SQUBIC1: AN INTEGRATED CONTROL CHIP FOR SEMICONDUCTOR QUBITS

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OVERVIEW

- General Introduction
- Scalability

- Electrical control of qubits

- Prototype chip SQuBiC 1
  - Bias Voltage DAC
  - Pulse DAC
  - DCO
  - VCO

- Next steps

- Discussion & Questions

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GENERAL INTRODUCTION

Quantum Computing

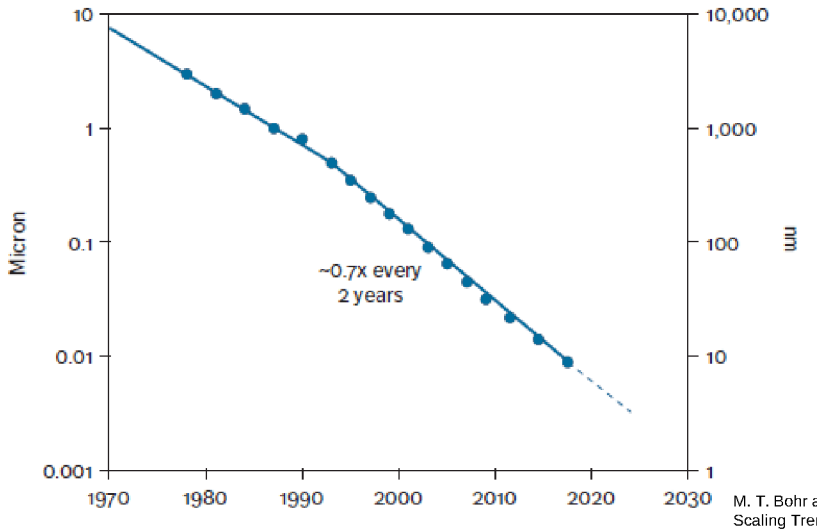
- Requirements for a quantum computer:
  - Large number (10^6-10^9) of physical Qubits operated in a cryogenic environment (< 1K)
  - Room temperature electronics to communicate with the Qubits
  - Scalable control and read-out electronics

- Challenges :
  - Interconnects to room temperature electronics
  - Cooling power limits the power budget for circuitry at qubit temperature
  - Design for scalability in terms of area and power

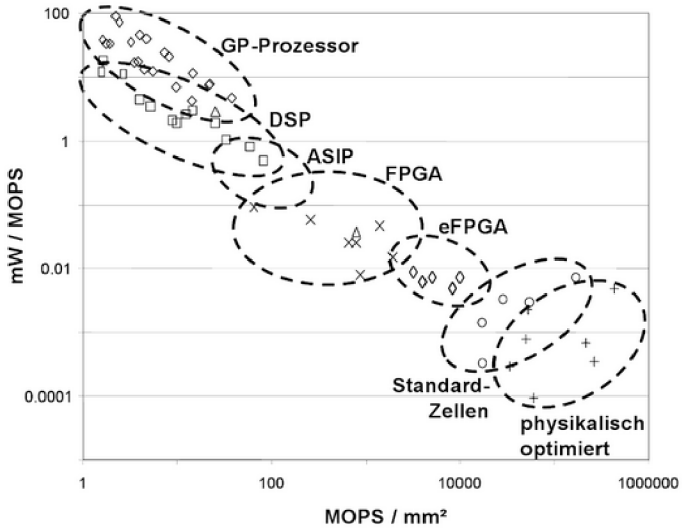
SCALABILITY

Integrated CMOS

- Integrated CMOS scaling is unmatched over the last 50 years (Moore's law)
- The best approach for a scalable system is an application specific solution with reduced flexibility
- Using state of the art CMOS with prospect of using dedicated cryo-CMOS in the future



M. T. Bohr and I. A. Young, "CMOS Scaling Trends and Beyond," in *IEEE Micro*, vol. 37, no. 6, pp. 20-29, November/December 2017.



H.Klar and T.G. Noll, „Integrierte Digitale Schaltungen: Vom Transistor zur optimierten Logikschaltung"

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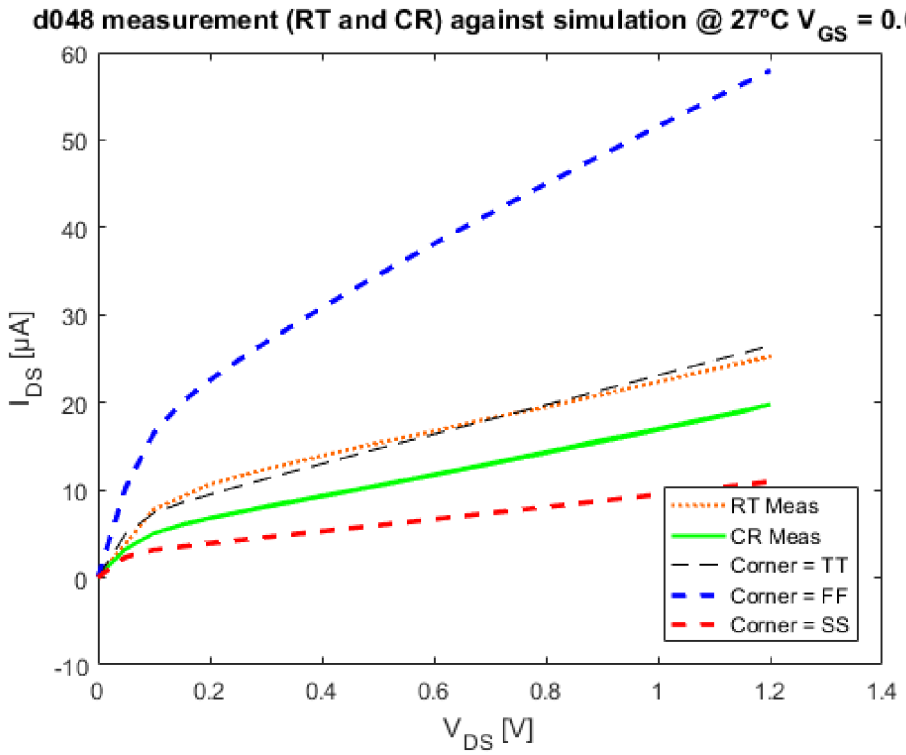
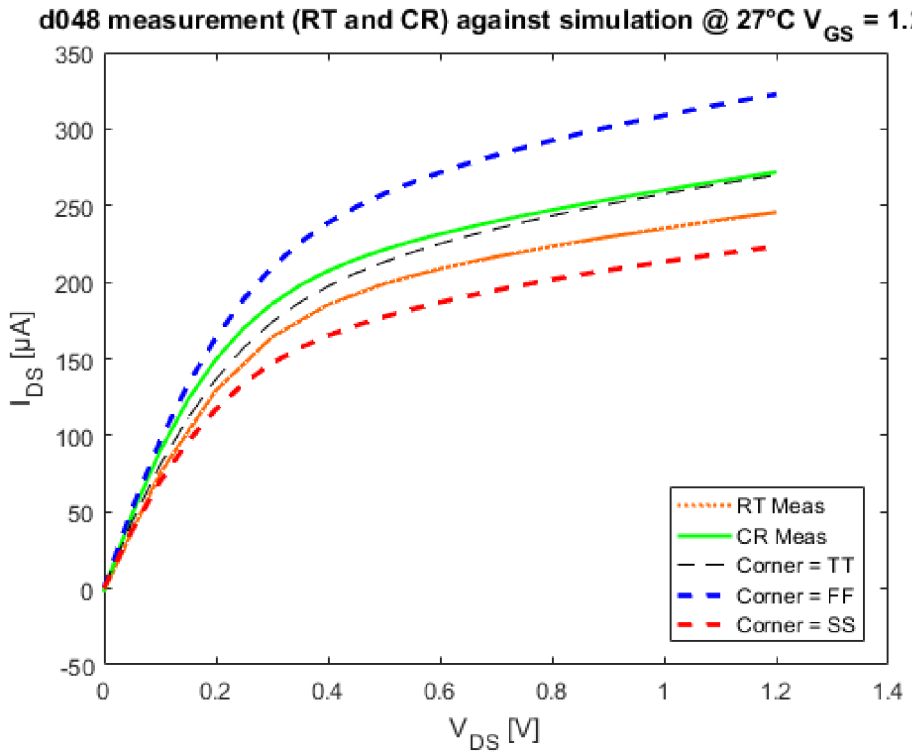
CRYOGENIC CMOS

Measurement Results for Transistors at Cryogenic Temperatures (CR) and Room Temperature (RT)





- Device: NMOS Core Bulk 1.2 V supply 480nm/60nm (V_{BS} = 0V)
- I²C Interface validated for liquid helium temperature

