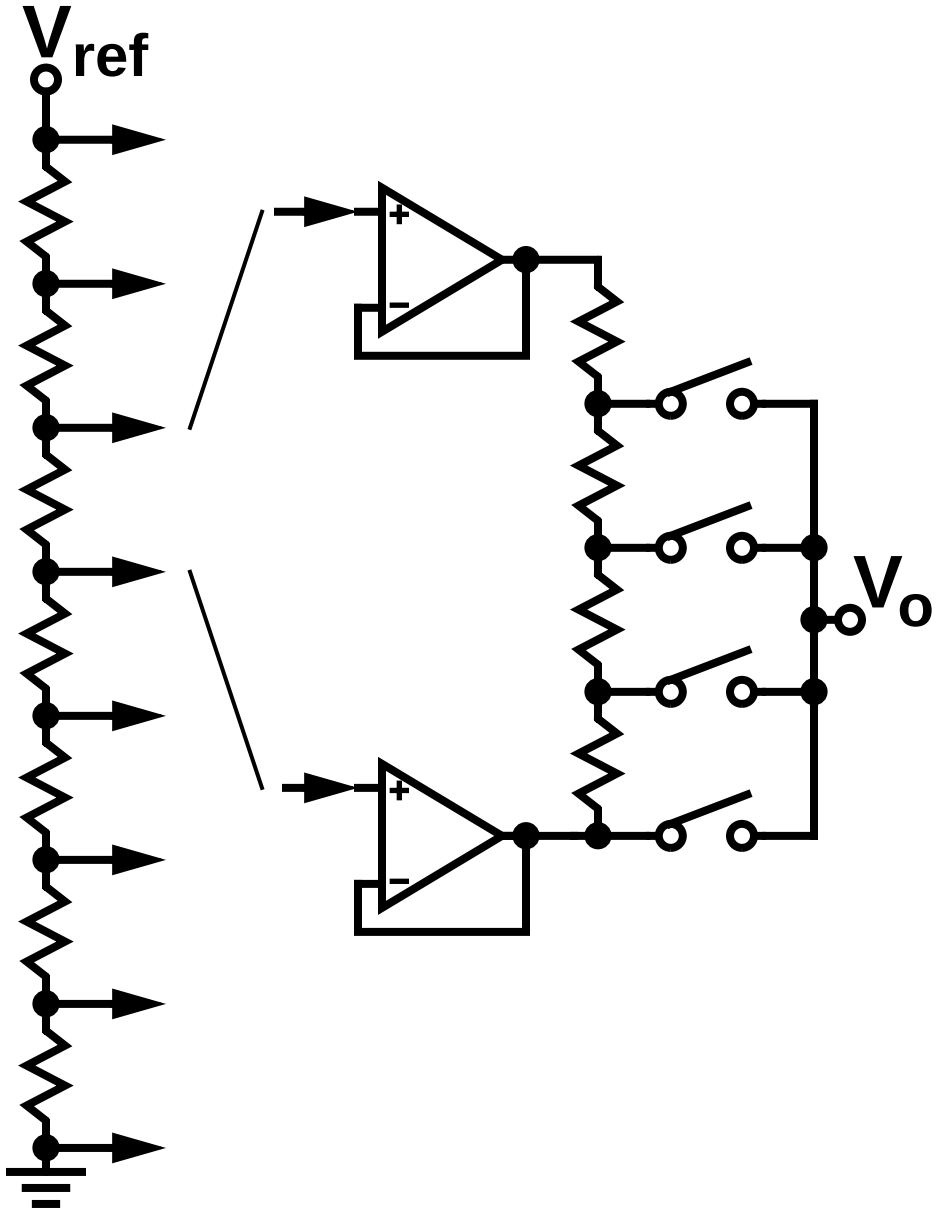
N-bit digital input selects one of 2^N equi-spaced analog values

$$V_o = (m/3)V_{ref}$$
$$m = 0, 1, 2, 3$$

\+ Simple. *Ratiometric*. *Monotonic.*

– *N*-bit DAC requires 2^N components

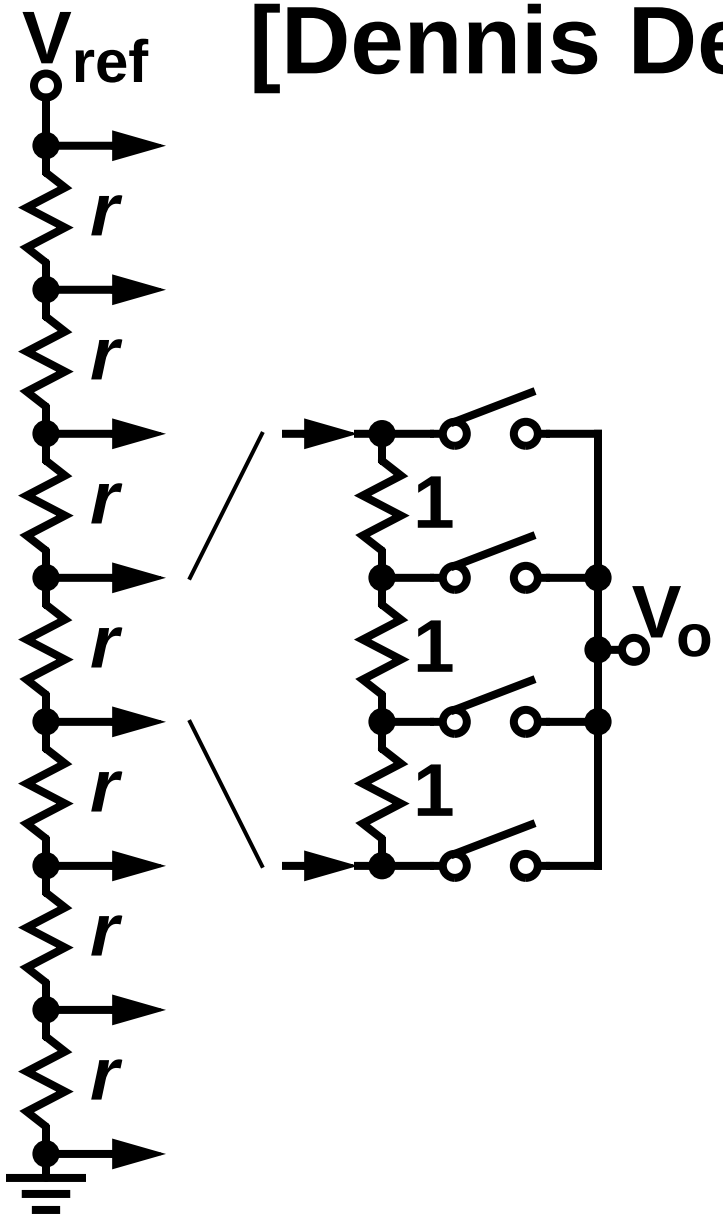
String DAC with Sub-String



+ **Number of units grows as $2^{N/2}$**
+ **Monotonic**
+ **Can repeat**
  - **sub-sub-string, etc.**

