

# **Distributed Active Decoupling Capacitors for On-Chip Supply Noise Cancellation in Digital VLSI Circuits**

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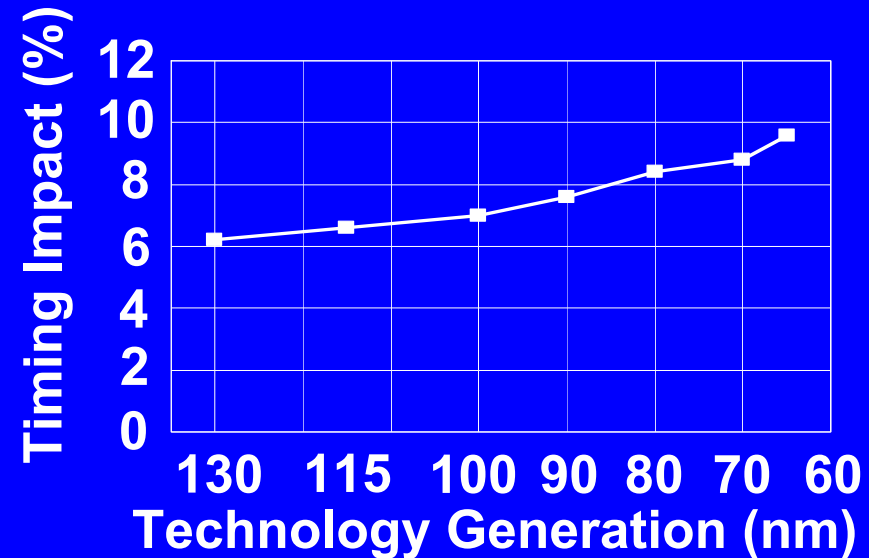
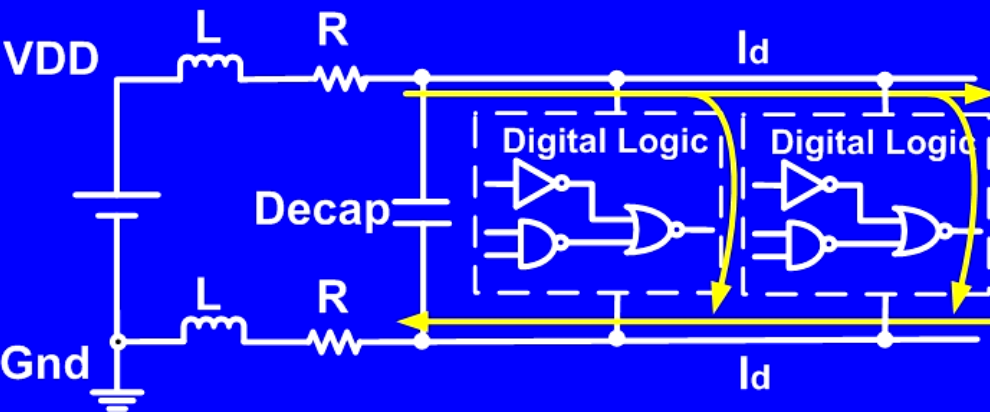
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# Outline

- **Introduction**
- **Proposed active decap circuits**
- **Simulated supply noise suppression**
- **Test chip implementation**
- **Supply noise measurement results**
- **Conclusion**

# Power Supply Noise

- Current density keeps increasing
- Wire impedance does not scale as desired
- Larger  $IR$  and  $Ldi/dt$  noise in scaled technology
- Causes timing, substrate noise, reliability issues

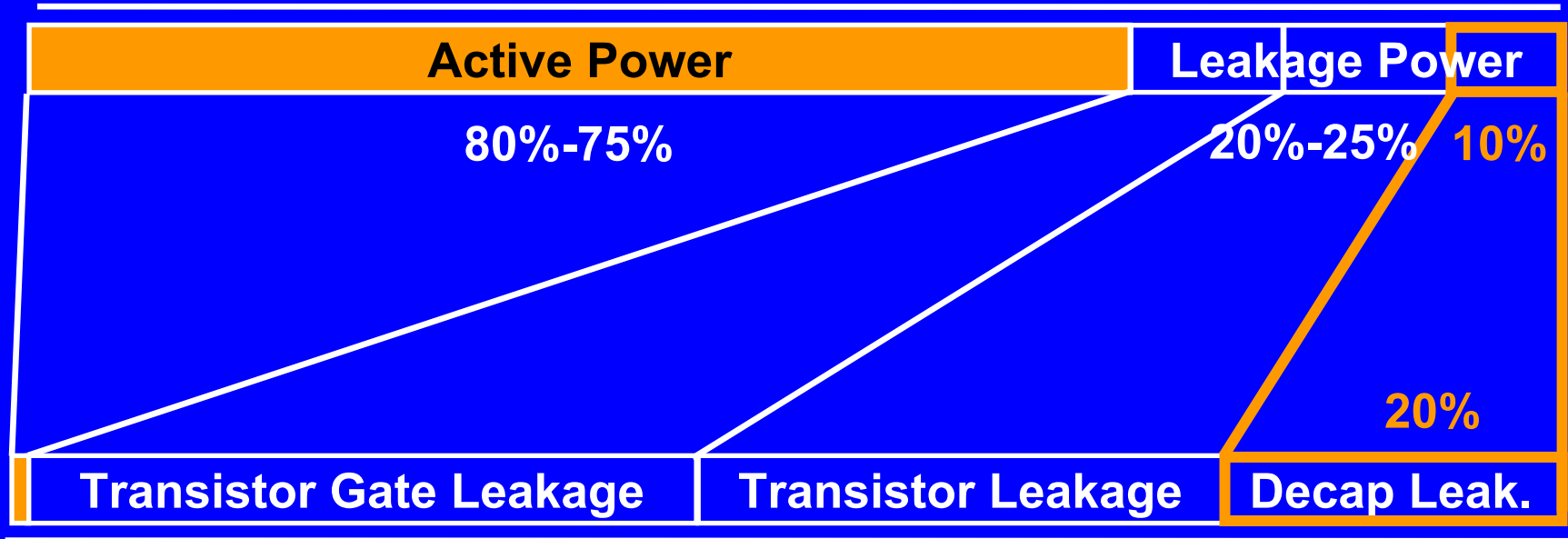


M. Saint-Laurent, Intel

# Problematic Decoupling Capacitor

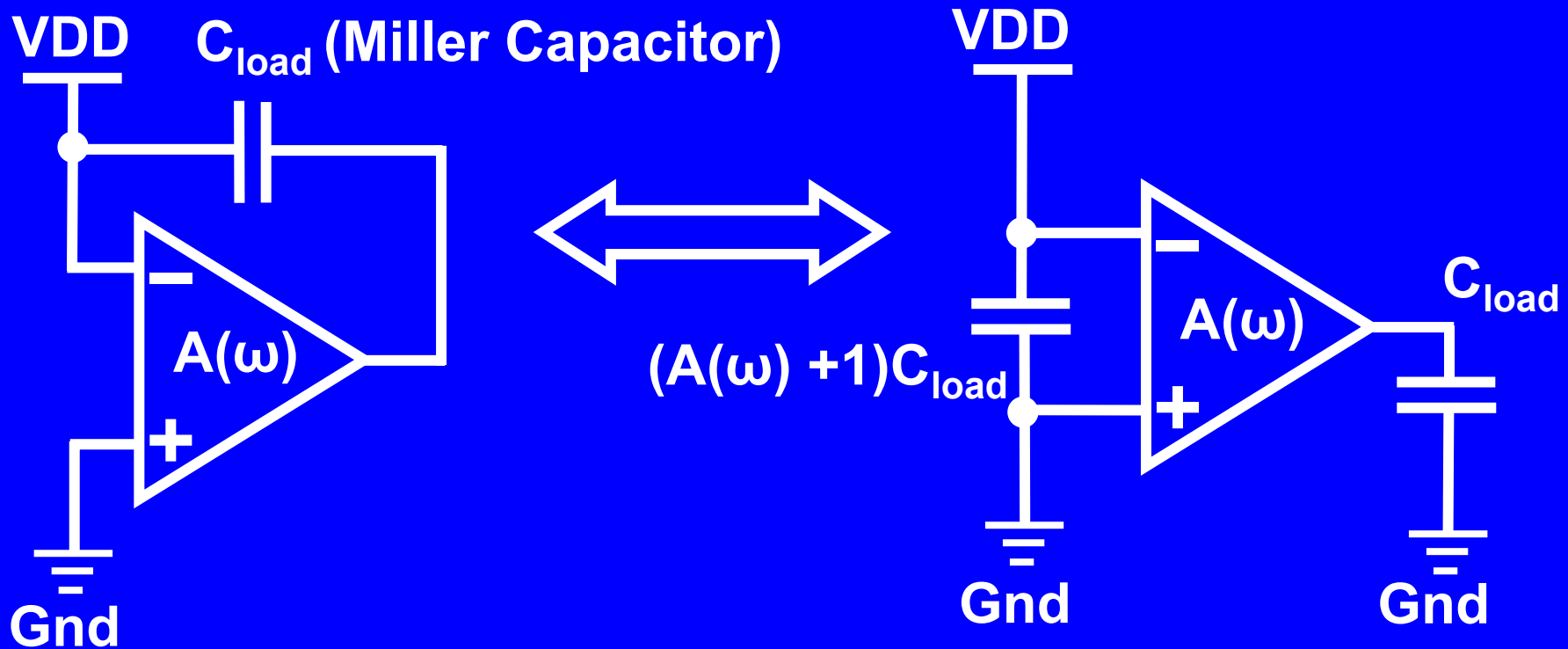
- 15% to 20% of die area occupied by decaps in high-end microprocessor
- 10% of total power due to decap leakage

