

Near-Threshold Notch Filter with Pole-Radius Variation

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Introduction

- **GOAL:** assess the energy-savings accomplished with near-threshold voltage operation of digital CMOS circuits
- **Study-case:** notch filter with pole-radius variation (rejects the 50 - 60 Hz band)
- **Application:** Electroencephalogram (EEG) and other health-care applications

Digital Notch Filter Design

Digital Notch Filter parameters:

$$\theta_0 = \frac{2\pi f_0}{f_s} [\text{rad}] \quad b = \frac{2\pi \Delta f}{f_s}$$

θ_0 digital notch normalized angle

b - 3dB rejected bandwidth

f_0 center frequency

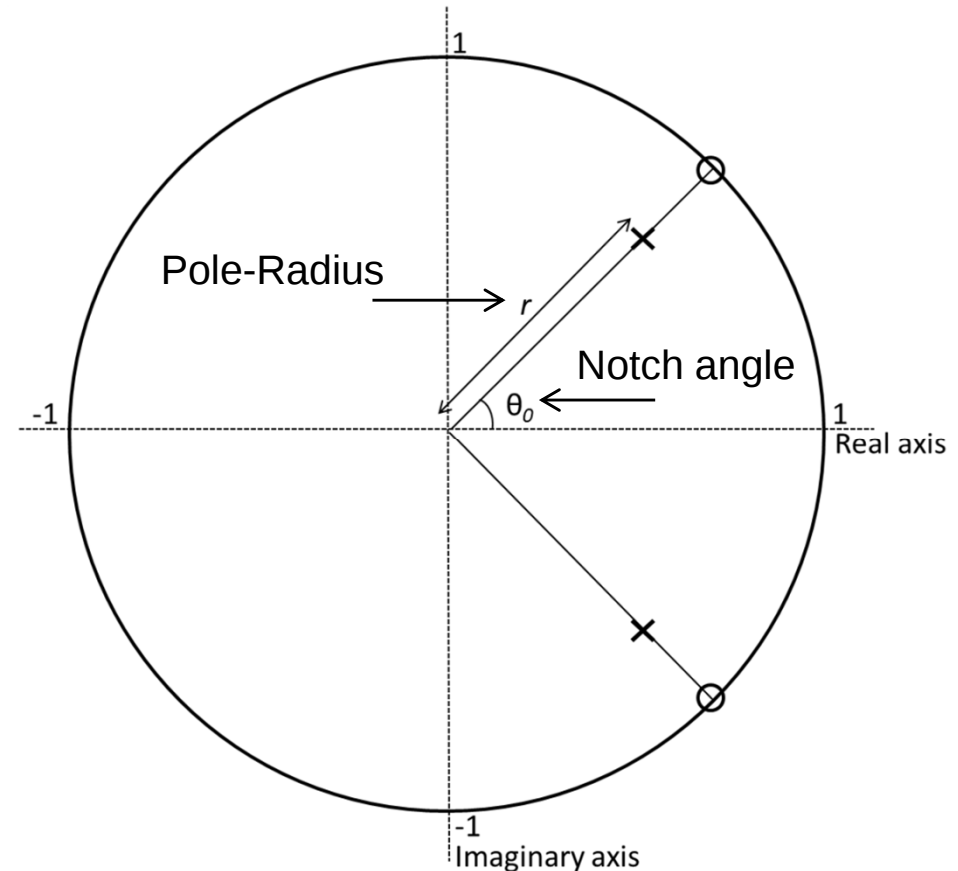
Δf ideal rejected bandwidth

f_s sampling frequency

Quality factor:

$$Q = \frac{f_0}{\Delta f} \Rightarrow \boxed{Q \approx \frac{\pi f_0}{(1-r)f_s}}$$