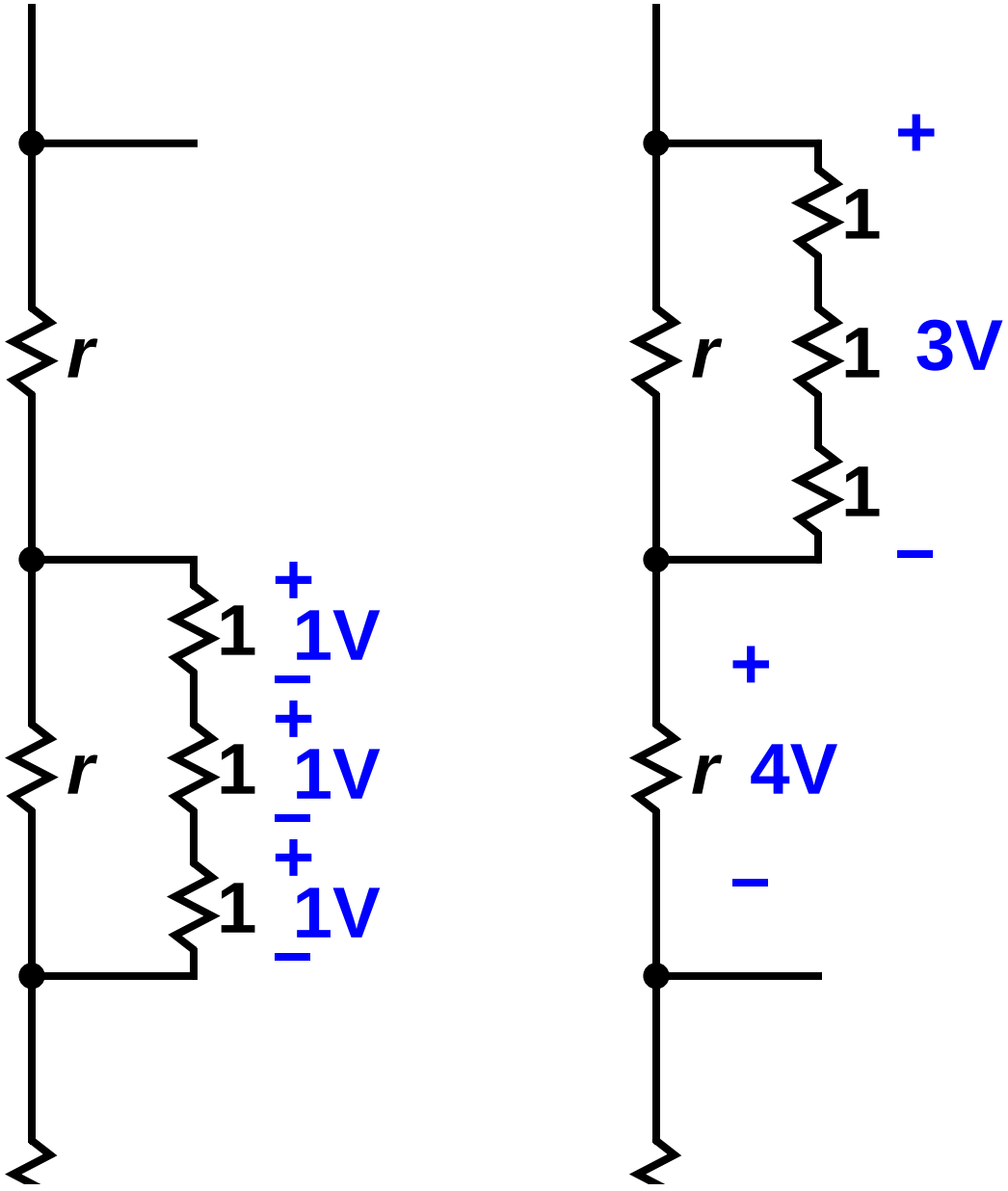
– **Needs buffers to prevent sub-string from loading the main string**
  - **Or does it?**

Unbuffered Sub-String
[Dennis Dempsey US5969657]



- Choose the resistor ratio *r* such that shifting the sub-string up one step increases the voltage at the common point by 1 LSB
- Note that the voltages elsewhere in the string are unaffected

Required Resistor Ratio



Solution:

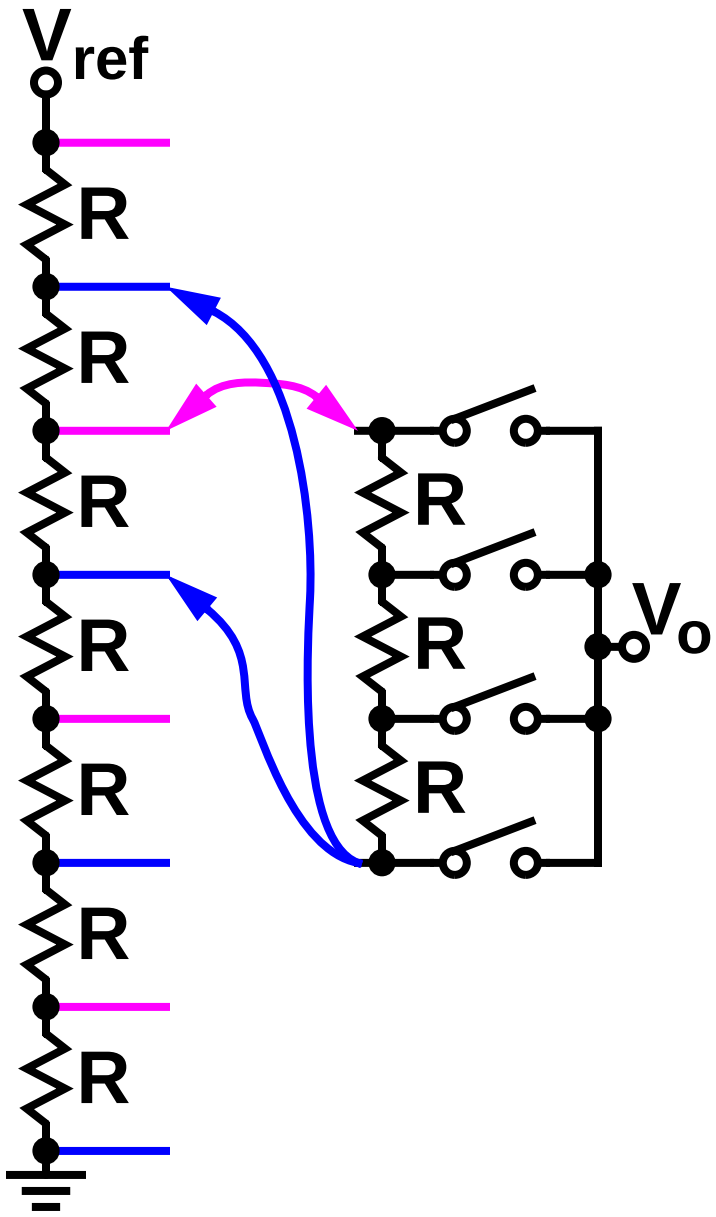
$$\frac{4}{r} = 3\left(\frac{1}{r} + \frac{1}{3}\right)$$

