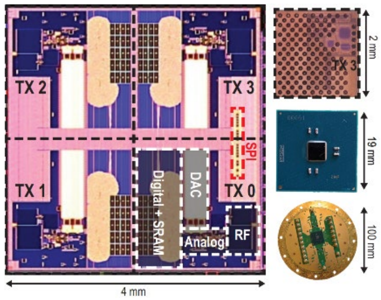
INTEL NEWS FACT SHEET

Intel ‘Horse Ridge’ Addresses Key Barriers to Quantum Scalability

Research Paper at ISSCC 2020 Highlights Features on Quantum Control Chip Designed for Scalability, Flexibility and Fidelity

February 18, 2020 — In collaboration with QuTech, Intel Labs has been advancing research into both the quantum hardware and software ecosystems to make quantum computers a commercial reality in the future. Interconnects and control electronics represent a major bottleneck in commercial-scale quantum computing facing the industry as a whole.

Building fault-tolerant, commercial-scale quantum computers requires a scalable architecture for both qubits and control electronics. Horse Ridge is a highly integrated system-on-chip (SoC) that provides an elegant solution to enable control of multiple qubits with high fidelity — a major milestone on the path to quantum practicality.

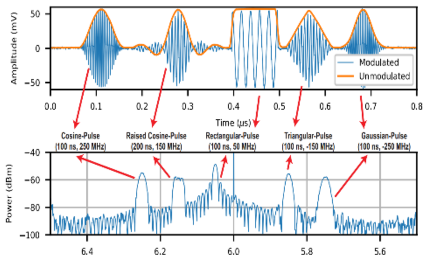


Horse Ridge Features

- Horse Ridge is a highly integrated, mixed-signal, cryogenic SoC on a 4-by-4 mm^2 silicon, implemented on Intel 22nm FFL (FinFET Low Power) CMOS technology. It integrates SRAM, digital core and analog/RF circuity into a single package to manipulate the state of the qubits in a quantum system with microwave pulses.

- Integrated, high-speed digital-to-analog converters and wideband up-converter ranging from 2 to 20 GHz.

- The amplitude and phase modulation information for pulse shaping (18Gb/s) is stored in on-chip SRAM, allowing envelopes up to 41µs, which are referenced by a look-up table (LUT) that can define 8 instructions per qubit.
  - Leveraging the LUT reduces the required data rate to the controller, which is further reduced to ~1Kb/s by the integrated programmable instruction set executed on external trigger with minimal delay between instructions.



Measured output signal for arbitrary pulses

- Horse Ridge features four radio frequency (RF) channels in a single device and leverages frequency multiplexing to control up to 128 qubits. Each RF channel uses direct digital synthesis with 32 numerically controlled oscillators to generate each of the 32 multiplexed qubit frequencies with high precision of 200 Hz.

Key Benefits

- Reduced form factor (chip and PCB size) and power required to operate quantum systems.
- Ability to scale to and control a larger number of qubits (up to 128 qubits).
- High flexibility in control pulses that can be generated with Horse Ridge reduces crosstalk among qubits with improved overall gate fidelity.
- The device can automatically correct phase shift, which occurs when controlling multiple qubits at different frequencies with the same RF line, with a digital codeword update after each pulse of the control electronics.

	ISSCC '20	**ISSCC '19**	**RSI '17**	**Spin qubit setup**
Operating Temperature	3K	3K	300 K	300 K
Qubit platform	Spin qubits + transmons	Transmons	Transmons	Spin qubits
Qubit frequency	2-20 gHz	4-8 gHz		< 20 gHz
Channels	128 (32 per TX)	1	4	1
FDMA	Yes, SSB	No	Yes, SSB	No
Data Bandwidth	1 gHz	400 gHz	960 MHz	520 MHz
Image & LO leakage calibration	On chip	Off Chip	Yes	
Phase correction	Yes	No	No	No
Fidelity	99.99%	-	-	-
Waveform / Instructions	Up to 40960 pts AWG	Fixed 22 pts symmetric		16M pts AWG
Instruction Set	Yes	No	Yes	Yes
Power / TX	Analog: 1.7 mW/qubit* Digital: 330 mW‡	Analog: <2 mW/qubit# Digital: N/A		850W
Chip area TX	4 mm^2	1.6 mm^2	Discrete	Rack mount
Technology	Intel 22nm FFL CMOS	28 nm bulk CMOS	Discrete components	Rack mount

Comparison Table

* including LO/Clock driver; only RF-Low active
# does not mention circuits included
‡ can be reduced with clock gating

[ISSCC'19] J. C. Bardin et al., "A 28nm Bulk-CMOS 4-to-8GHz <2mW Cryogenic Pulse Modulator for Scalable Quantum Computing," ISSCC Dig. Tech. Papers, pp. 456-458, 2019.
[RSI'17] C. A. Ryan, B. R. Johnson, D. Ristè, B. Donovan and T. A. Ohki, "Hardware for dynamic quantum computing," Rev. Sci. Instrum., 2017

About Intel

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