Relation between Q and r



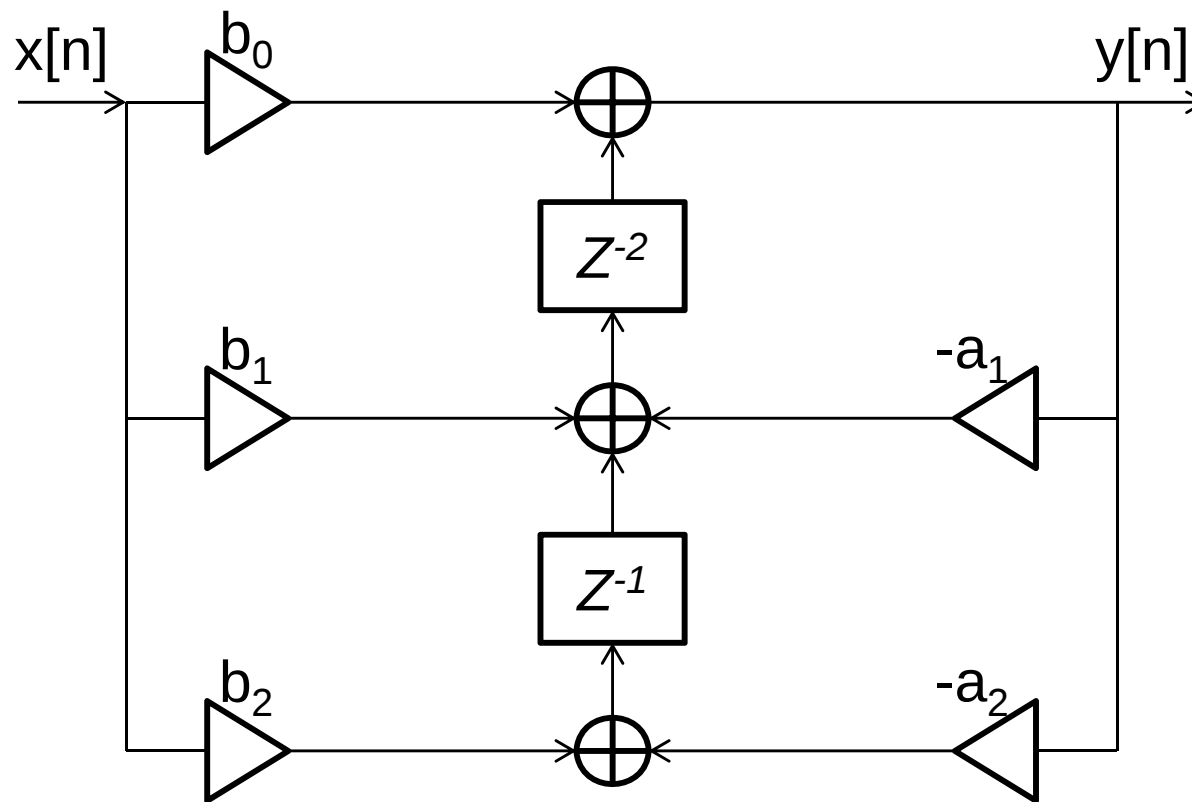
Notch Filter Transfer Function:

$$H(z) = \frac{1 - 2\cos(\theta_0)z^{-1} + z^{-2}}{1 - 2r\cos(\theta_0)z^{-1} + r^2z^{-2}}$$

Hardware Architecture & Synthesis

- Direct Transpose II:

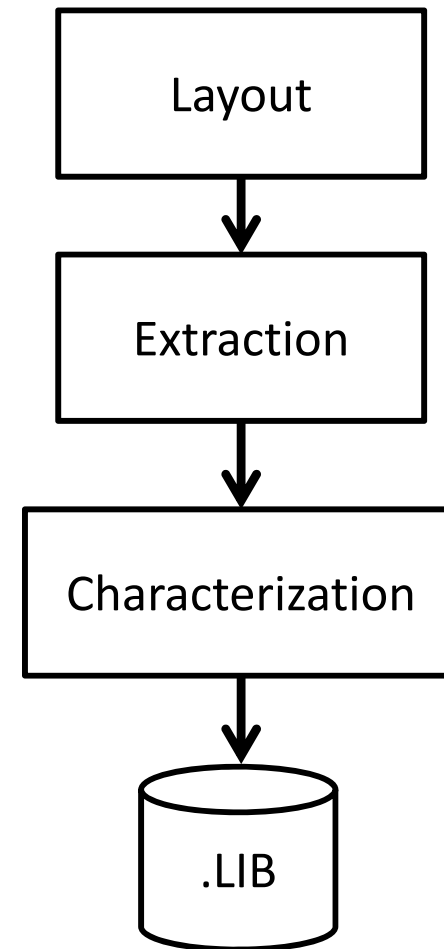
✓ 3x 32-bit multipliers ✓ 3x 32-bit adders ✓ 3x 32 registers