$$4 = 3 + r$$

$$r = 1$$

- $r = 1$ **regardless of the number of units in the sub-string!**

More String Cleverness



- **Walk the sub-string up the main string in an alternating fashion rather than shift it one step at a time**

⇒ **The number of switches on the main string is halved**

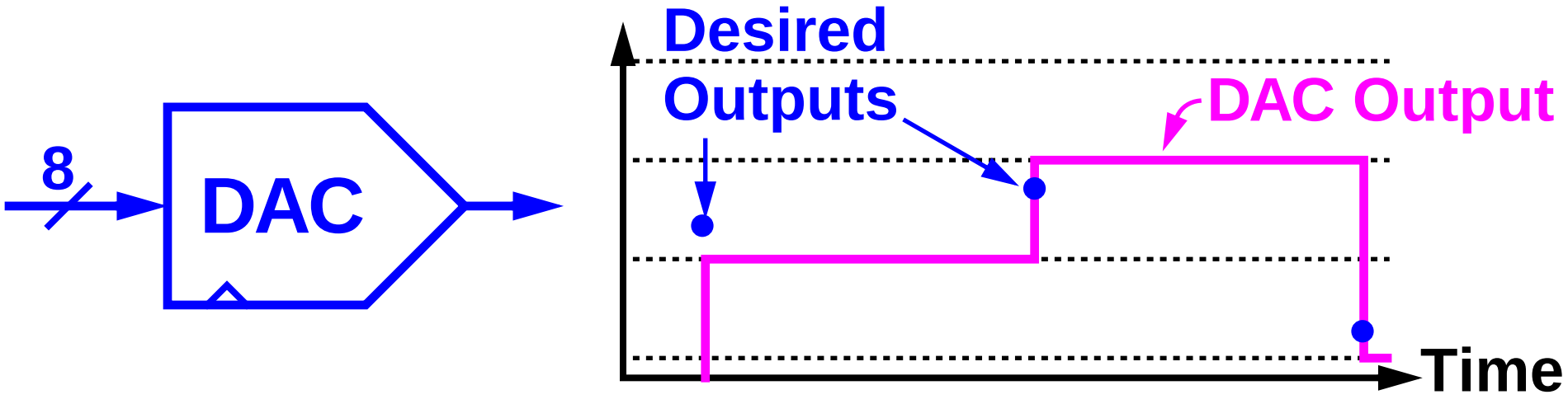
2. Delta-Sigma (ΔΣ) DAC

- **Suppose you have a fast and accurate, but limited-resolution DAC**

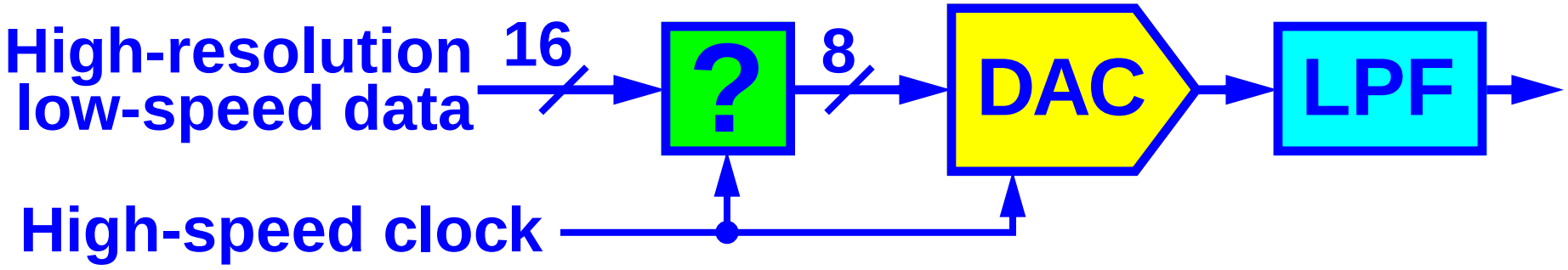
Q1: How can you get more resolution?

