Power and Temperature Control on a 90nm Itanium® Family Processor

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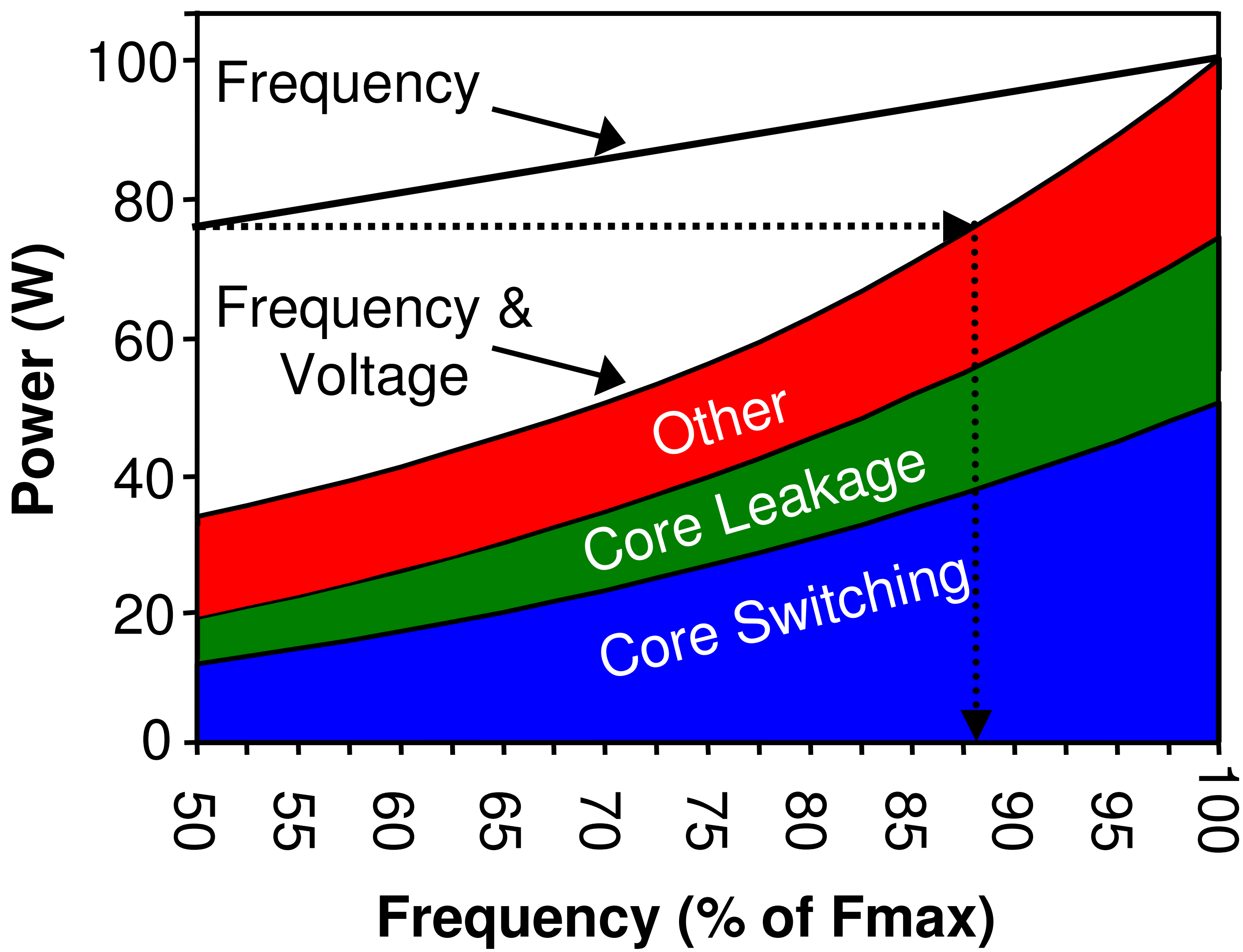
Motivation

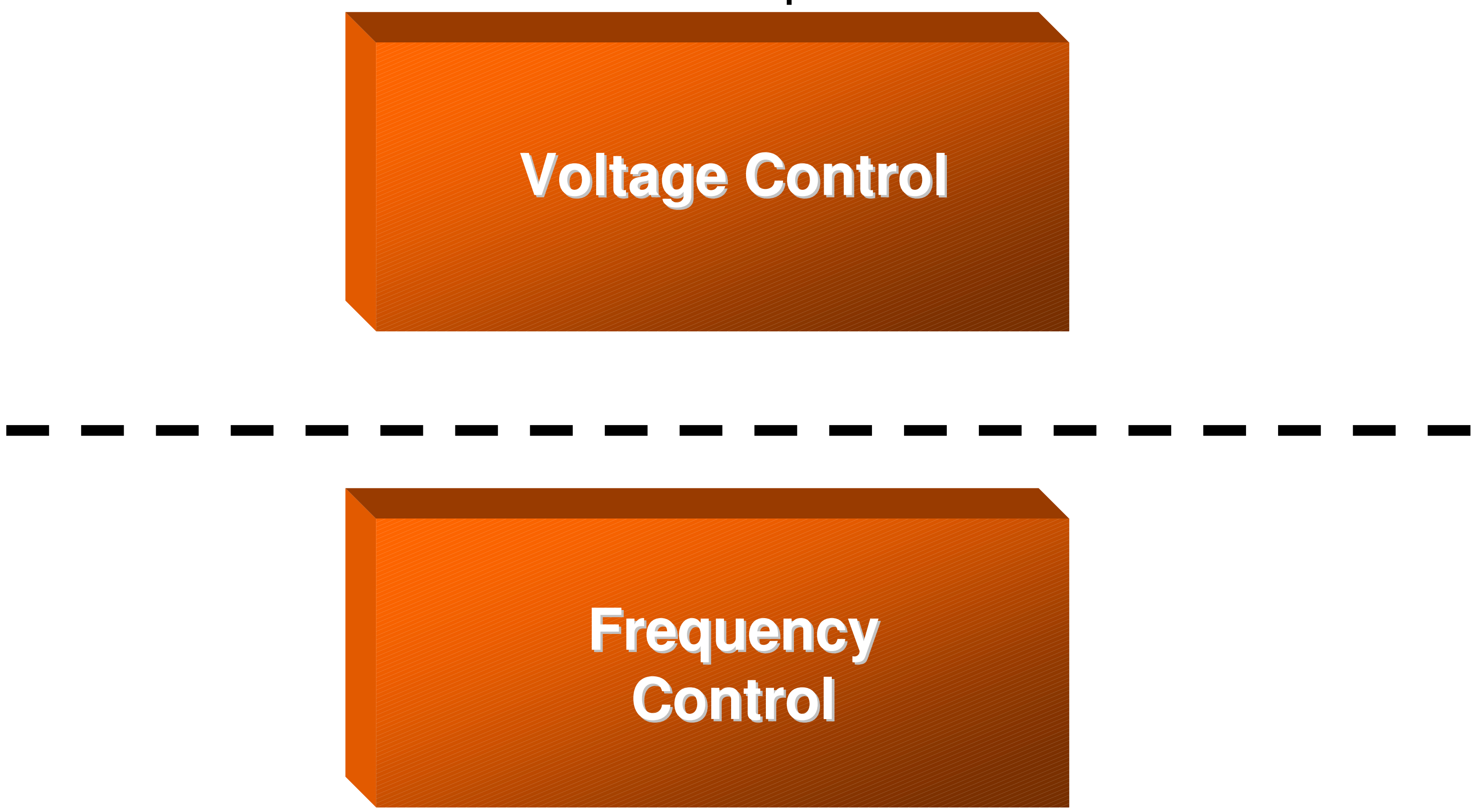
- Maximize performance per Watt
- Latest Itanium II (130nm) consumes **130 Watts**
  - **Single** core, **9MB** L3 Cache
- Montecito (90nm) consumes **100 Watts**
  - **Dual** core, **24MB** L3 Cache
- Simple port would be well over **200 Watts**
  - Need something more than low power circuit techniques to address power problem
- Take advantage of $P \propto V^2F$