Total Power @  $T=30^{\circ}\text{C}/V_{cc}=1.15\text{V}$



Burn-In Condition @  $T=100^{\circ}\text{C}/V_{cc}=1.61\text{V}$

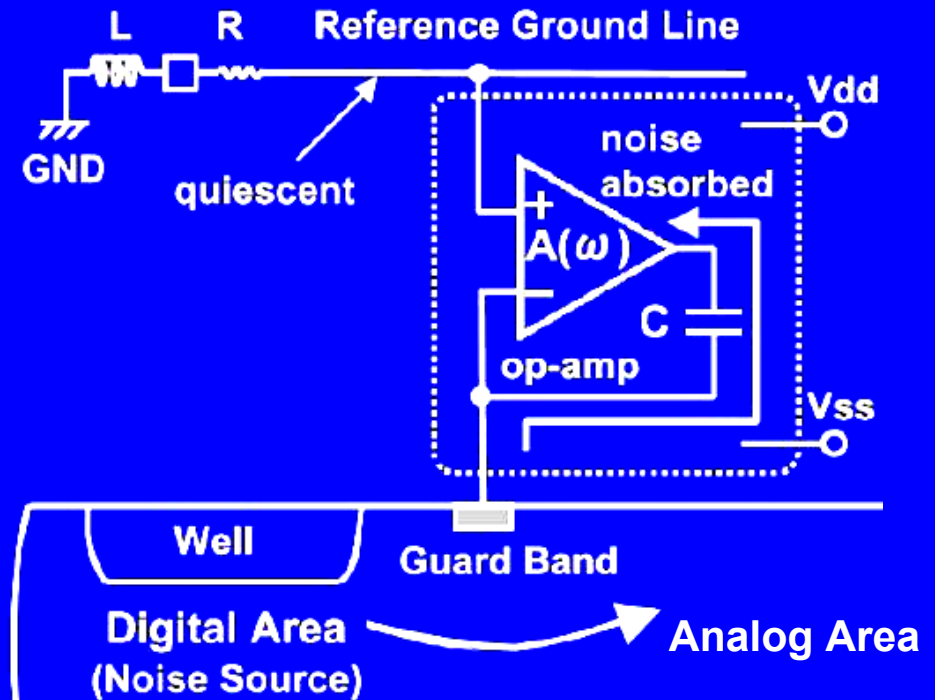
# Principle and Design Target



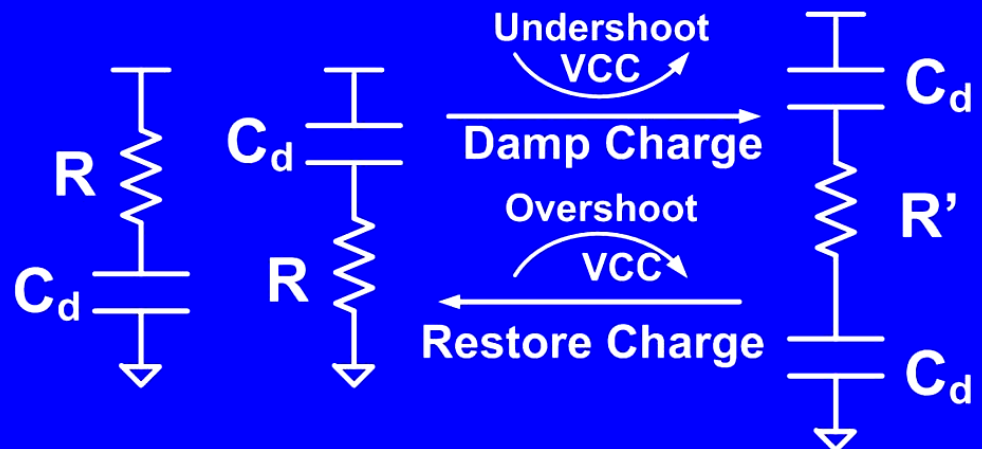
- New circuit technique to boost decap value
- Decap area reduction
- Self-biasing for implementation in digital IC

# Previous Work

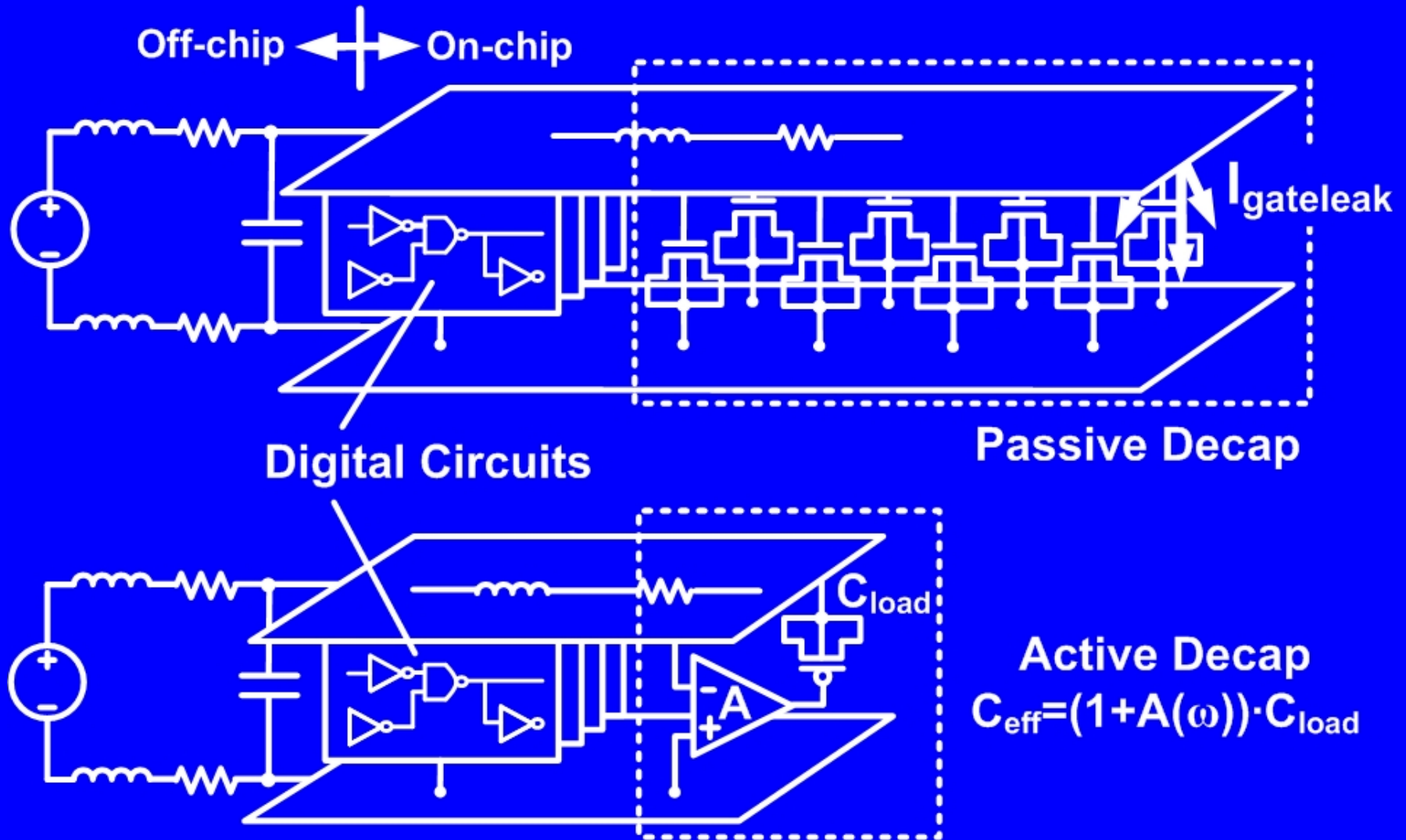
- **Active decap for crosstalk suppression**  
(T. Tsakada, JSSC, 2005)