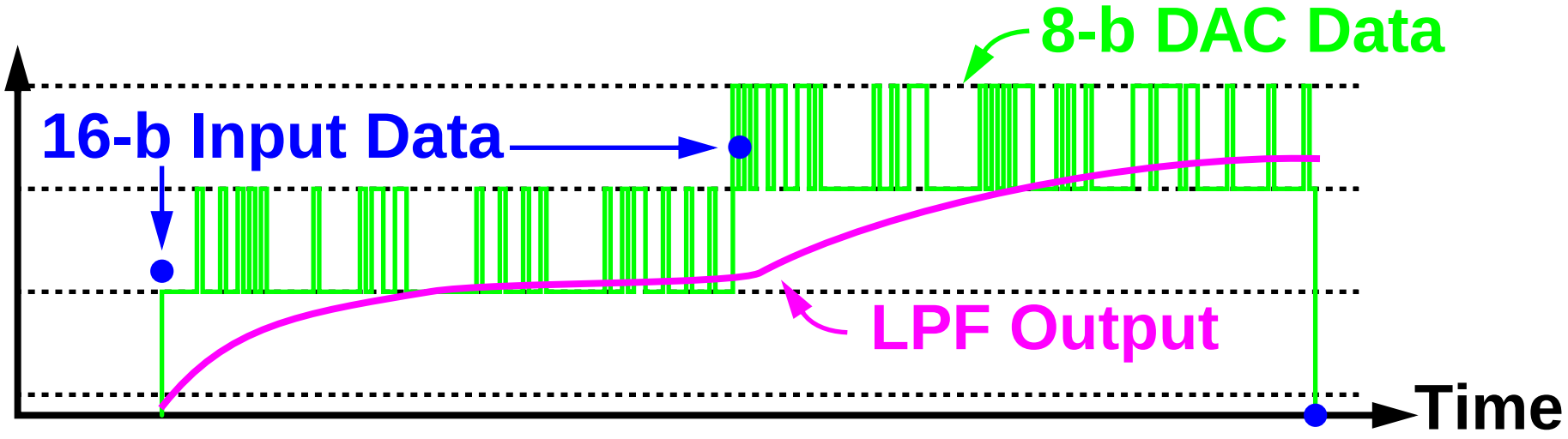
OR

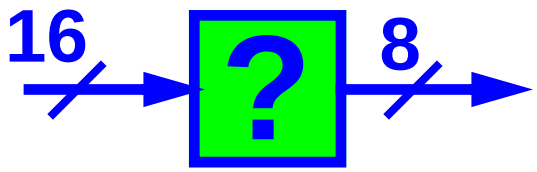
Q2: How can you get an output that is between two DAC levels?

