An Advanced 16-Qubit (up to 32-Qubit) Control and Measurement System for Superconducting Quantum Computing

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Using classical computers, scientists and engineers write programs to solve difficult problems and run complicated simulations. As the performance gains for a single processor become more difficult to achieve and problems become more complex, supercomputers are introduced to attack problems using massive arrays of parallel processors. Although quite powerful, supercomputers rely on algorithms that divide tasks into parallel sets of subtasks while still providing any required interdependent data between the subtasks. While classical computers are excellent at many problems, they are not efficient at certain types of problems including large prime factorization, molecular modeling, and optimization analyses. Enter quantum computing.

The field of quantum computing was initiated in the 1980s and became practical after 2006 due to faster classical processors and more capable field programmable gate arrays (FPGAs). Like classical computers, quantum computers use bits (in this case quantum bits, or qubits) to carry information. The single classical bit may be a '1' or '0', whereas a quantum bit takes advantage of the quantum mechanical phenomenon known as superposition to represent BOTH '1' and '0' simultaneously. In contrast to a classical 64-bit register which stores 1 value at a time, the 64-qubit register can represent all 2^{64} values simultaneously using the quantum superposition effect at the atomic level. To encode the interdependencies of the problem to be solved by a quantum computer, another important quantum mechanical phenomenon called entanglement is employed. When entangled, the qubits are no longer independent, their interactions and behaviors instead become linked. With superposition and entanglement, a set of linked qubits evolve according to quantum mechanical principles inside the quantum processor in accordance with the predefined algorithm and the given input state.

A simplified semiconductor quantum computing physical layer is illustrated in Figure 1. The high-speed D/A generates the microwave signal to initiate the initial state of the qubits. The qubits evolve to all possible results states, all presented at the same time inside the processor. At the instant of qubit measurement, all possible states collapse into a single result to be read out from the processor using high-speed A/Ds. Repetitive cycles of "initiate and measure" yield the most probable answers to the encoded problem.

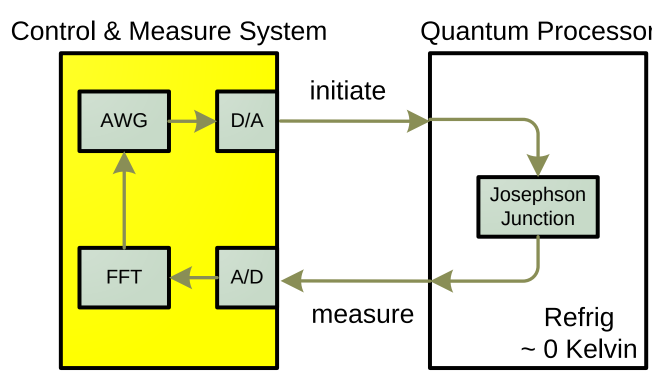

Figure 1. Simplified semiconducting quantum processor physical layer

Innovative Integration has been a leading supplier in the real-time embedded system market for more than 30 years, and is proud to be the control and measurement system provider to many key players in the quantum computing field. In Figure 2, a single VPX system hosts four X6-1000M modules and supports up to 4-qubit operations synchronously. Qubit entanglement is supported with dedicated, low-latency Digital IOs.

Figure 2. Single VPX system supports up to 4-qubit operations

Figure 3 illustrates how X6-1000M modules are configured to provide two qubits entanglement and read-back. Innovative Integration's VPX-based system integrates readily with external microwave sources, mixers, filters, and attenuators to provide a flexible and robust Quantum Qubit Controller and Read Out system.

