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Commercial Quantum Computing Made Possible

By R. Colin Johnson

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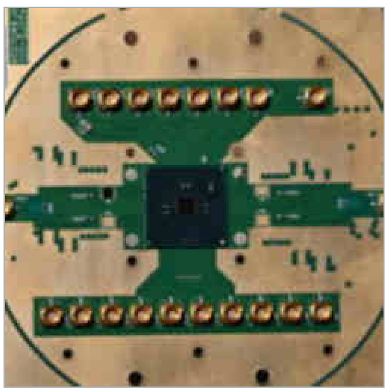

Intels Horse Ridge chip (here on a printed circuit board) reduces the size of quantum computers from that of an oil drum to a rack-mountable size by integrating the bulky copper tubing down to a single CMOS chip that can be situated within the supercooled refrigerator alongside the qubits.

Credit: Intel

Quantum computers are no longer just a dream. D-Wave has been selling special-purpose adiabatic quantum computers specializing in optimization for a decade. Likewise, Switzerland's ID Quantique has successfully specialized in quantum computing cryptography, U.K. cybersecurity firm Post-Quantum and Australian cybersecurity firm Quintessence Labsin quantum cybersecurity, and Japan's Quantum Biosystems in quantum-based DNA sequencers.

The ultimate goal remains a general-purpose quantum computer, as is being pursued by Alibaba, Cambridge Quantum Computing, Google, Hewlett Packard, Honeywell, IBM, IonQ, Regetti, and Toshiba.

Last year, Google announced it had attained quantum supremacy using a programmable superconducting processor, by using its general-purpose quantum computer prototype to solve a problem that it claimed would take conventional supercomputers 10,000 years to solve. IBM, which already has a commercial quantum computer, promptly accused Google of exaggerating its quantum supremacy claim by demonstrating how IBM's more-advanced implementation of the algorithm on a classical system could solve Google's benchmark in 2.5 days, rather than 10,000 years.

The benchmark bickering between giant conglomerates is irrelevant, however, according to the semiconductor makers of the world, which claim that supremacy is best achieved by reducing the complexity of quantum computing devices to make them more affordable than today's computers, as illustrated recently by Intel's Horse Ridge chip (a single chip cast in its 22-nanometer complementary metal oxide semiconductor (CMOS).

"Horse Ridge takes us a step closer to moving the control electronics inside the supercooled chamber that houses today's quantum qubits," according to Martin Reynolds, vice president of research company Gartner. "Today the control wiring that comes out of the refrigerator to control the qubits is the primary barrier to scalability. That's why Google's latest QC (quantum chip) looks so much bigger than its earlier systems—look at Google's photos and you can see its last-generation QC was gallon-paint-can-sized, but when scaled up to 53 qubits has grown to oil-drum size, because of all the wiring coming out of the refrigerator to connect to room-temperature control electronics."

Reynolds believes that to make quantum computers as affordable as today's classical computers, they must be integrated onto chips so more qubits will fit into smaller spaces. "Horse Ridge is the first step in the direction of integrated control logic inside the refrigerator, letting us get away from all those bulky copper tubes that define the large size of a quantum computer today."

To create general-purpose quantum computers with built-in error correction, according to Reynolds, the industry needs to scale up to hundreds of thousands of qubits. That will allow the error correction that is needed to make them a commercial success. Today, error correction is not economical because of the QC's giant size. But with hundreds of thousands of qubits in a compact supercooled enclosure with integrated control circuitry, QCs will "begin to start solving some heavy-duty problems," said Reynolds. "Horse Ridge is how we will get to the necessary number of qubits; it is on the path to one of the 10X jumps we need to get to general-purpose use of quantum computers in the 2030s."

Reynolds predicts Horse Ridge and copycats from other semiconductor makers will roughly double the number of qubits QCs contain every year, with multiple 10X advances needed to reach unquestioned quantum supremacy. Once the boost to error correction is here, then "the doubling of qubits every year will be able to get us to our commercial quantum computer goal somewhere in the 2030s."

