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# Design of Low Current Voltage Dividers

Shiming Song

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# Outline

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- Introduction
  - Background
  - Criteria
  - Experiment
- Designs
  - Resistors in Series
  - Off-State MOS
  - Switched-Capacitor
- Future Work
- Q&A
- Conclusion
- Acknowledgement

# Outline

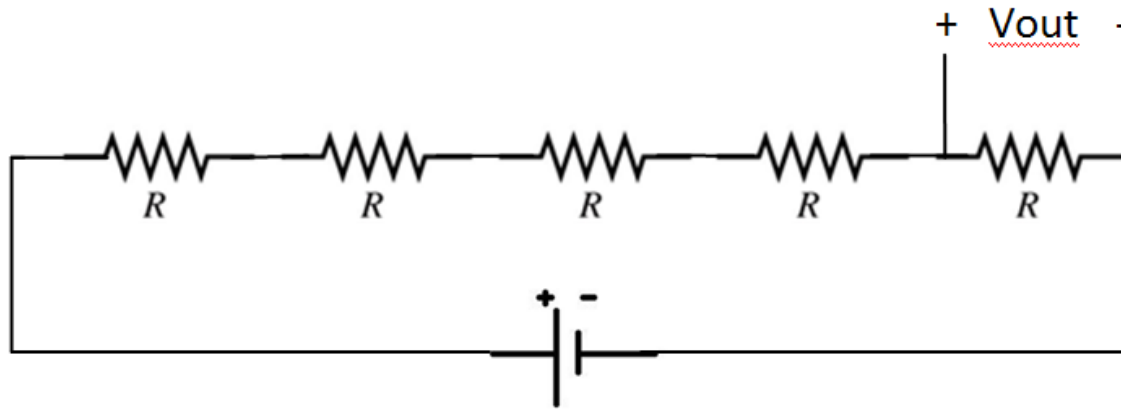
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# Introduction

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- Background:
  - Traditional design is too big to be implemented for low current range



- Area and resistance
  - 10 pA ( $10^{-12}$ ) current -> 100 G  $\Omega$  ( $10^{-9}$ )  
-> several  $\text{mm}^2$  area (huge!)

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# Introduction

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- Criteria:
  - Current level
    - The steady-state current drawn from power supply
  - Accuracy
    - Closeness to the aim voltage
  - Area
    - The actual size of the design
  - Robustness
    - The ability to withstand threshold and size variation

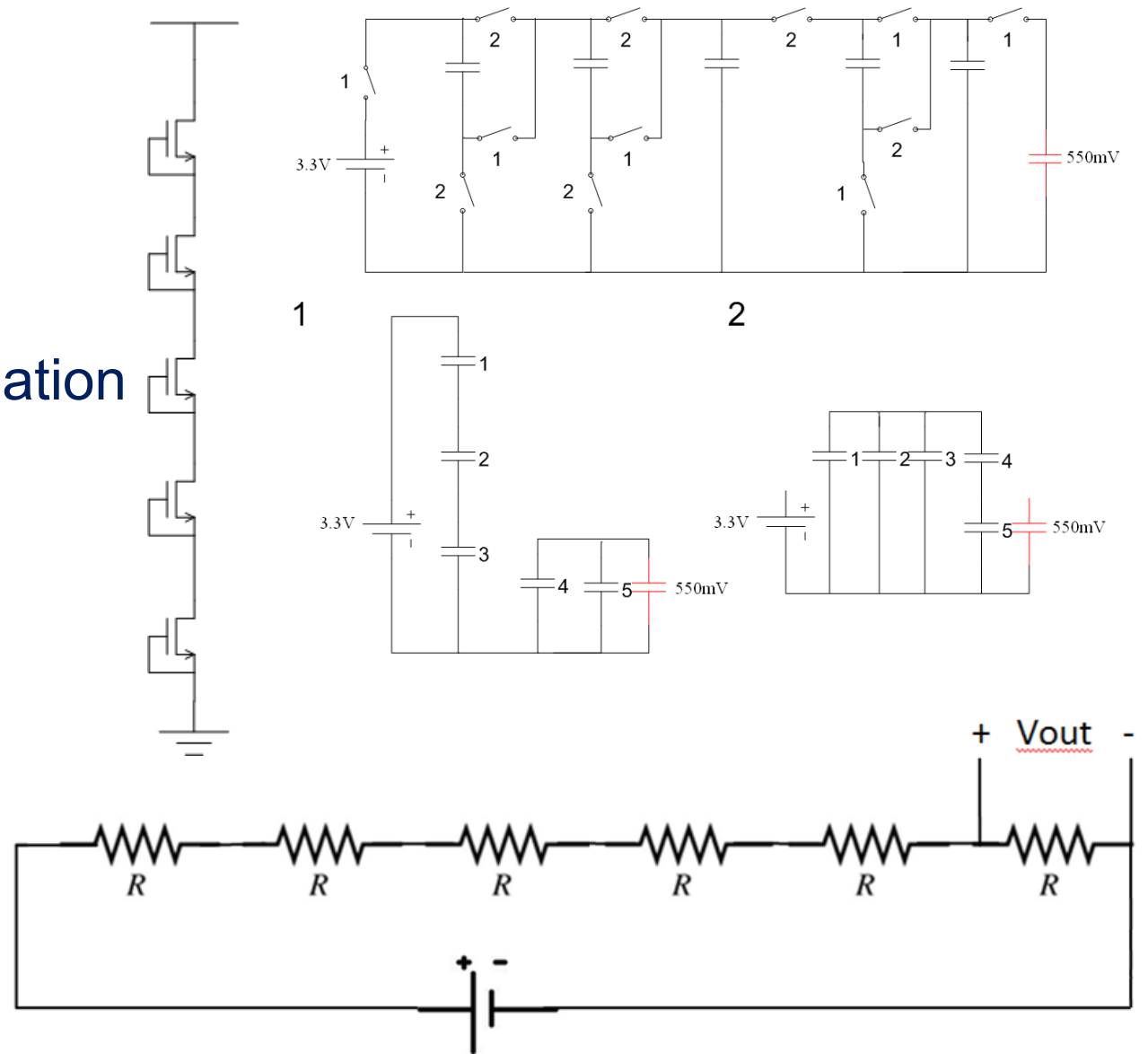
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# Outline

- Experiment
- Dividing by 6
- Results from simulation





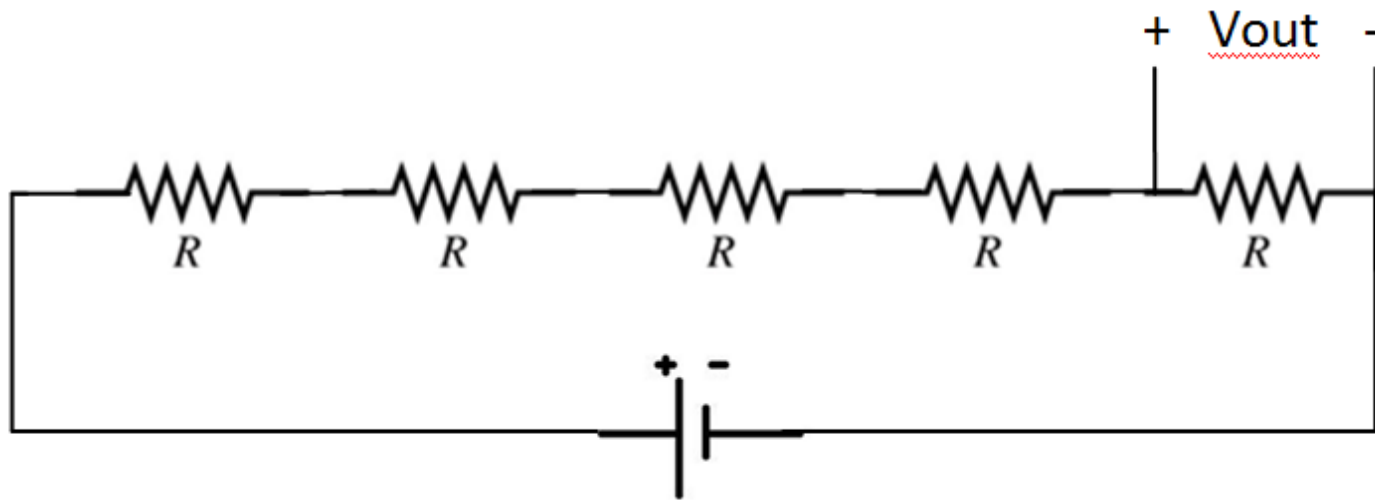
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# Resistors in Series