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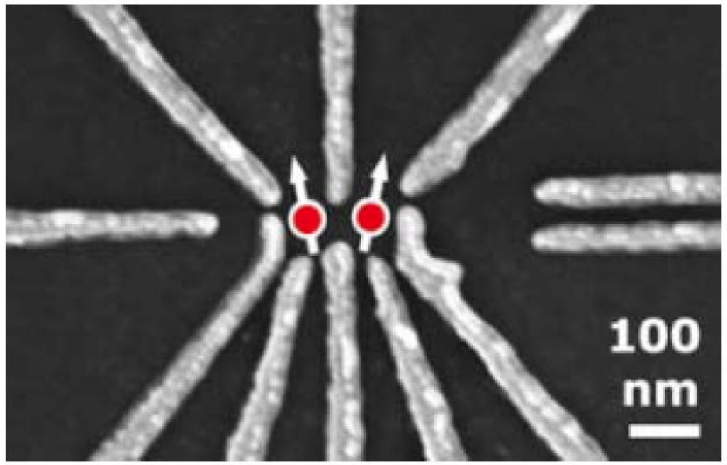
ELECTRICAL CONTROL OF QUBITS

Requirements SiGe Spin Qubits

- Microwave source 20..40 GHz
- IQ modulation, frequency modulation + 500 MHz
- Amplitude on/off, time resolution ~ 1..5 ns (pi pulse in 50 ns)
- Phase: 0 and π (equals x-axis and y-axis rotation on Bloch sphere)

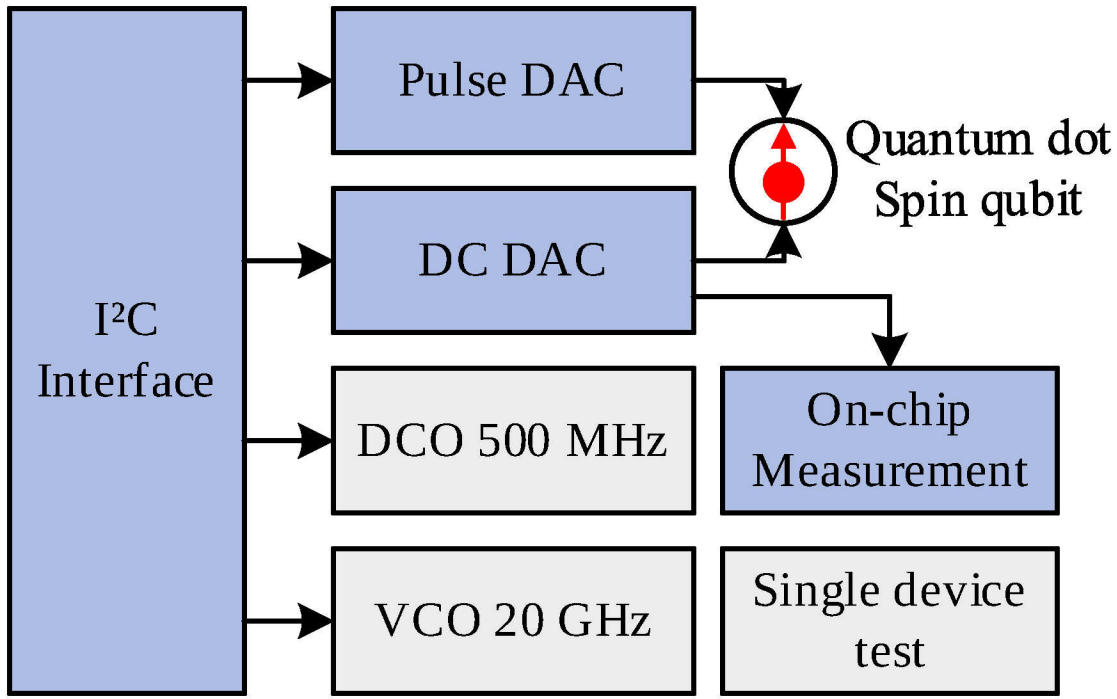


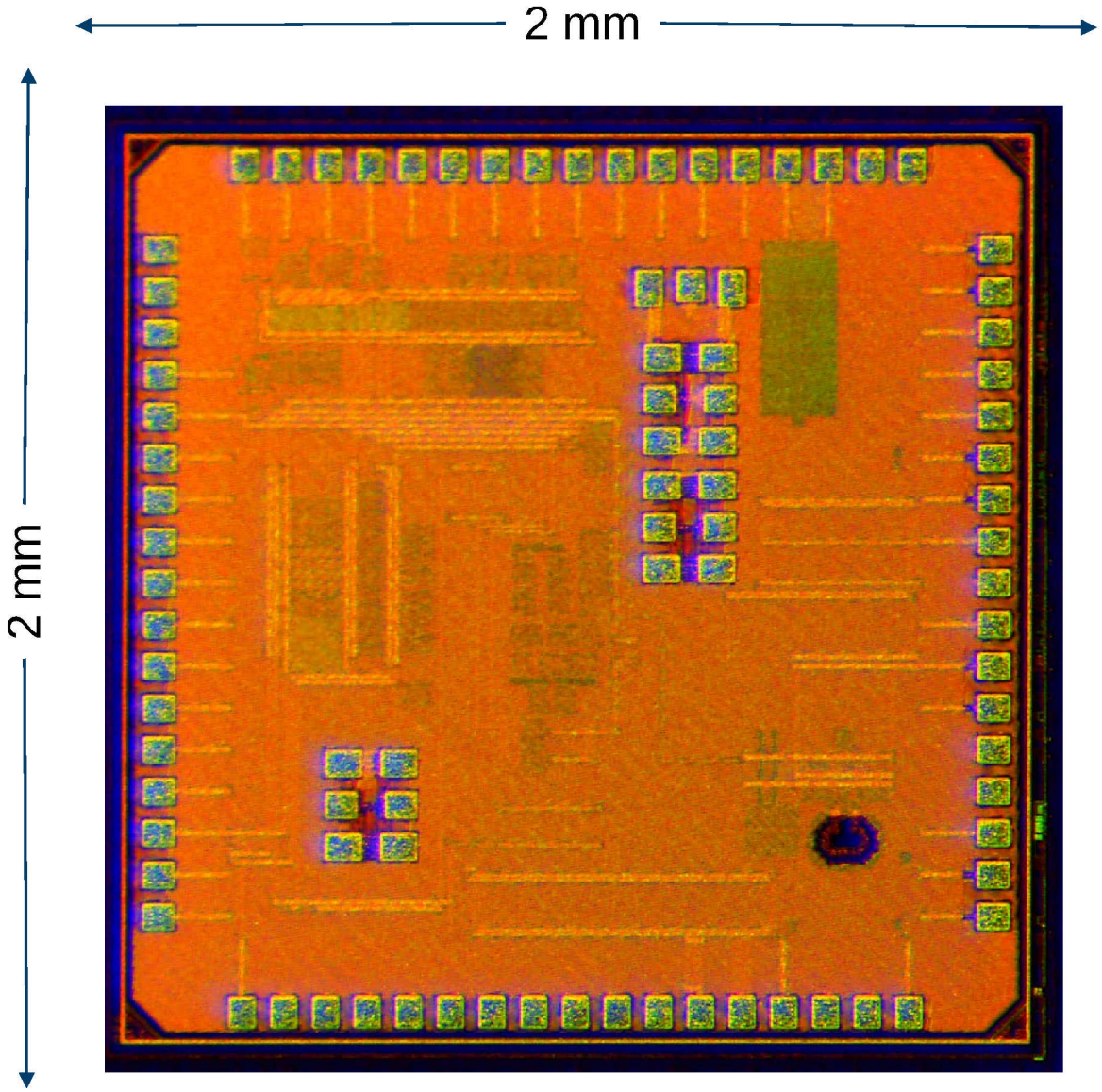
Cryoelectronic for Si qubits
L.Schreiber | IQI, RWTH Aachen University

Characteristic	Specification
DC voltage range	±1 V
RF Frequency	20 GHz
RF Amplitude	~ 3mV
Max output power	-30 dBm
Maximal power dissipation	<<1W

SQUBIC1

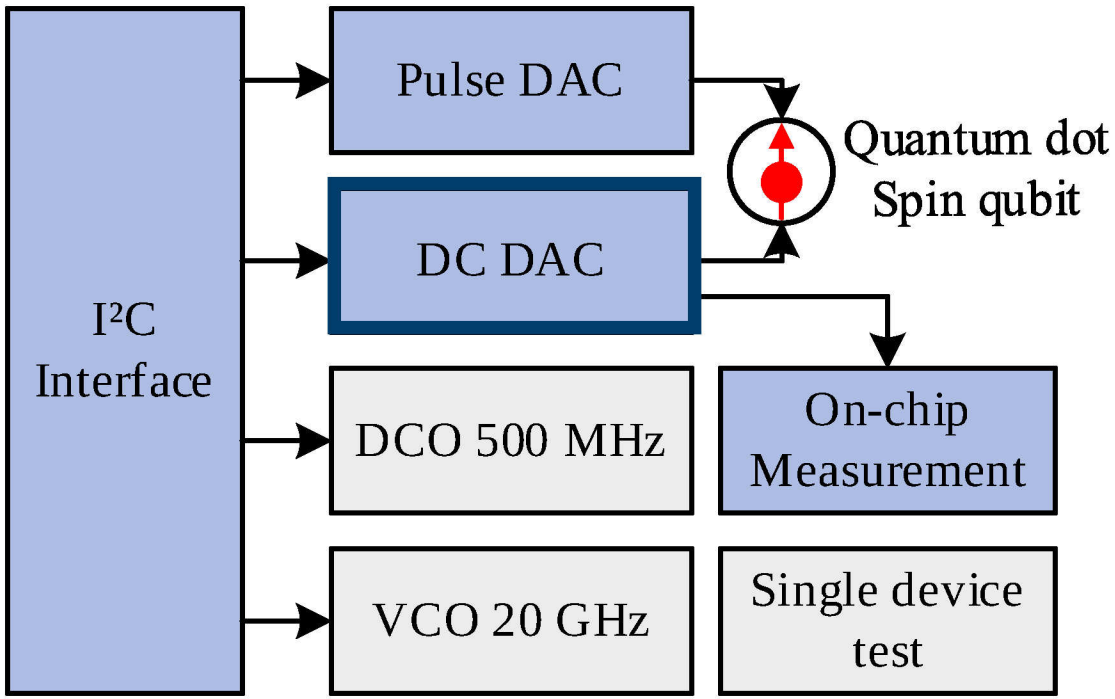
- **S**calable **Qu**antum **Bi**t **C**ontrol