Take Advantage of $P \propto V^2F$



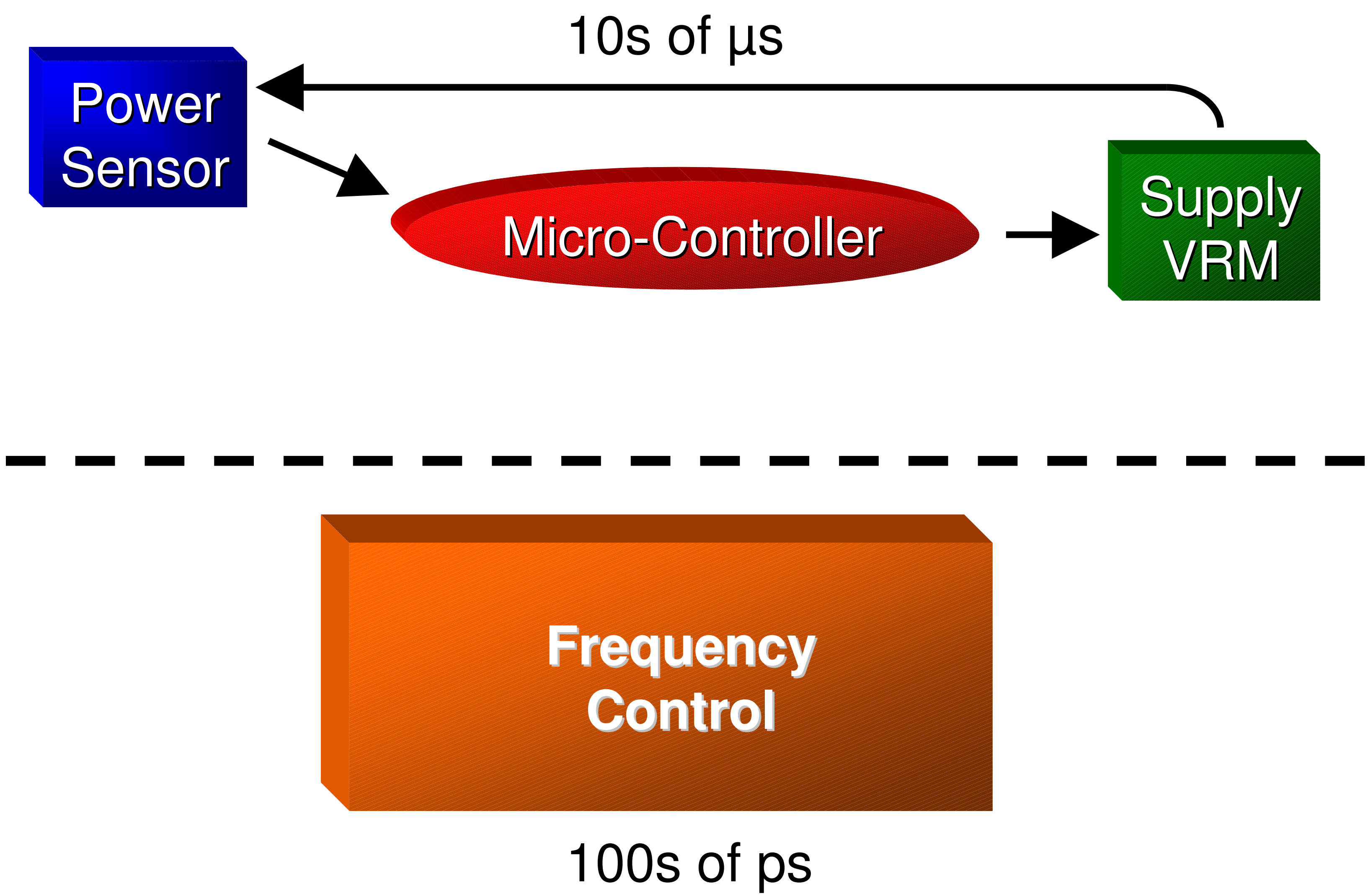
High Level View of System

10s of µs



100s of ps

High Level View of System



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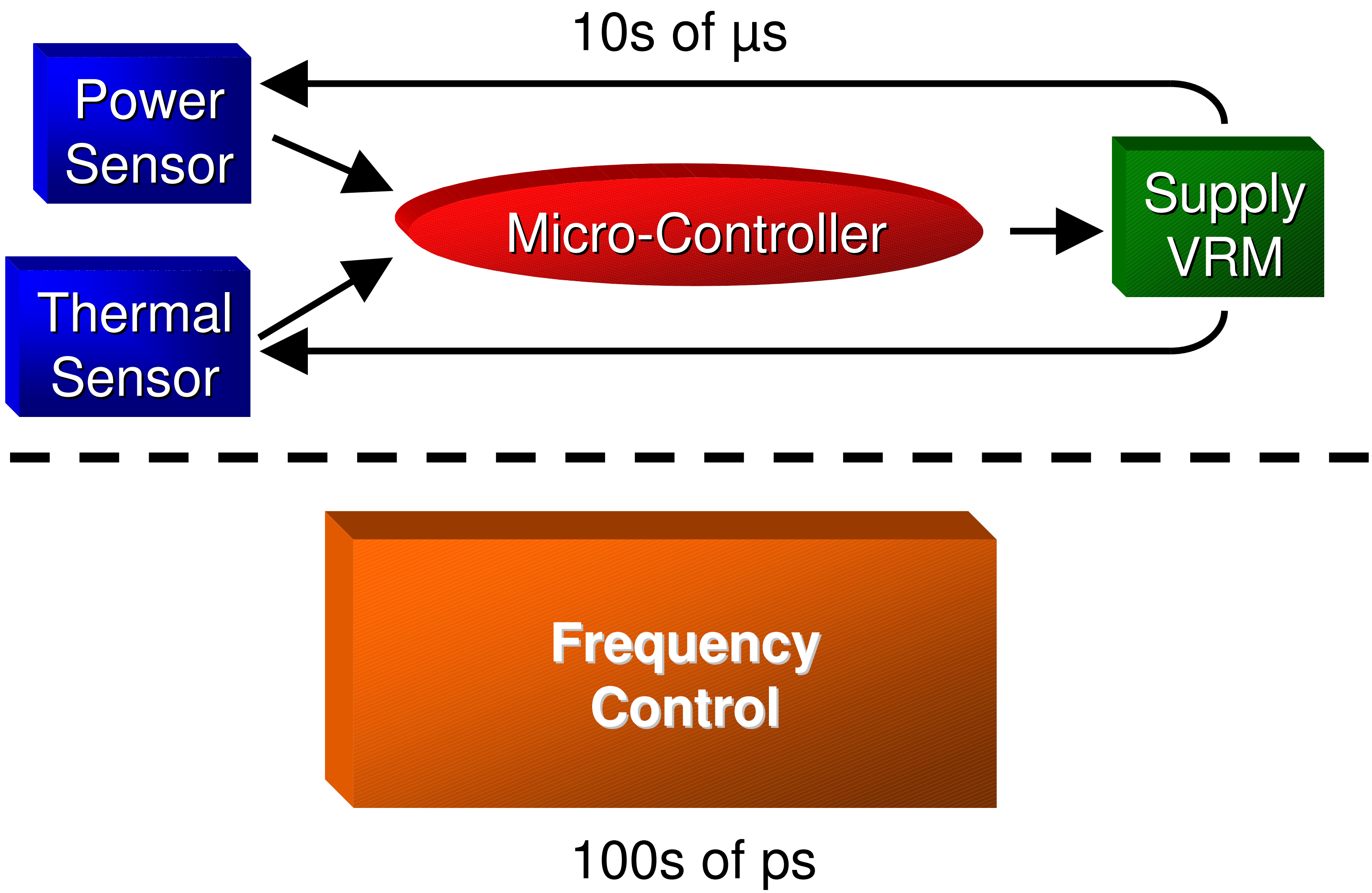