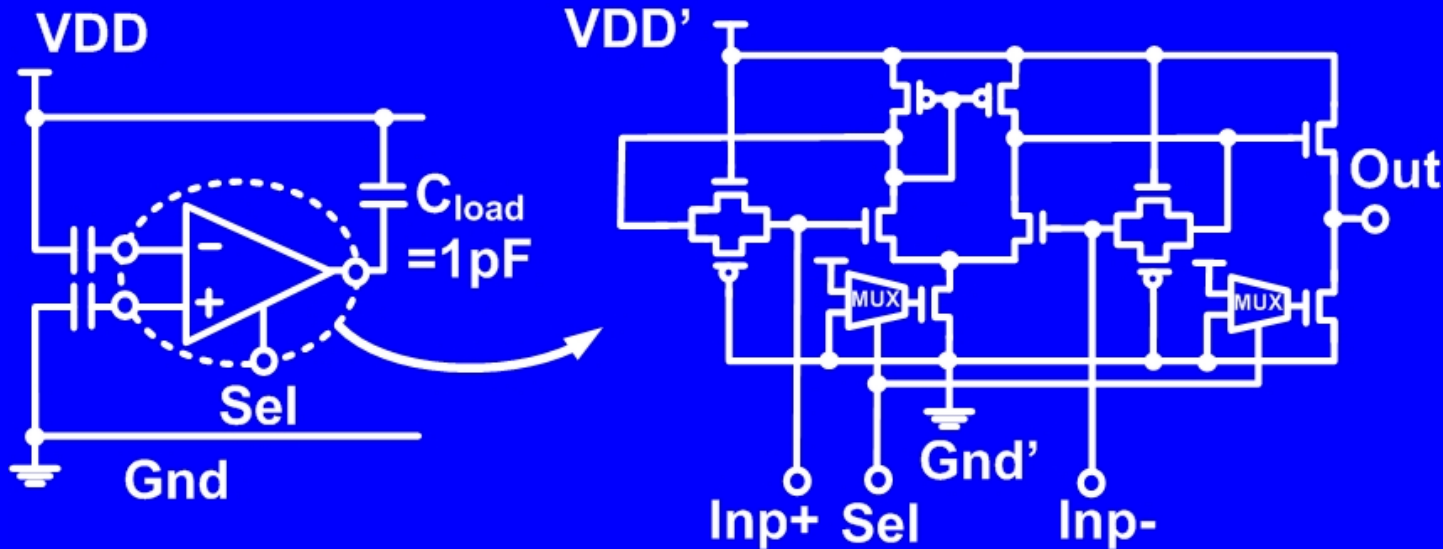
- **On-chip voltage regulator using switched decaps**  
(M. Ang, ISSCC, 2000)



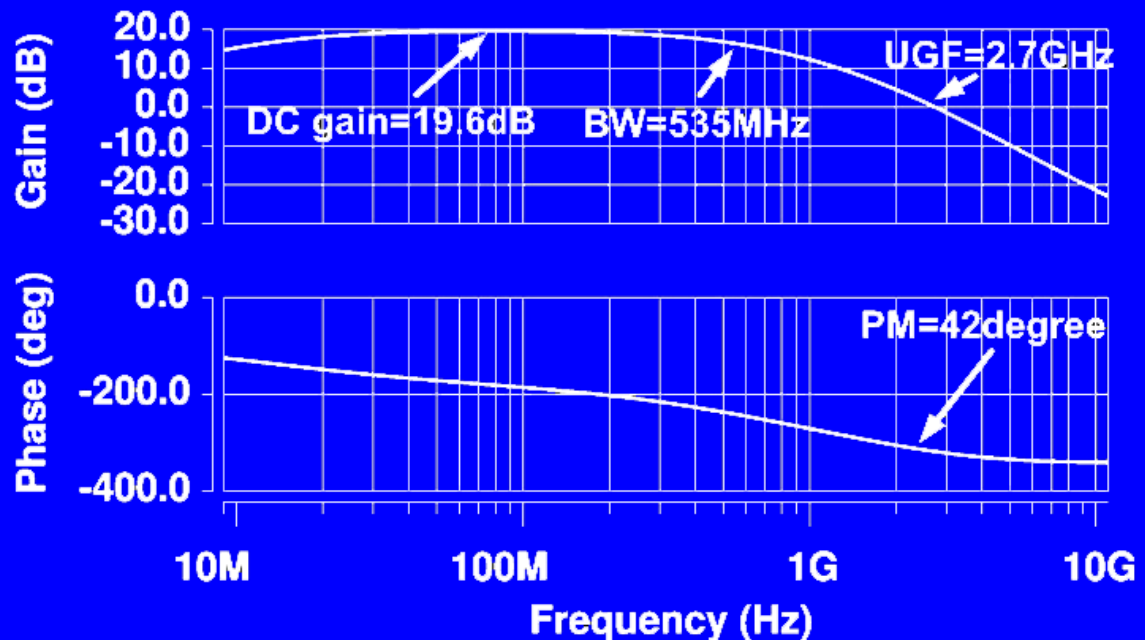
# Proposed Use of Active Decap in Digital IC