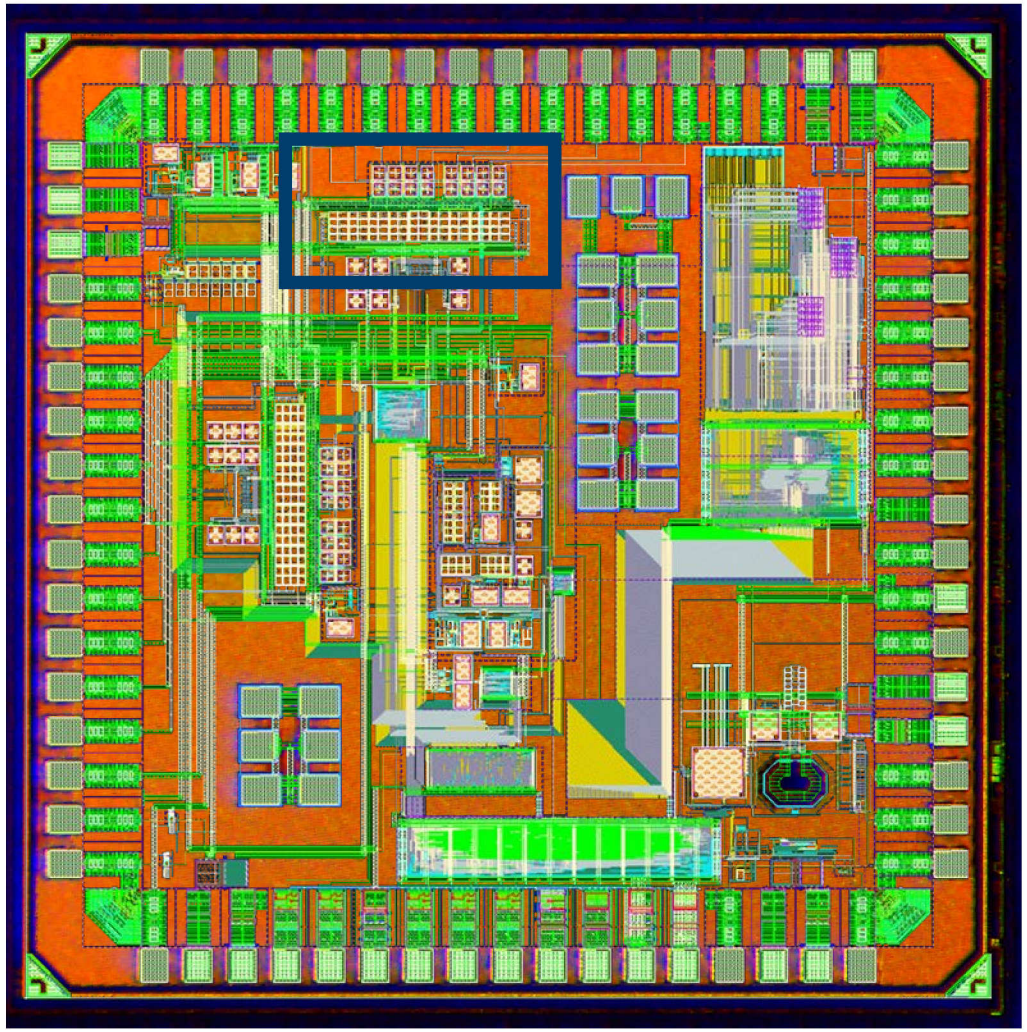




BIAS VOLTAGE DAC

- **S**calable **Qu**antum **Bi**t **C**ontrol
- DC DAC





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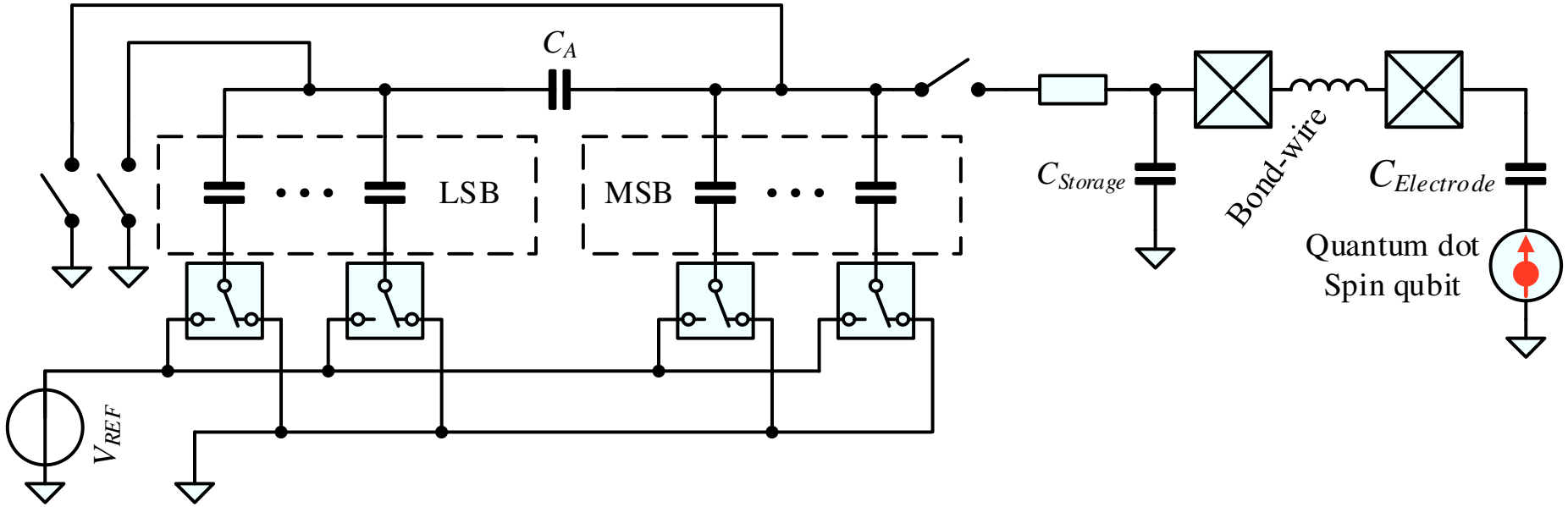
BIAS VOLTAGE DAC

Charge-Redistribution Topology



- No static power dissipation
- Low thermal noise: $\bar{V}_N^2 = \frac{K_B \cdot T}{C}$
- Multiple output channel per DAC
- Iterative charging to compensate voltage drop, no output buffer needed
- Coarse setting reference voltage, reduce power and bits in charge redistribution part