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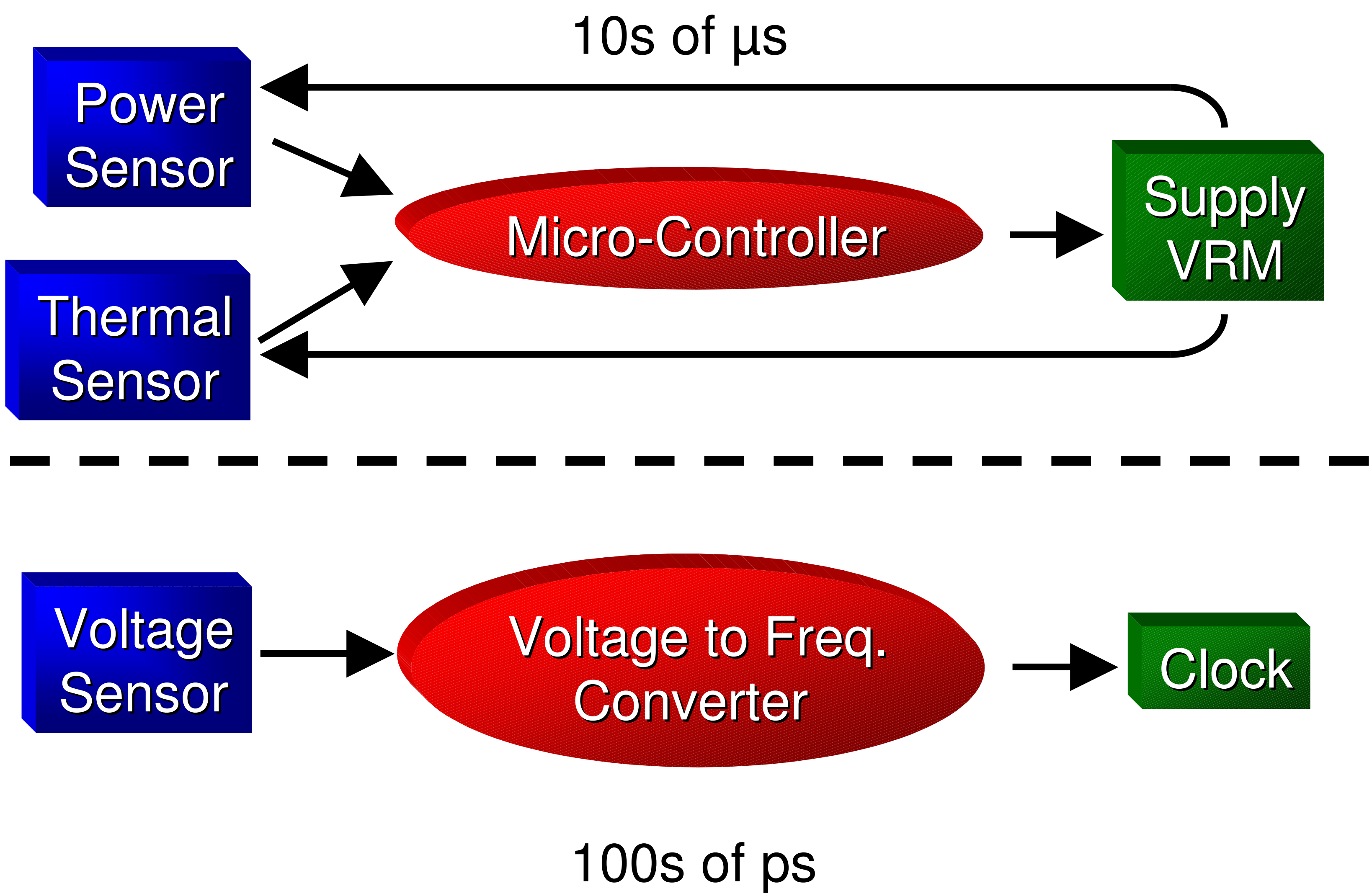