# Design of Active Decap Circuits

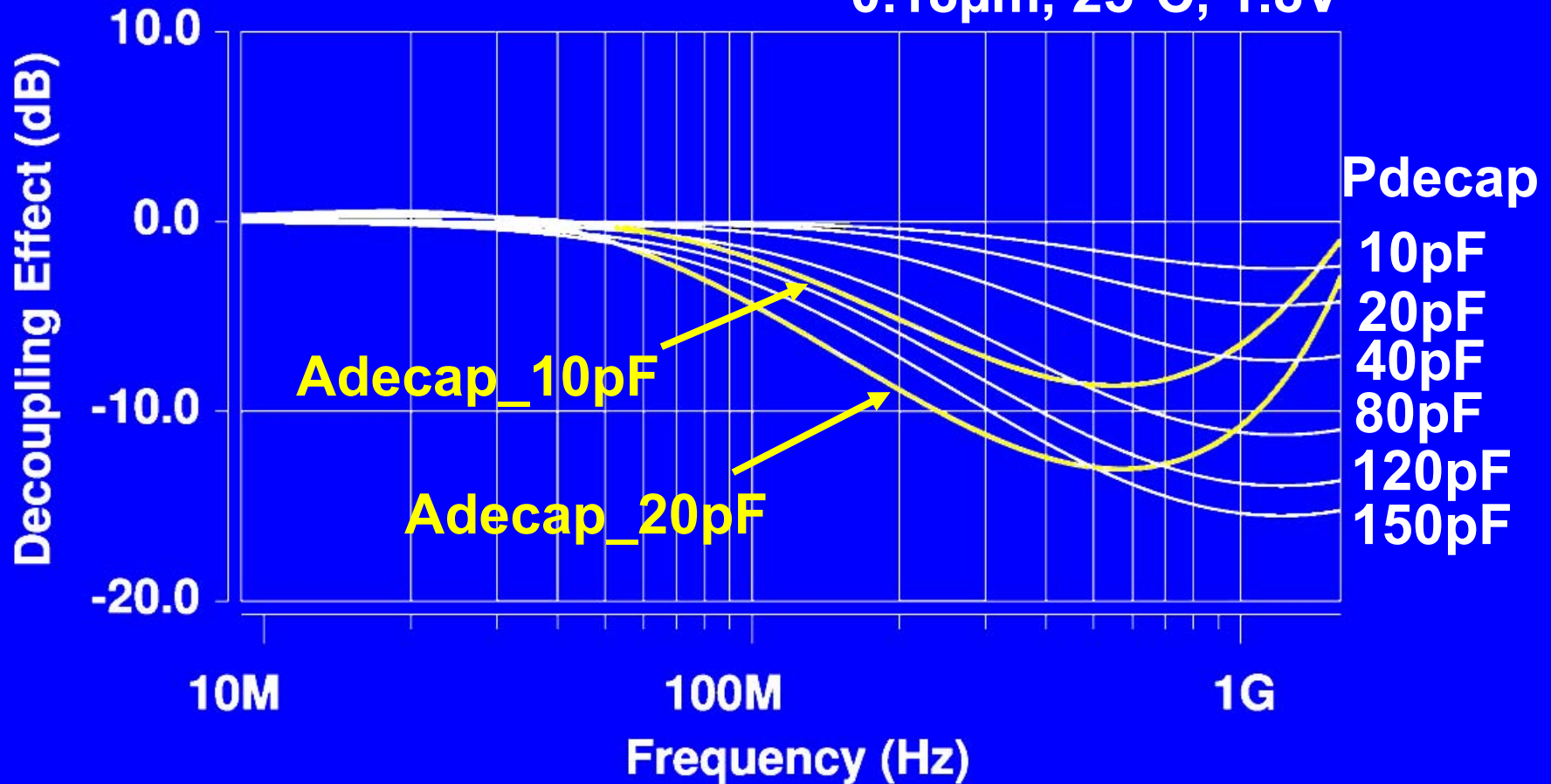


- 10MHz~2.7GHz
- Current: 3.8mA
- C-coupled inputs
- Self-biasing
- On/Off switch



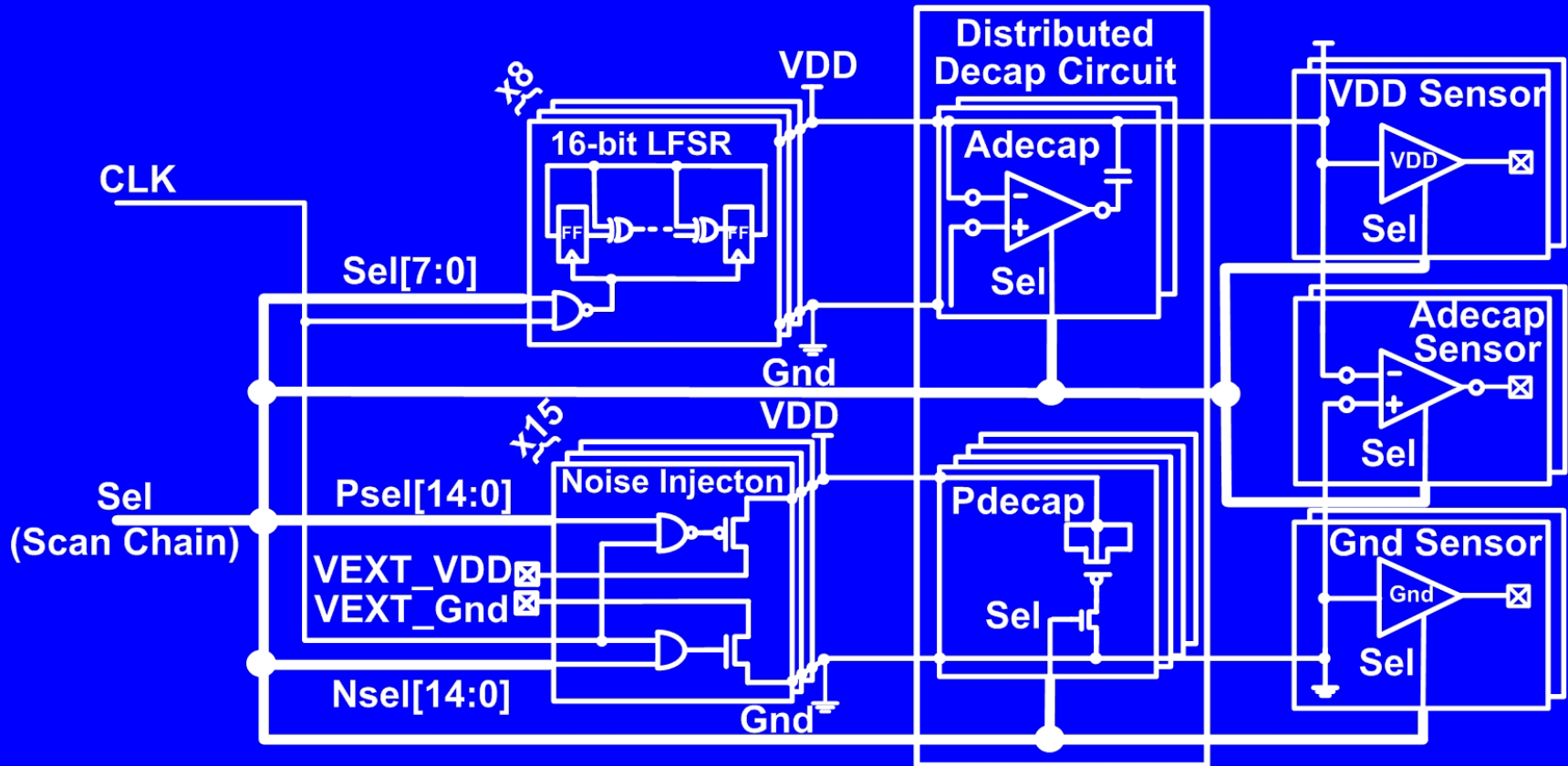
# Simulated Decoupling Effects

0.18 $\mu$ m, 25°C, 1.8V



- Decap boost 4x ~ 11x up to 1GHz
- Small pdecap required for high frequency noise

