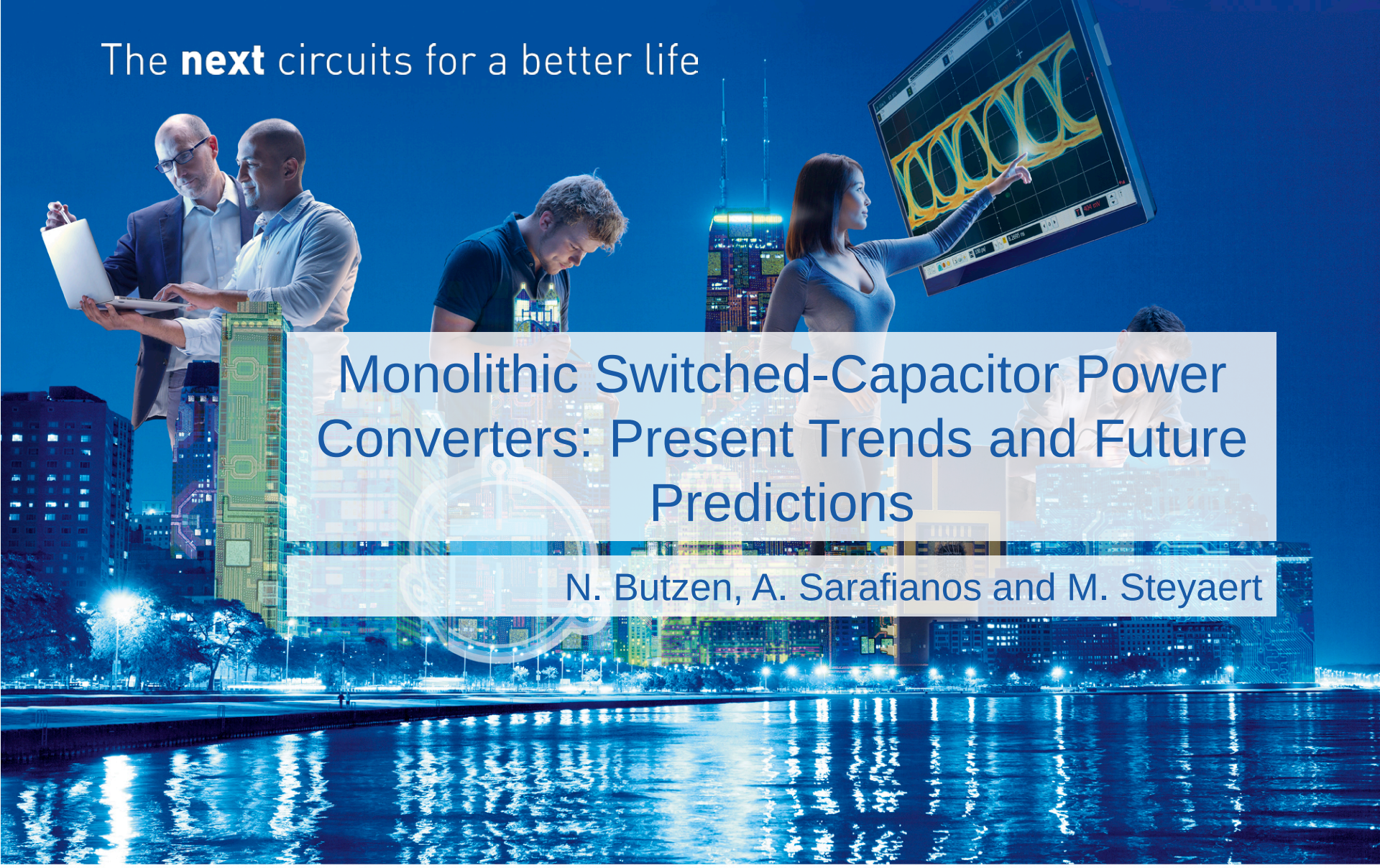

Monolithic Switched-Capacitor Power Converters: Present Trends and Future Predictions

N. Butzen, A. Sarafianos and M. Steyaert

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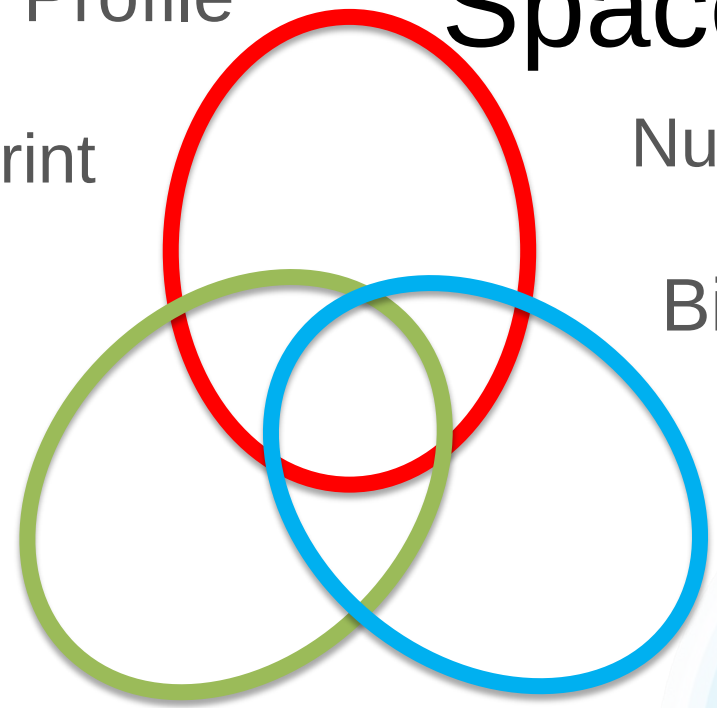
Overview

- Introduction
- Switched-Cap: Trends
- Switched-Cap: Present Focus
- Conclusions

INTRODUCTION

Why Monolithic?



Profile

Space

Footprint

Number of pins

Bill of Materials

IR Ldi/dt

Cost

Power

Regulation

High volume
Silicon
Technologies

Why Switched-Capacitor?

- Both Switches and Capacitors are used in Digital Circuits
  - Readily available
  - Scale well to advanced nodes