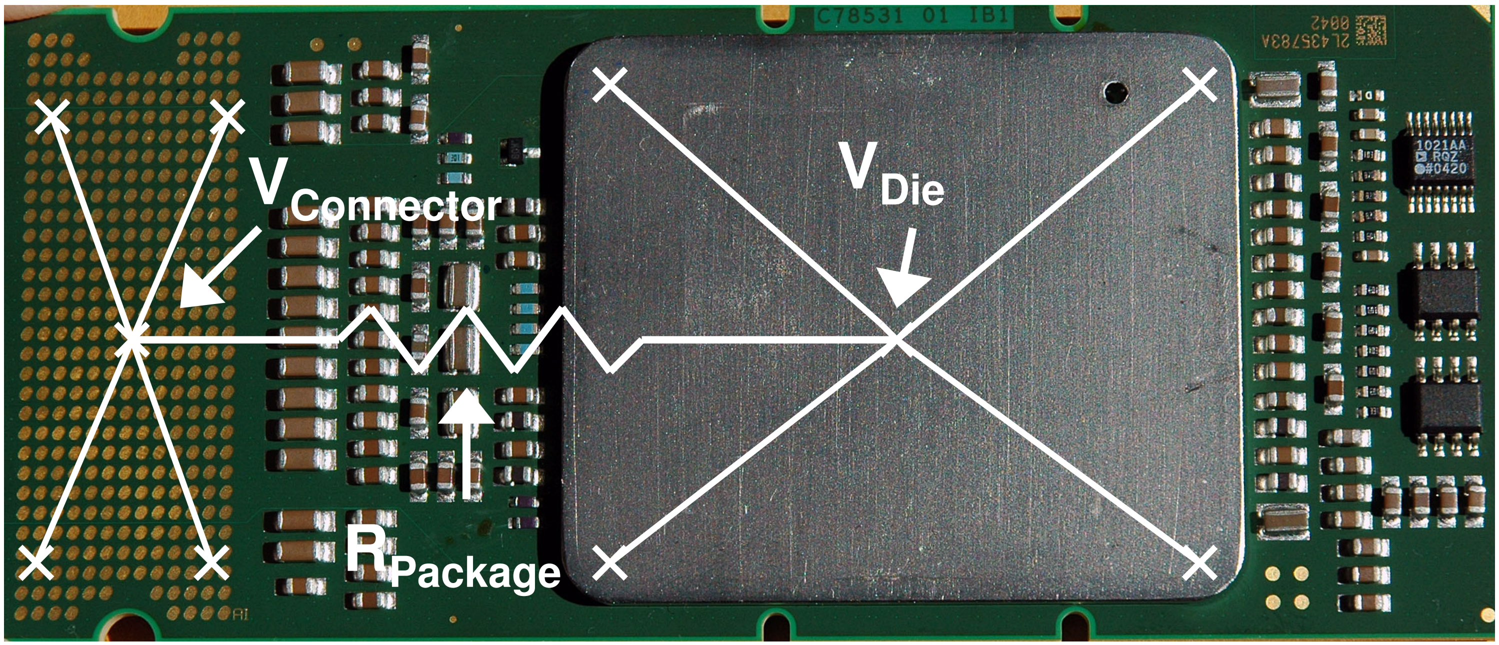
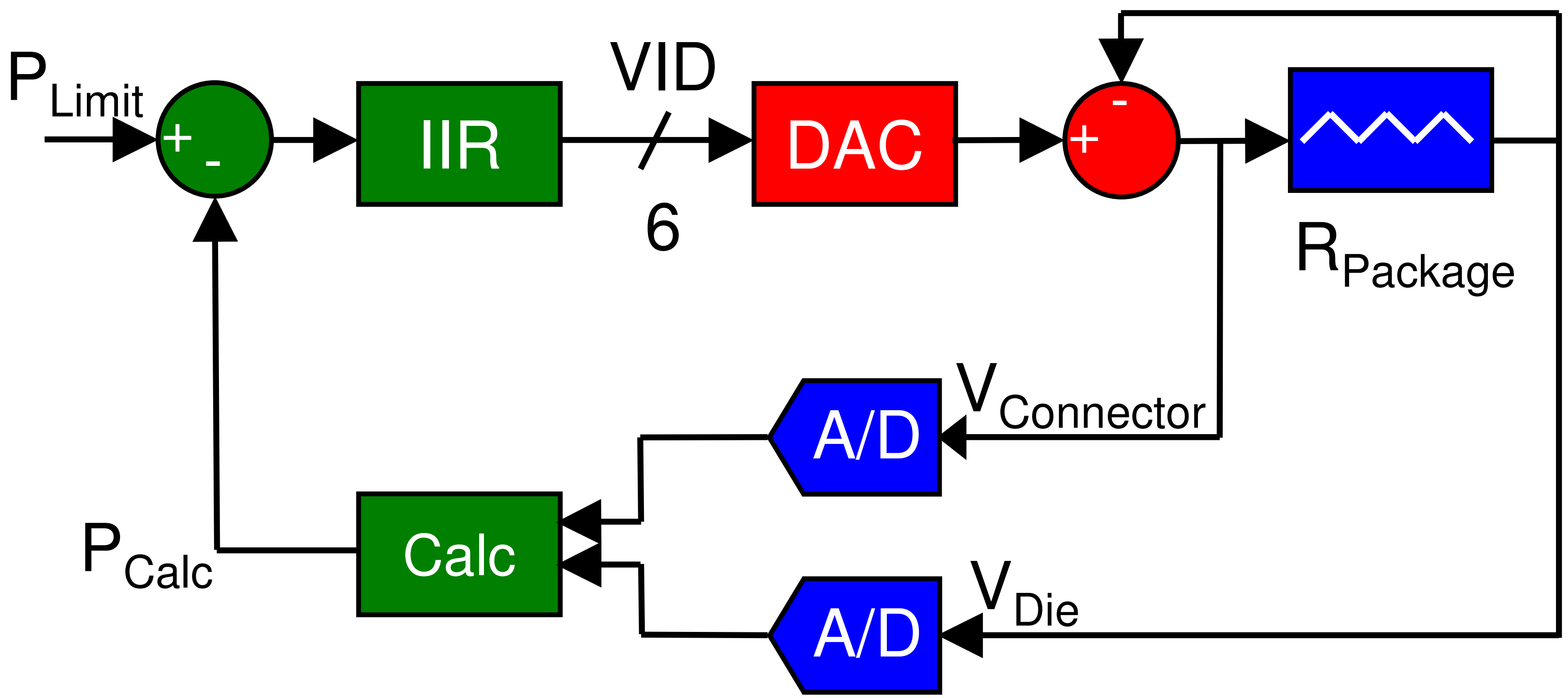