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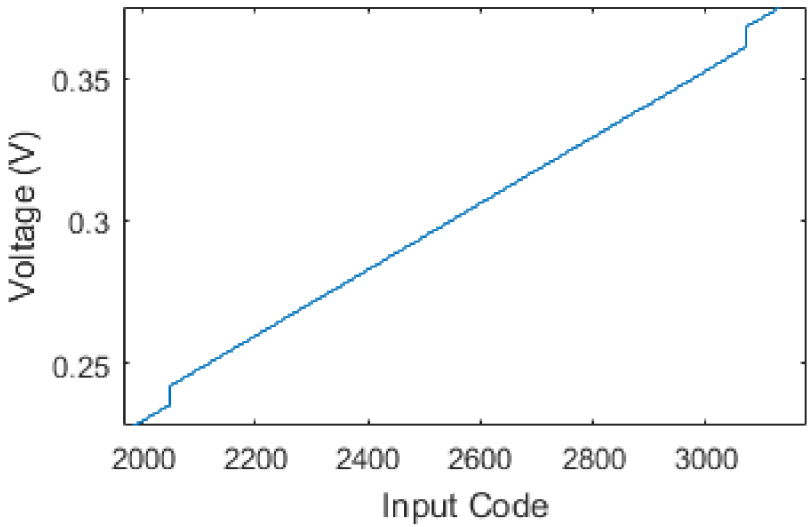
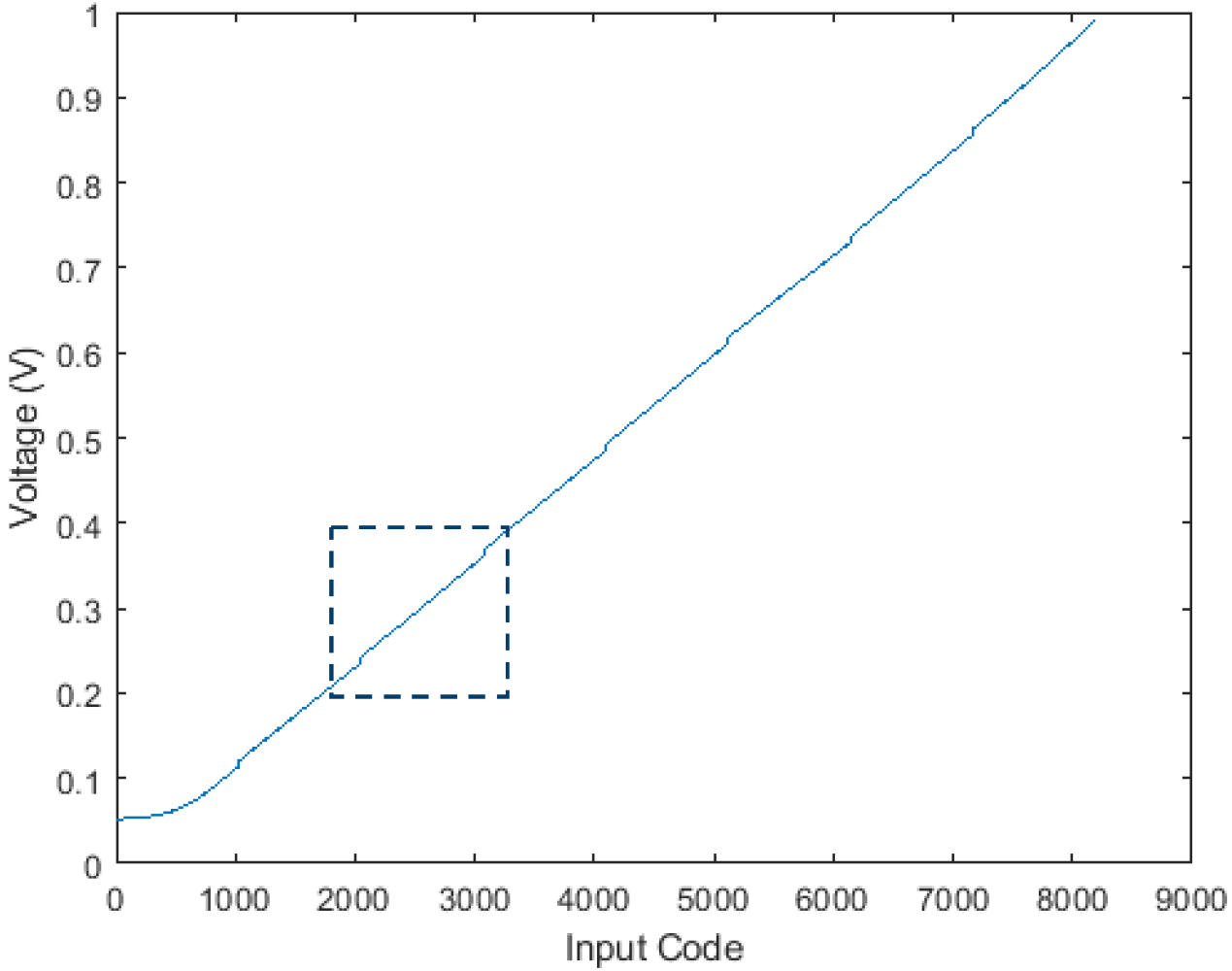
BIAS VOLTAGE DAC

Measurement Result

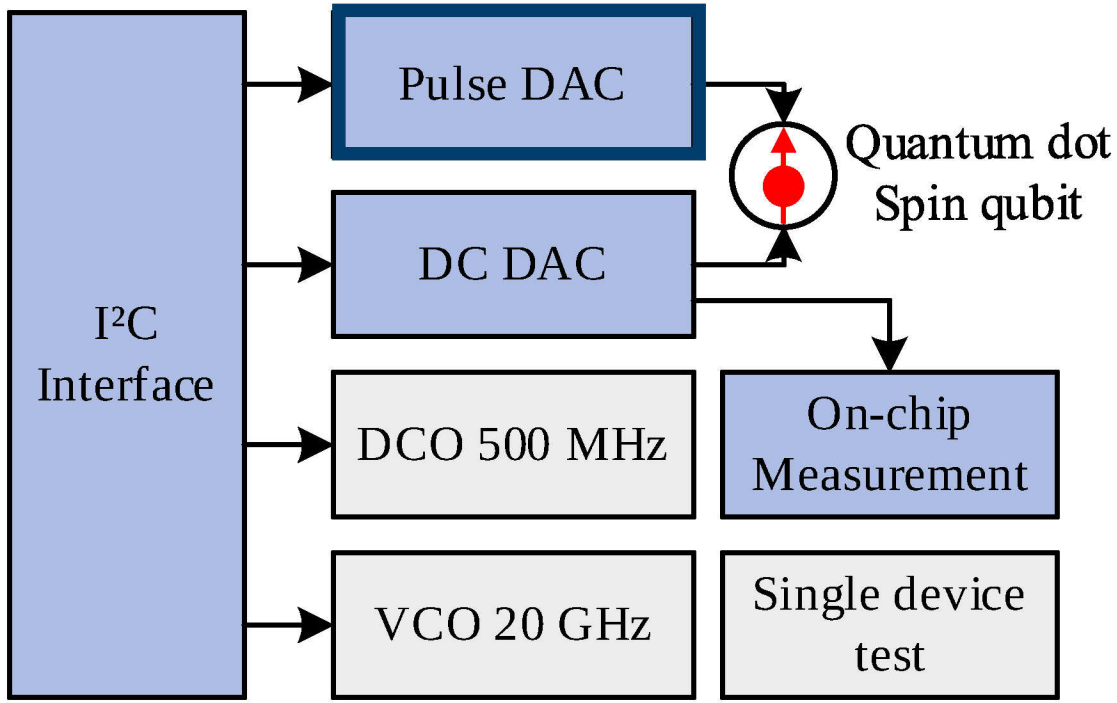
- DC characteristic measured at room temperature
- Region close to 0 limited by output range of the buffer