This decade-long development process is typical of radically new technologies. D-Wave, for instance, started building its adiabatic QC in 1999, but could not commercialize it until 2011, due to the same need for supercooled electronics integration. That is one reason to anticipate a similar timeline—the 2030s—for the widespread commercialization of general-purpose QCs. D-Wave's adiabatic approach does not require error-correction, but does require similar control logic to harness the qubits into a configuration capable of solving optimization problems. As a result, D-Wave realized early on that its control circuits and other logic, most of which is on the same chip as its qubits, would need to operate inside the supercooled refrigerator.

Said D-Wave vice president of engineering Dave Pires, his company "understood from the beginning that control circuitry was needed at the processor to enable the rapid scaling we achieved with successive generations of D-Wave systems. Thus, all of D-Wave's systems since the original D-Wave One have incorporated cold electronics."

According to Bob Sorensen, Senior Analyst at Hyperion Research, Intel is the first semiconductor manufacture to realize this, and Horse Ridge could become the cornerstone that persuades other QC makers to forgo building their own cold-operating application specific integrated circuits (ASICs)—as D-Wave did—and to instead buy Intel's Horse Ridge and its successor QC chips.

"Intel, as a technological and market leader in the semiconductor space, is a natural to position itself in this critical part of the overall QC hardware stack by consolidating an assembly of otherwise complex electronics into a single SoC [system on chip] that can sit alongside other cryogenic QC components," said Sorensen. "Currently, emphasis in the QC development community centers on the advance of better performing–and more numerous–qubits. With Horse Ridge, however, Intel has taken a major step in addressing one of the many other key QC hardware essentials needed to assemble a fully functional QC system, that of essential qubit control capability and QC processor communication with the world outside the refrigerator."

So far, Intel is only sharing the Horse Ridge (HR) chip with its closest partners, such as Netherlands-based QuTech, the company Intel consulted with to define the HR architecture. Yet as a chip provider, rather than a system builder like Google and IBM, Intel plans to offer a line of QC support chips, according to Jim Clarke, Intel Labs Director of Quantum Hardware.

"QC vendors are going to have to start making commitments to one of the major hardware and software paradigms. It is still early in the development of the sector for any single choice to be irreversible, but that day may be coming sooner than many think," said Sorensen.

According to Intel, Horse Ridge is just the first glimpse of its future QC chip line, aimed at supporting the hundreds of thousands of qubits necessary to achieve commercial QCs with foolproof error-correction.

"The goal of our research collaboration with QuTech is to speed the development of commercial-scale quantum systems, so we are certainly sharing insights from early tests with our Horse Ridge chip," said Clarke. "Horse Ridge controls basic qubit operations to manipulate the state of the operational qubits and, ultimately, produce the quantum readout. Designed to act as a radio frequency [RF] processor, Horse Ridge is programmed with instructions that it translates into electromagnetic microwave pulses to manipulate the state of multiple qubits."

This is significant, because today every qubit is individually controlled through hundreds of connective wires inside tubes running into and out of the cryogenic refrigerators where the real quantum computing occurs. Today's brute-force approach will not scale to the thousands of qubits needed to affect real change, according to Clarke. With Horse Ridge, researchers can reduce the complexity of quantum control from hundreds of cables to a single unified package operating within the quantum refrigerator. This eliminates interconnect and control electronics bottlenecks, according to Clarke, enabling Intel to control multiple qubits and allow for future scaling of larger and more complex quantum systems.

"Currently, Horse Ridge operates within the quantum refrigerator as close to the qubits themselves as possible. As research progresses with spin qubits in silicon—a technology that closely resembles a single electron transistor which Intel has spent decades advancing—Intel aims to explore the potential to raise the operating temperature of these quantum units," said Clarke. "This research, discussed internally as 'hot qubits,' is exploring the possibility for silicon spin qubits to operate at less-cold temperatures. This advancement would pave the path for Intel to leverage its expertise in advanced packaging and interconnect technologies to create a solution with qubits and controls in one streamlined package."

R. Colin Johnson *is a Kyoto Prize Fellow who has worked as a technology journalist for two decades.*

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