Measuring Power



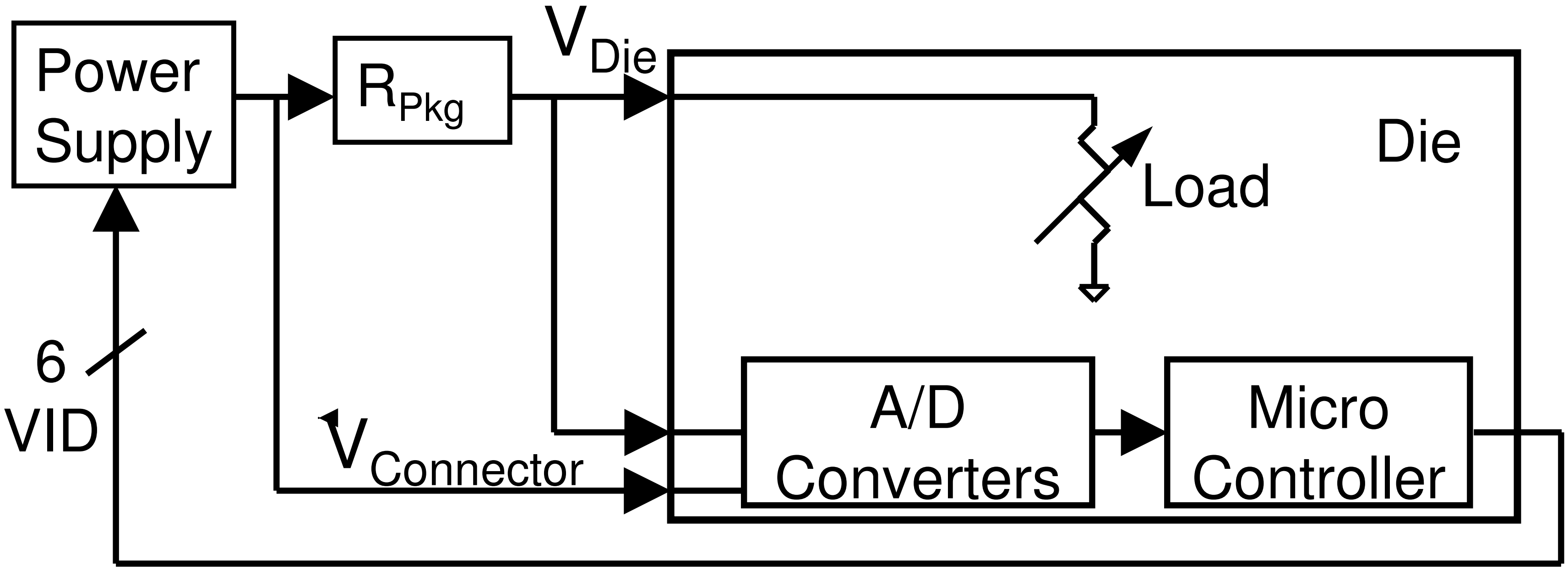
- Use package resistance to measure power
- Avoids burning extra power in measurement
- Portable, self-contained solution
  - No dependence on external power supply

Power Control System



Micro-Controller | Power Supply | Package/Die

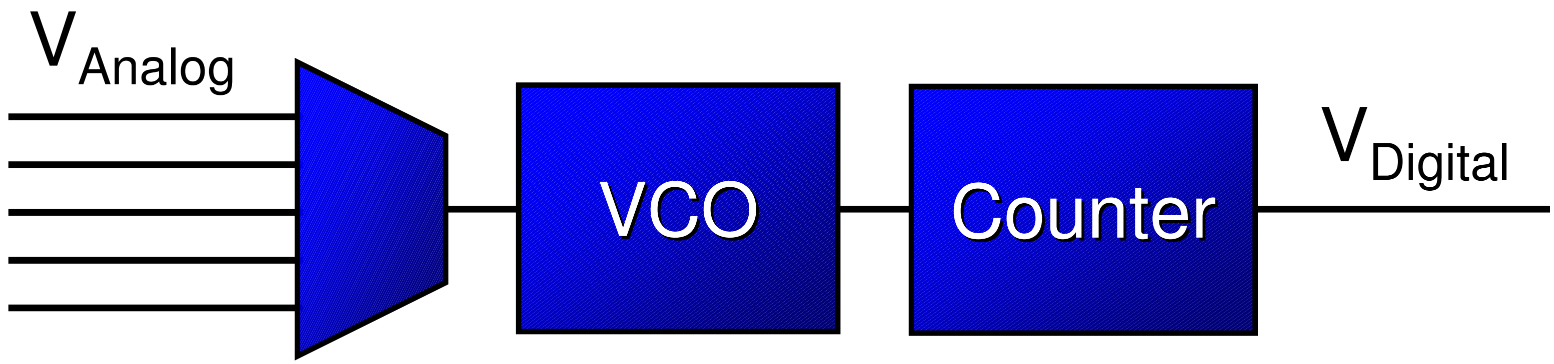
System Architecture – Power Measurement



- Measure voltages at both sides of the package to determine current and compute power (8µs sample period)

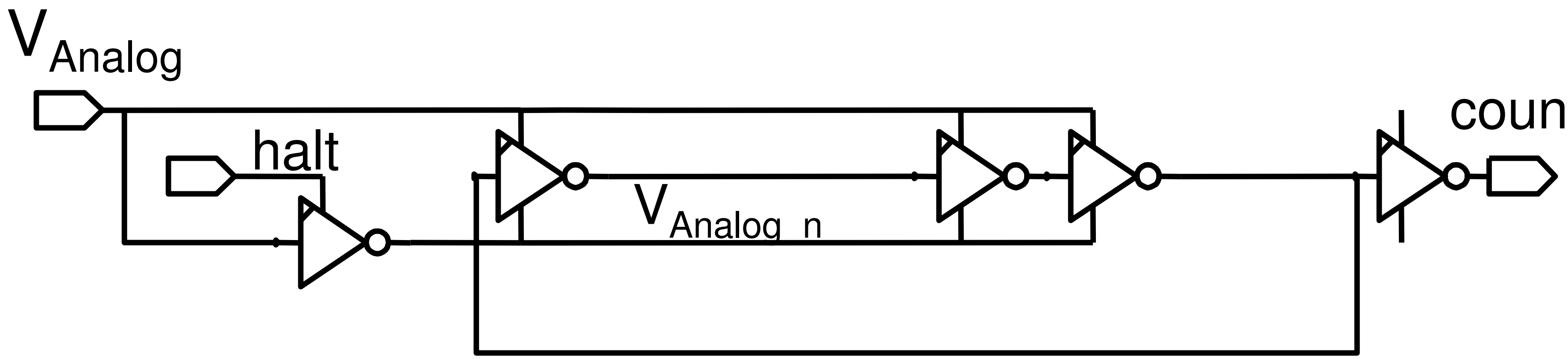
$$Power = V_{Die} I_{Die} = V_{Die} \frac{\left(V_{Connector} - V_{Die}\right)}{R_{Package}}$$