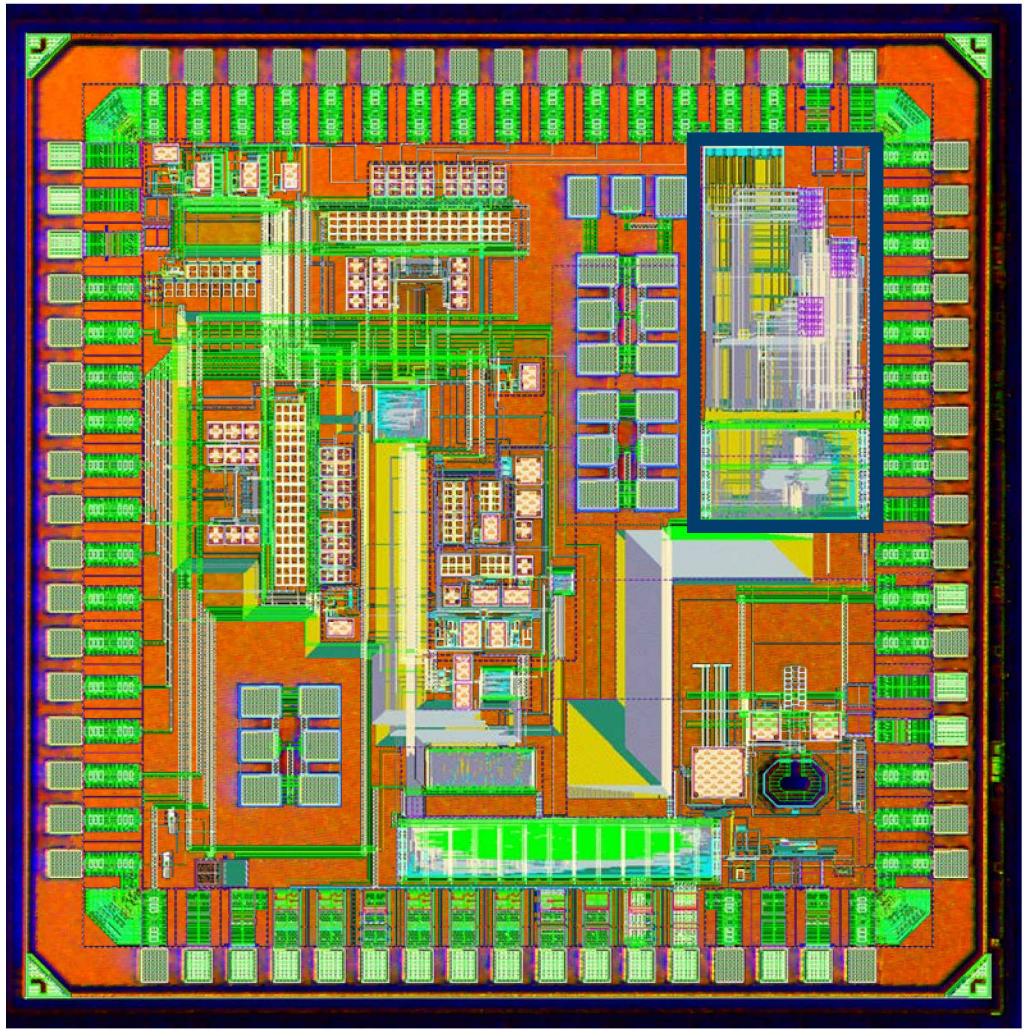




QUBIT DAC

- **S**calable **Qu**antum **Bi**t **C**ontrol
- Pulse DAC





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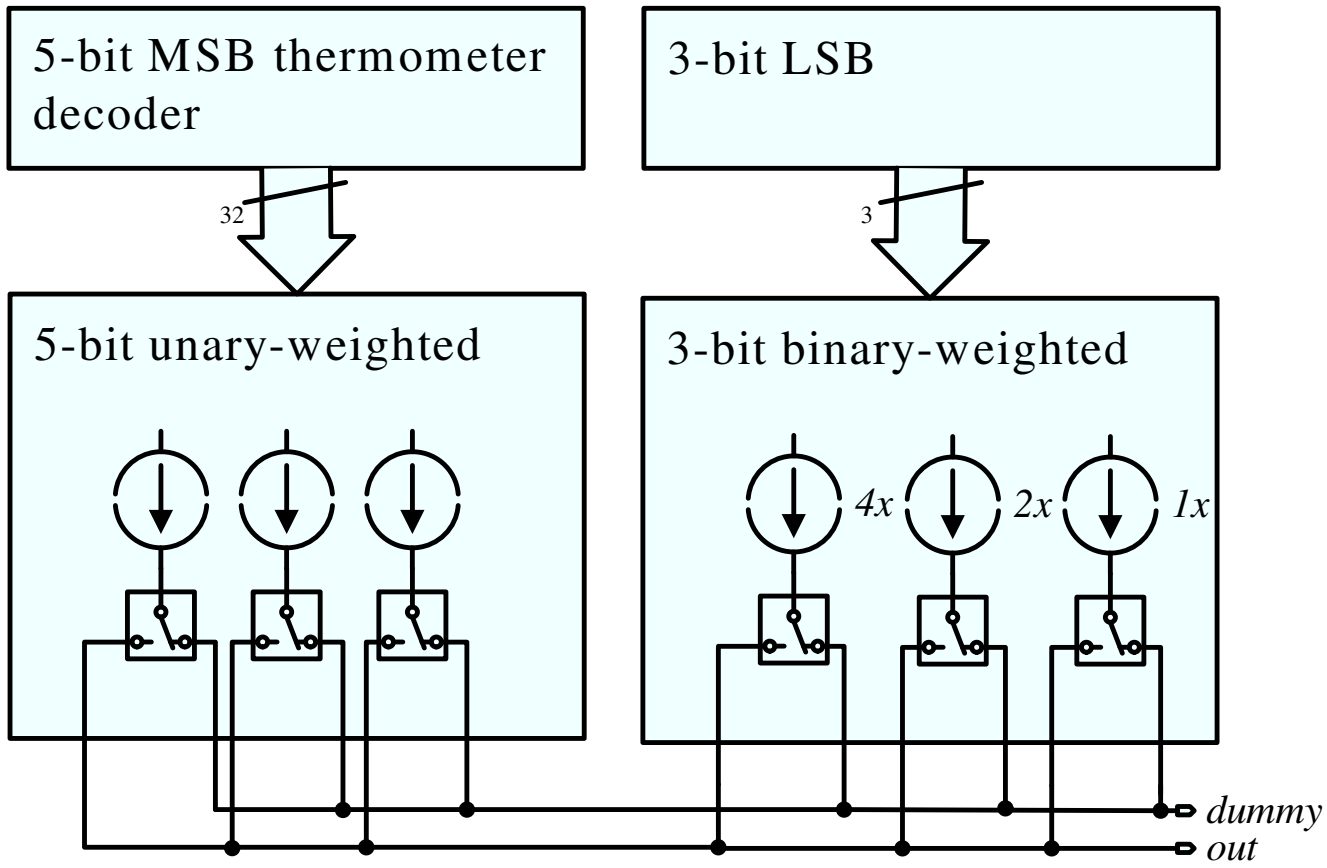
PULSE DAC

Current Steering

- Segmented current steering topology

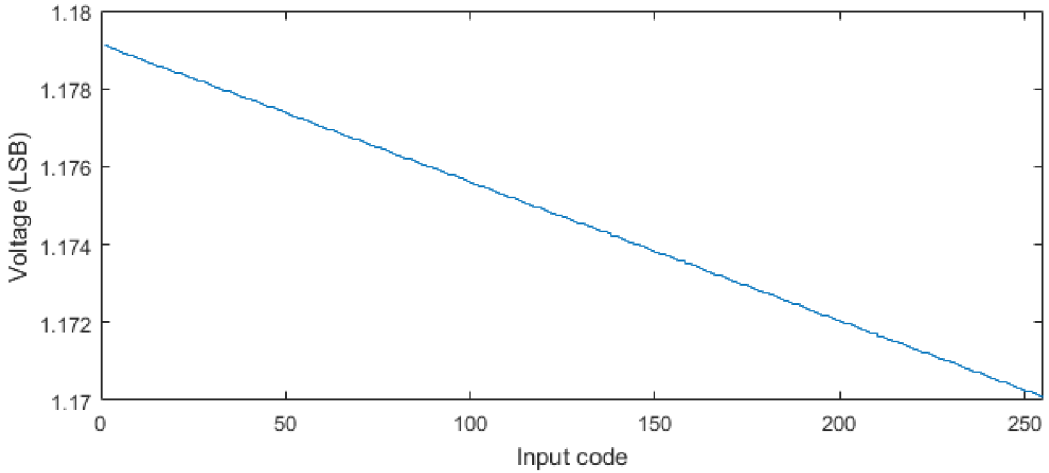
- 5-bit unary weighted
- 3-bit binary weighted

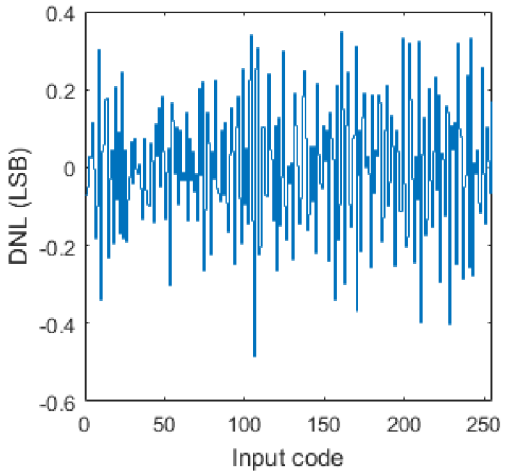


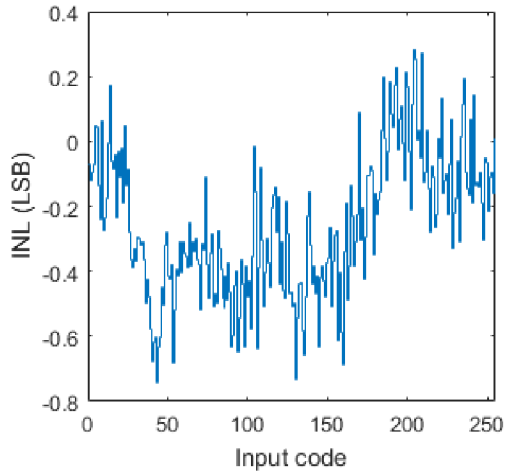
PULSE DAC

Current Steering

- DC characteristic measured at room temperature
- Monotonic
- Improvement possible through calibration