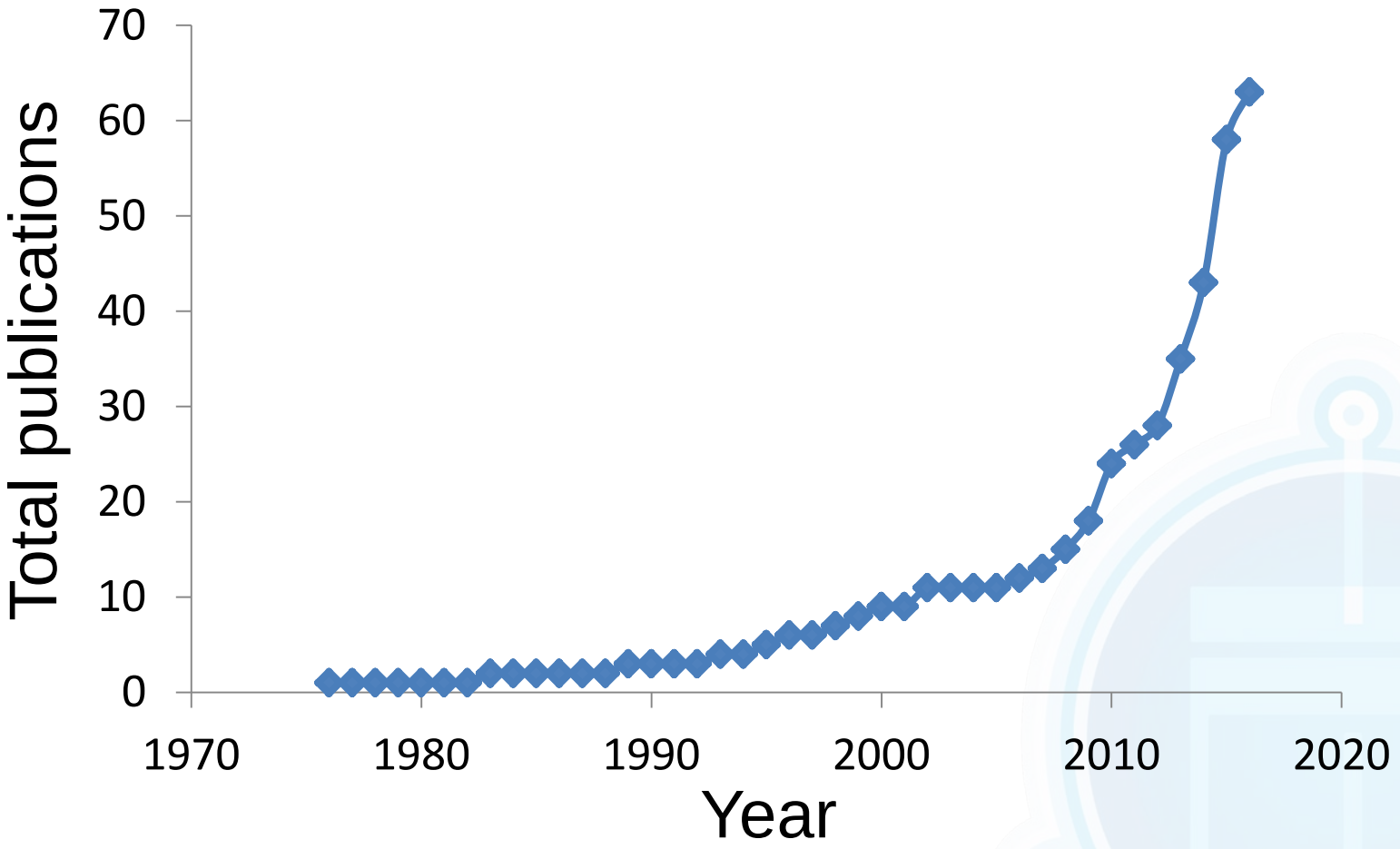
Switched-Capacitor Survey

- Select publication titles (TPEL, JSSC, ISSC, APEC, …)
- A total of 63 publications
- From 1976-2016

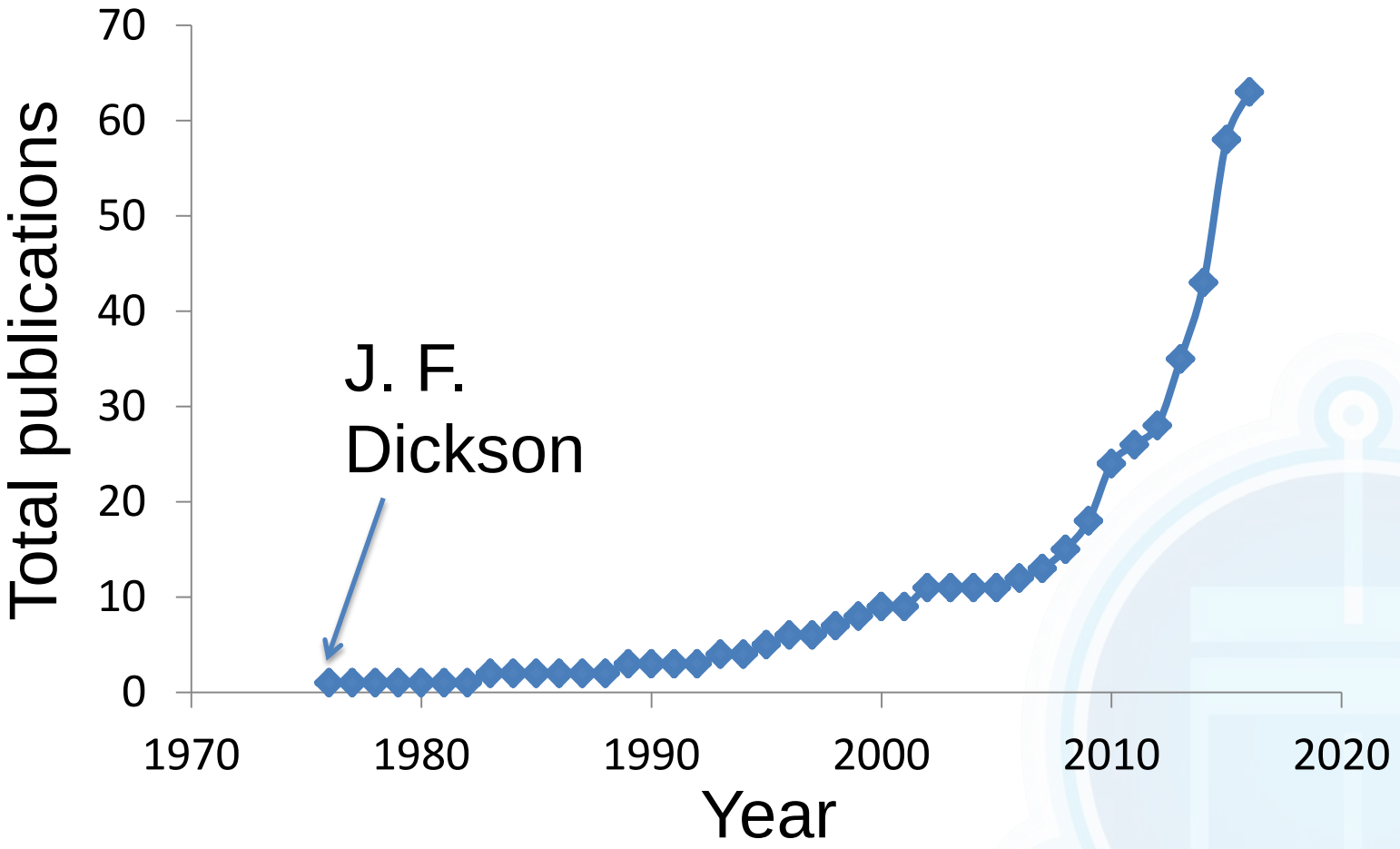
M. Steyaert, N. Butzen, H. Meyvaert, A. Sarafianos, P. Callemeyn, T. Van Breussegem and M. Wens, "DCDC performance Survey", [Online]. Available: http://homes.esat.kuleuven.be/~steyaert/DCDC_Survey/DCDC_PS.html