Voltage Measurement



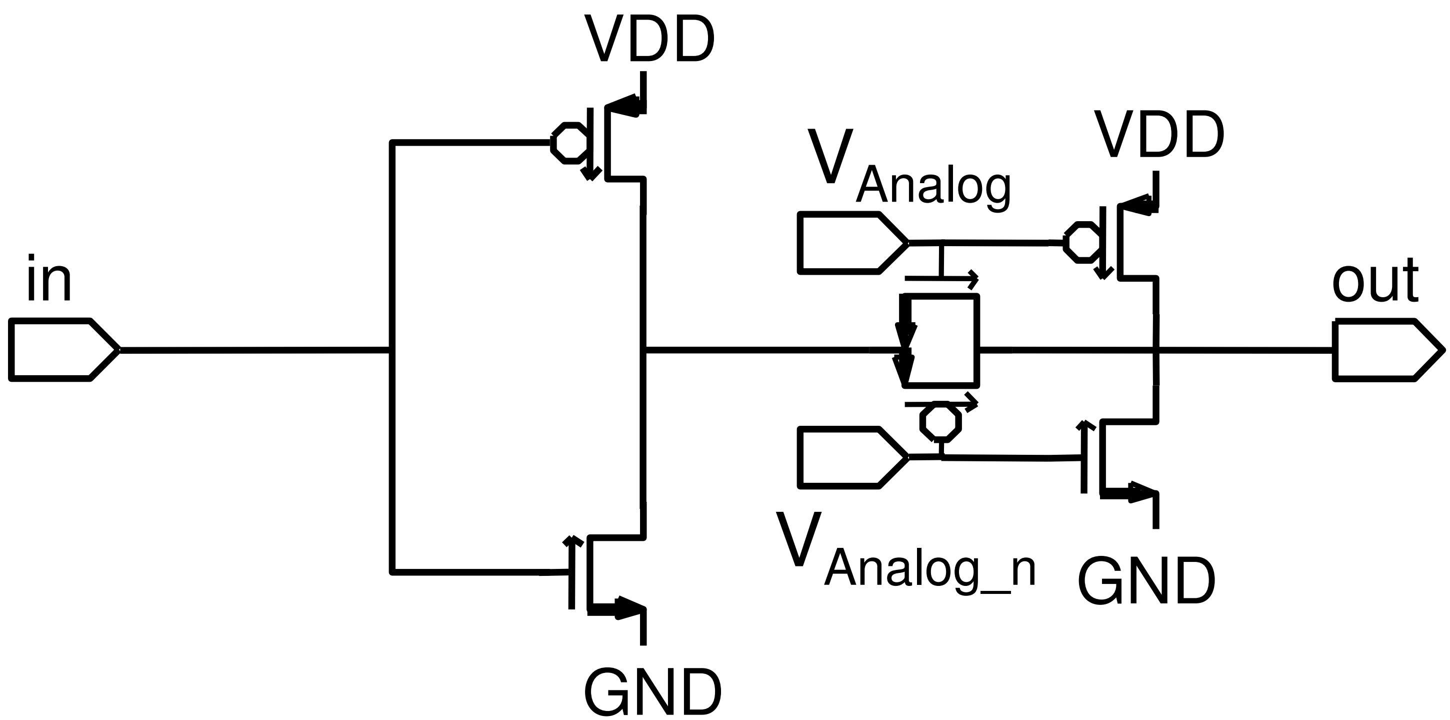
- By using an analog mux, we can reuse the same VCO to measure voltages from multiple sources
  - On die voltmeter
- High speed counter, >>10GHz for ~100μV measurement granularity
- 8μs counting interval for filtering and resolution

VCO Detail



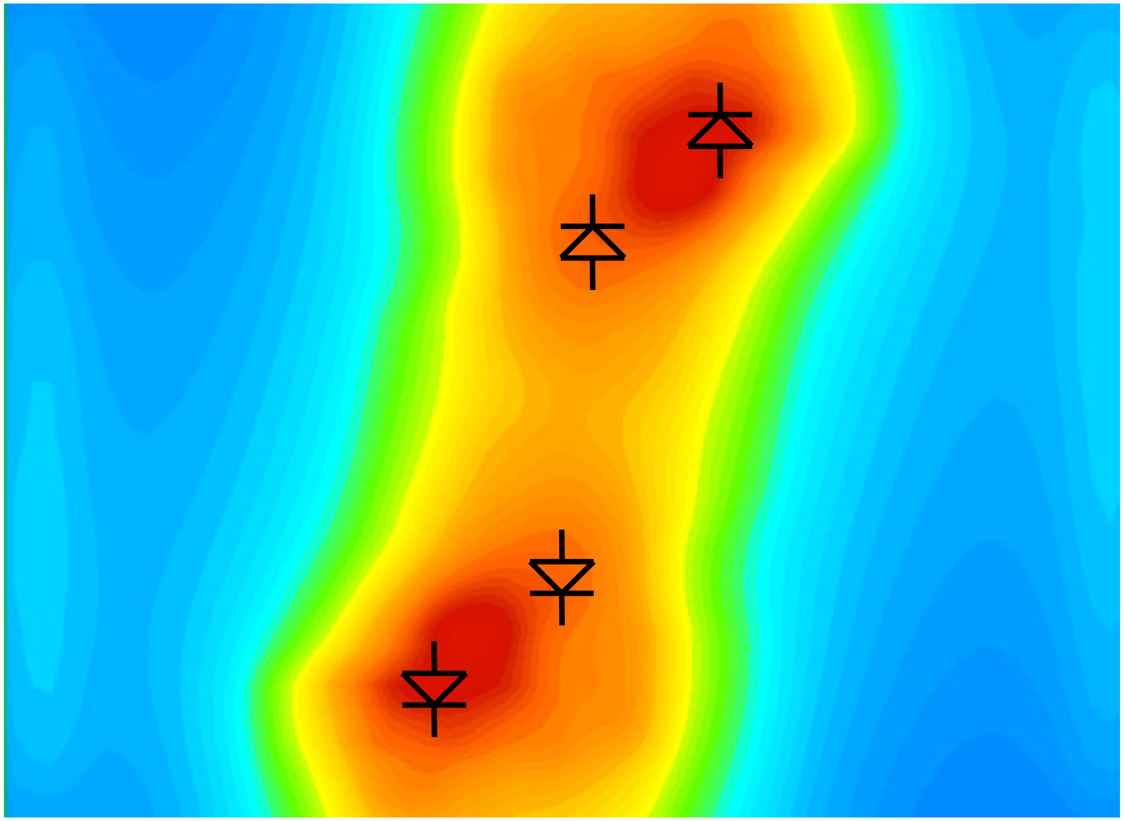
- Short loop for high speed
- Analog "inverter": bias circuit for complementary control signal, also starts/stops oscillation
- Performs averaging function by running at over 10GHz for 8µS