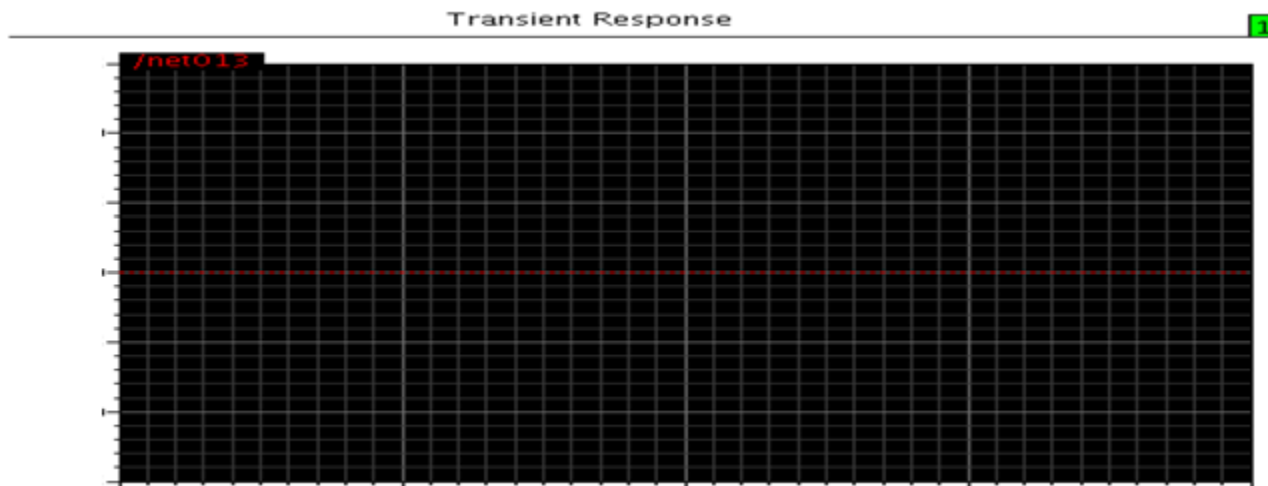
- Design:



# Resistors in Series

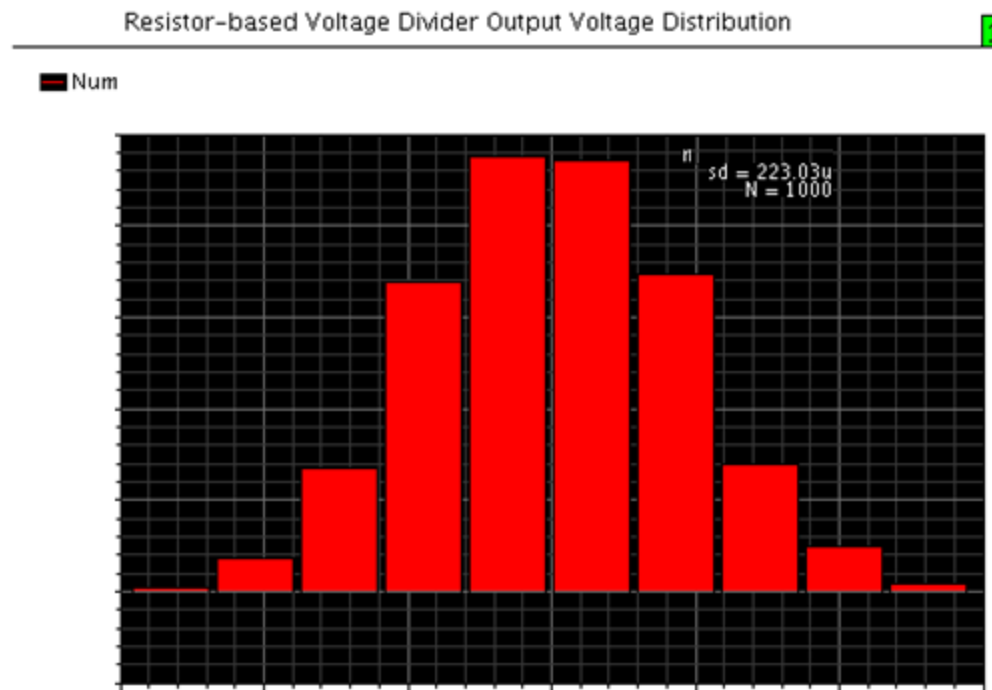
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- Test results:
  - Current level: around 100 pA
  - Area: around 10 mm<sup>2</sup>
  - Accuracy: the output is stable and well-matched



# Resistors in Series

- Test results:
  - Robustness:
    - Monte Carlo Simulation:
      - sample distribution for a circuit aiming at 660mV



# Resistors in Series

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- Summary:
- *Advantage*
- Good accuracy and robustness
- *Disadvantage*
- Not realizable because of the huge area
- *Potential improvement*
- Trade off some current

# Outline

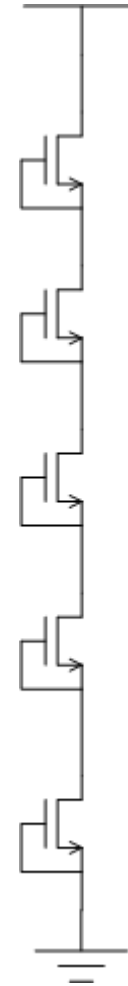
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# Off-State MOS

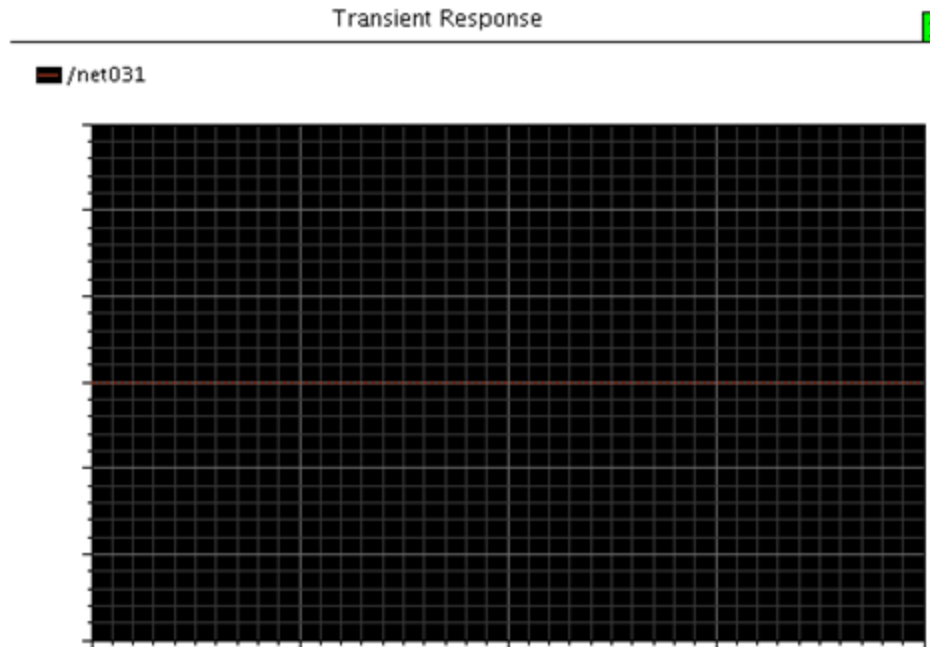
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- Design
  - $V_{gs} = 0$  for all the MOSFETs.
  - Current is through leakage.