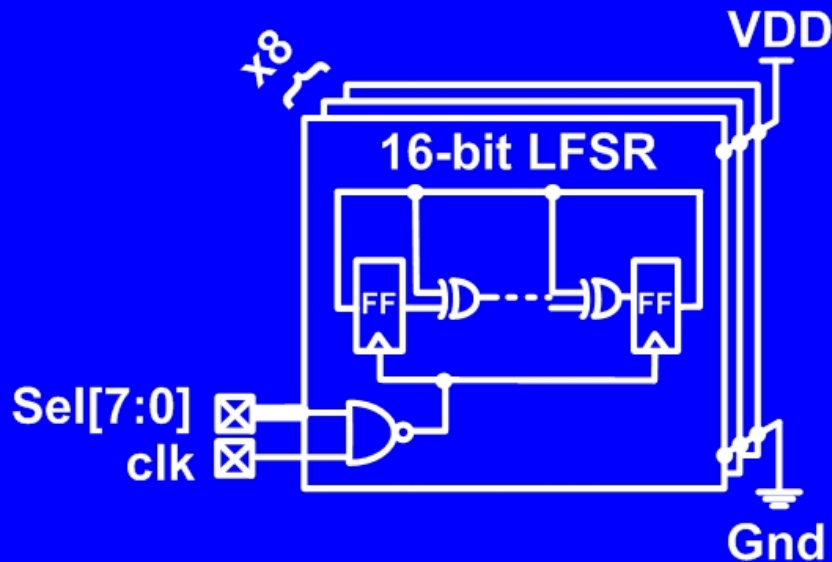
# Test Chip Organization



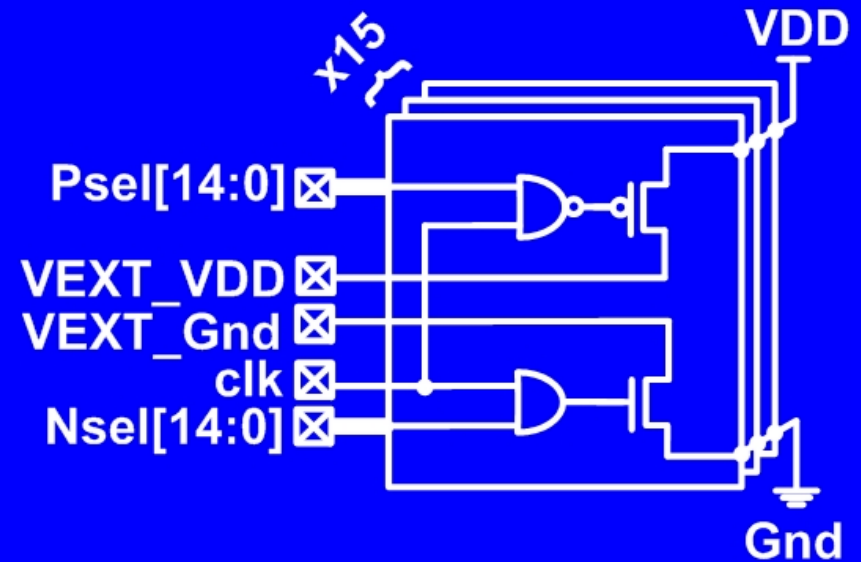
- Scan chain to activate each module of circuits
- Selection of different values of pdecap and adecap
- Adecap sensor to measure differential noise

# Noise Generation Circuits

## LFSR Circuits



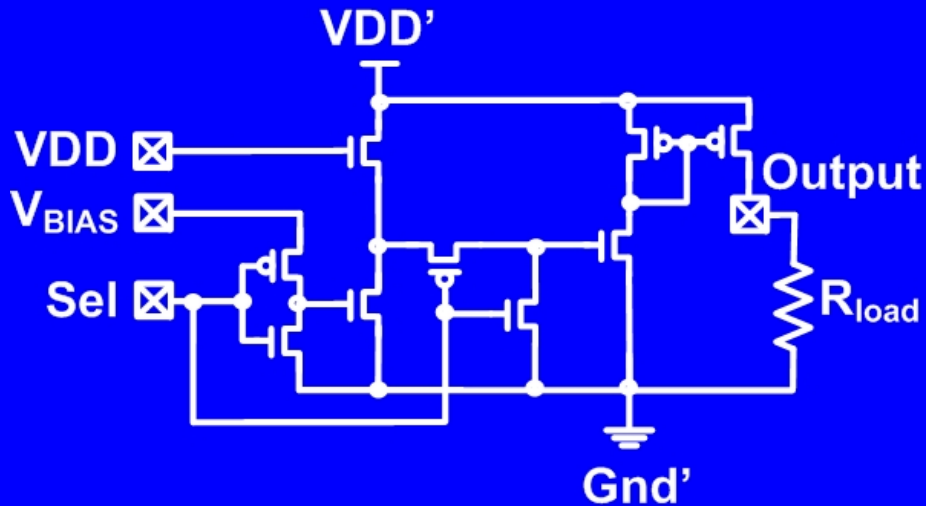
## Noise Injection Circuits



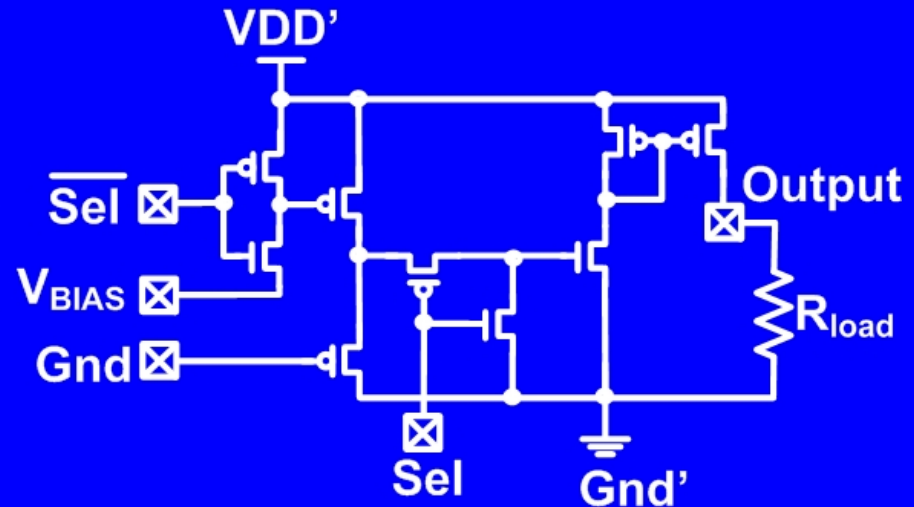
- Capable of adjusting supply noise shape and frequency
- Noise injection circuit can produce more ideal noise waveforms for testing purposes