VCO Detail– Delay Element



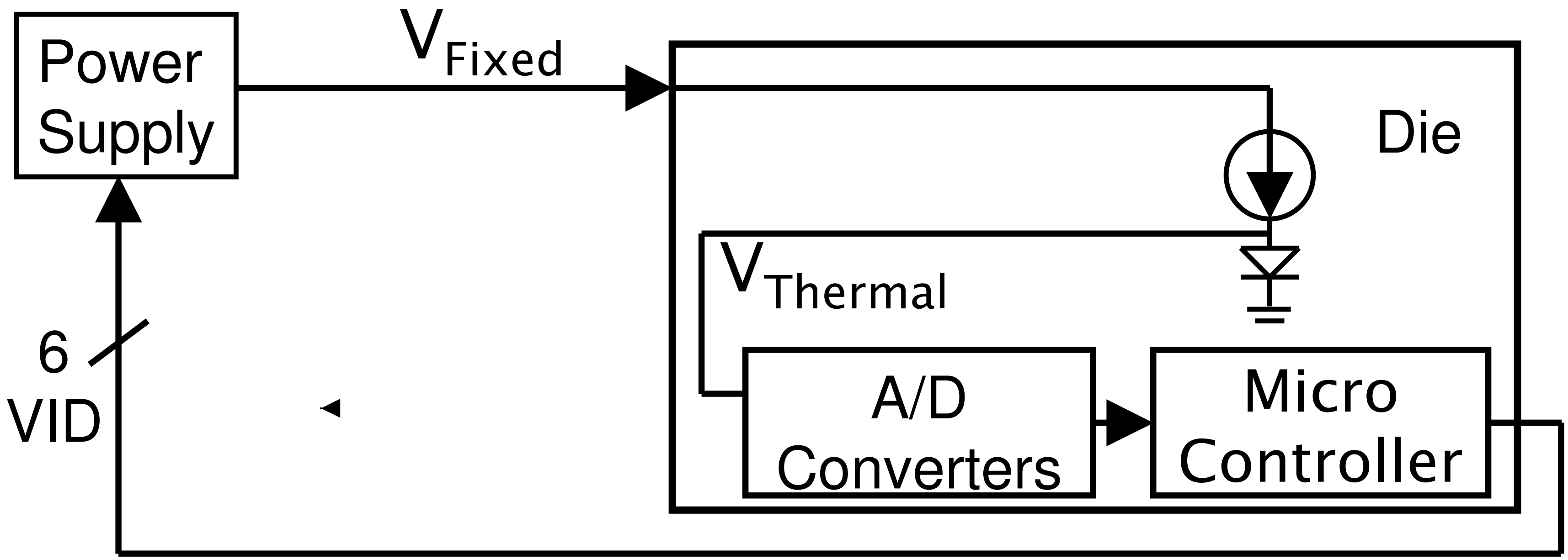
- Modulate output current via series output resistance combined with controlled drive fight
  - Large input voltage range with very linear response

Measuring Temperature



- Two thermal sensors per core
  - Mux thermal diodes into VCOs to measure temperature

System Architecture – Temperature Measurement



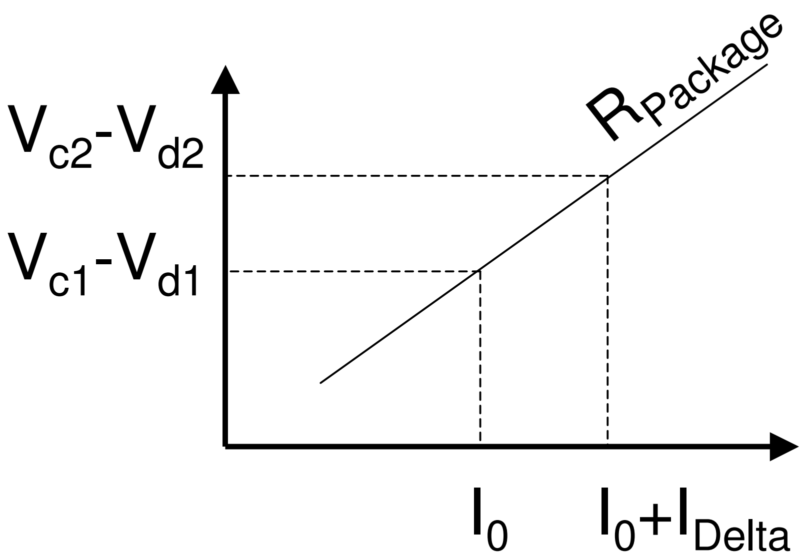
- Calibrate the voltage drop at test to T_J target (90C)
- Use the known -1.7mV per degree C temperature coefficient to calculate die temperature
- Measure the voltage drop across the diodes every 20ms

Sources of Error and Inaccuracy

- $R_{Package}$ variation with manufacturing process
- $R_{Package}$ variation with temperature
- <25mV DC voltage drop across package
  - 1% accuracy target requires 250µV
- Noise on the measurement system supply
  - VCO designed for speed, not power supply rejection
- VCO gain and frequency variation over PVT
- Inherent inaccuracies in the reference components