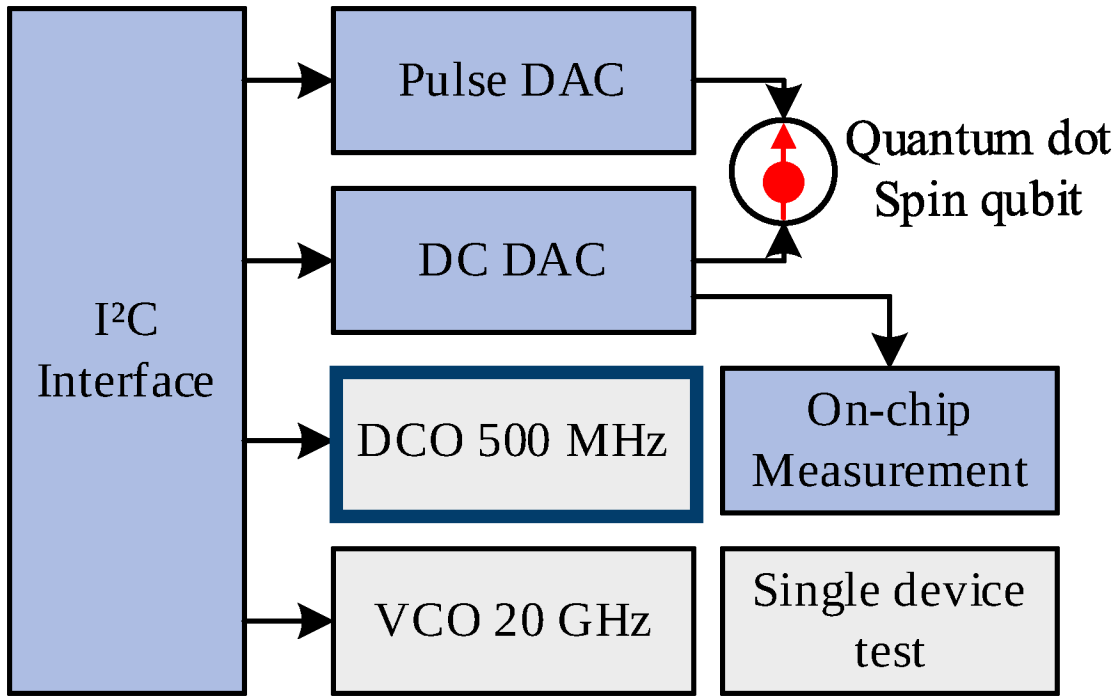


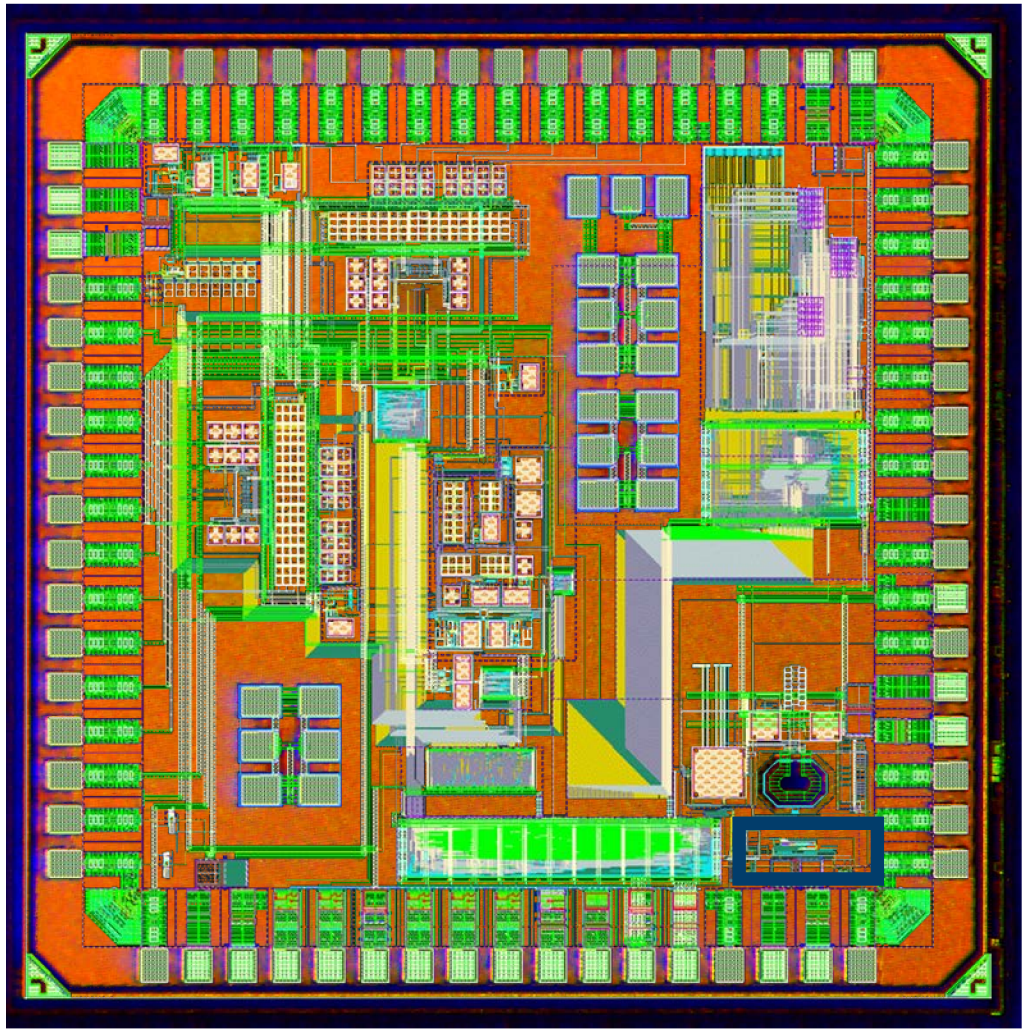




DIGITALLY CONTROLLED OSCILLATOR

- **S**calable **Qu**antum **Bi**t **C**ontrol
- DCO





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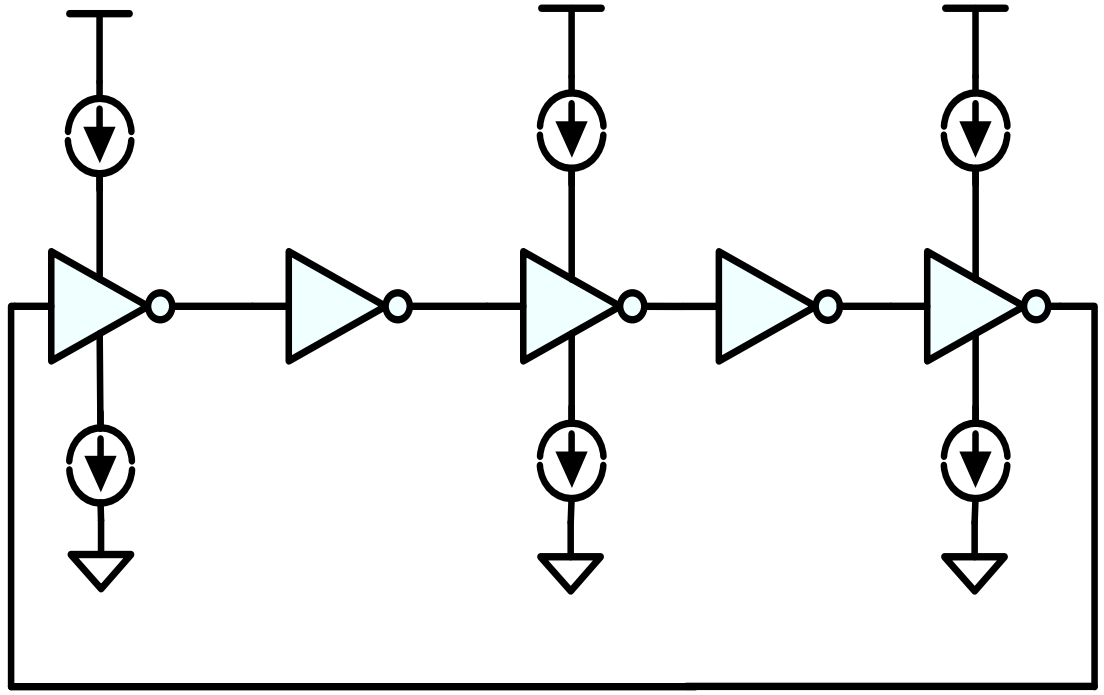
DIGITALLY CONTROLLED OSCILLATOR

Topology

- Current starved ring oscillator topology
- Frequency control by starving inverter current
- Alternating normal and current starved inverters to restore slope steepness



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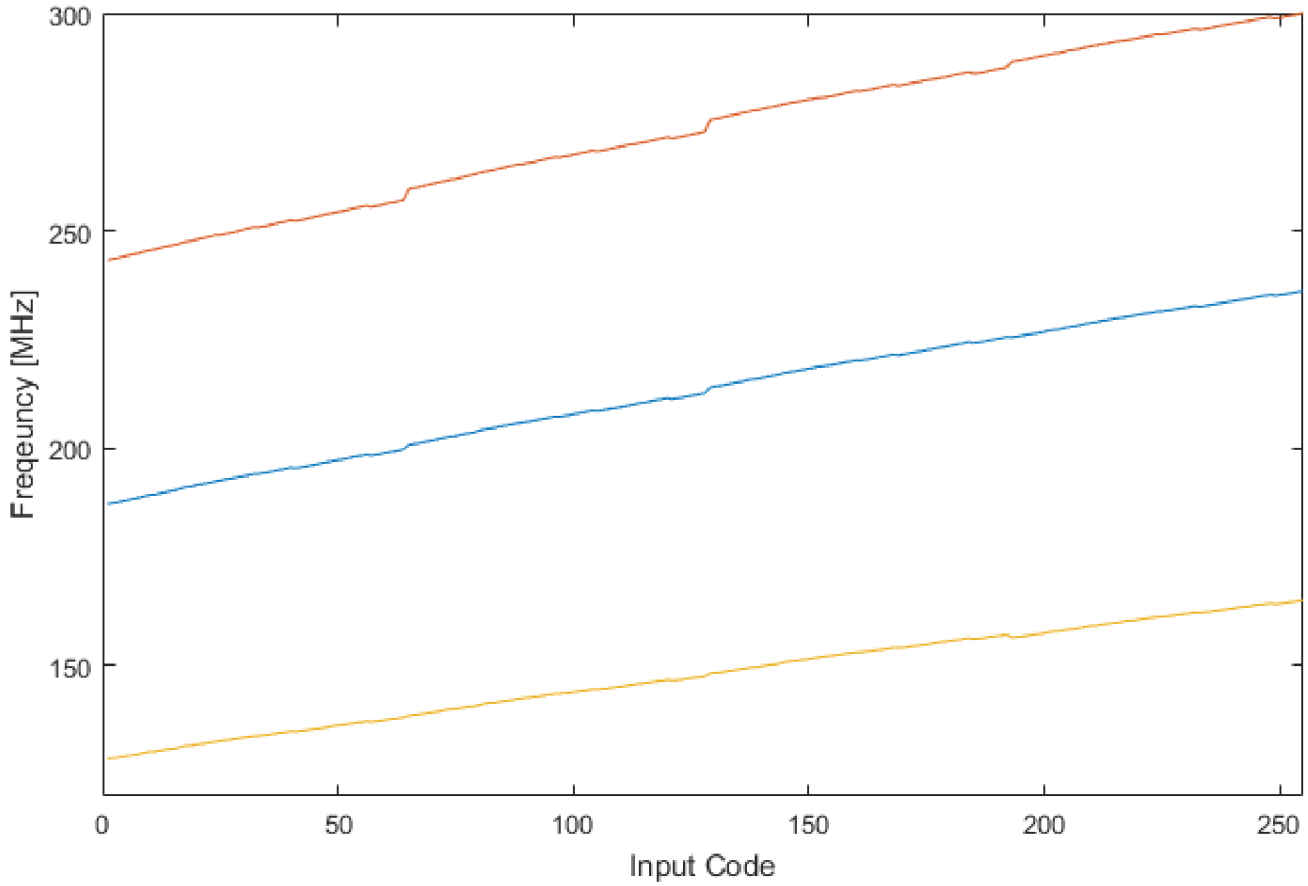
DIGITALLY CONTROLLED OSCILLATOR