# Off-State MOS

- Test results;
  - Current level  $\leq 1\text{pA}$  ( $10^{-12}$ )
  - Area around  $1000\text{ }\mu\text{m}^2$
  - Accuracy stable accurate output
  - Robustness smaller MOSFETs are sensitive to variation





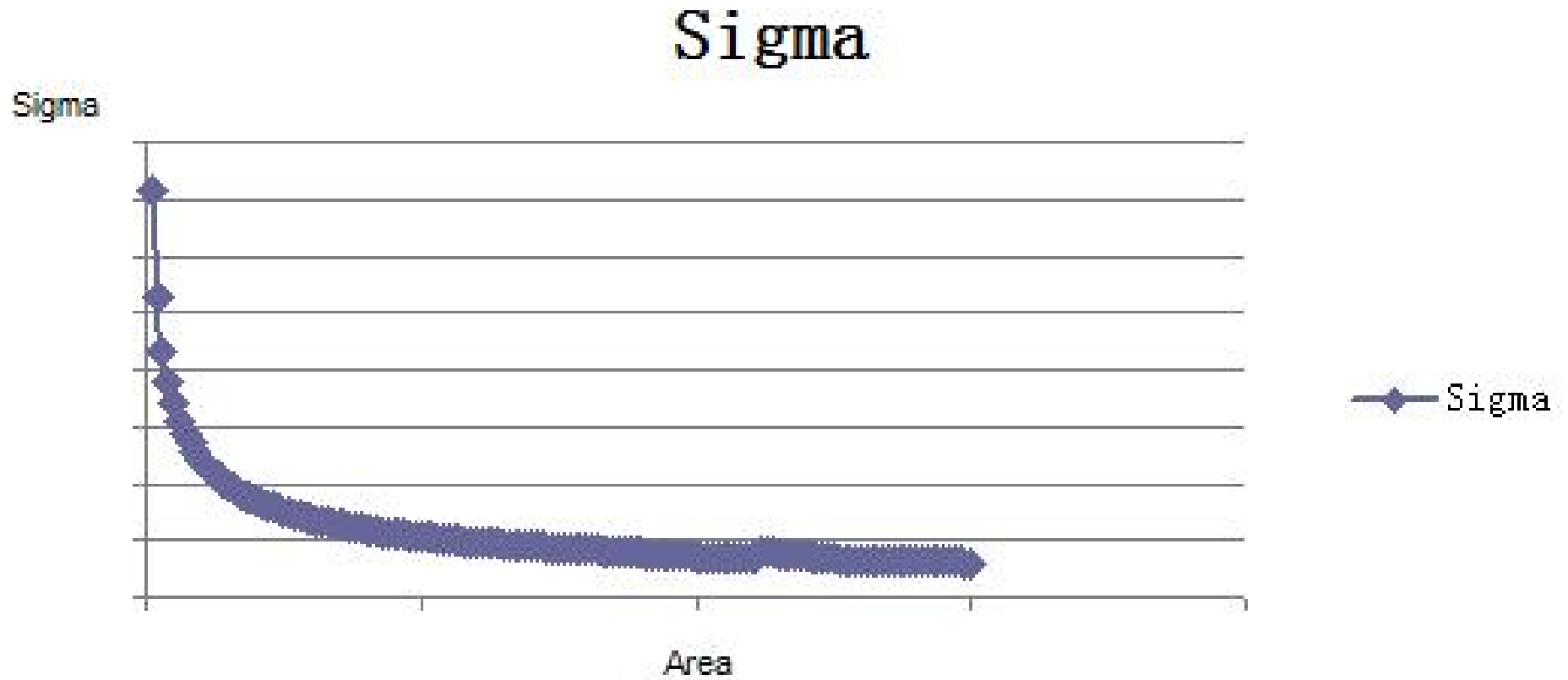
# Off-State MOS

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- Summary
- *Advantage:*
  - Small
  - Accurate
- *Disadvantage*
  - Sensitive to variation
- *Potential Improvement*
  - Trade off the area

# Off-State MOS

- Sample Sigma-Area Plot:



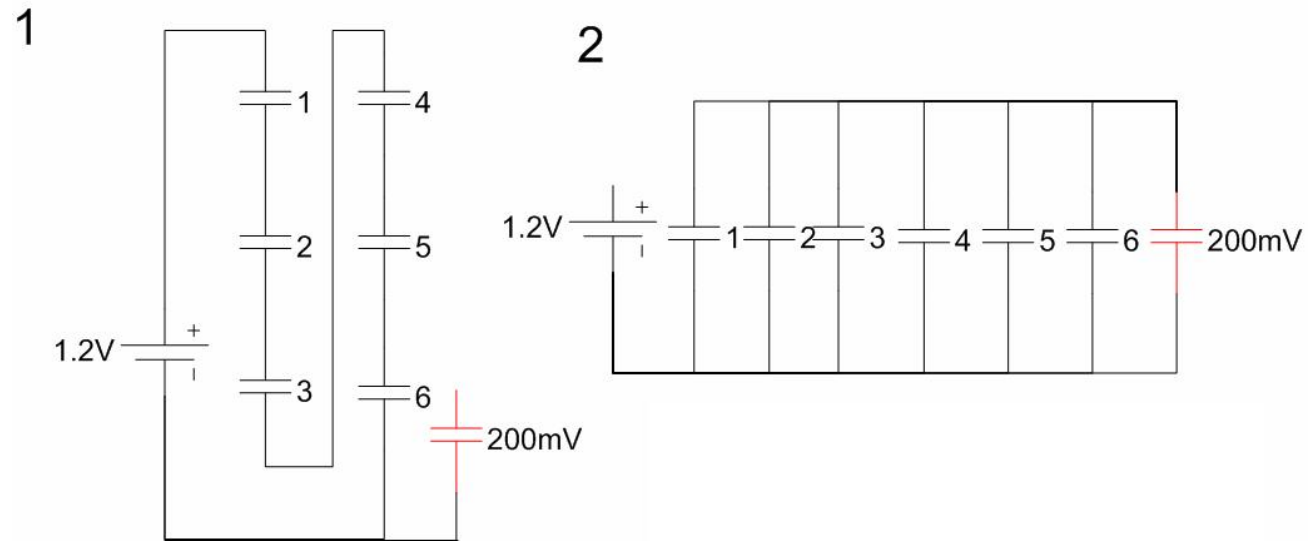
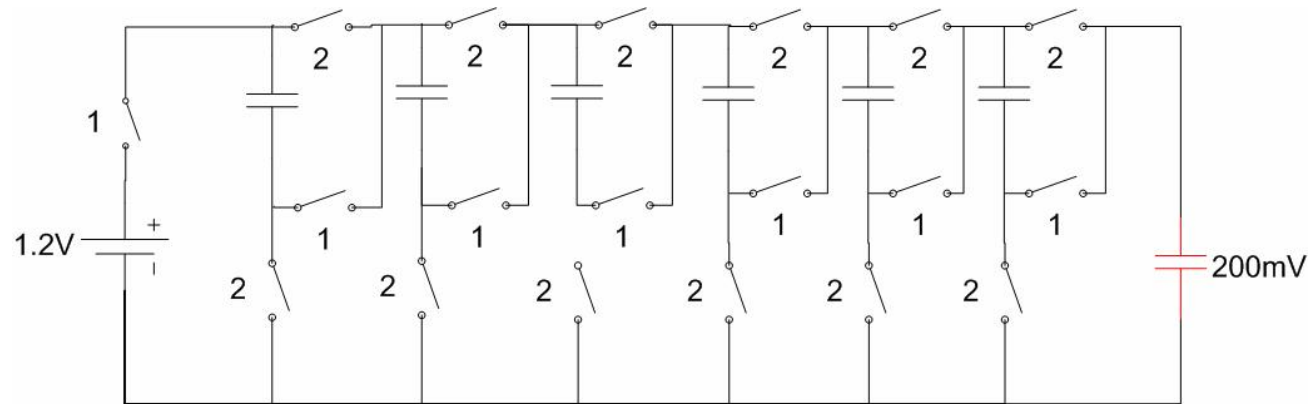
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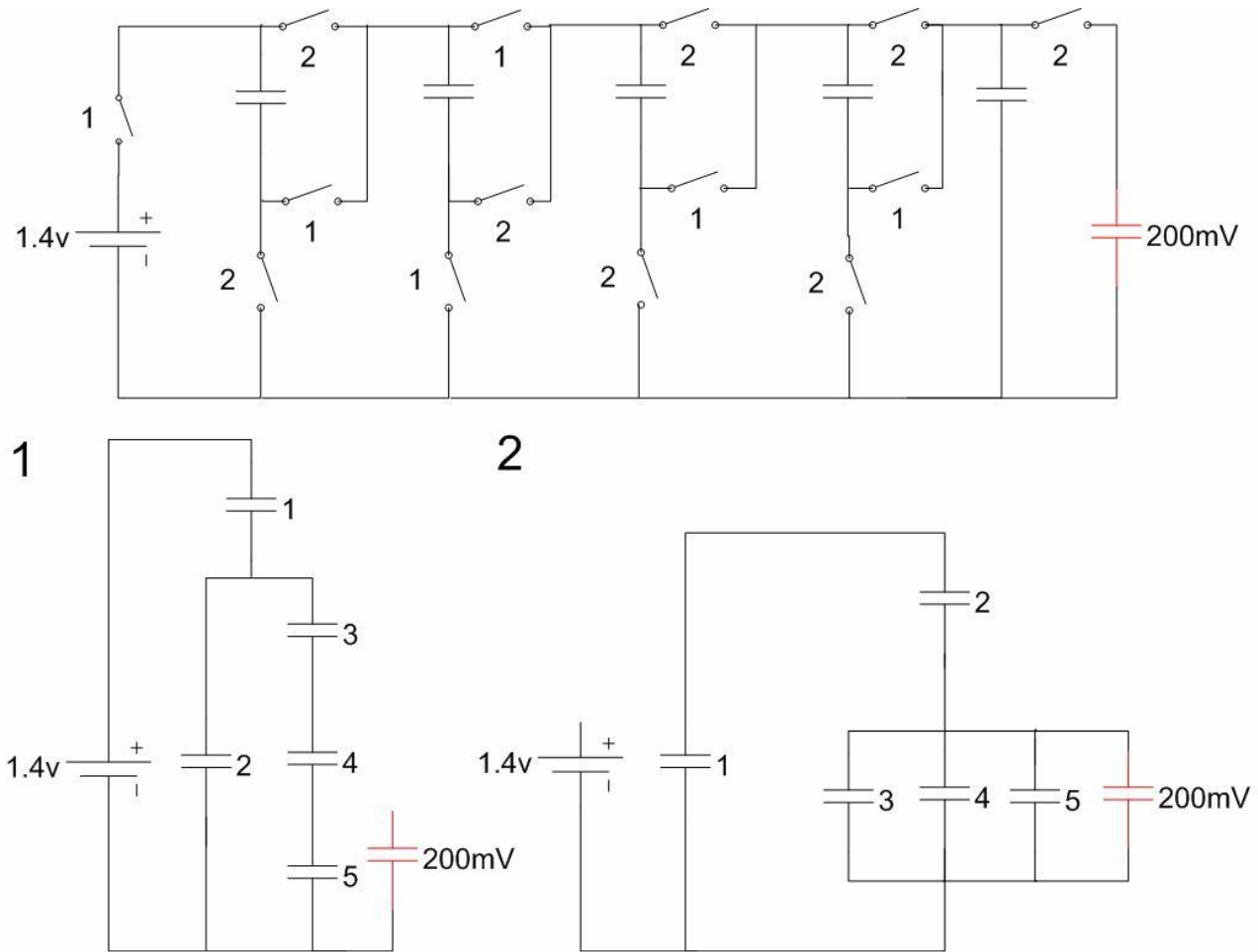
# Switched-Capacitor

- Design
  - A sample divide-by-six design



# Switched-Capacitor

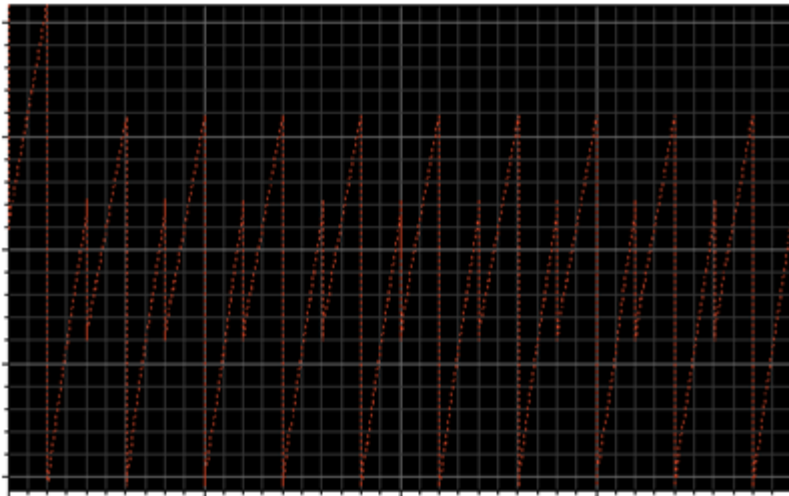
- Design
  - A sample divide-by-seven design



# Switched-Capacitor

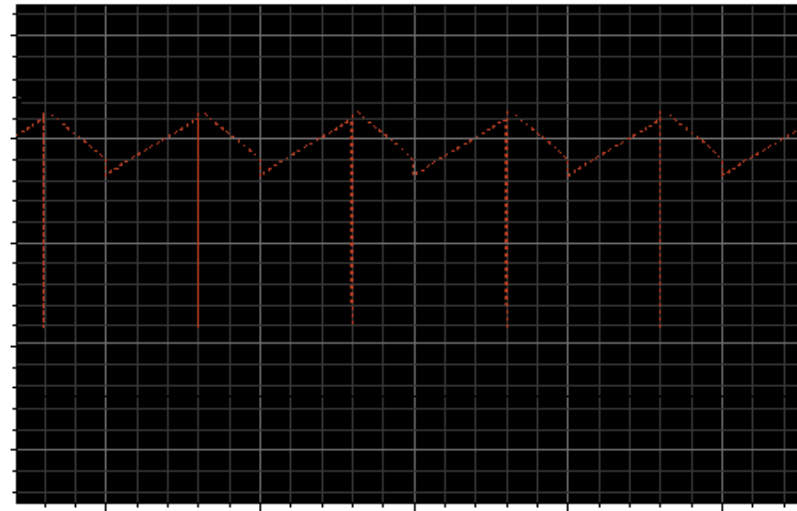
- Test results:
  - Current level: several pA range
  - Area: several thousands of  $\mu\text{m}^2$
  - Accuracy: The output is oscillating but the oscillation can be suppressed into acceptable range