SWITCHED-CAP: TRENDS

Switched-Capacitors are Hot



Switched-Capacitors are Hot



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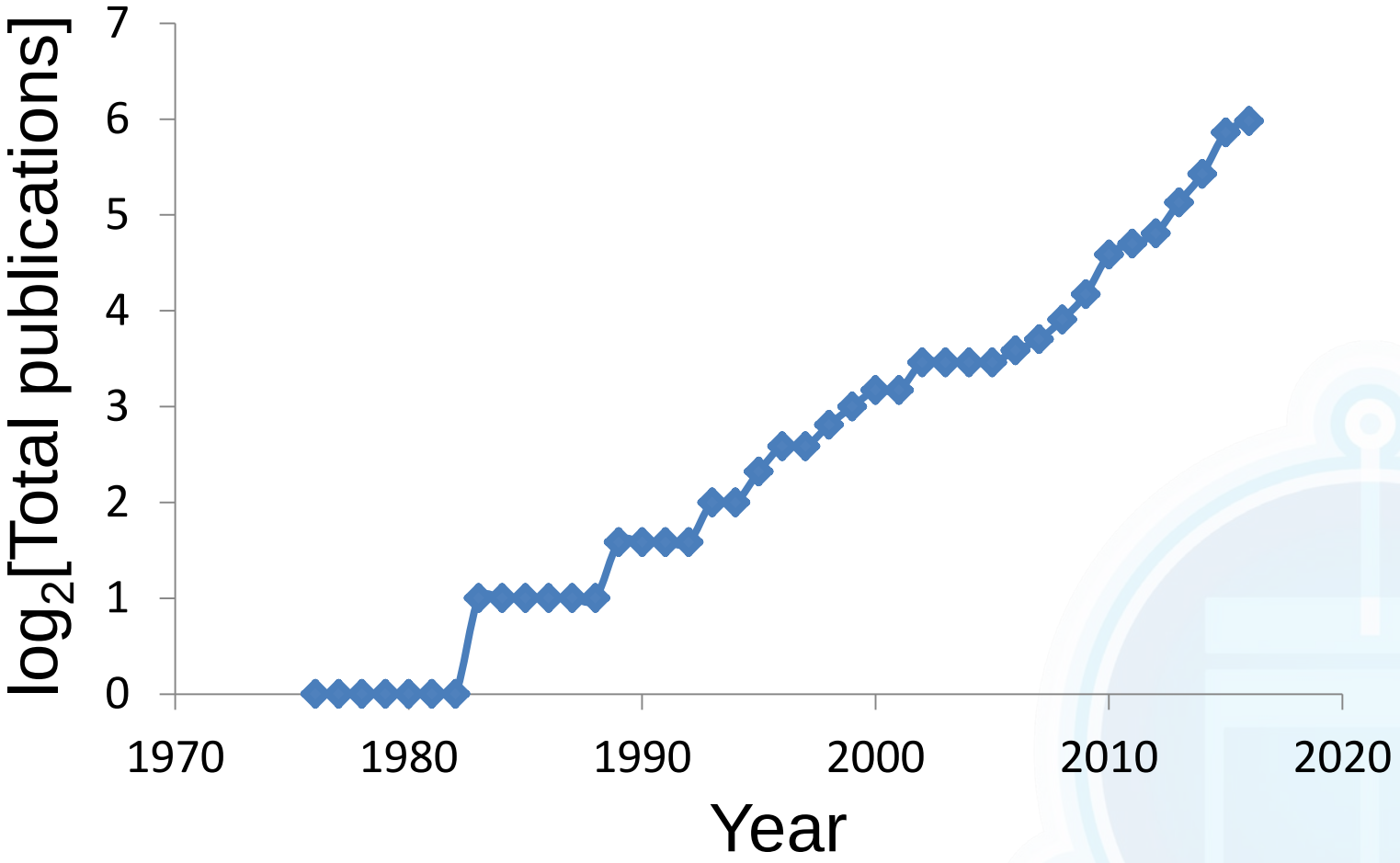
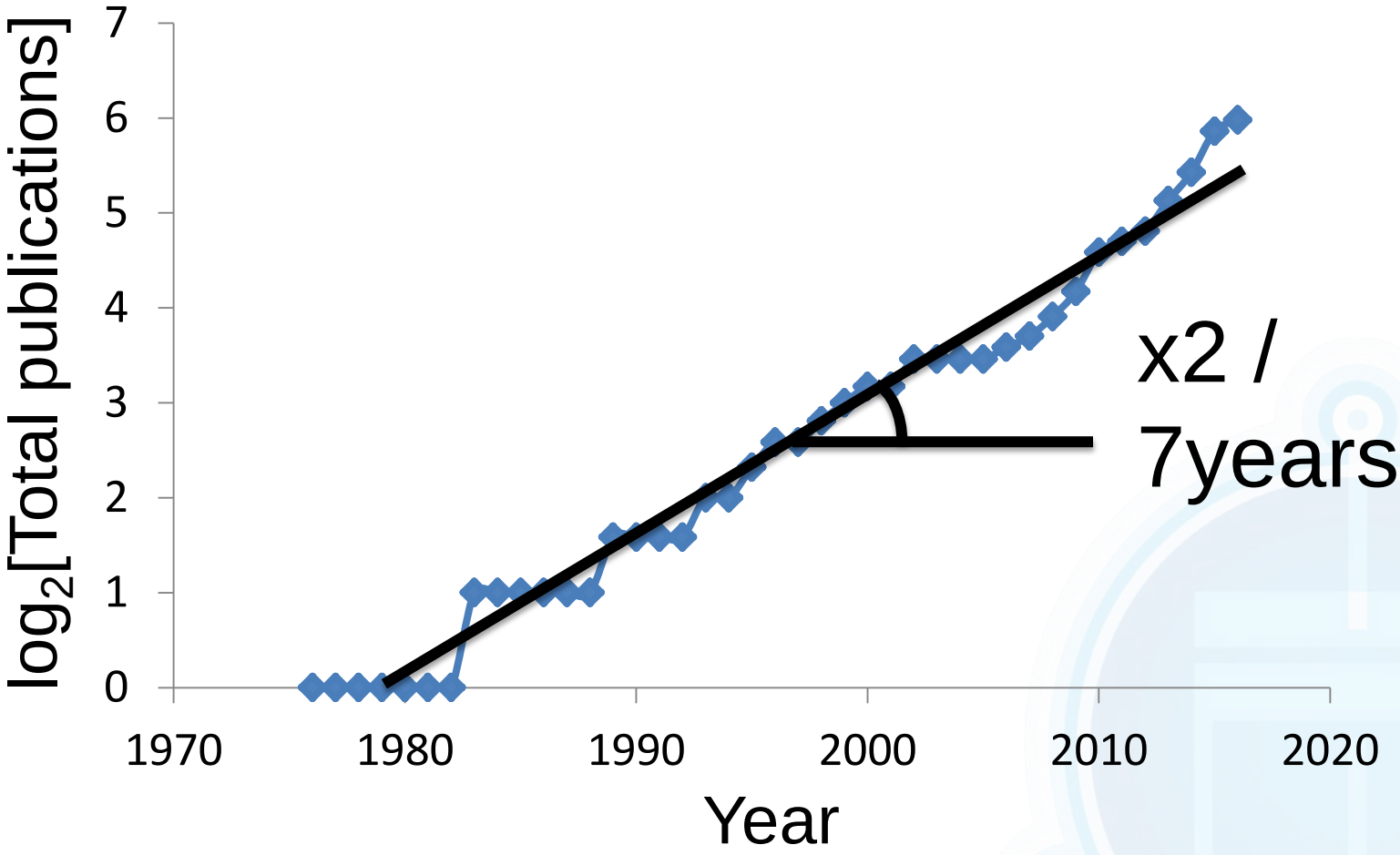
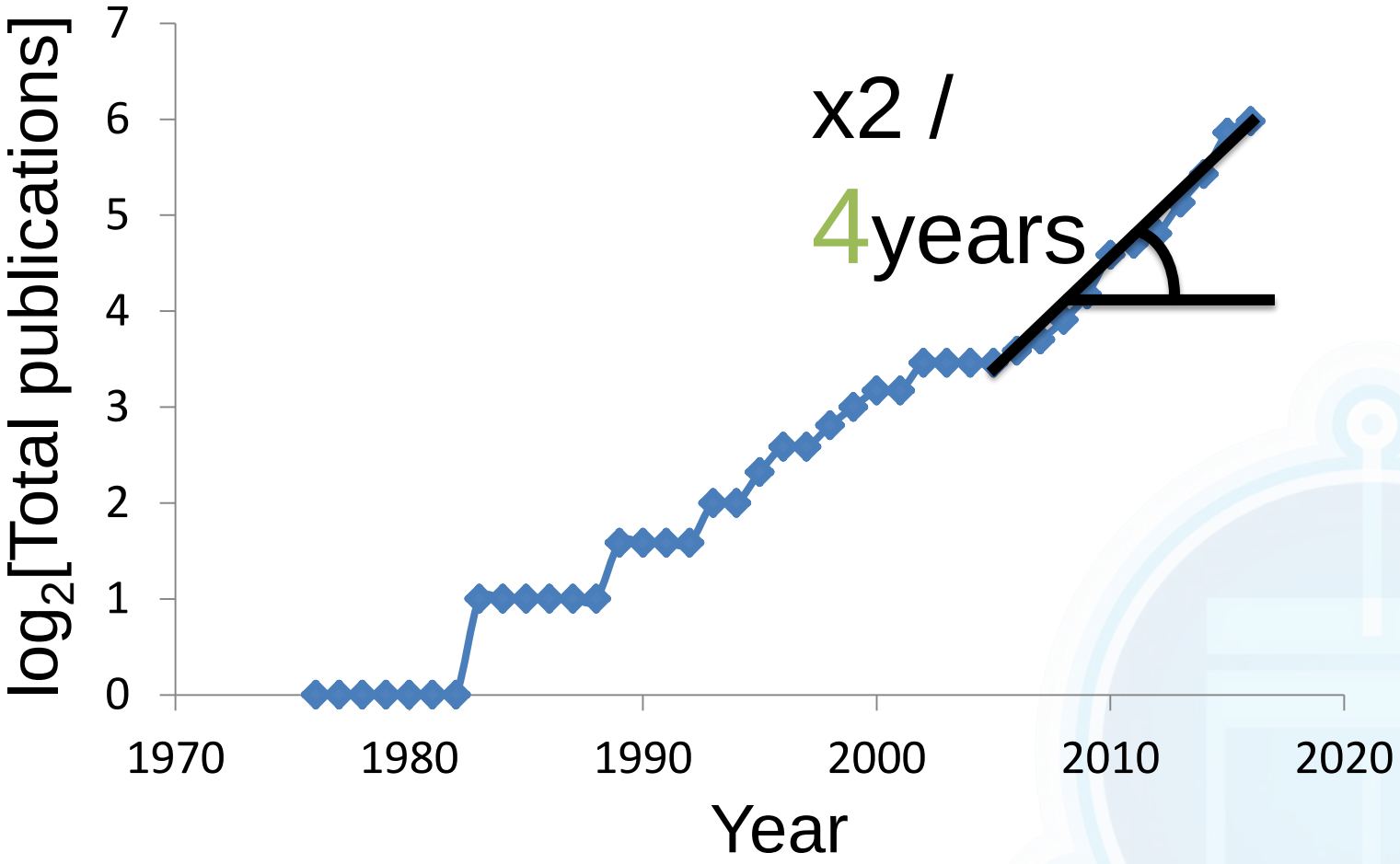