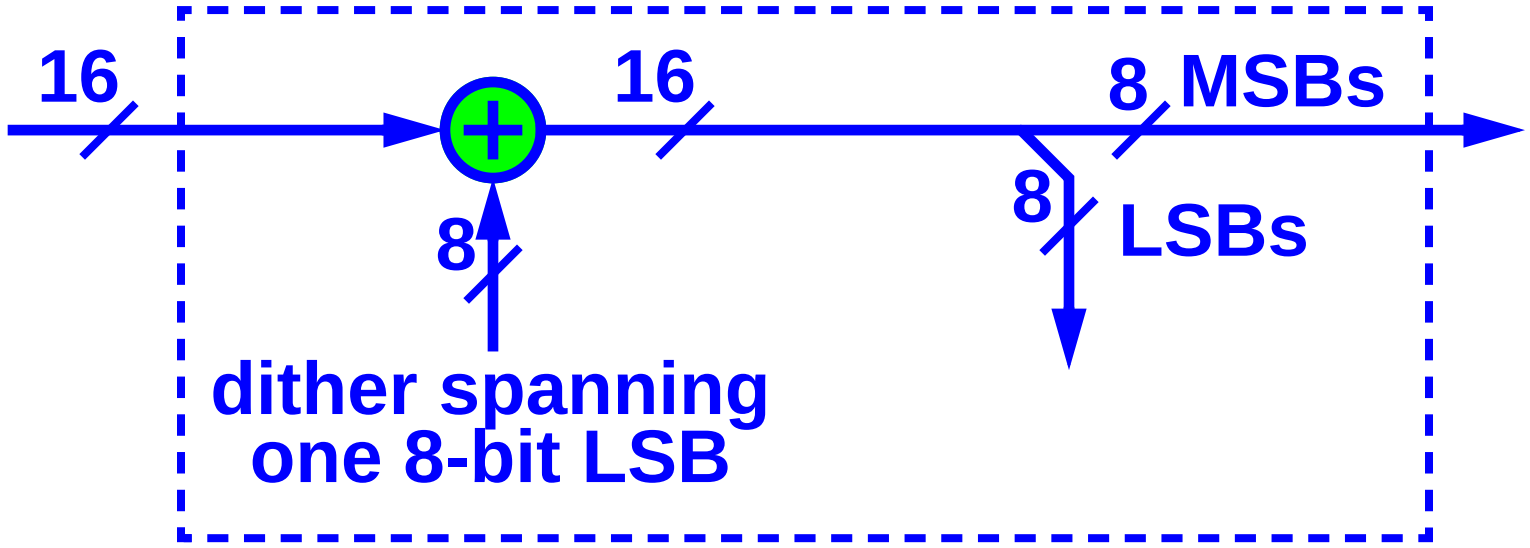


Switch back and forth quickly; Average with a lowpass filter





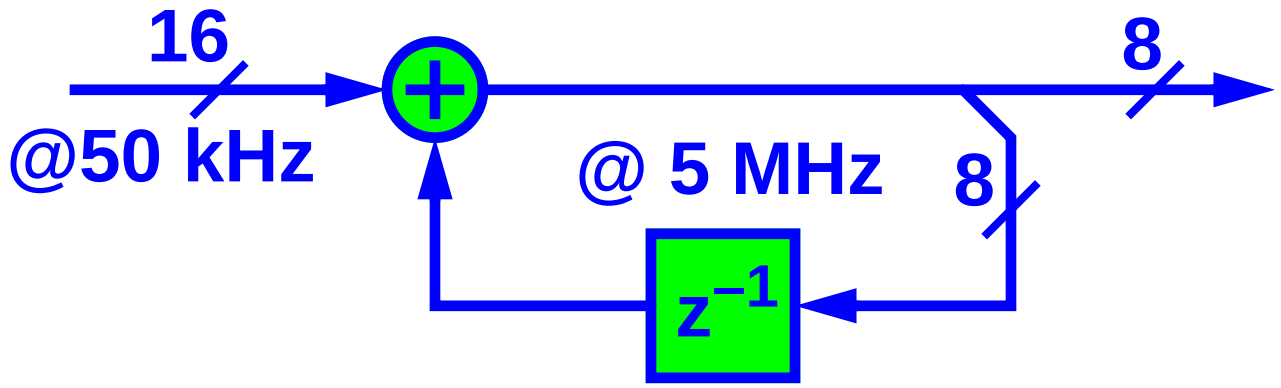
One  Digital Block

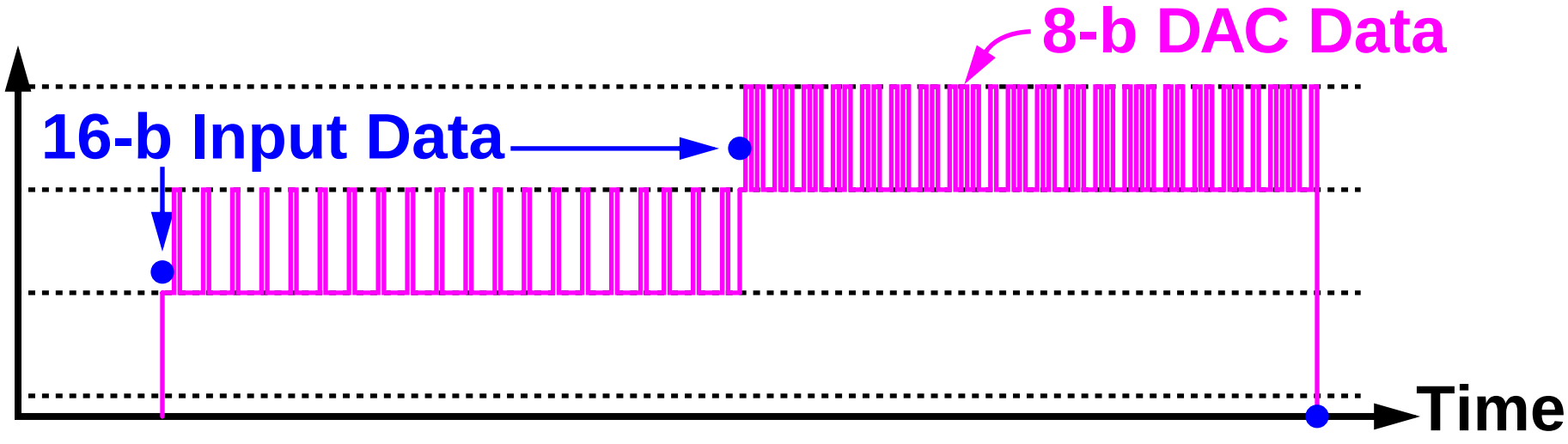


- The decision to quantize high/low is made independently of any previous decision
- Turns the truncation noise into white noise spread uniformly over frequency

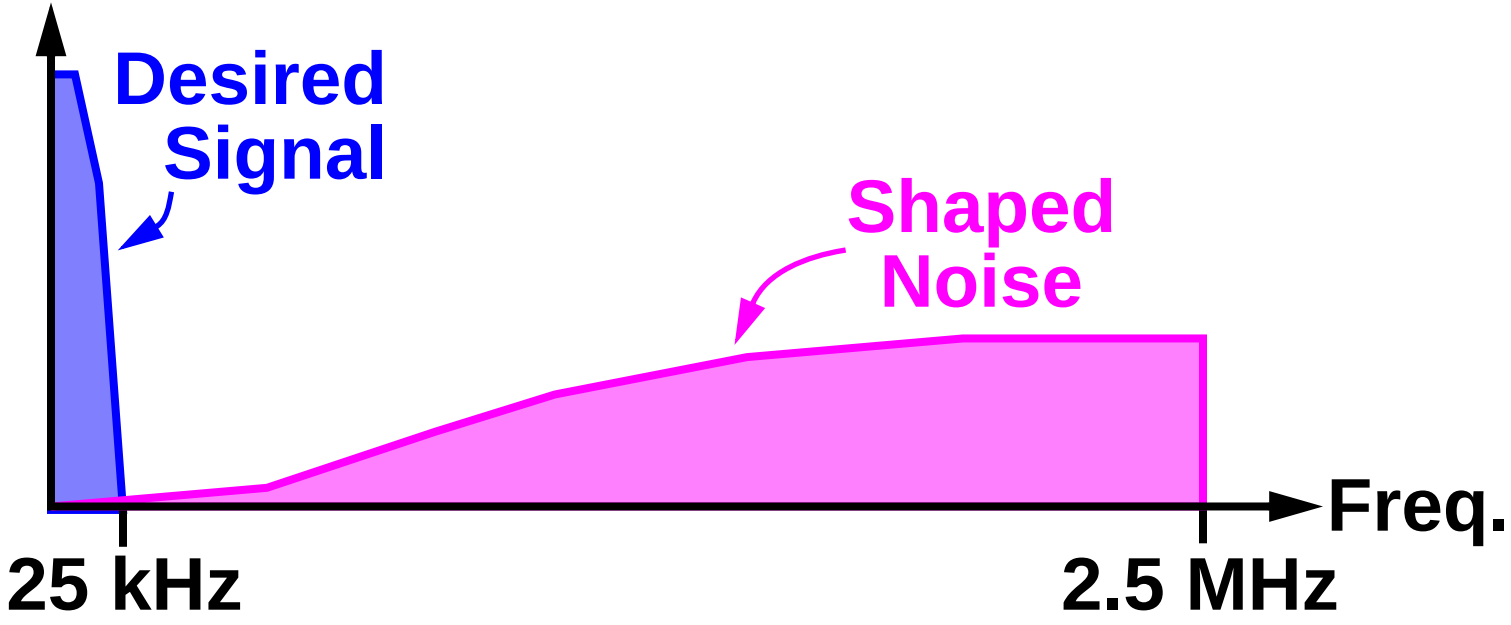
The ΔΣ Way

- **Re-circulate the LSBs to bias the next decision**





Spectral Implications



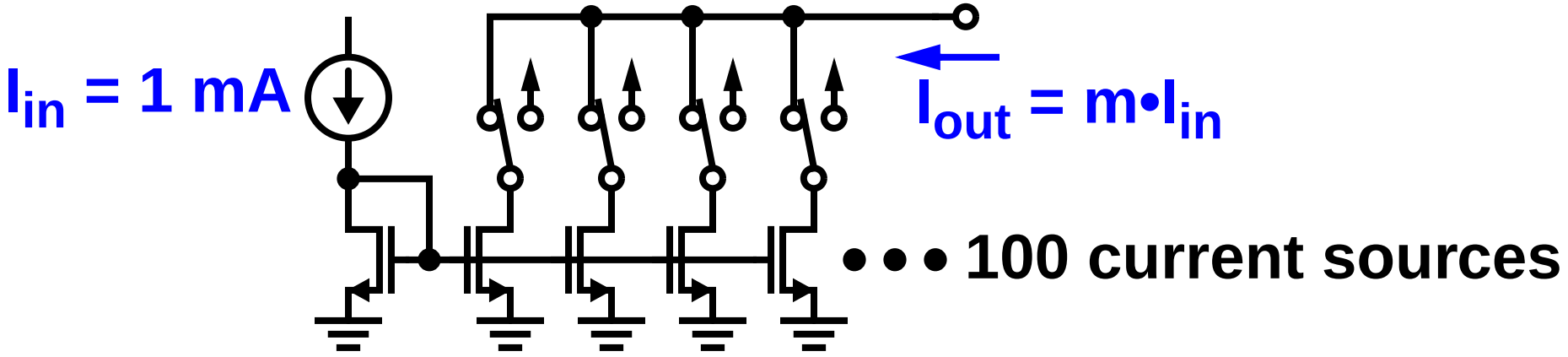
- Truncation noise is still spread over a broad frequency range, but not uniformly
- Very little noise is present in the signal band!