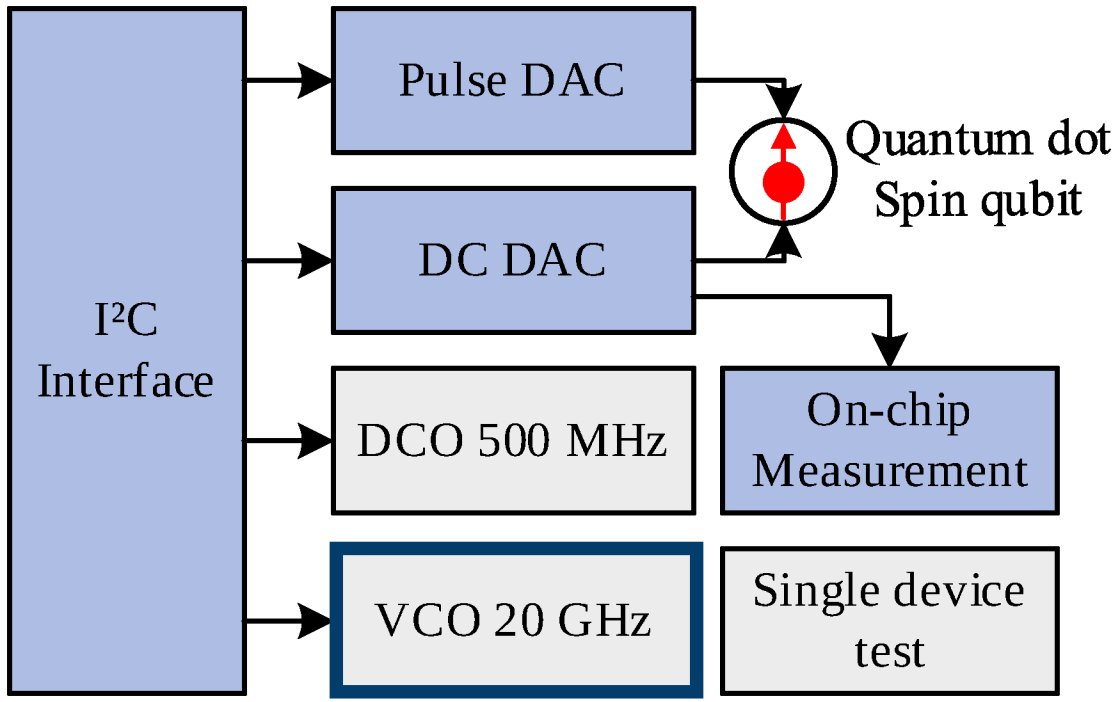
RT Measurement

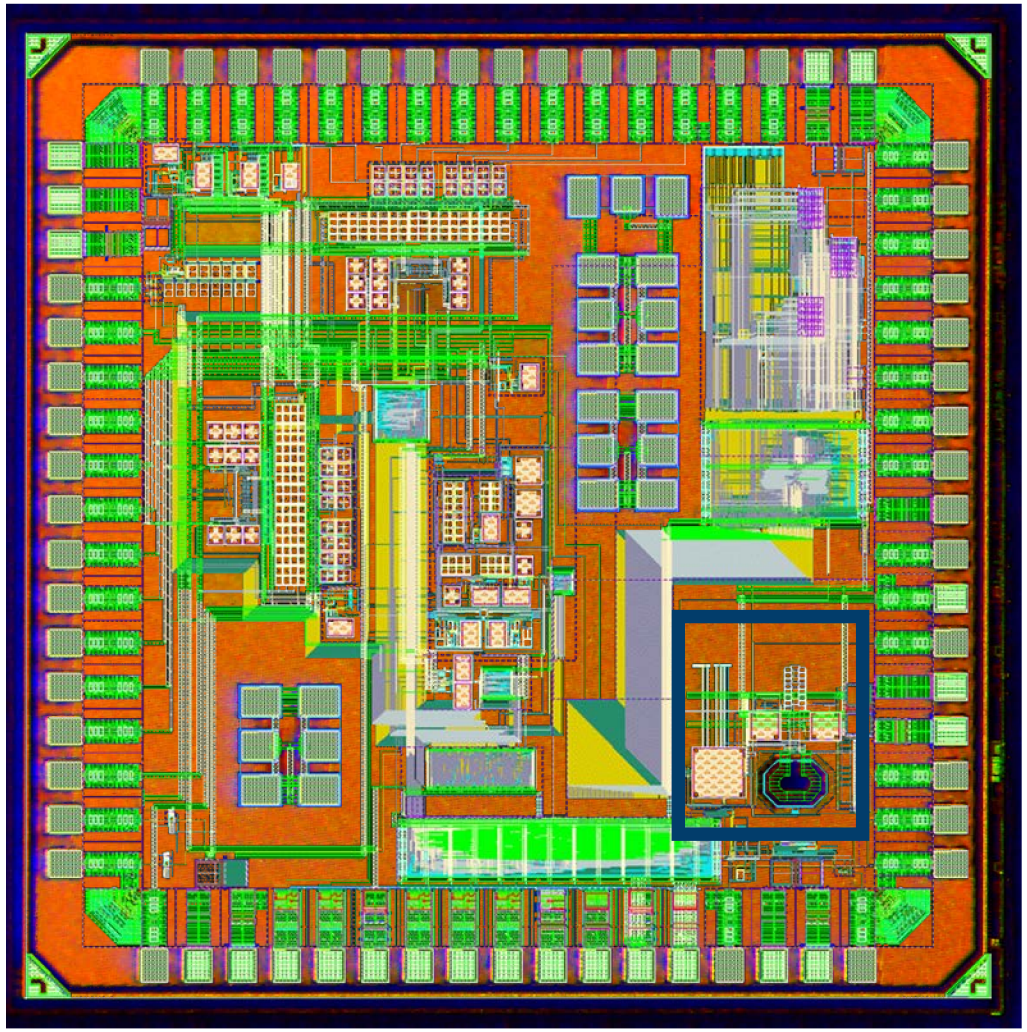
- Frequency over input code for different bias currents
- Frequency increases with decreasing temperature