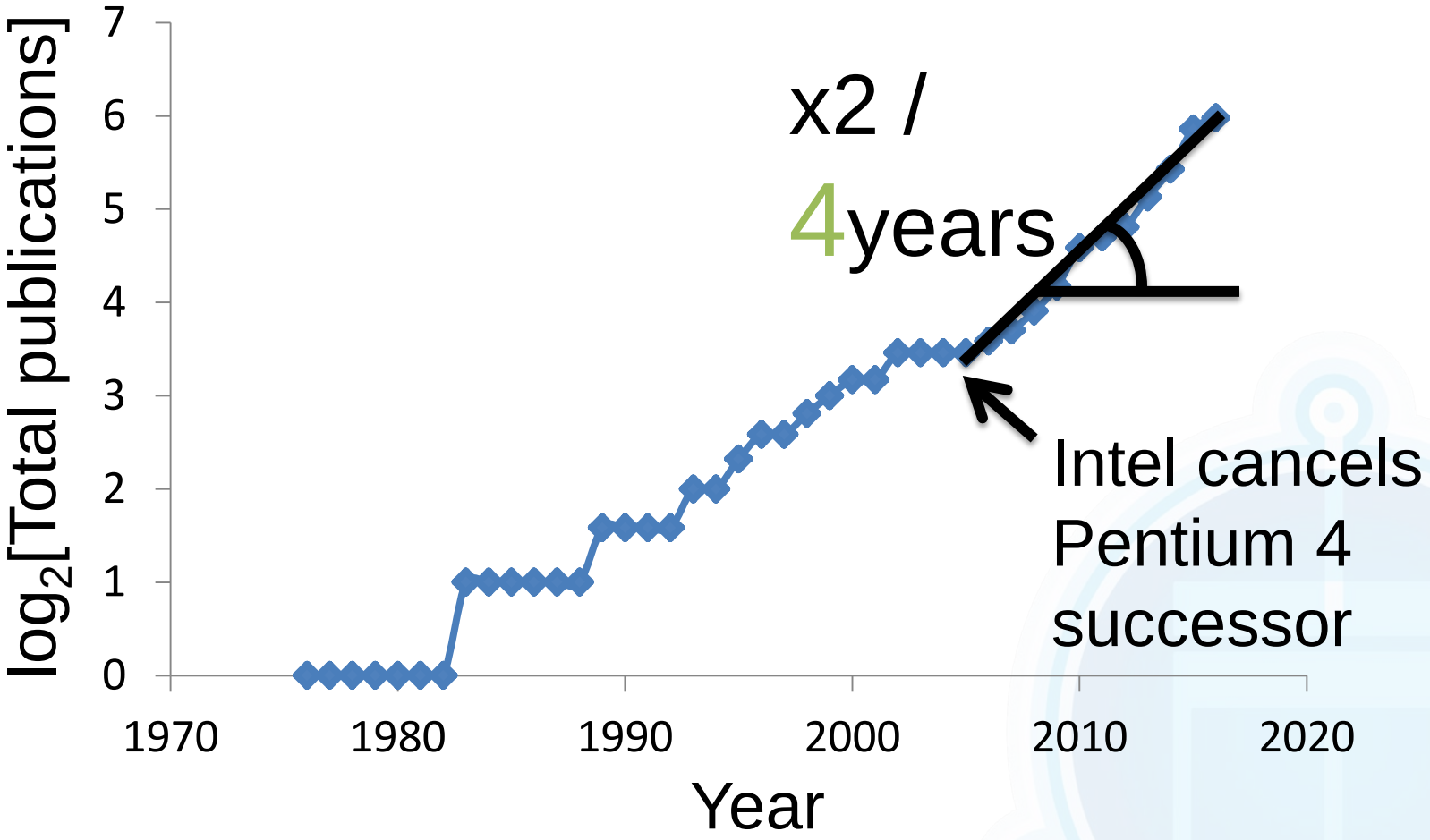
Switched-Capacitors are Hot



Switched-Capacitors are Hot



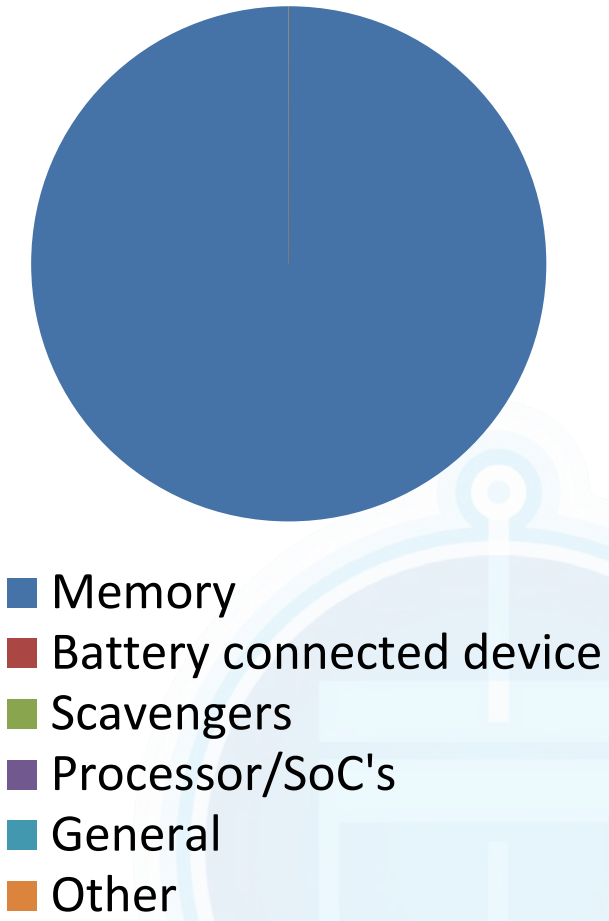
Switched-Capacitors are Hot



For what application?

- 1976-1995
  - ‘Charge-pumps’
  - Memory (EEPROM)

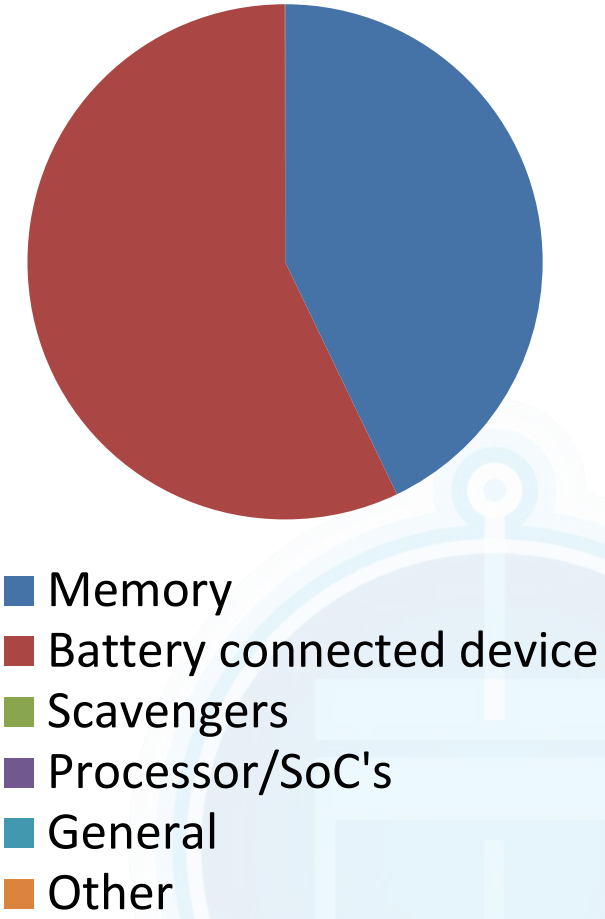
⇨ High VCR /
Low Efficiency



For what application?

- 1996-2006
  - Portable devices

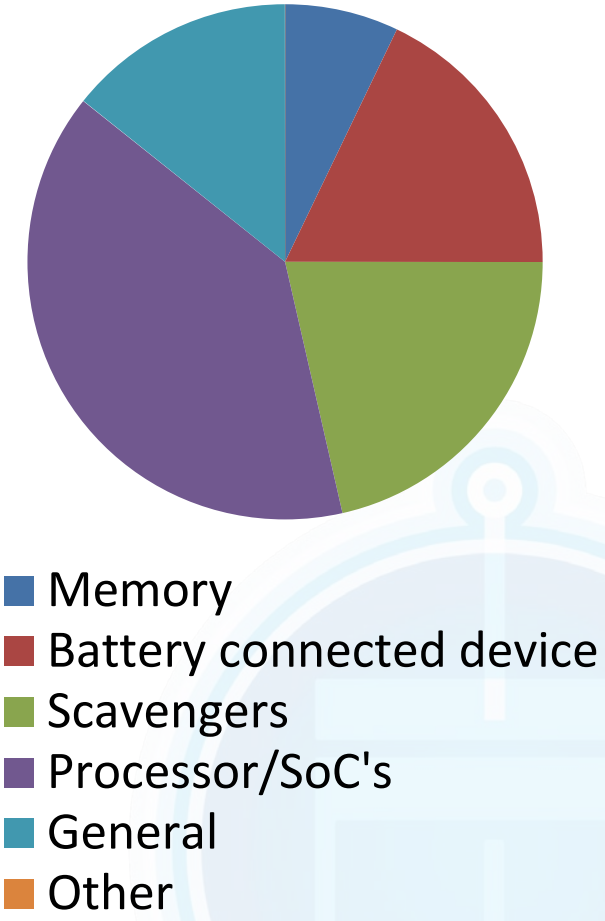
Efficiency becomes important



For what application?