Requires frequent calibration

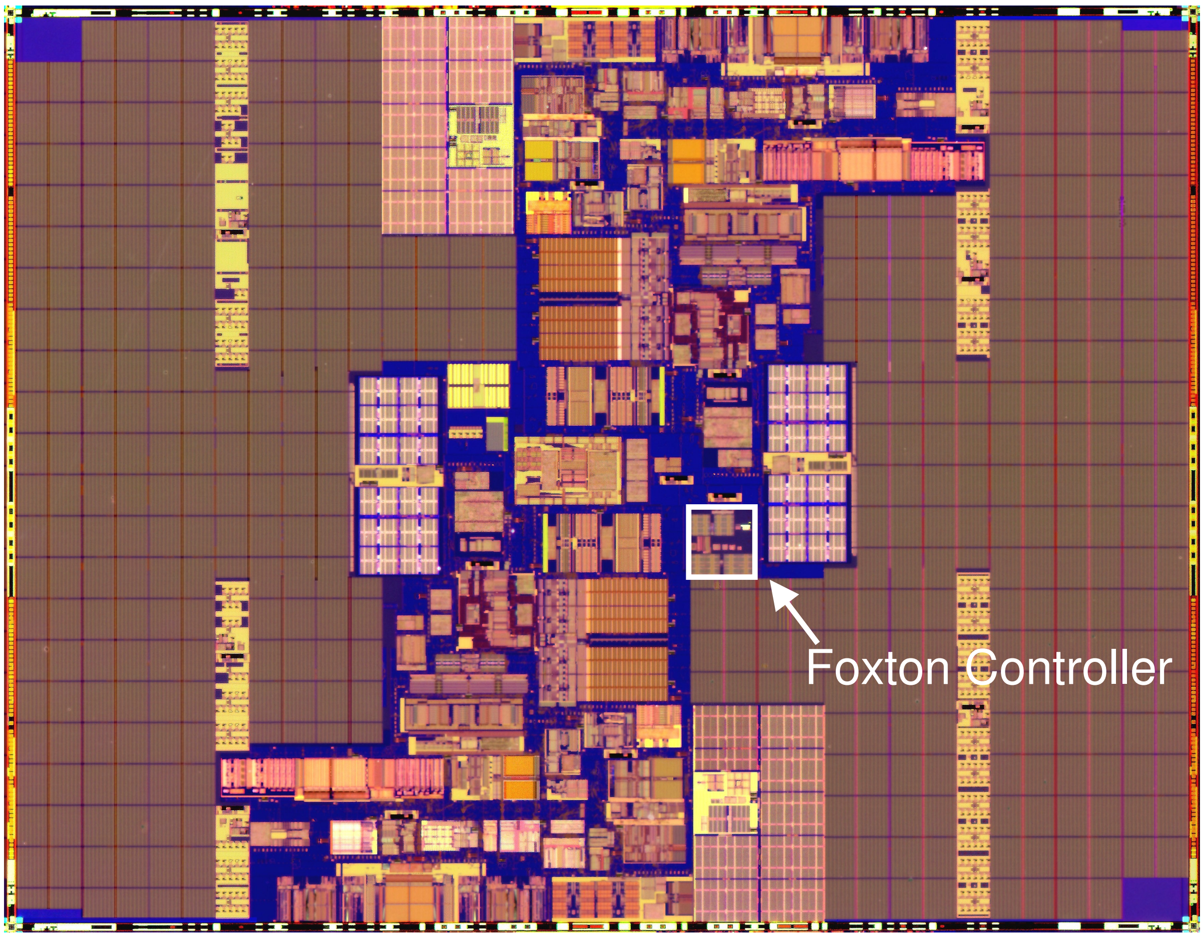
Package Resistance Calibration



$$R_{Package} = \frac{(V_{c2} - V_{d2}) - (V_{c1} - V_{d1})}{I_{Delta}}$$

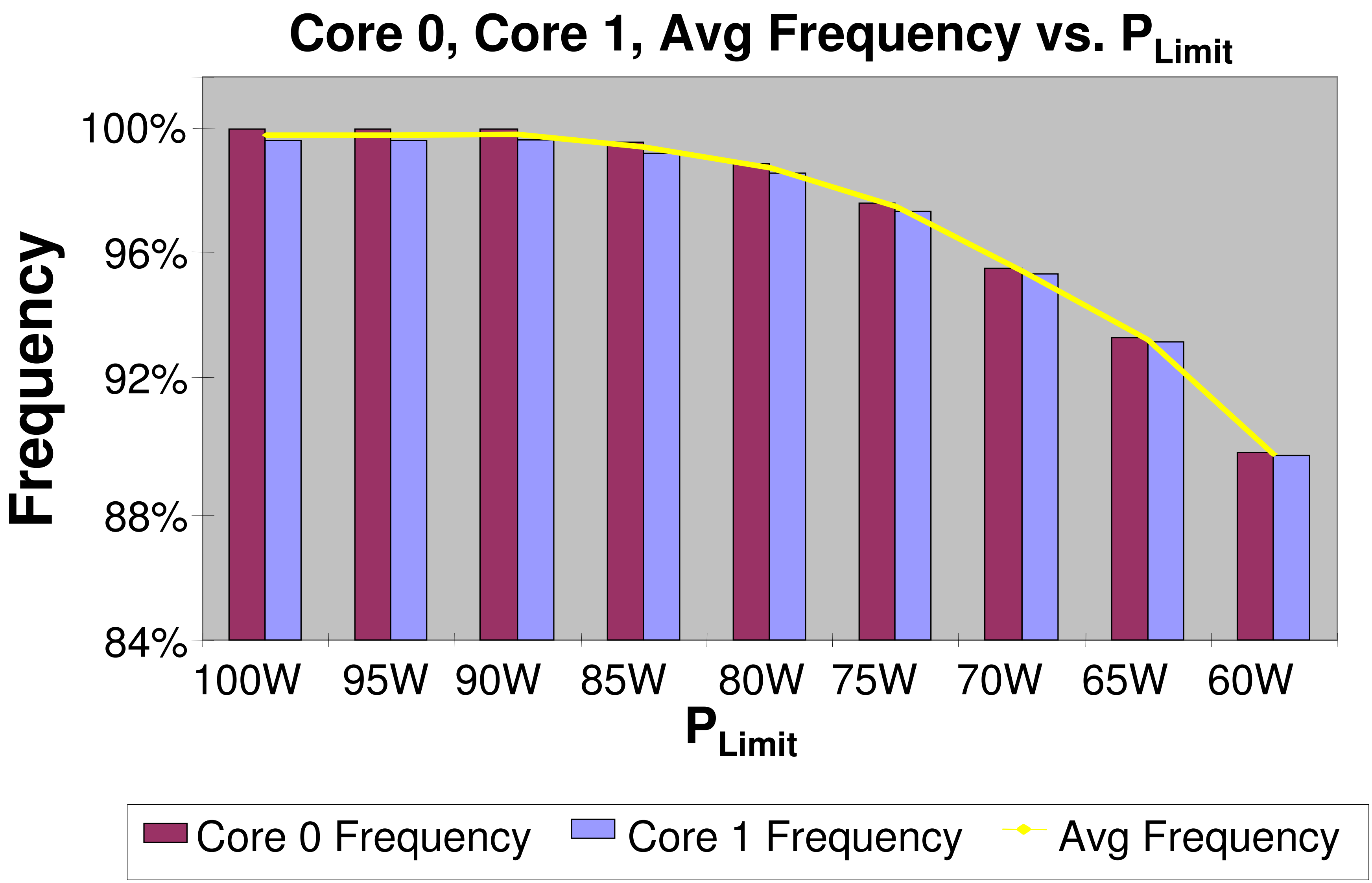
- Package resistance can be computed with two voltage measurements with processor stalled
  - Pulling quiescent current I_0
  - Pulling I_0 + a precision, on-die generated current I_{Delta}
- On-package precision R for consistent I_{Delta}
- Recalibrate every 66ms (<0.2% perf. hit)

System Overhead



- Burns less than 0.5W, less than <0.5% area

Frequency vs. Power Limit



Measured Data

Voltage

Power

Current

Conclusions

- Power and temperature control system using voltage and frequency modulation
  - Maximizes perf./Watt for at least a 25% efficiency gain
  - 90^{o}C on-die temperature control with graceful throttle for improved reliability and performance
  - Programmable power limit
- Voltmeter and package resistance calibration enables
  - 3% average power measurement accuracy
  - 1^{o}C temperature control accuracy
- Embedded on die and package, consuming <0.5W and occupying <0.5% of the die