VOLTAGE CONTROLLED OSCILLATOR

- **S**calable **Qu**antum **Bi**t **C**ontrol
- Measurement only





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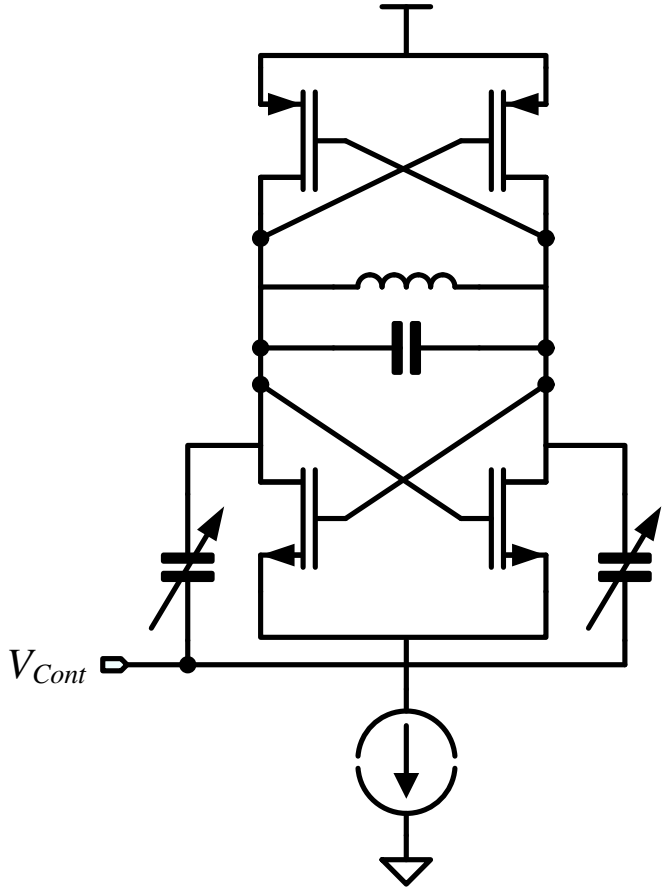
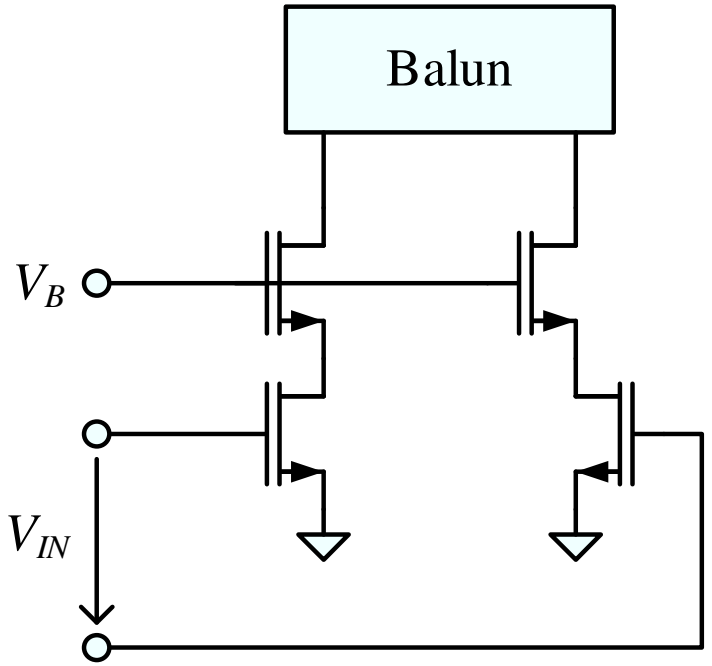
VOLTAGE CONTROLLED OSCILLATOR

Topology

- LC-Oscillator
- Two cross coupled pairs
- Pseudo differential cascode amplifier with off-chip Balun





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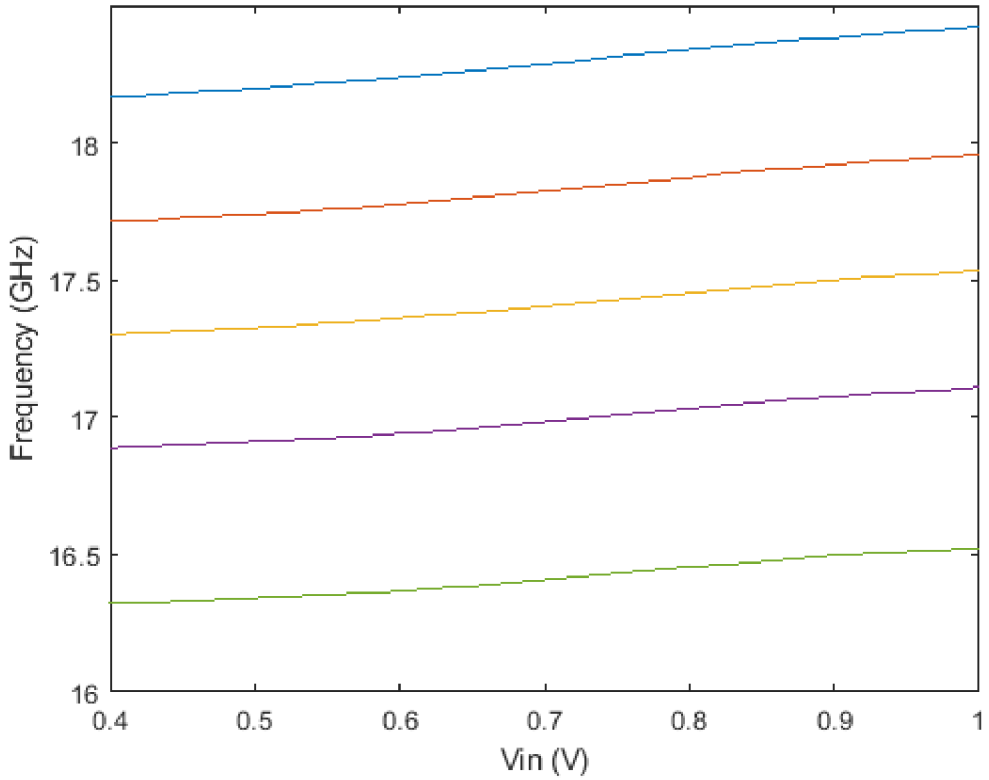
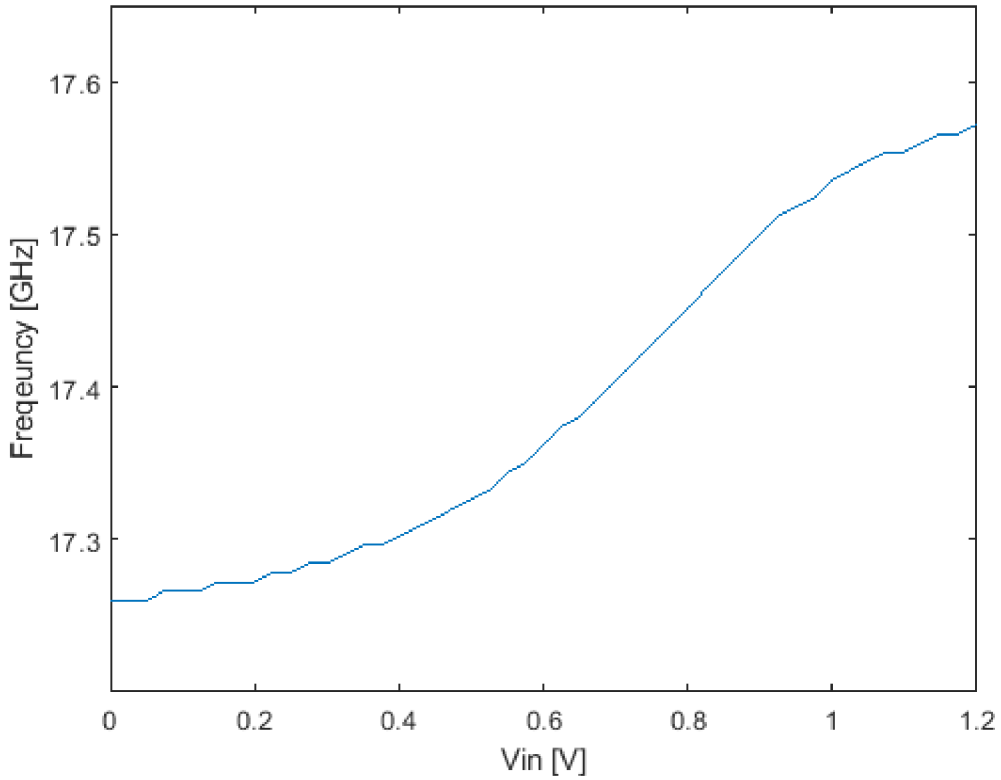
VCO

RT Measurement





NEXT STEPS

- Measure SQUBIC1...

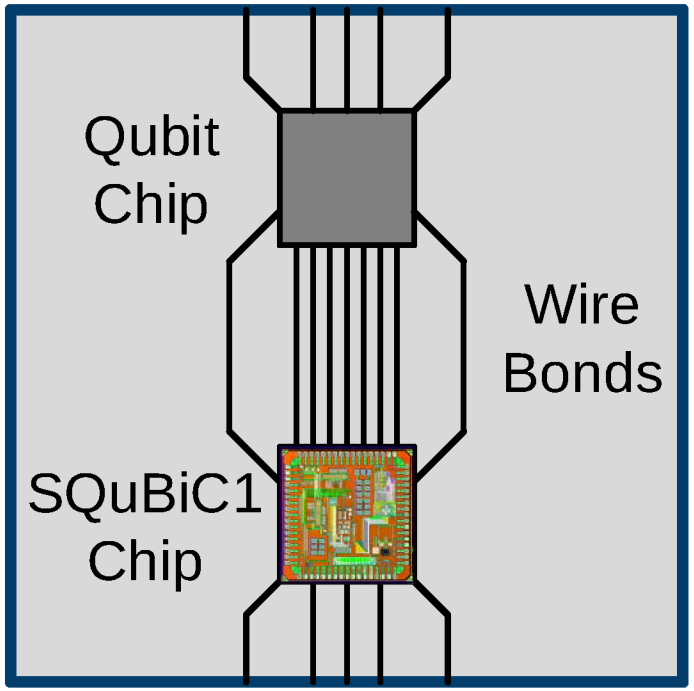
  ...room temp. and cryogenic temp.

- Proof of principle

  ➔ Qubit operation with cryogenic integrated chip

- Outlook:

  ➔ Road to full scalability



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QUESTIONS ?