- 2007-2011
  - Systems on Chip
  - Energy Harvesting
  - General papers

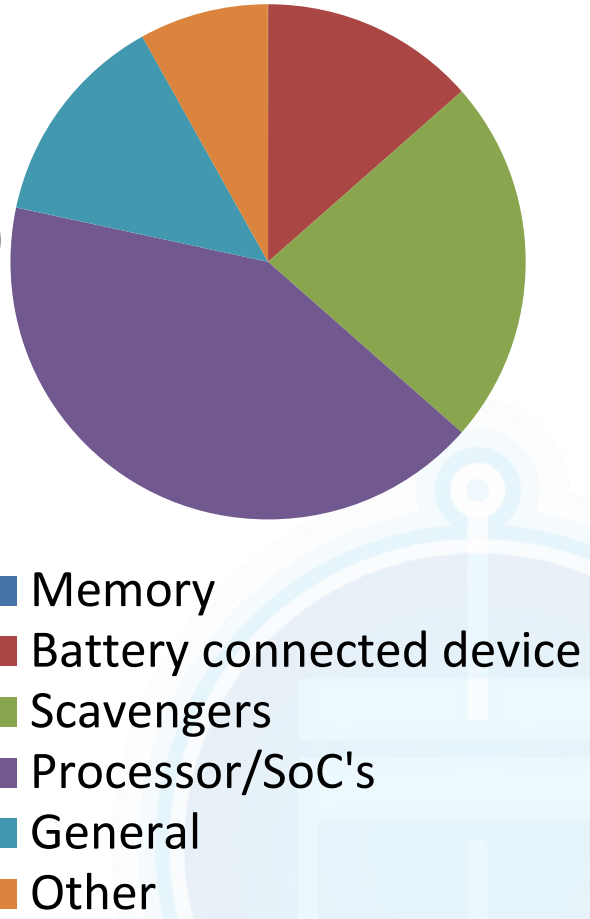
‘Allround designs’



For what application?

- 2012-2016
  - Processors (DVS/DVFS)
  - Automotive/MEMS/ Actuators

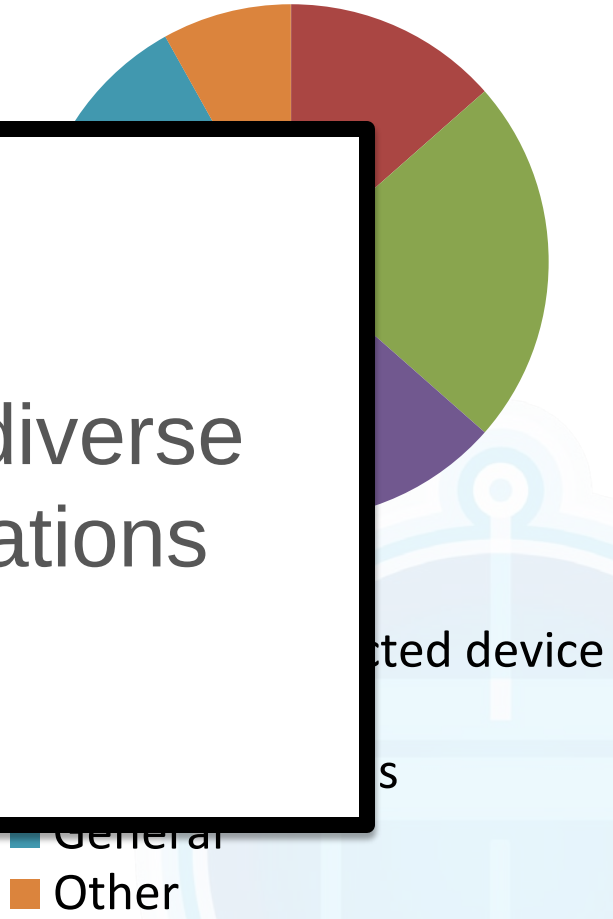
⇨ High Power, Voltage Range



For what application?

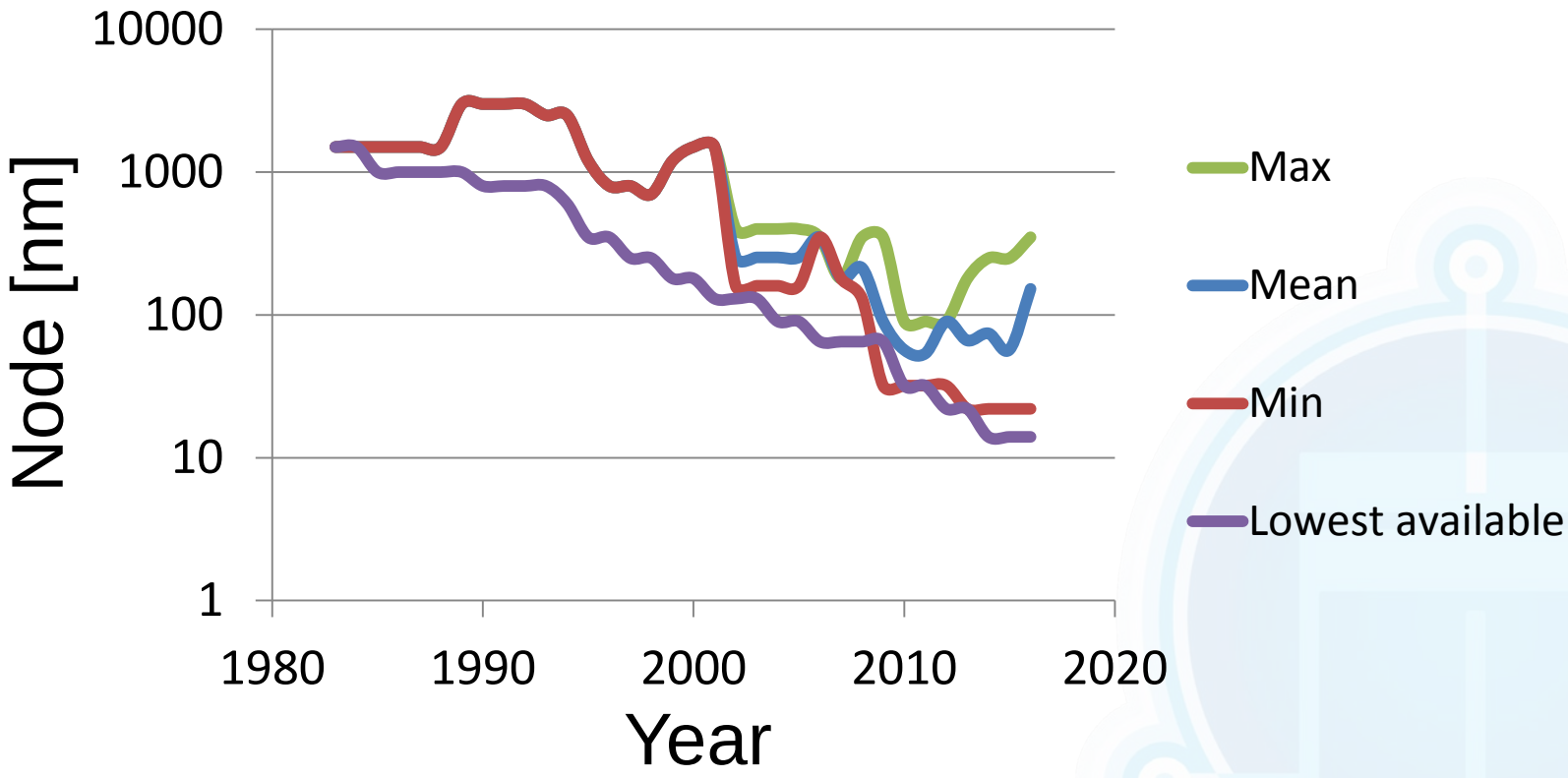
- 2012-2016
  - Proc
  - Auto
    Actu
  - Hig
    Ra