# Supply Noise Sensors

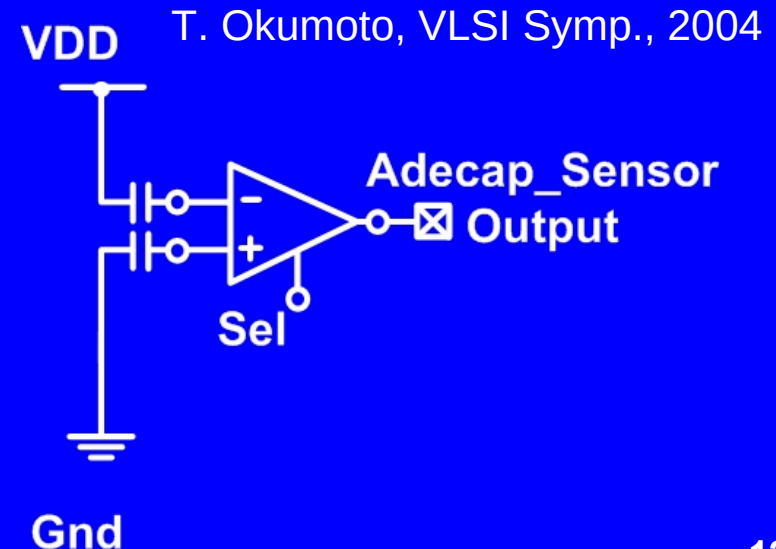
## VDD sensor



## Gnd sensor

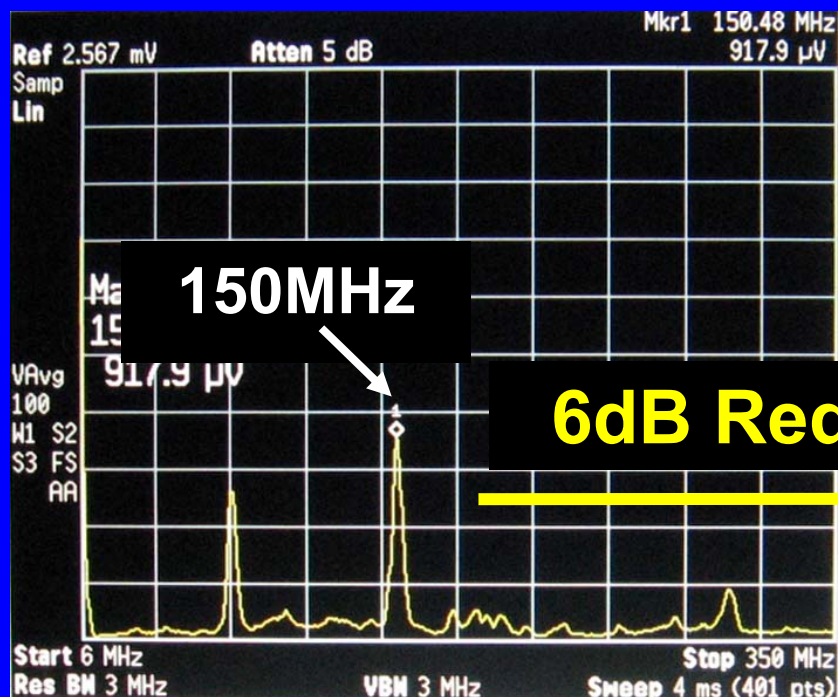


- Placed at different locations
- Adecap sensor for differential supply noise

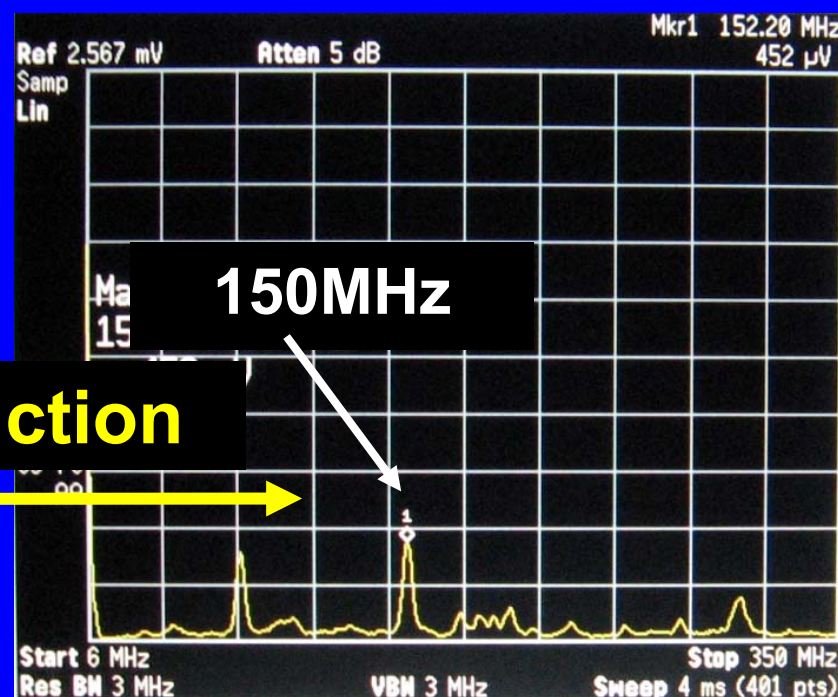


# Measurement Result

Adecap Off



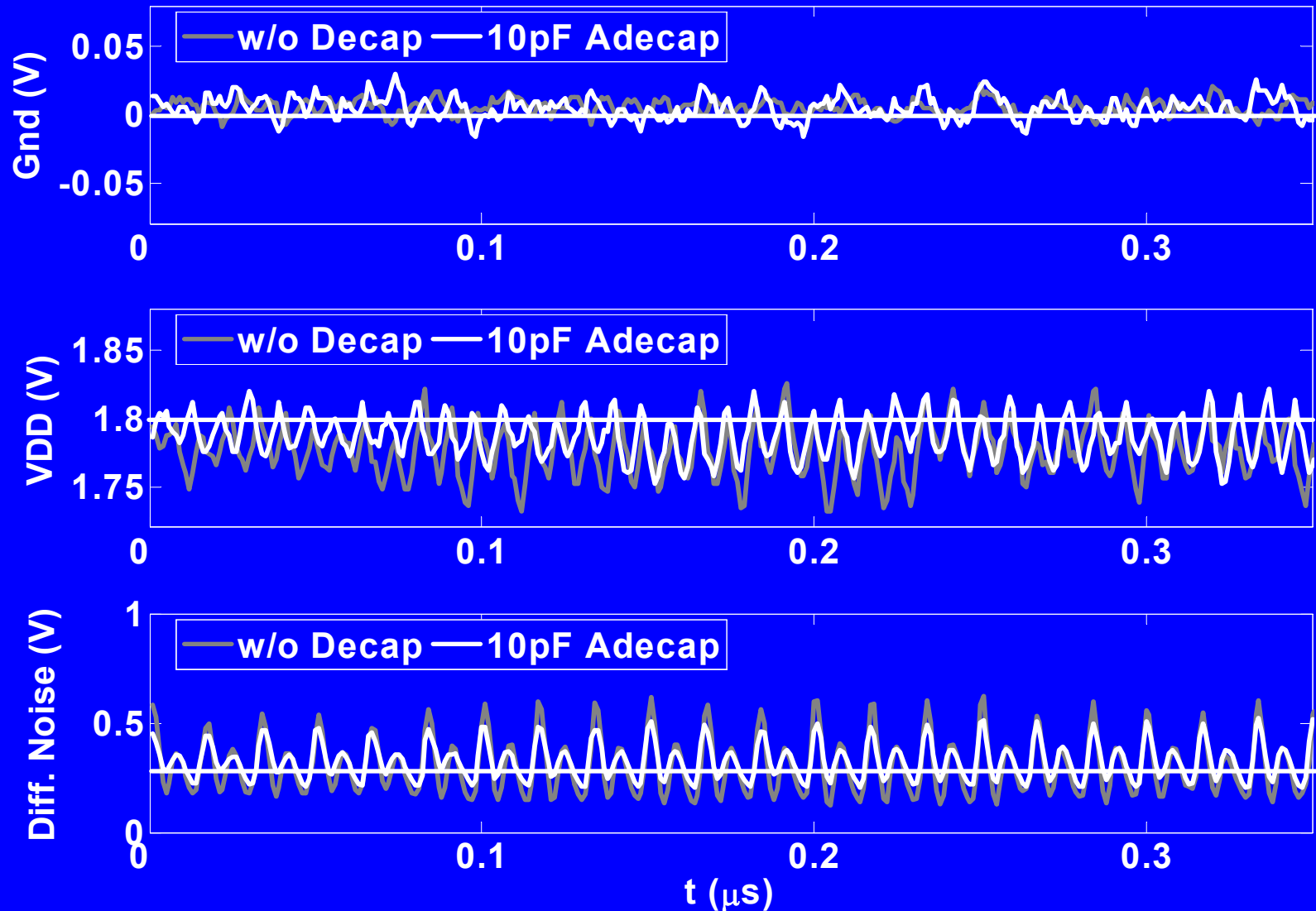
Adecap On