- 5kHz target frequency
- Signed fixed point format (Q 2.30)

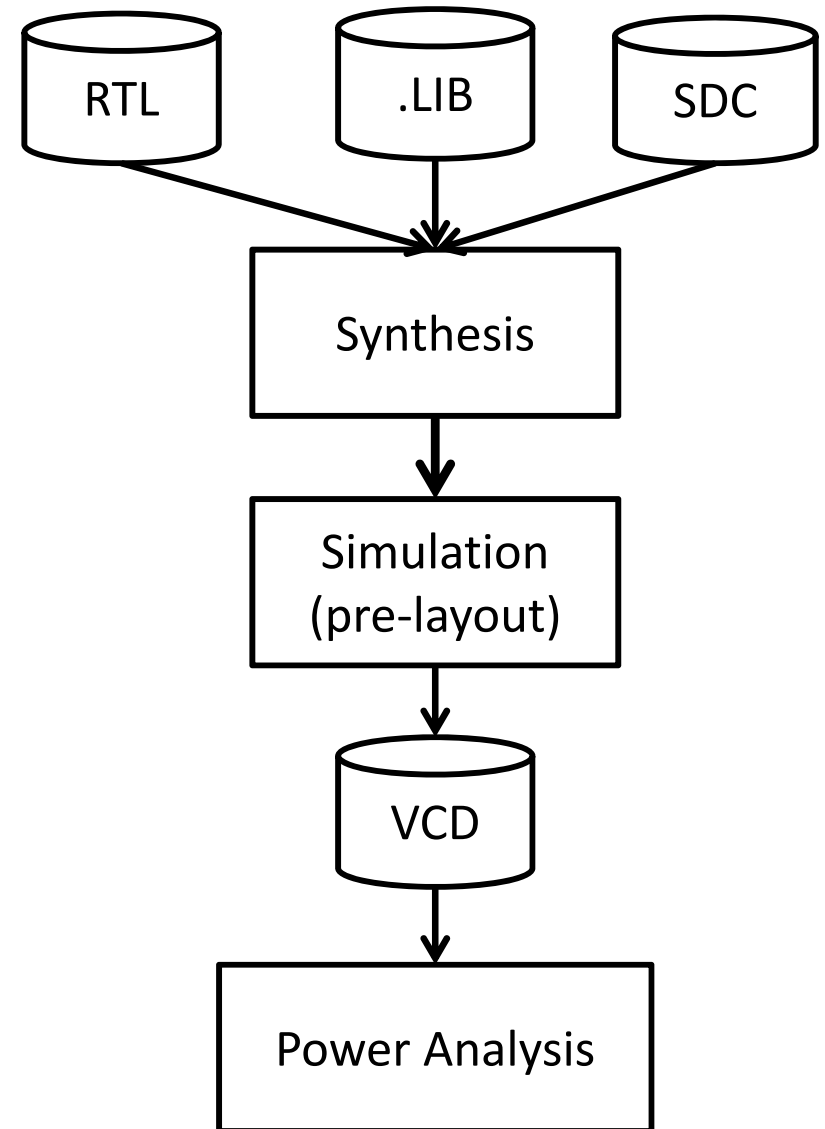
Near-Threshold Voltage Library

- Custom 65nm near-threshold voltage library
- Minimum size cells:
 - NAND, NOR, INV, DFF
- Flow: layout, extraction, characterization
- Characterization Corners
 - Typical process
 - 35 Degrees Celsius (near body temp.)
 - 0.45V, 0.55V, 0.80V, 1.2V