Increasingly diverse set of applications



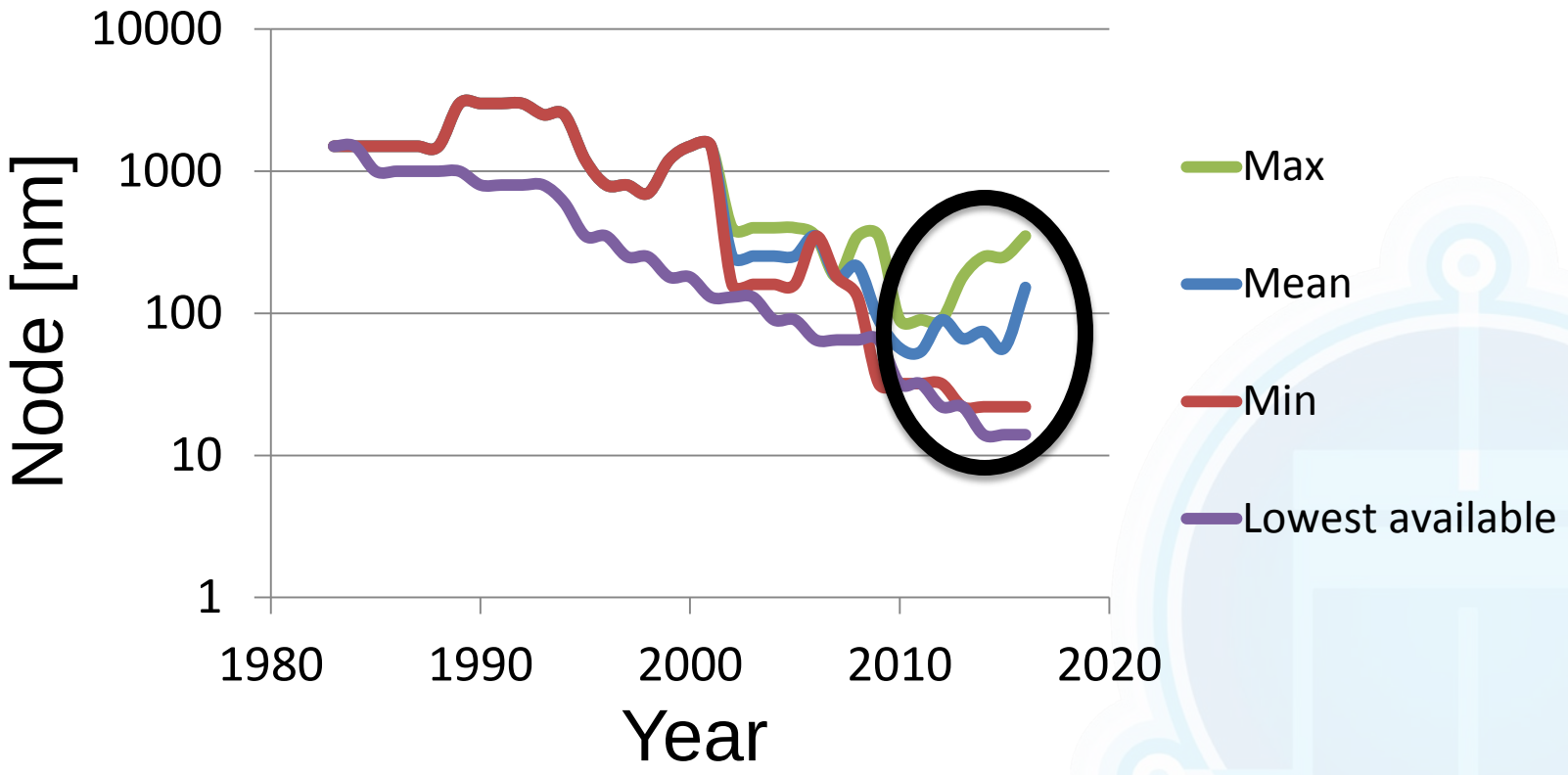
What about technology?

- SC's are on the bleeding edge



What about technology?

- But don’t need to be



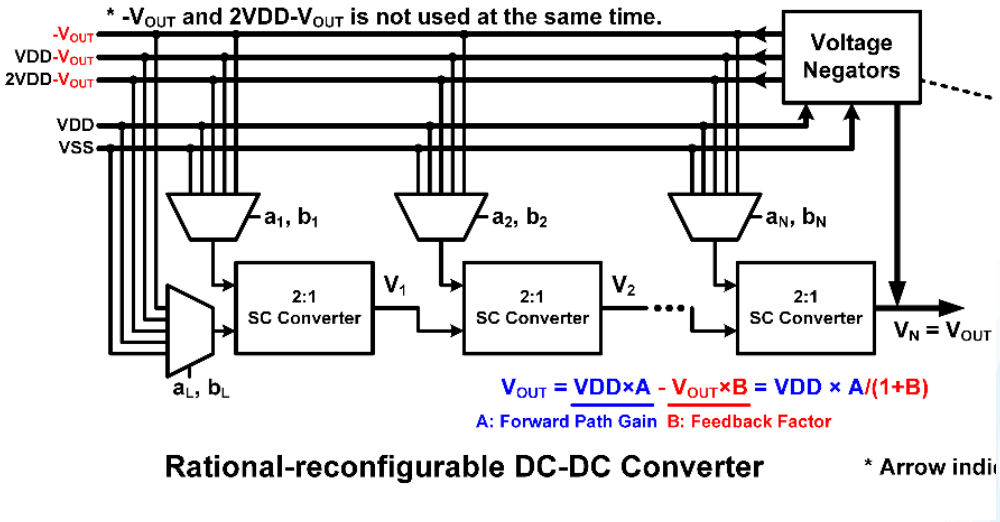
SWITCHED-CAP: PRESENT FOCUS

A Selection

- Wide efficient Voltage Range
- Efficiency/Power Density Limits

Wide efficient Voltage Range

- Efficiency limited by Conversion Ratio
  → Use a lot of VCR's



[Jung2016]

Wide efficient Voltage Range

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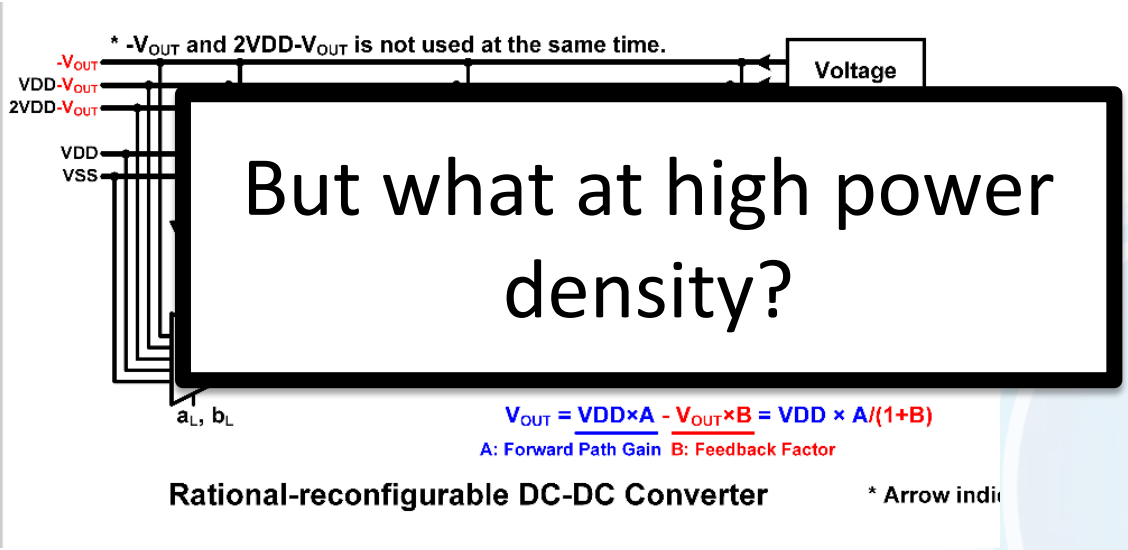
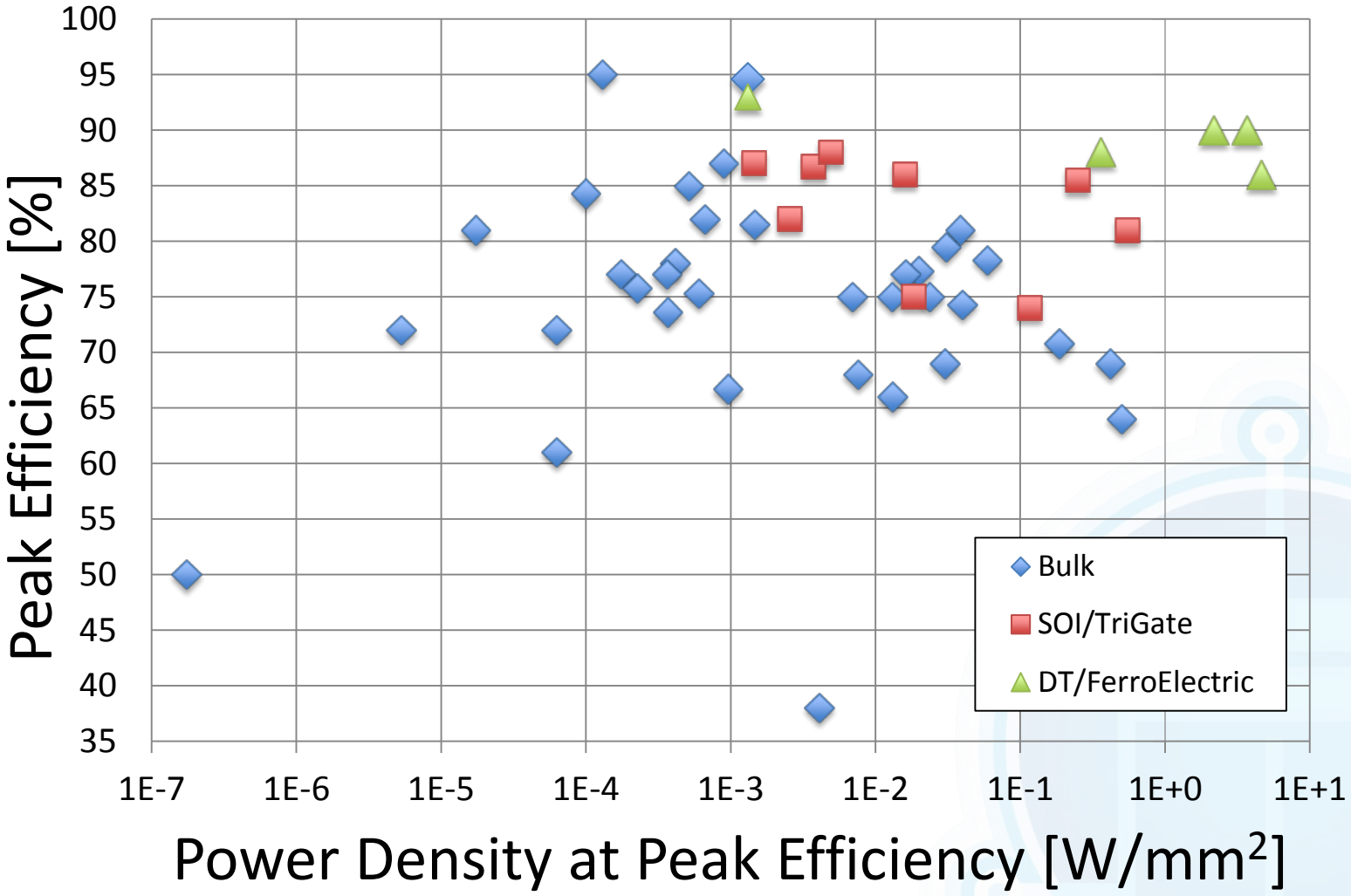