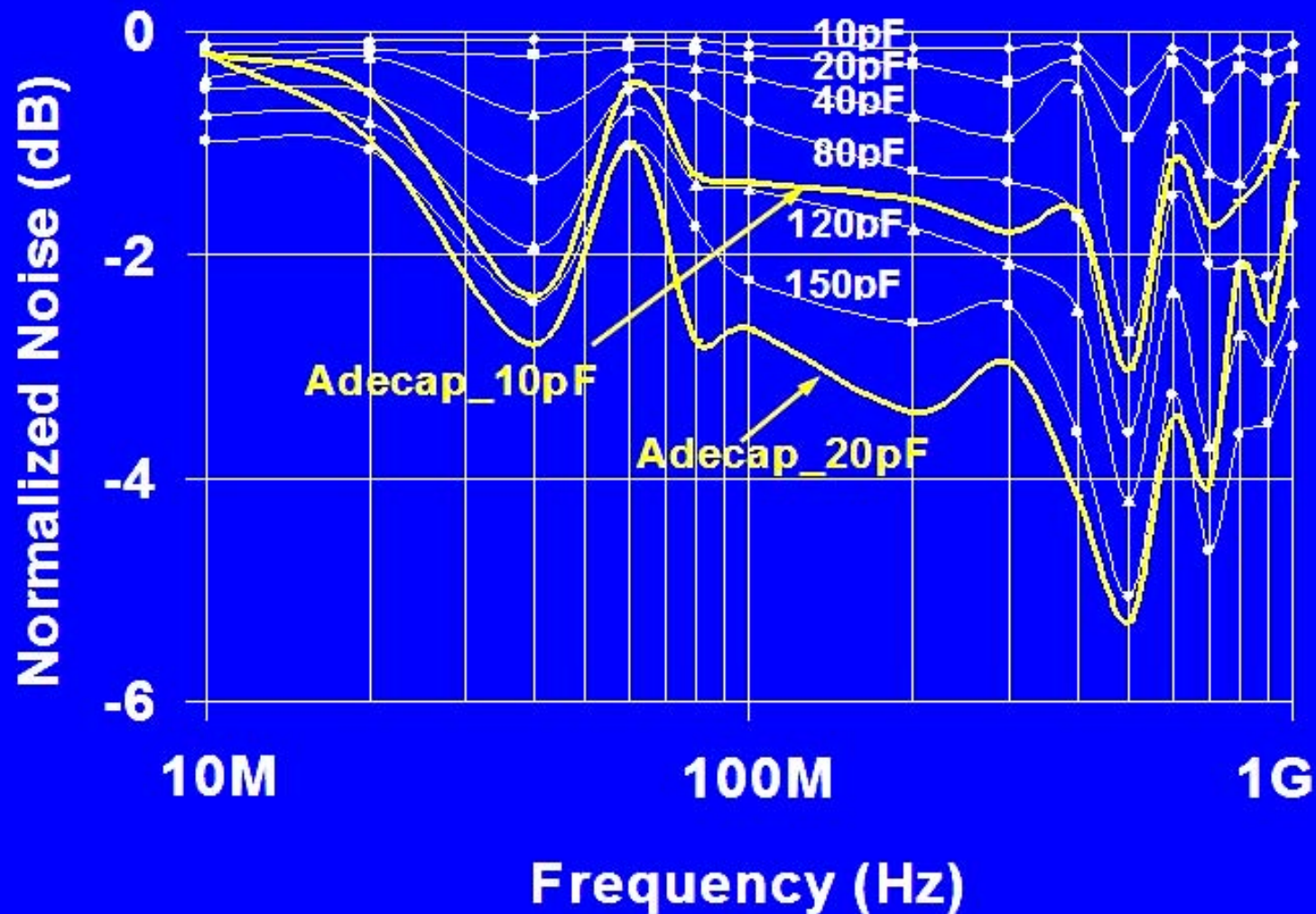
6dB Reduction

- Noise injection circuit clocked at 150MHz
- Resonant supply noise at 70MHz
- 6dB reduction of supply noise using adecap

# Measurement Results: Supply Noise Waveform

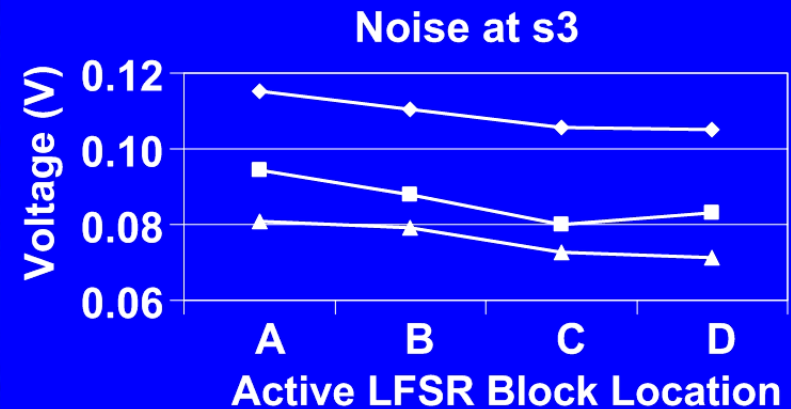
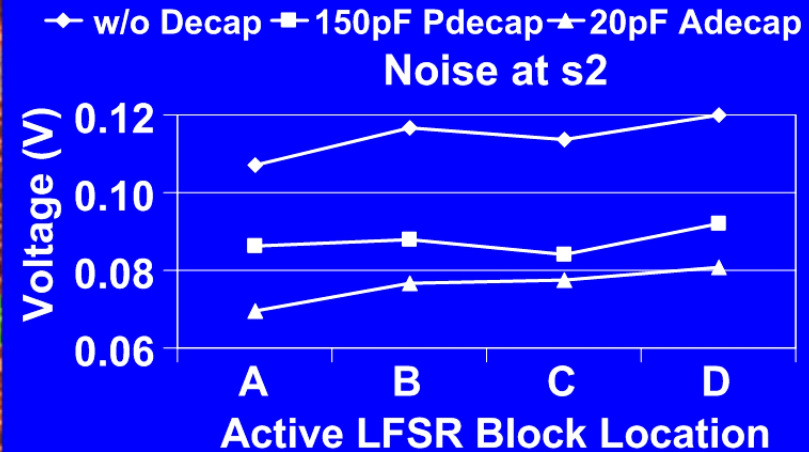
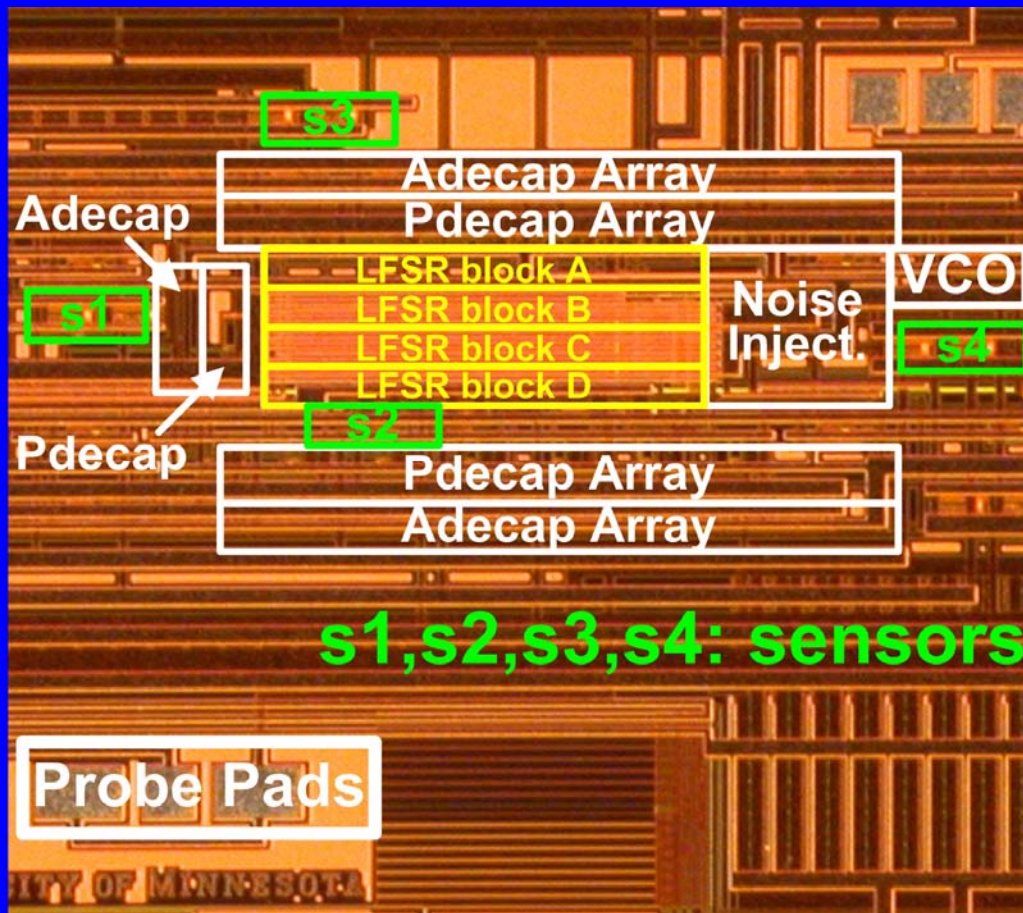