$\Rightarrow$ With the $\Delta\Sigma$ technique, a low-resolution DAC can be turned into a high-resolution DAC

3. Debugging

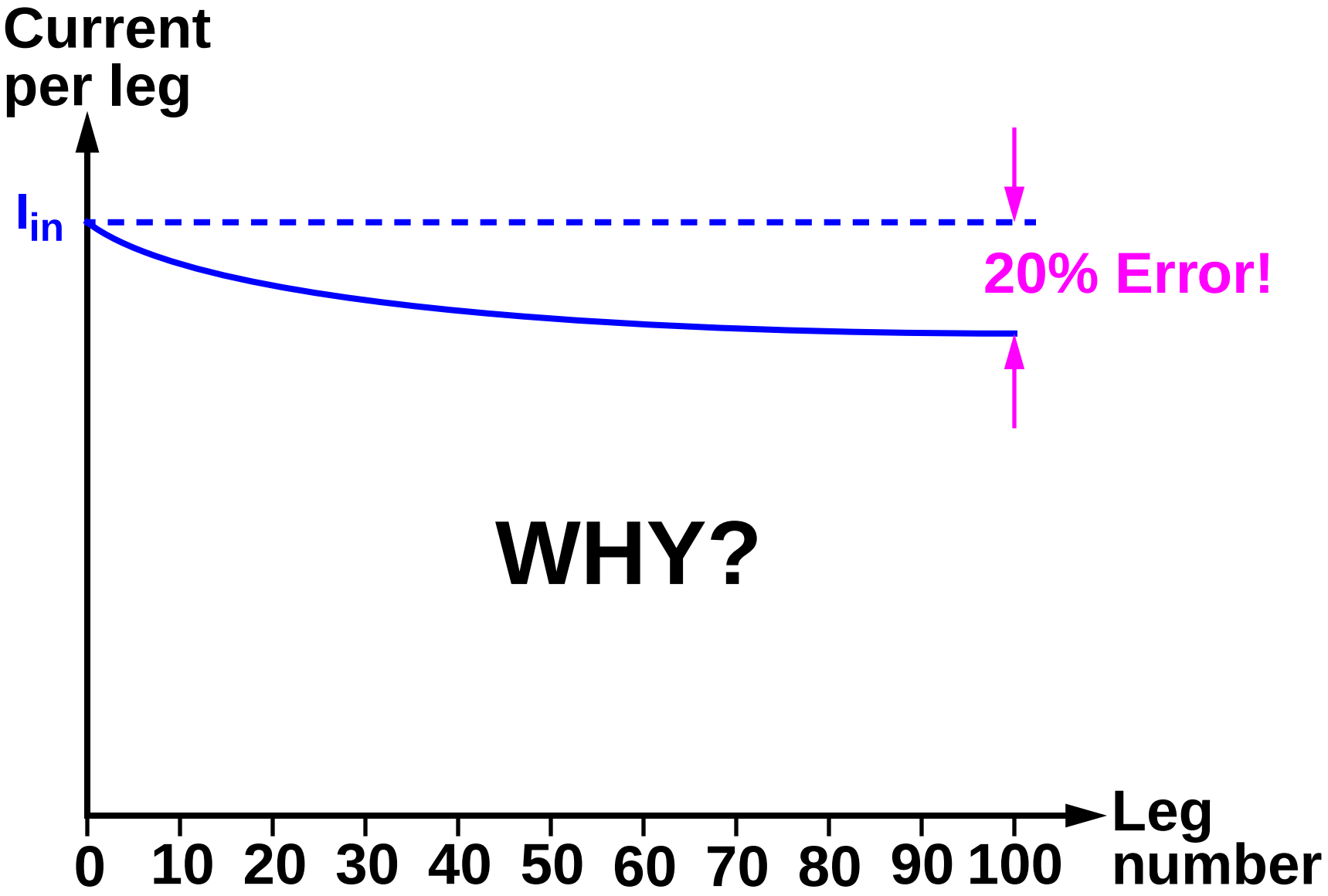
Where circuits designed in the virtual world collide with reality

- One of the most important *and instructive* aspects of analog IC work
- Consider a current-mode DAC:

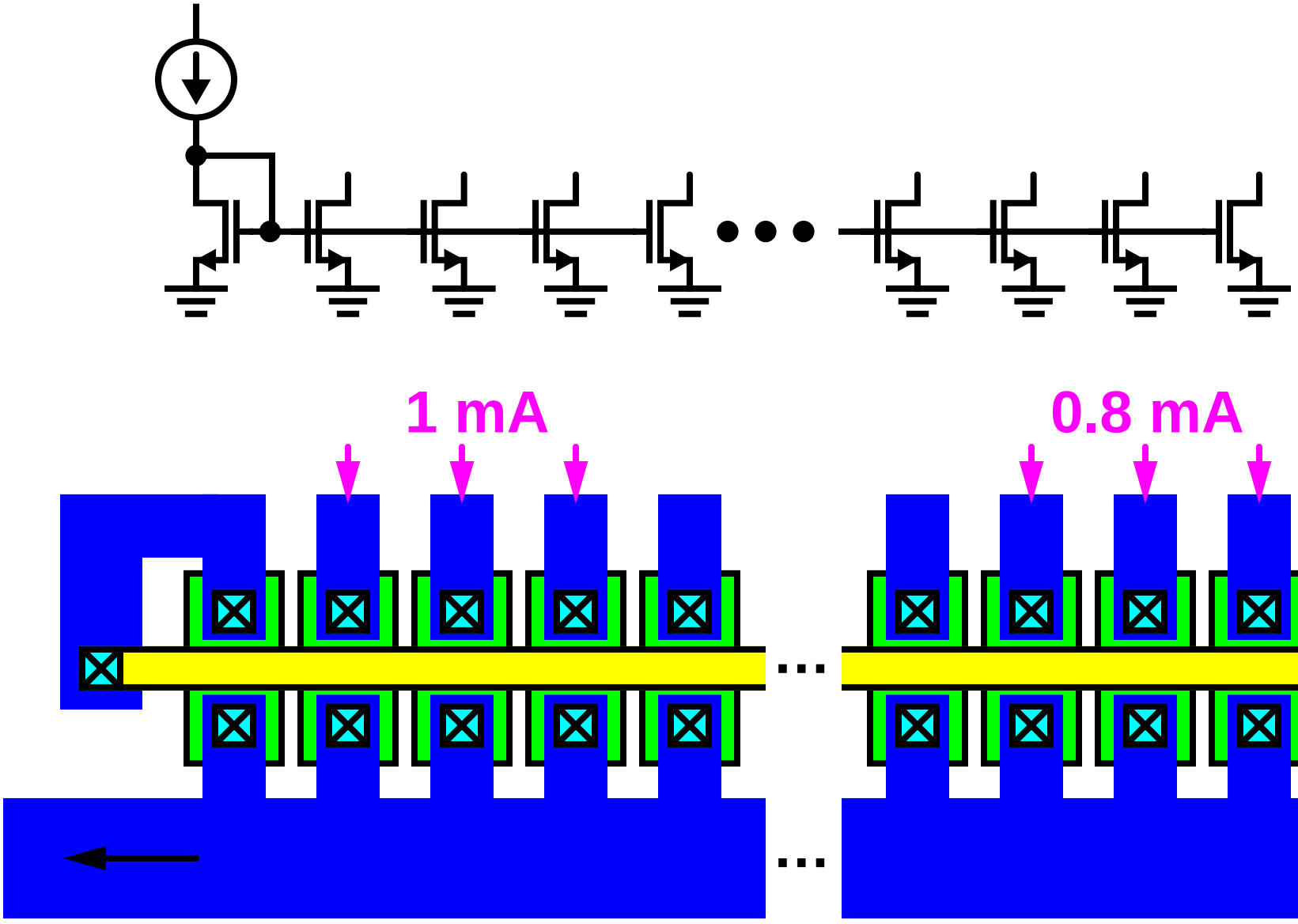


Need each leg to carry the same current as the master NMOS to within, say, 1%

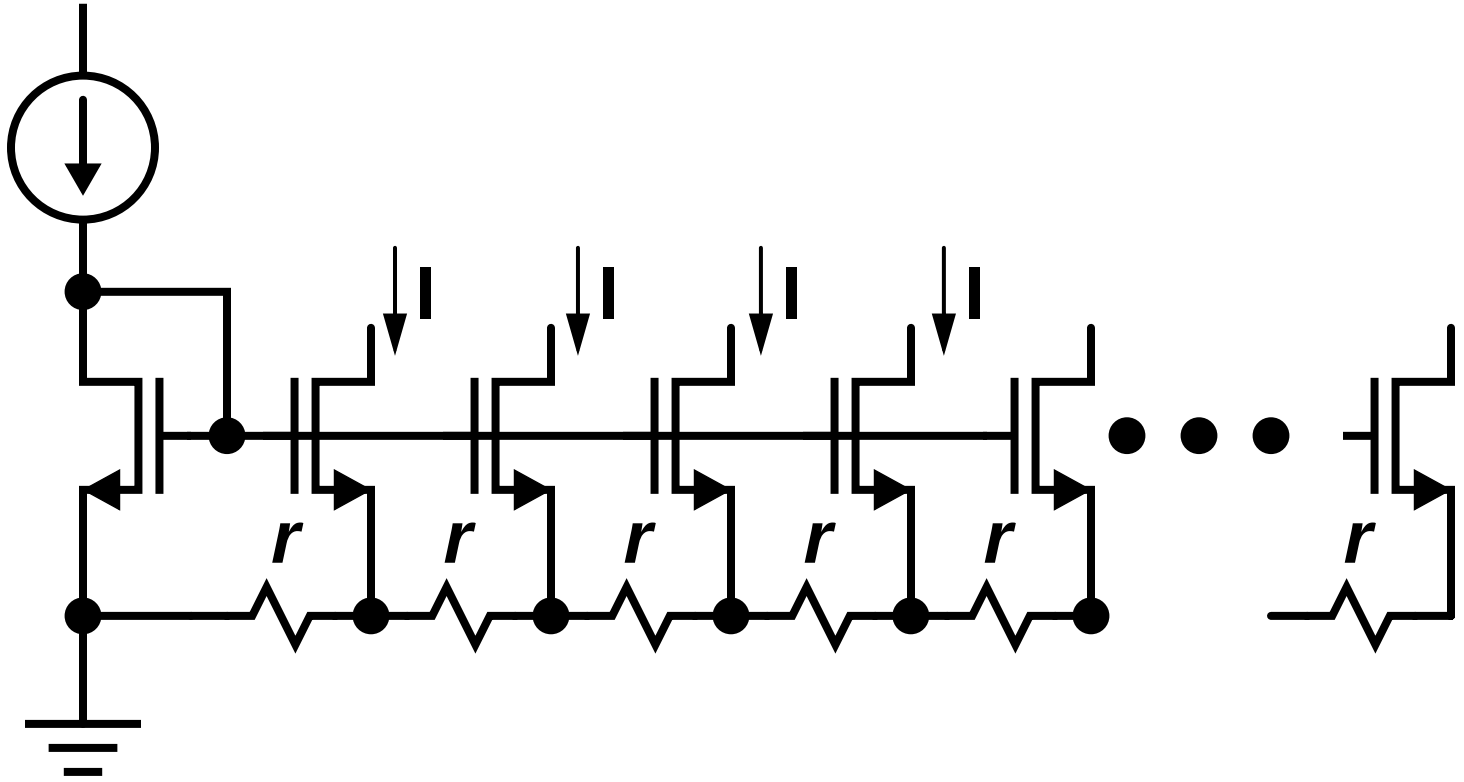
Measurement Result— Disaster!