■ /V\_5



Example oscillating output

■ /Vout

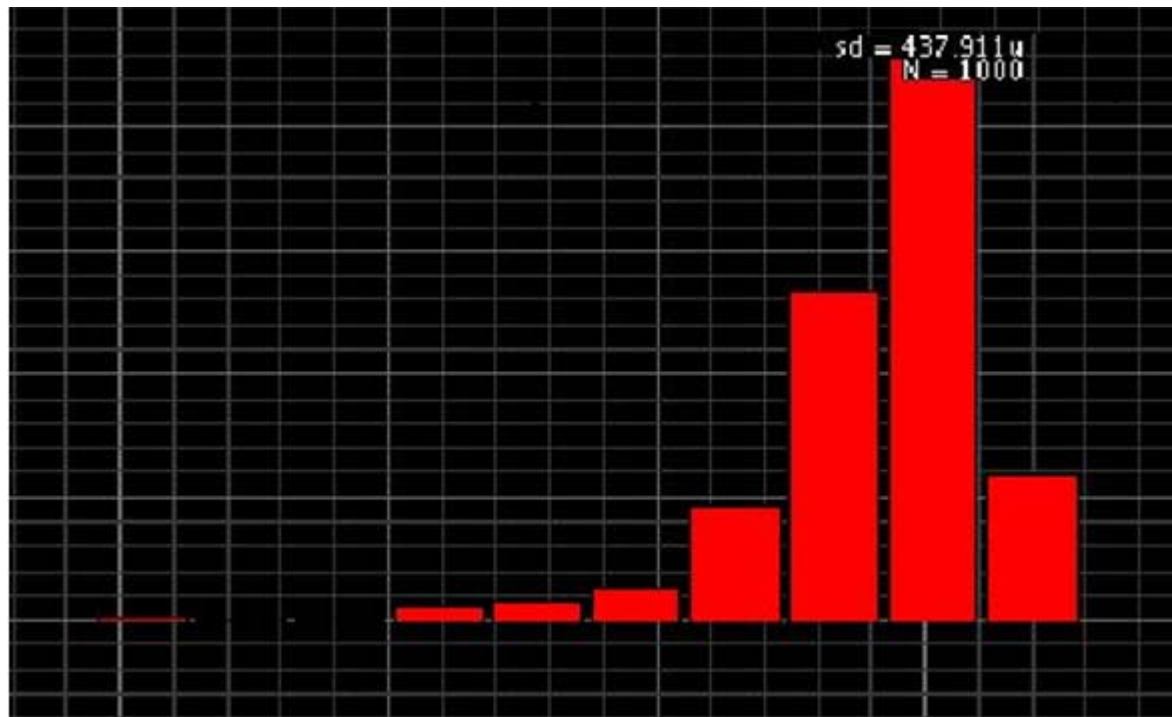


Example well suppressed oscillation

# Switched-Capacitor

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- Test results:
  - Robustness:
    - Sample Monte Carlo Distribution



# Switched-Capacitor

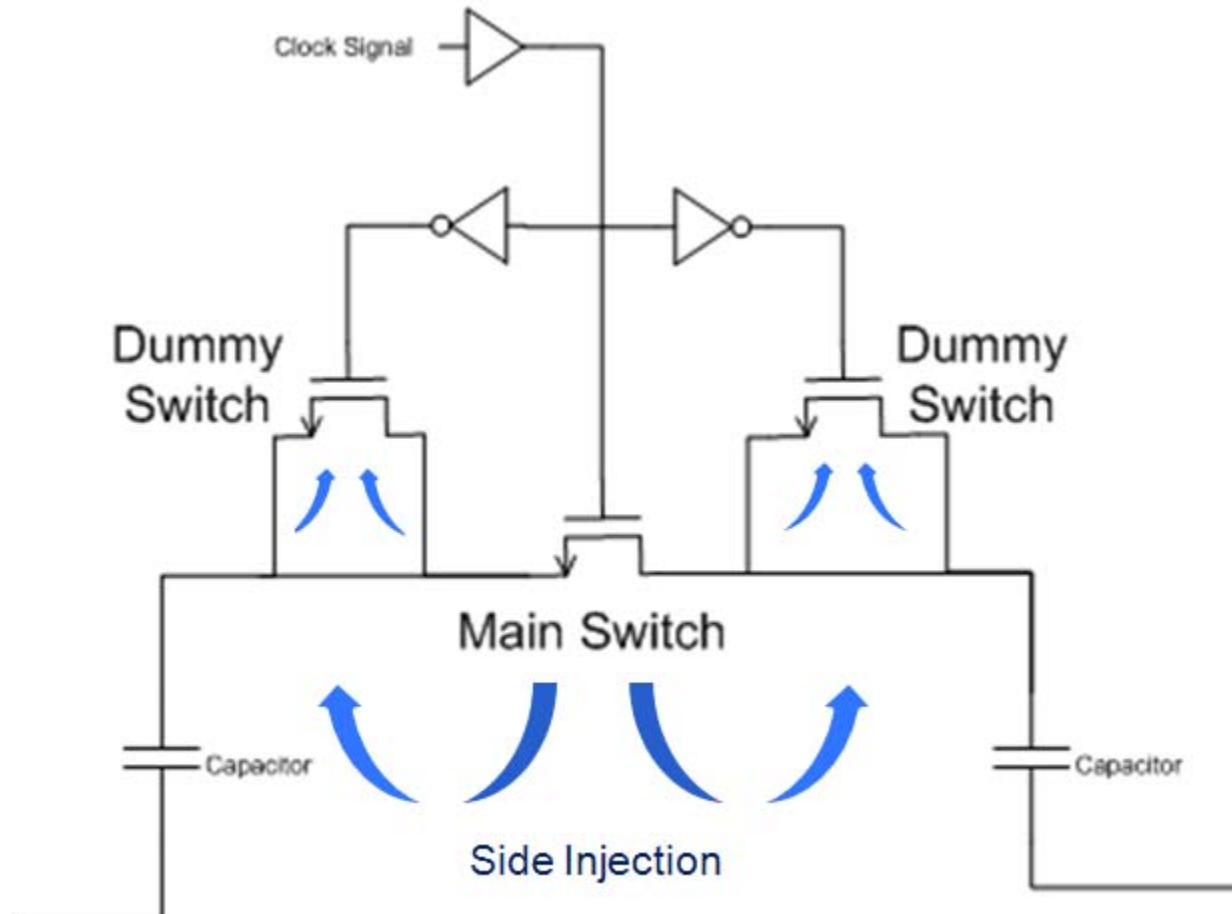
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- Conclusion
- Advantage
  - Robust
  - Flexible in the sense of power delivery
- Disadvantage
  - Large Area
  - Oscillating output
  - High Current Spikes
- Potential Improvement
  - Dummy switches
  - Current Limit