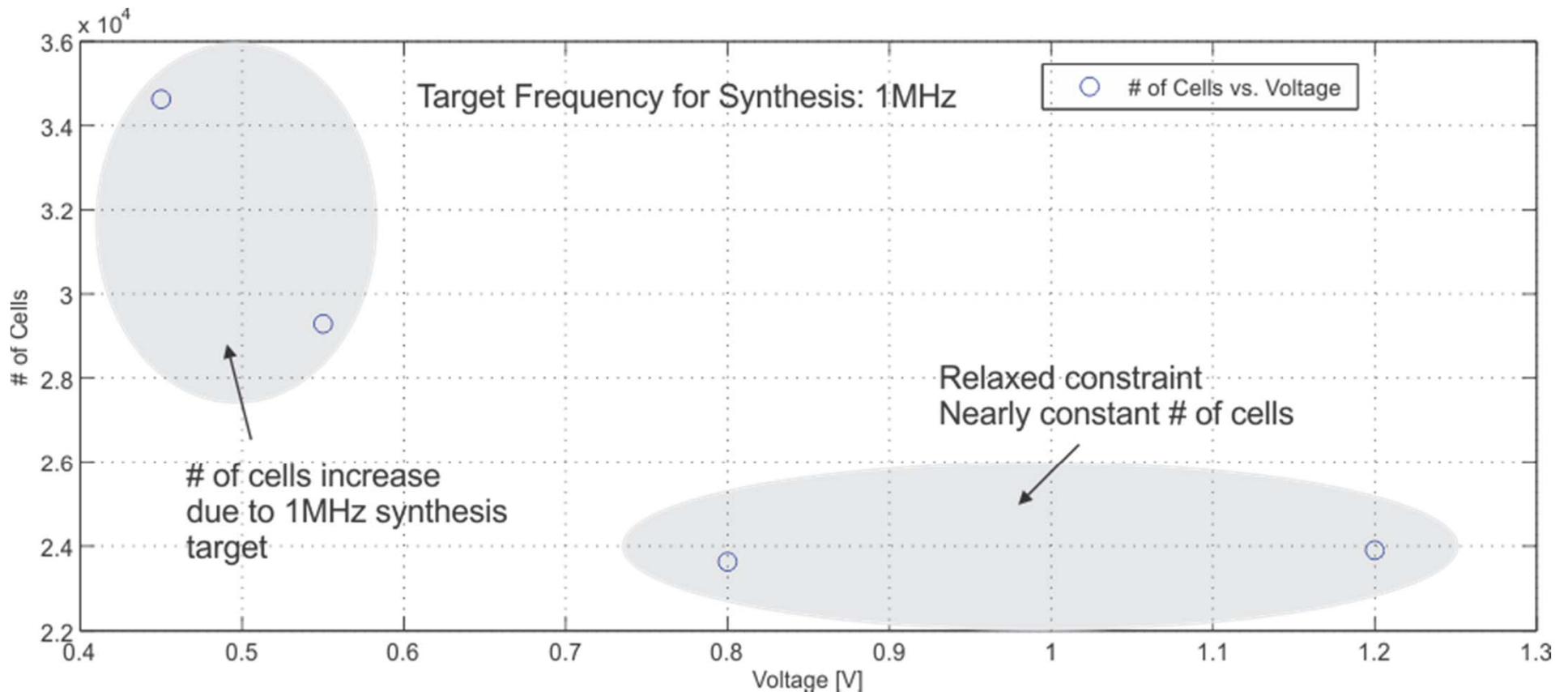


Results Methodology for Power Analysis

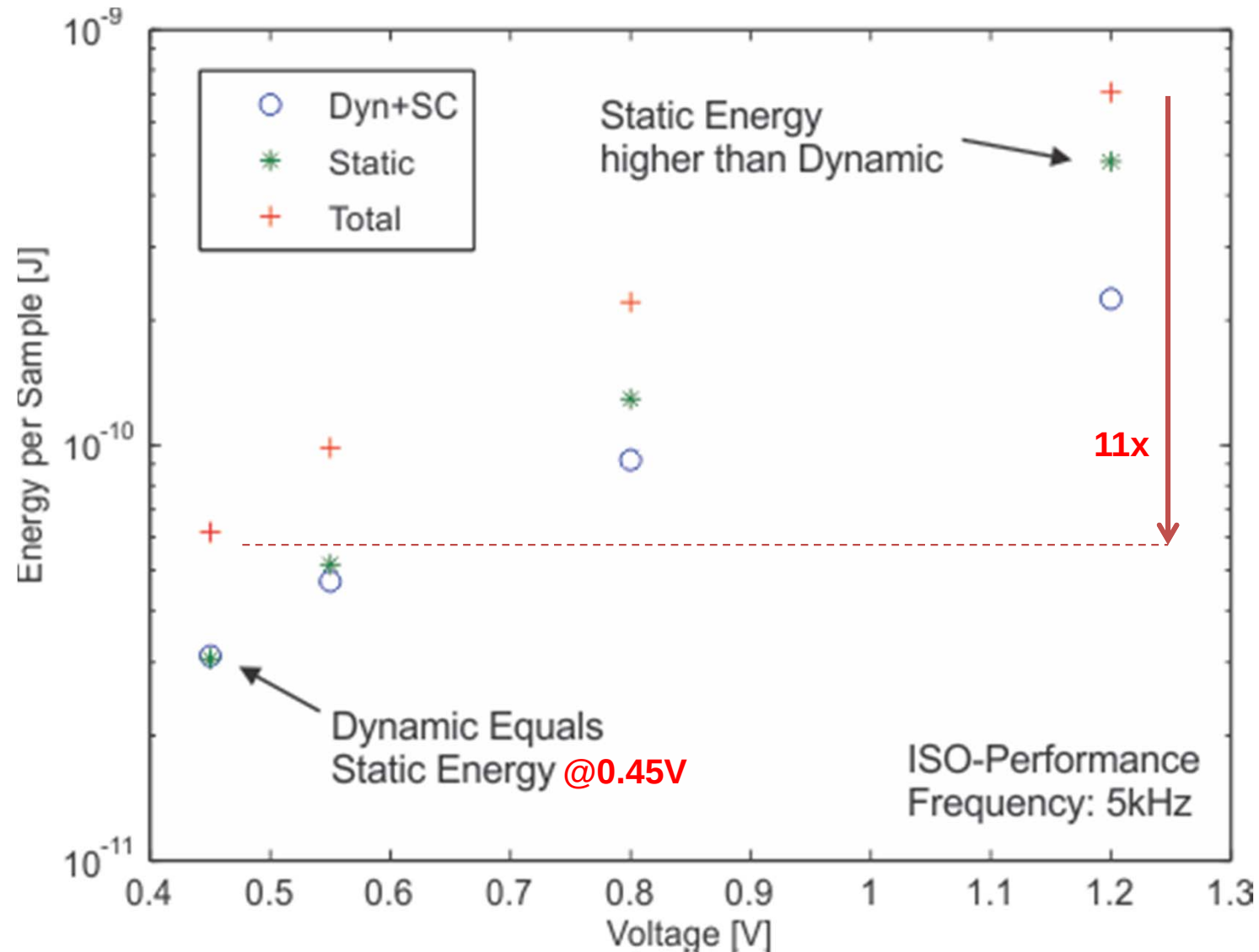
- Synthesis with near-threshold libraries
 - Typical process
 - 35 Degrees Celsius (near body temp.)
 - 0.45V, 0.55V, 0.80V, 1.2V
- Pre-layout simulation in order to extract waveform information (VCD file)
- Power analysis taking into account the activity profile of each net in the design