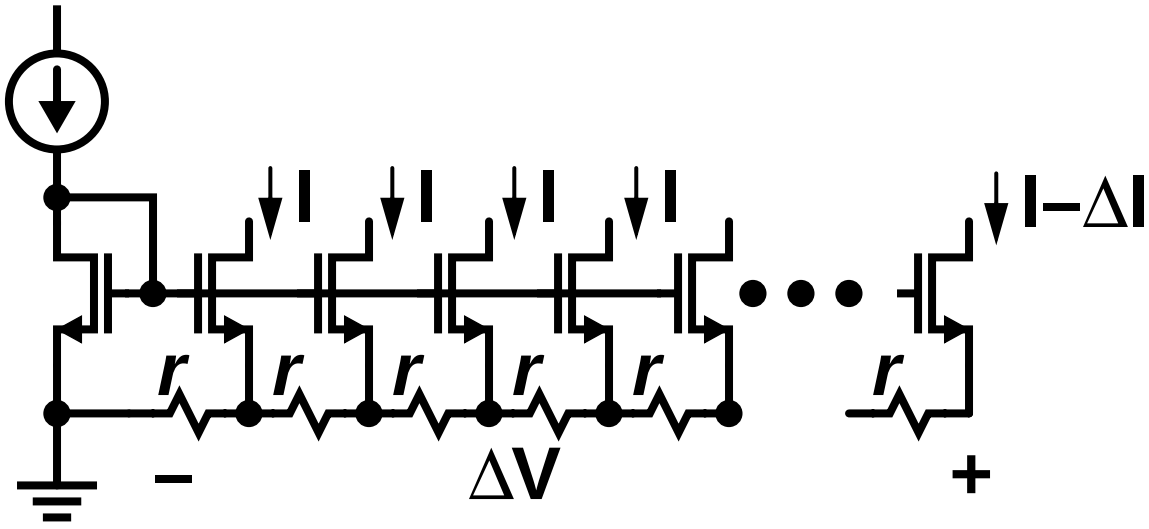
The Circuit Layout



Aha!
Wiring Resistance



Analysis



$$\Delta I = g_m \Delta V \qquad \Delta V = (n^2/2) r I$$

$$g_m = 2 \text{ mA/V} \qquad n = 100$$

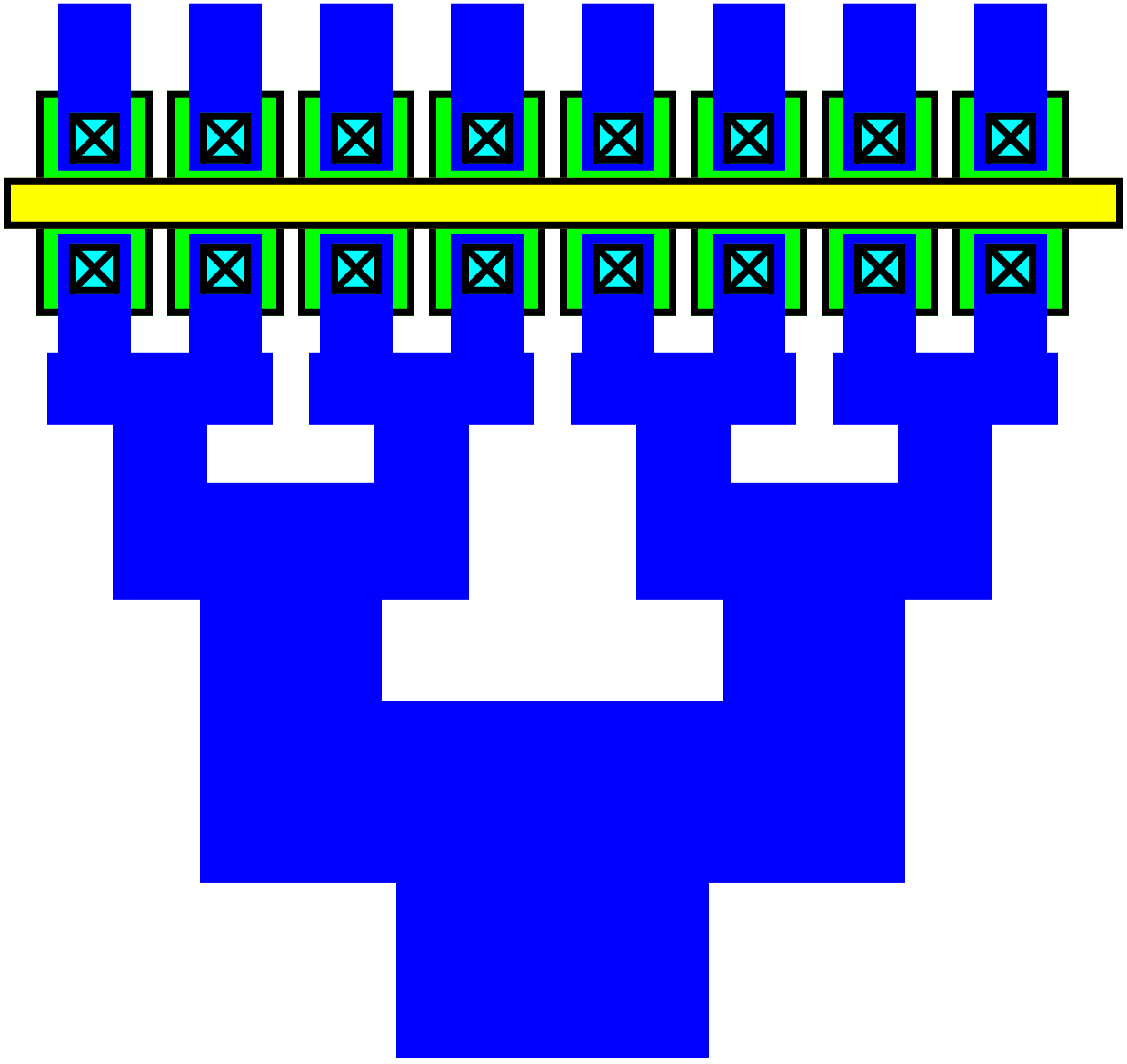
$$\Delta I = 0.2 \text{ mA} \qquad I = 1 \text{ mA}$$

$$\Delta V = 0.1 \text{ V} \qquad \boxed{r = 20 \text{ m}\Omega}$$

How To Fix This Problem?

- **To get 20x better matching, need $r < 1\ \mathrm{m}\Omega$**
  - **Good luck with that.**
- **Hopeless?**

Tree Connection



Summary

- **Peeked at 3 examples of analog IC cleverness**
  - **Circuit-level: clever architecture**
  - **Signal-processing: clever algorithm**
  - **Physical-level: clever layout geometry**
- **Innovation exists at many more levels and in various combinations**
- **There is still fresh ground to explore and exploit**
  - **The bulldozer that is digital CMOS is blazing a trail into new territory, enabling techniques that were impractical with earlier technologies.**
  - **E.g. Reliance on digital signal processing; using time intervals to represent analog quantities.**

$\Rightarrow$ **Analog IC design provides good entertainment**