# Switched-Capacitor

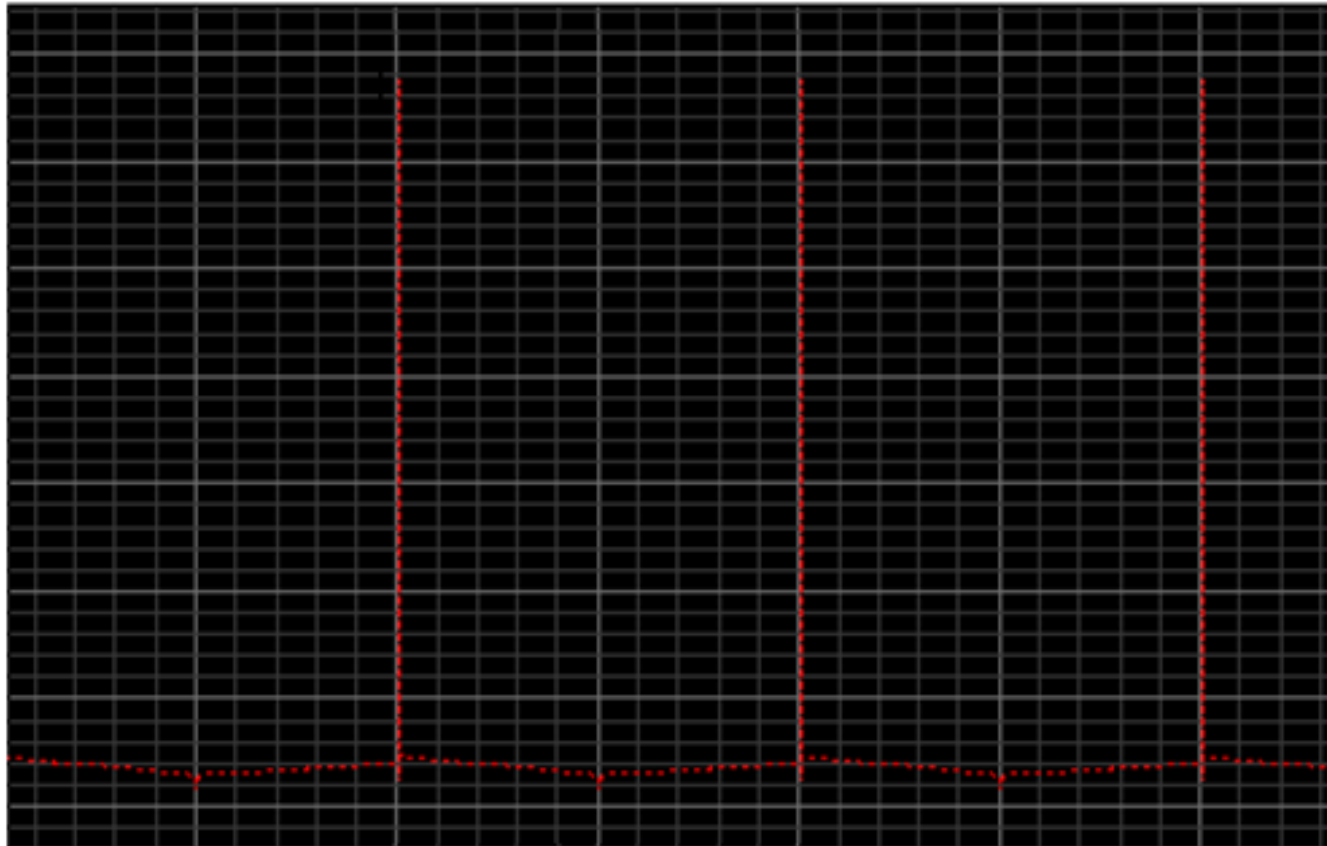
- Dummy Switches



# Switched-Capacitor

- Dummy Switches

■ /Vout



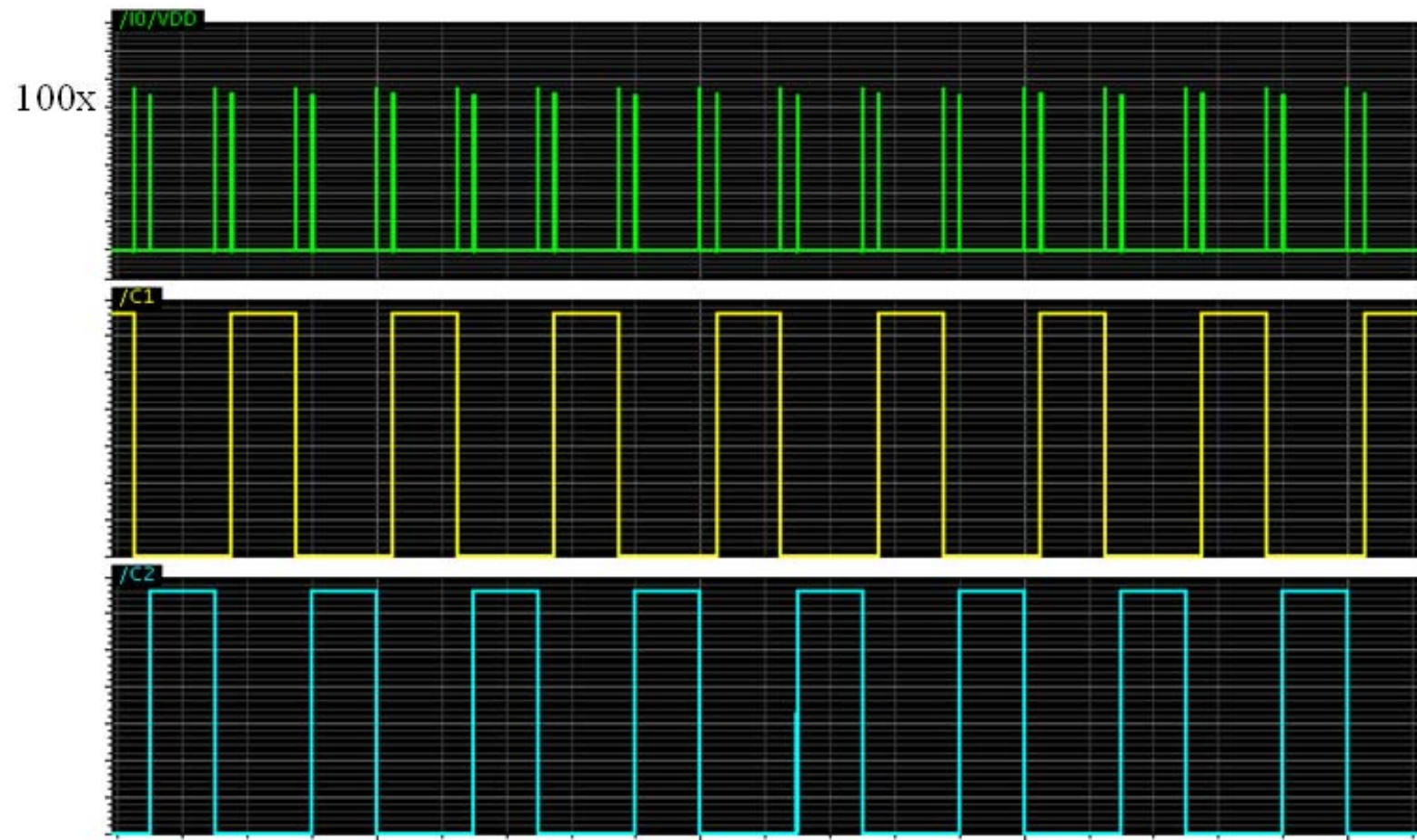
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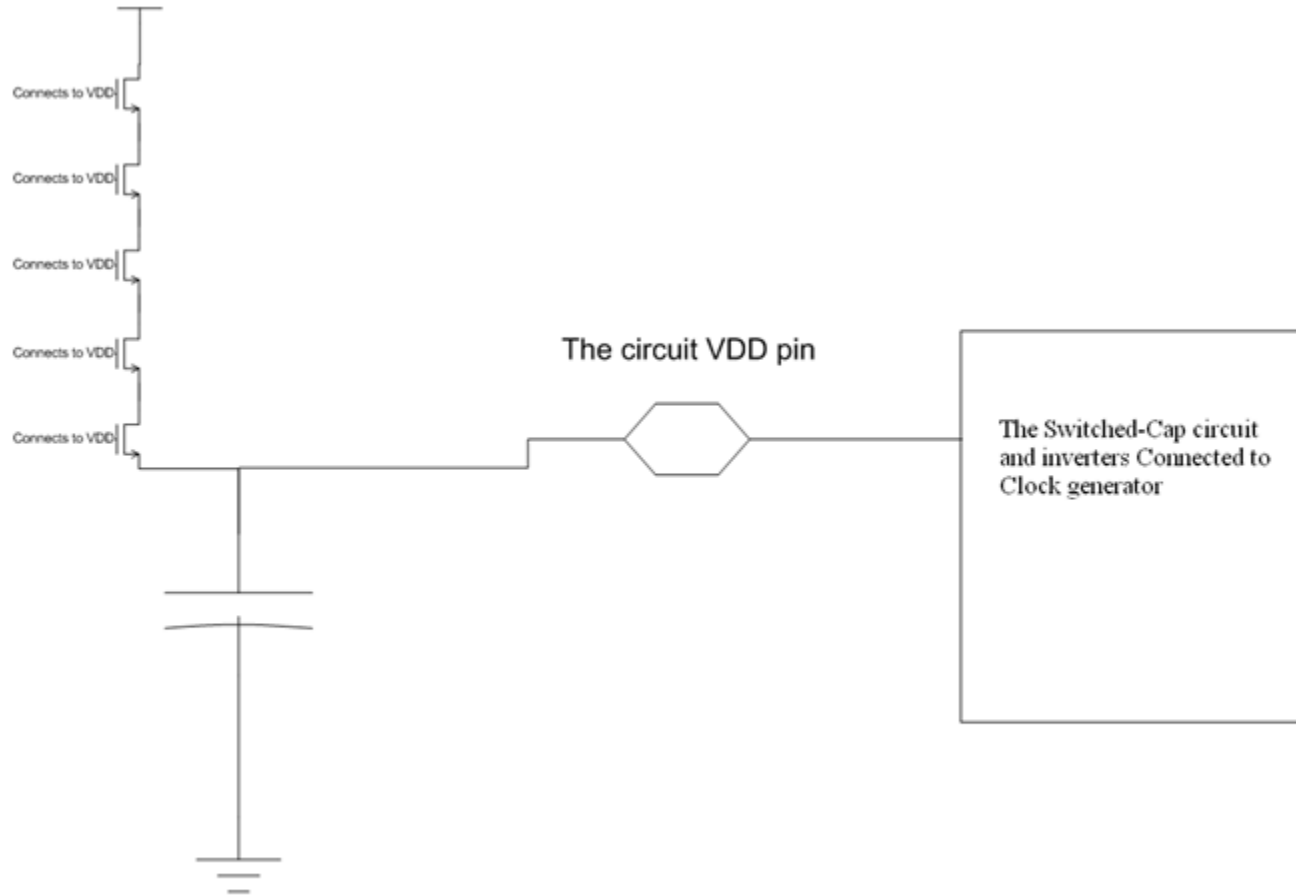
# Future Work