[Jung2016]

Efficiency/Power Density Limits



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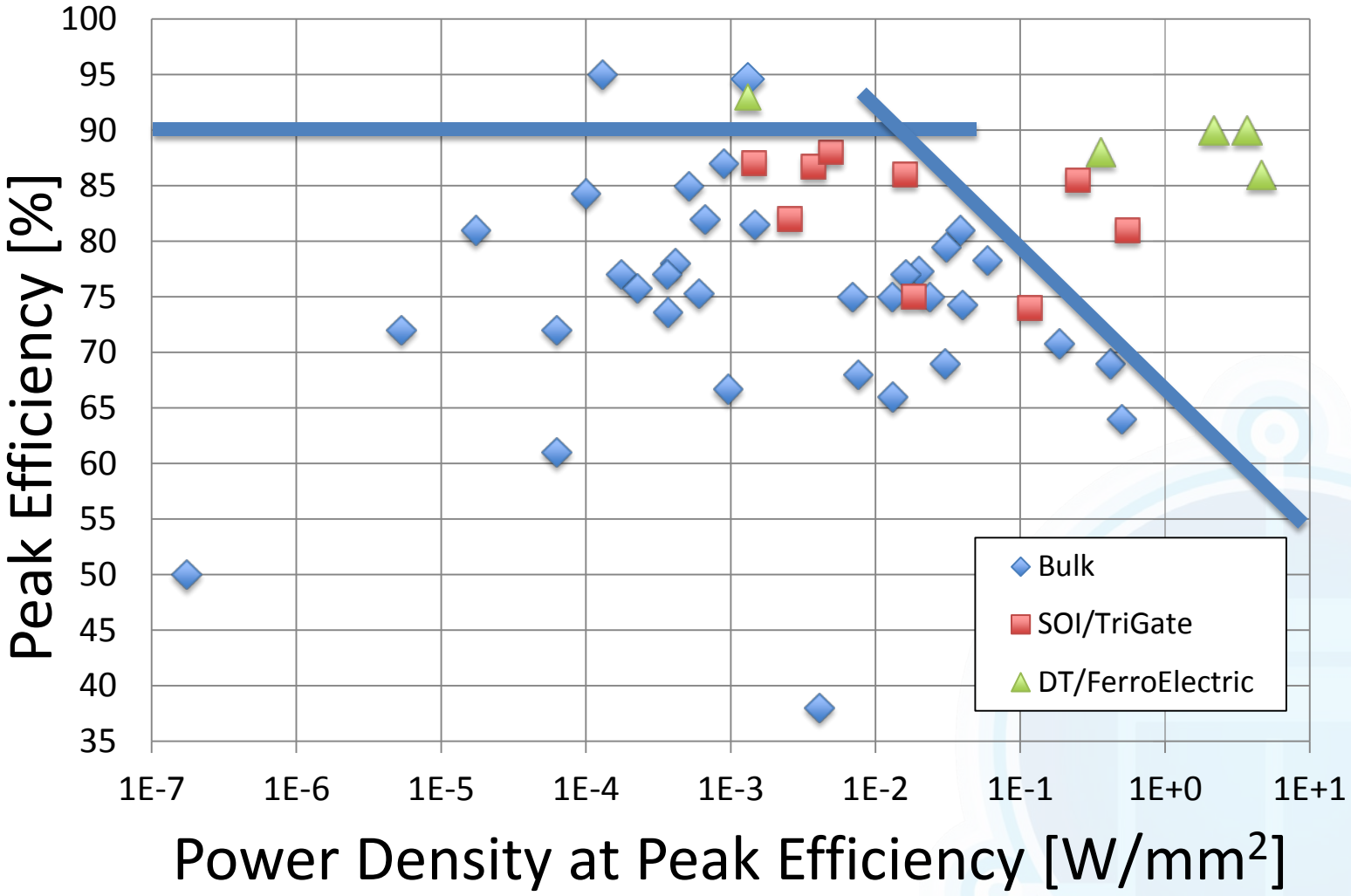
Efficiency/Power Density Limits