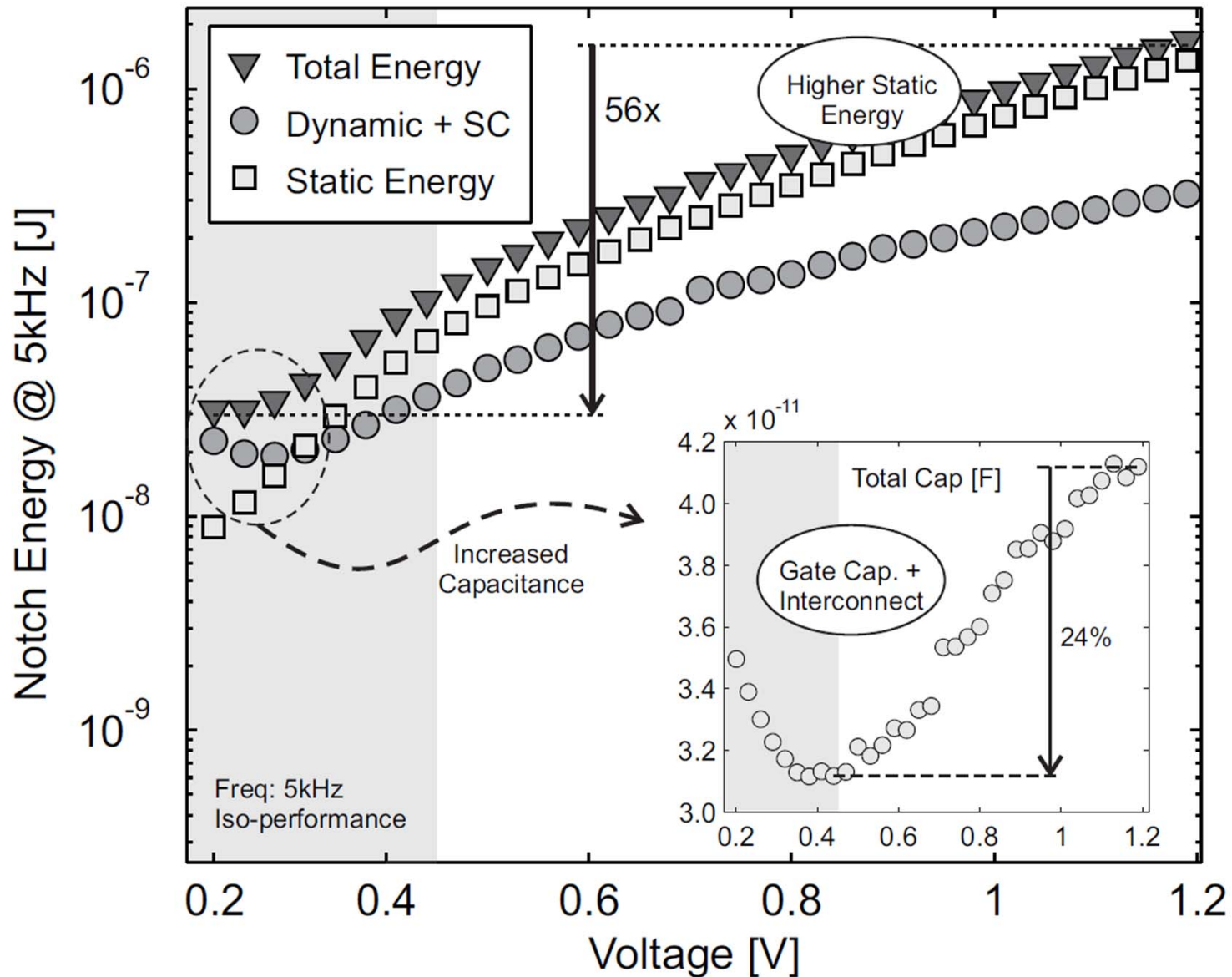
Results on Number of Cells



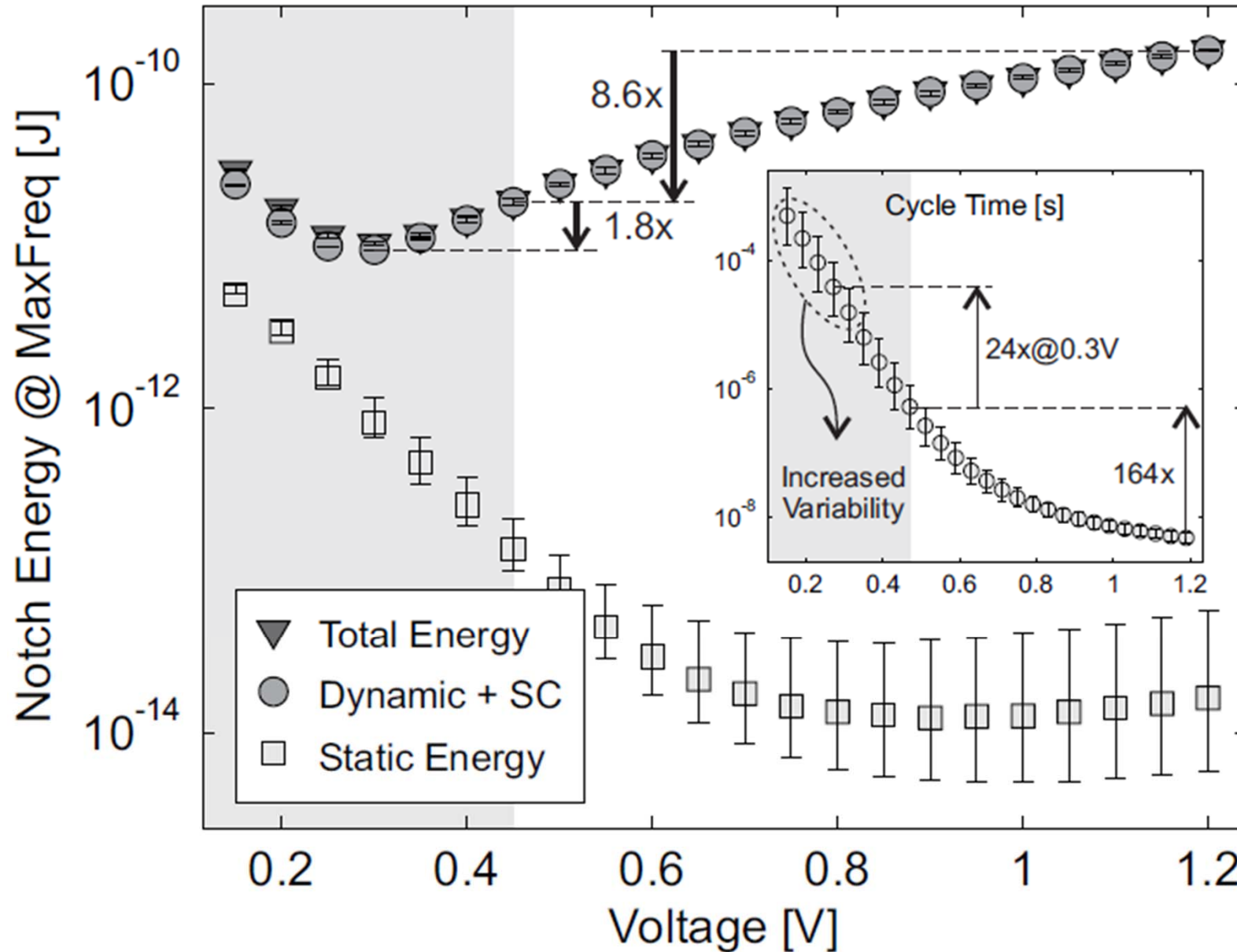
Results on Dynamic/Static Energy



Later work: up to 56x energy-savings



Later work: maximum-frequency



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Conclusion

- Near-threshold library and 25kgates Notch filter design are proposed
- **11x** energy-savings are achieved at 0.45V (61pJoules/sample)
- **Later work** showed **56x** energy-savings through deeply scaled supply voltage

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Thank you!
Questions?

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