- Current Spike Limiting



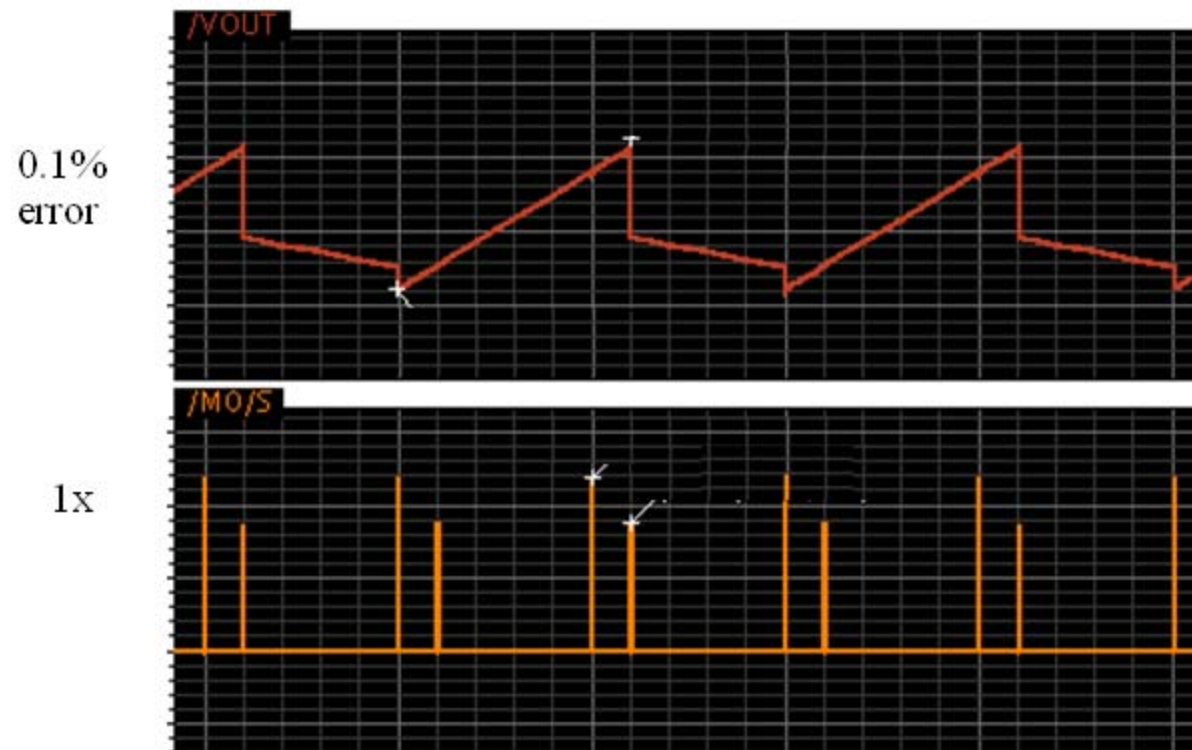
# Future Work

- Solutions:
  - 1. stack transistors



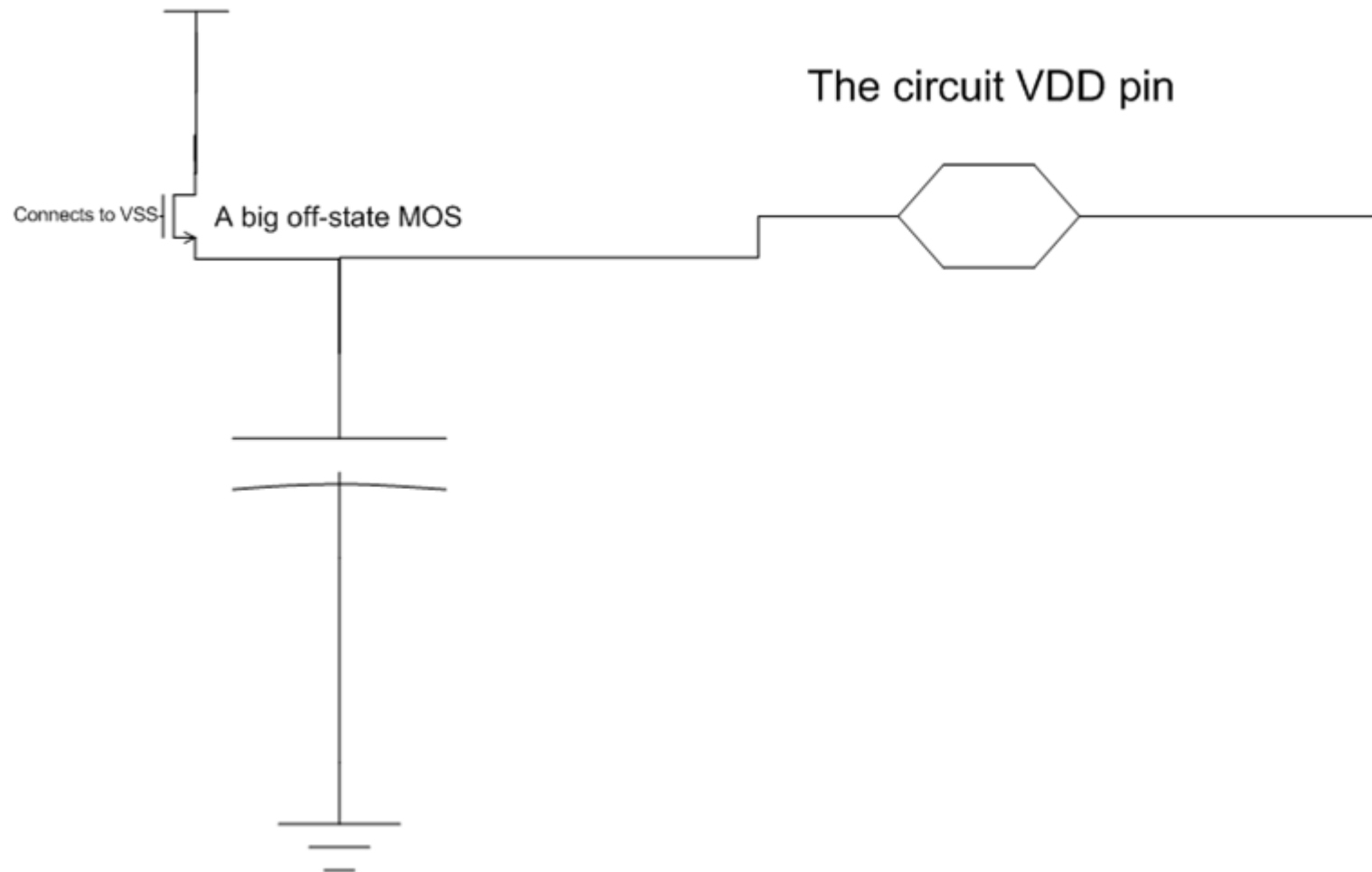
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- Solutions:
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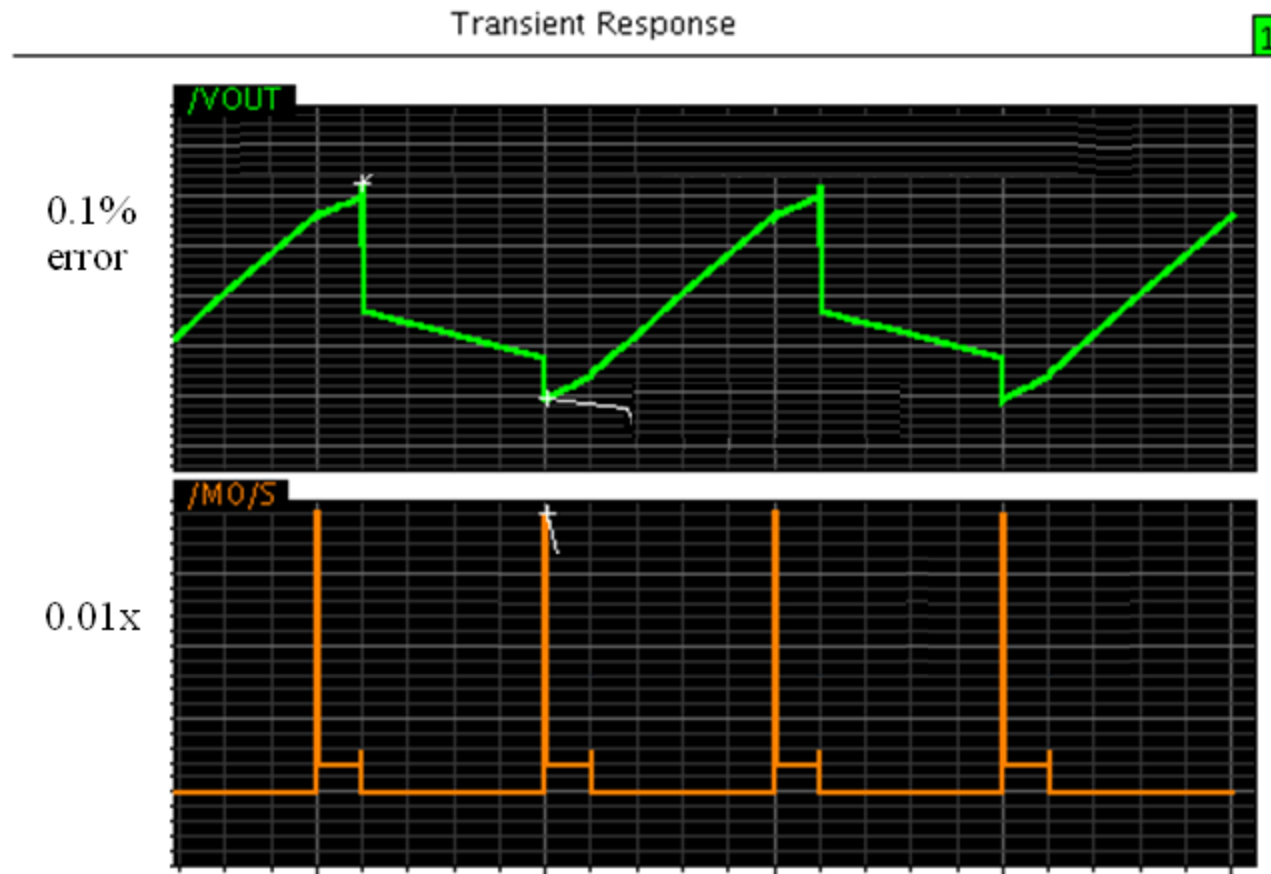
# Future Work

- Solutions:
  - 2. subthreshold design



# Future Work

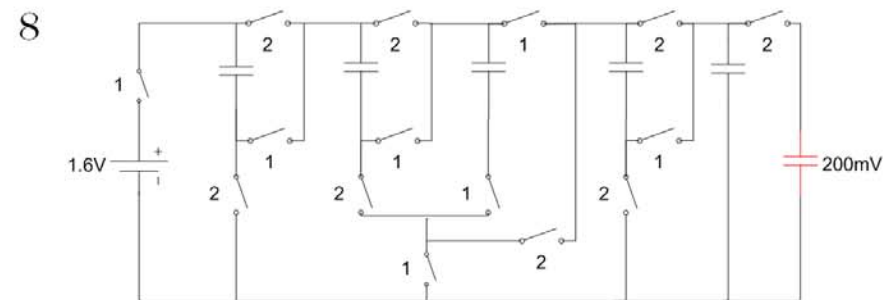
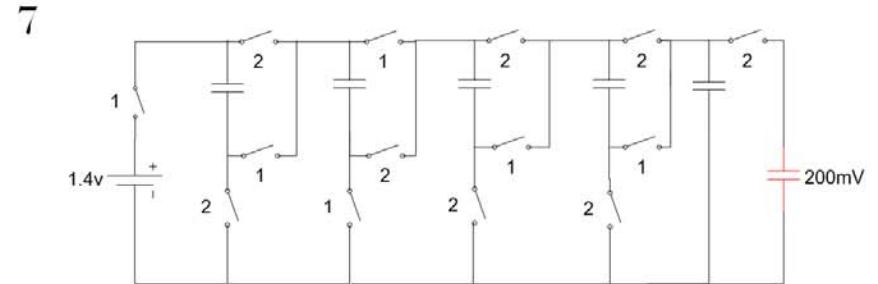
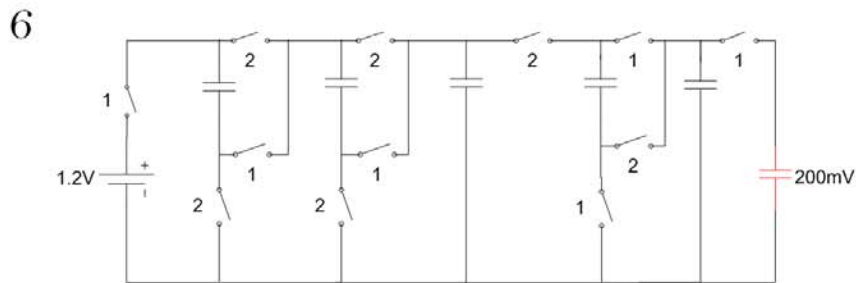
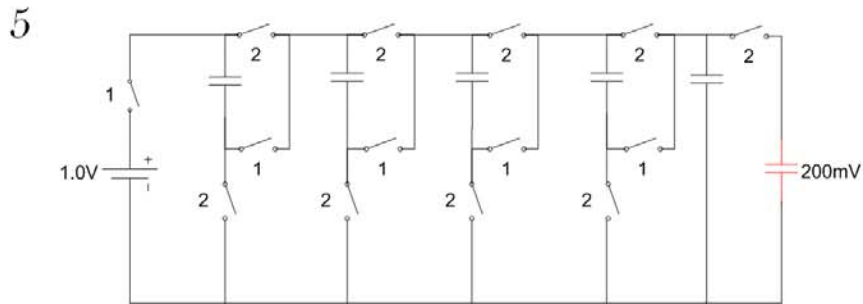
- Solutions:
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# Future Work

- A unified switched capacitor circuit



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# Q& hopefully A

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# Conclusion

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- The resistor-in-series design is still the most robust to variations but not realizable because of the size.
- Off-state-MOS is the easiest to implement. The area and current are both acceptable.
- Switched-Capacitor is not much bigger than the MOS design but has the potential to have much lower current and more robustness.

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# Acknowledgement

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# Thank You

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**どうもありがとうございました！**