# Measured Decoupling Effect: Pdecap vs Adecap



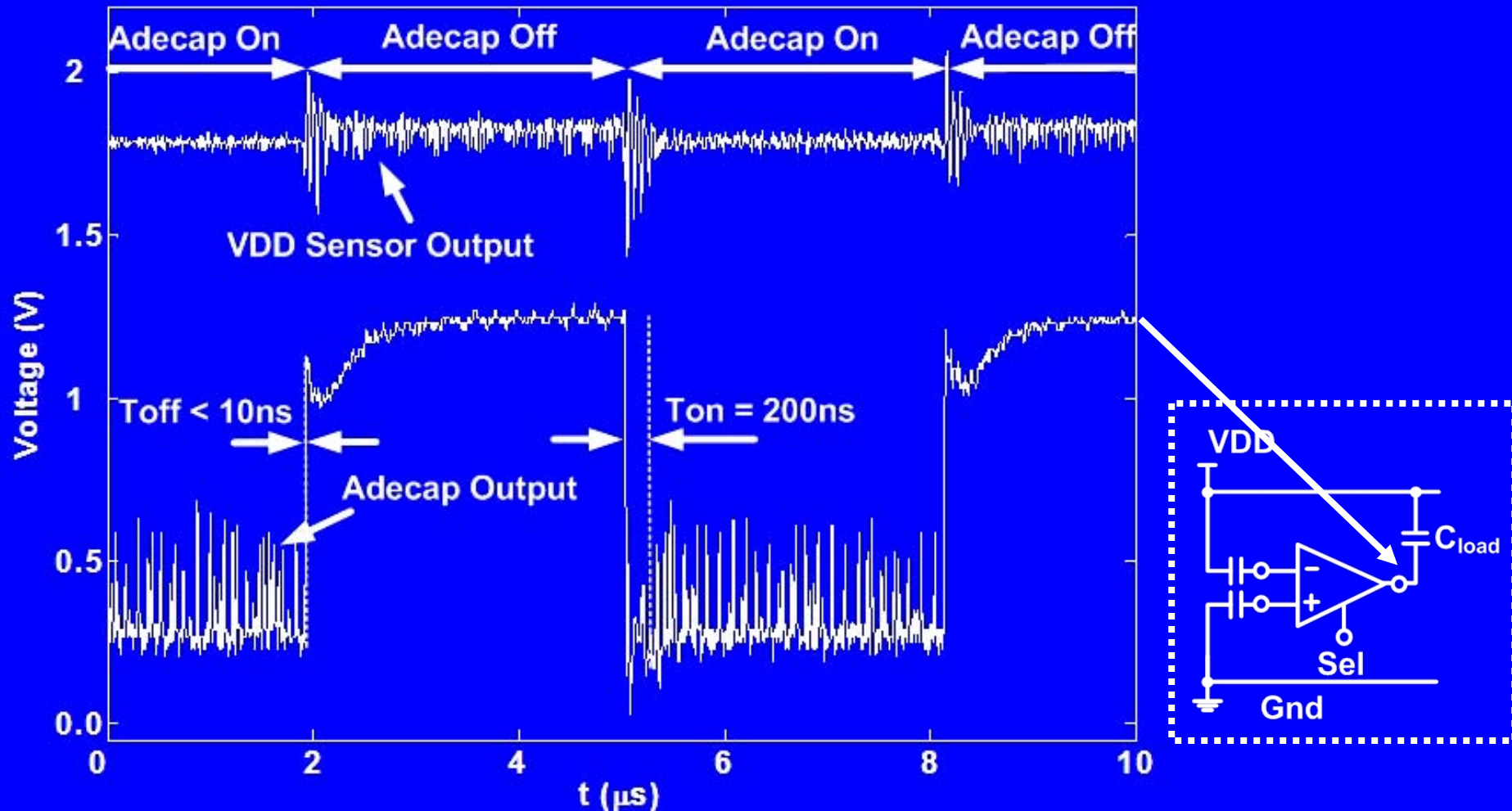
(Noise generated by LFSR circuits)

# Local Supply Noise Measurement



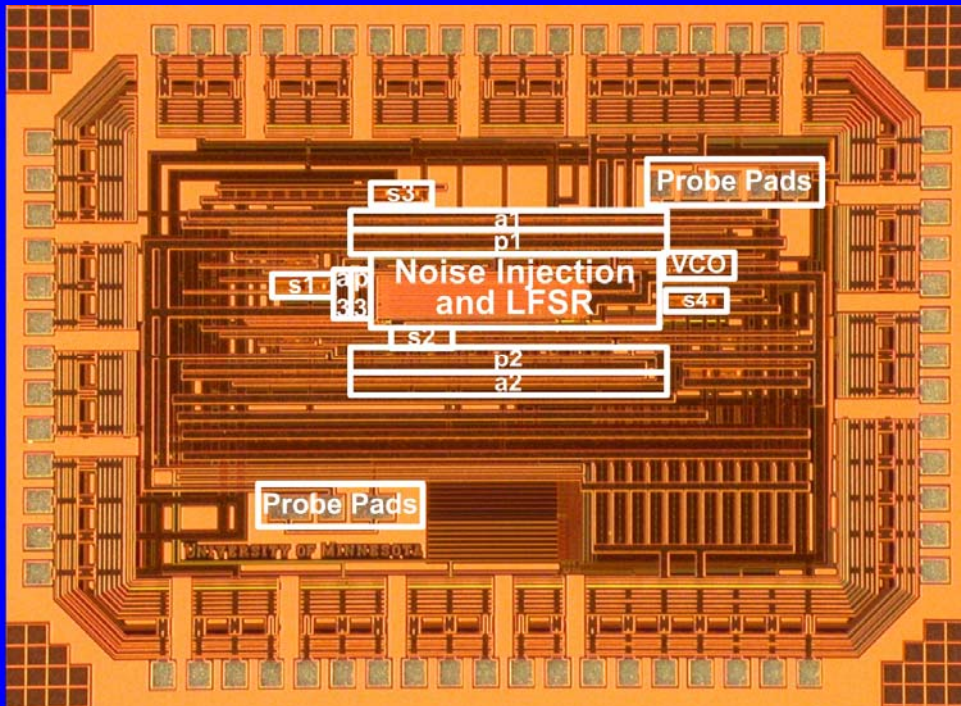
- Larger noise at location closer to noise source

# Switching On/Off Active Decaps

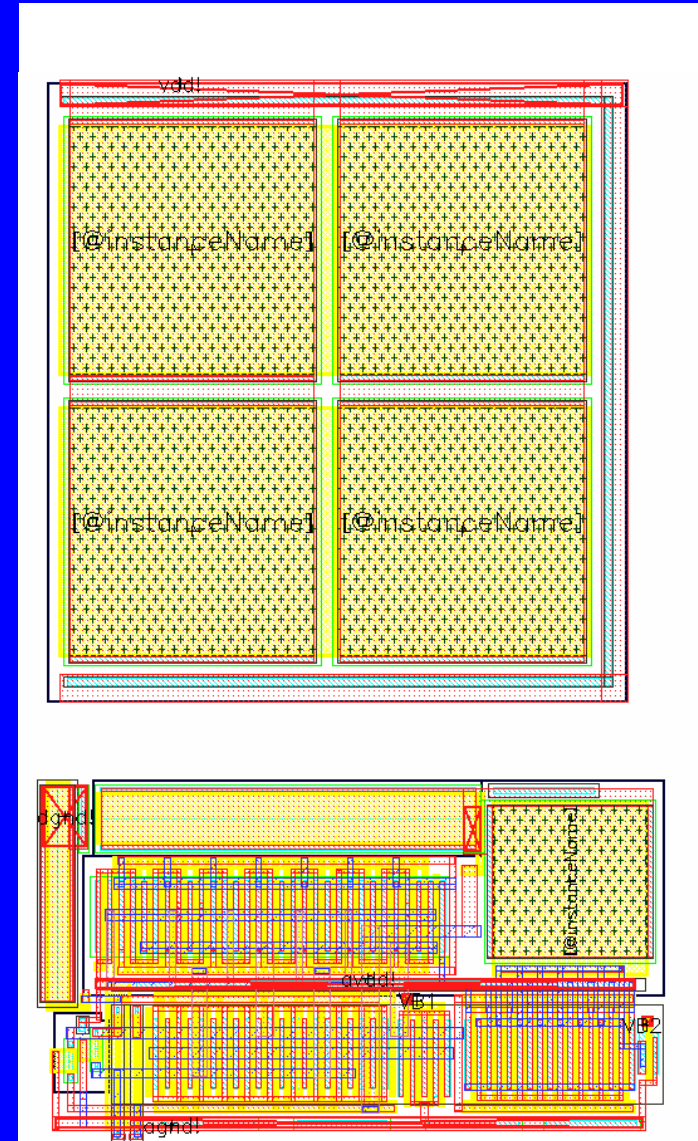


- $T_{on} \sim 200\text{ns}$  (can be improved to less than 10ns)
- $T_{off} < 10\text{ns}$

# Die Photograph



|                      |                                                   |
|----------------------|---------------------------------------------------|
| Technology           | 0.18 $\mu$ m                                      |
| $V_{DD}$             | 1.8V                                              |
| Passive Decap (10pF) | 44 $\mu$ m $\times$ 41 $\mu$ m                    |
| Active Decap (10pF)  | 25 $\mu$ m $\times$ 44 $\mu$ m<br>(40% reduction) |



# Conclusions

- **Passive decap occupies large area and consumes gate tunneling leakage**
- **Self-biased active decoupling capacitor circuits proposed to boost decap performance**
- **4x ~ 11x boost in decap value up to 1GHz with 40% area saving**
- **Decap gating capability was tested for power saving**