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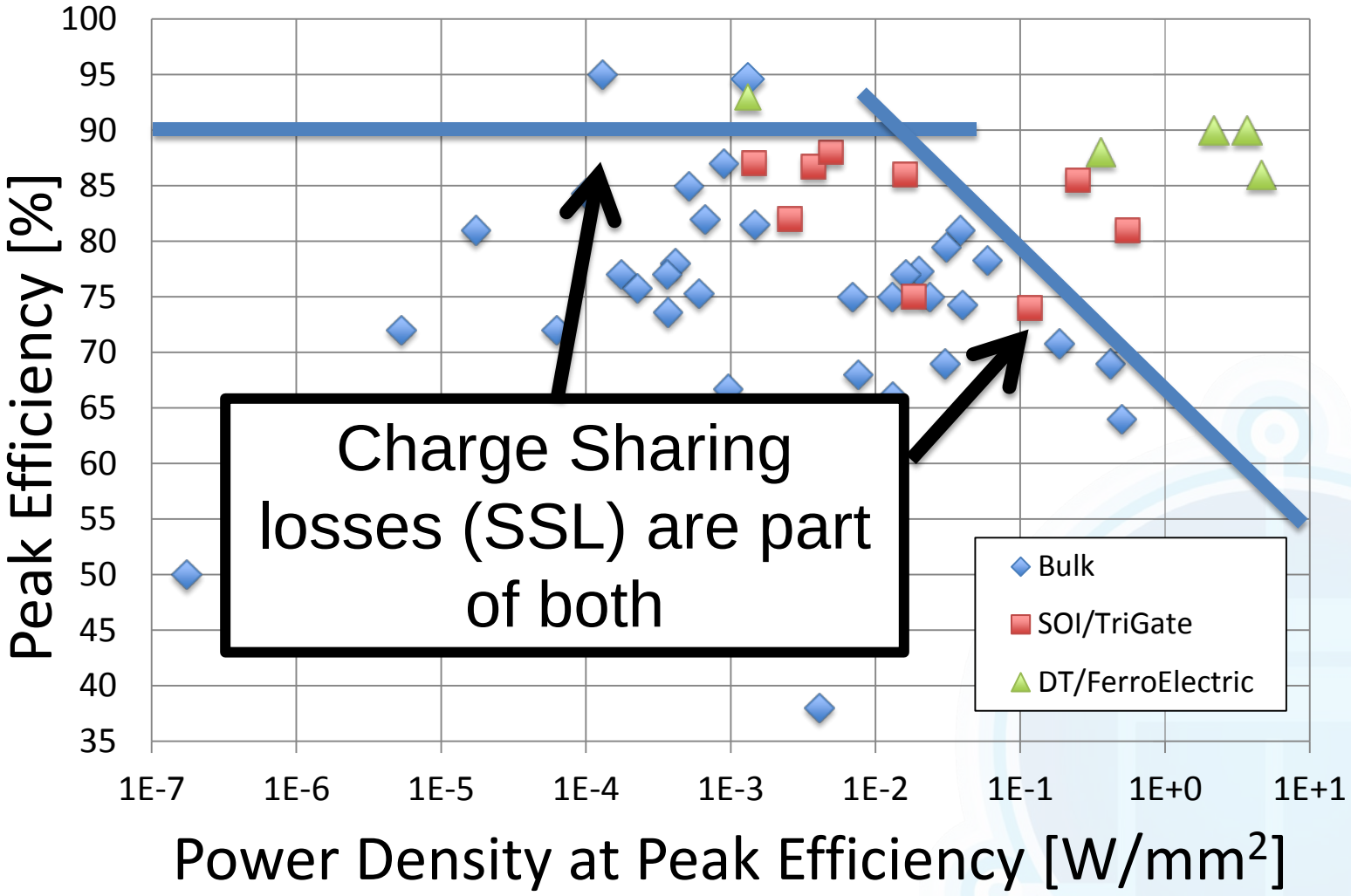
Efficiency/Power Density Limits



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Pushing The Limits

- Three Strategies:
  - Hybridization
  - Rethink power delivery
  - Advanced Multiphasing

Hybridization

- Adding Inductor makes Caps Better
  - Resonant Converters [Kesarwani2015]
  - Soft-switching [Lei2013]

➕ Better Efficiency / Output Power

➖ Requires External component (potentially PowerSiP)

Rethink power delivery

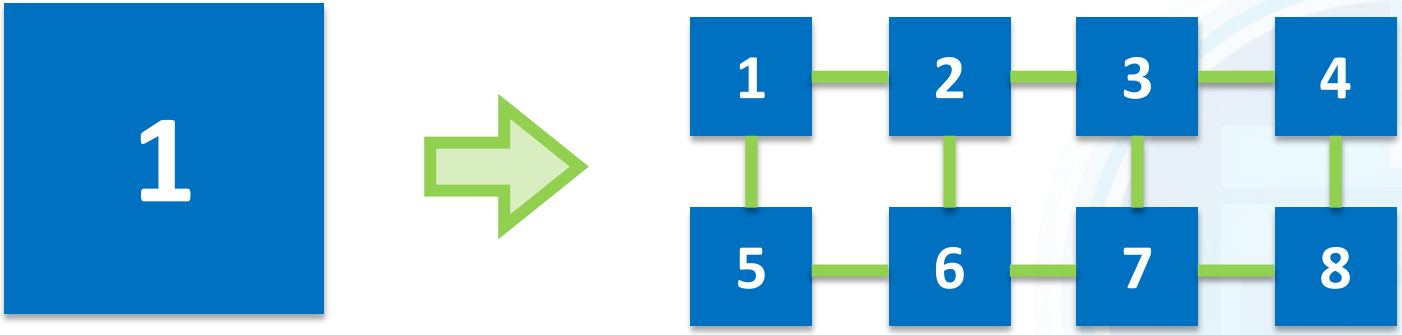
- Change how load gets power (or in which form)
  - Voltage Domain Stacking [Rajanpandian2005]
  - Flying Domain CMOS [Salem2016]
  - Allow large Ripple [Zimmer2015]

\+ Better Efficiency / Output Power
\- Requires changes in load design

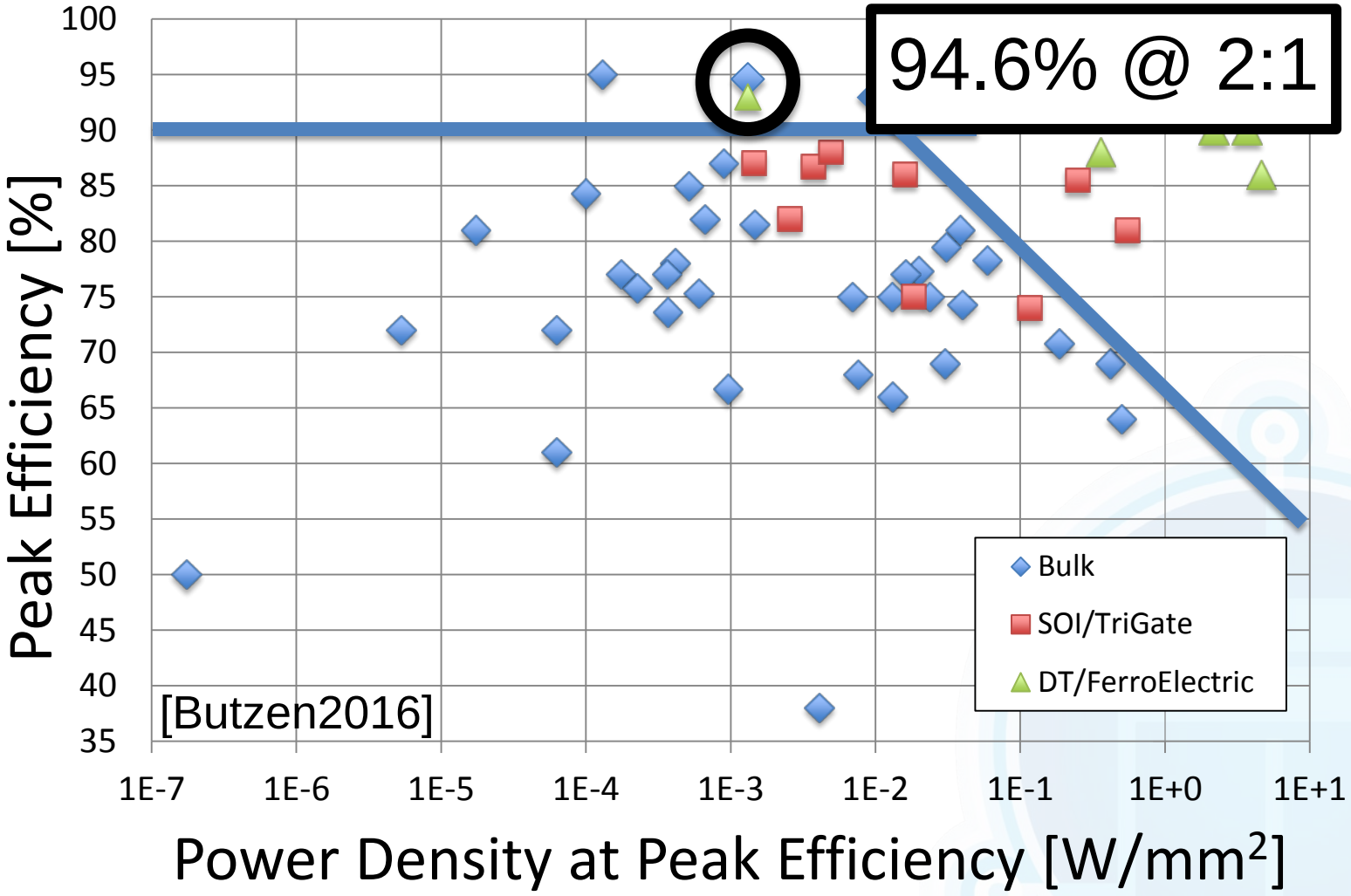
Advanced Multiphasing

- Make use of CMOS' strengths
  - Low Complexity Cost
  - High Frequency ceiling
  - Low Fragmentation cost

"Whole is bigger than sum of its parts"



Advanced Multiphasing



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Advanced Multiphasing

Confidential

Advanced Multiphasing

Confidential

CONCLUSIONS

Conclusions

Switched Capacitors are…

- (still) on the rise, being continuously used in new Applications
- part of very **diverse** research area

Many Promising research directions

⇒ Still a lot of research to be done!

Thank you for your attention!

QUESTIONS?