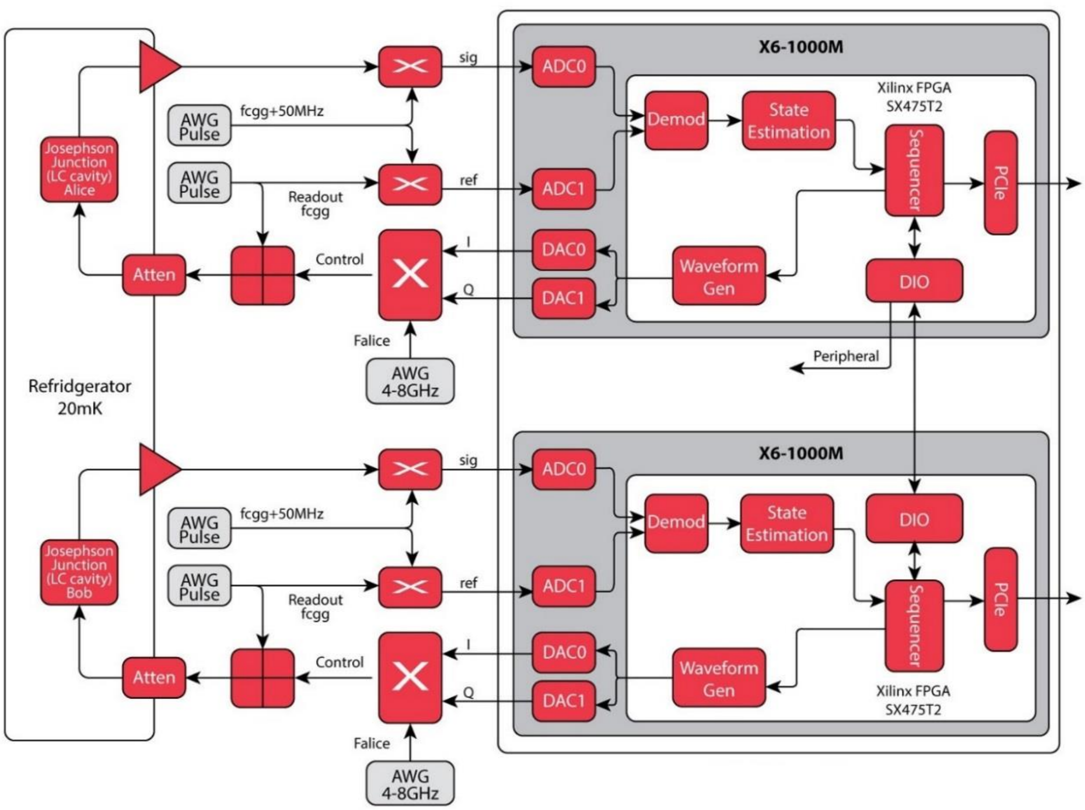

Figure 3. Two entangled qubits using two X6-1000M modules

As shown in Figure 4, using high-speed, low-latency X6-1000M modules inside a compact VPX PC, a synchronous system to control and measure up to 32 entangled qubits is readily configured. With state-of-the-art FPGA technology, quantum computing engineers perform FFTs and generate waveforms to create synchronous qubits within 250ns. A low-latency system is valuable for performing as many operations as possible before quantum decoherence occurs.

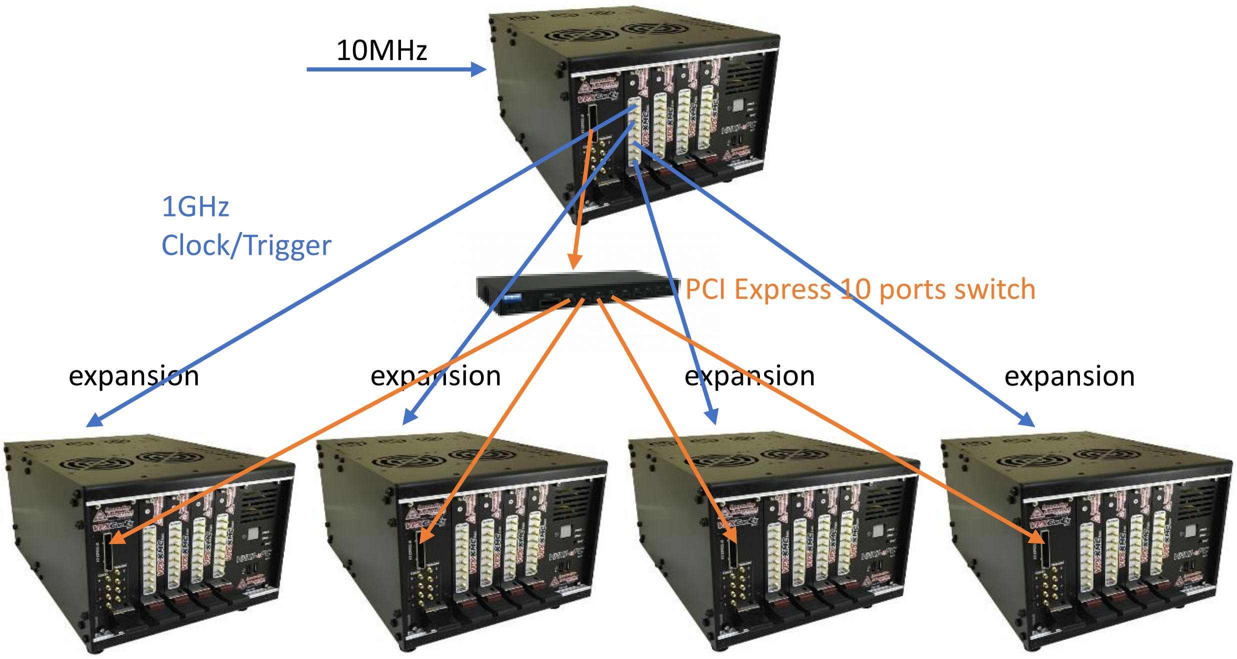

Figure 4. Scalable master-slave system hosts 16 of X6-1000M modules for 16 qubits

Key Features:

- 16-qubit compact VPX control and measure system; potentially up to 32-qubit
- Synchronous, high-speed, low-latency 32x 1GHz, 16-bit D/As; and 32x 1GHz, 12-bit A/Ds
- Low-latency crossbar switch for qubit synchronization; 4 digital IOs per qubit
- Built-in precise digital sequencer for peripheral devices control
- One Xilinx FPGA per qubit for real-time DSP/FFT/state estimation
- Graphical FPGA firmware devkit using Matlab/Simulink and Xilinx System Generator
- Does NOT include external microwave sources, mixers, filters, attenuators, refrigerator

Innovative Integration is dedicated to supporting the challenge of building practical quantum computers. We look forward to continuing to partner with the quantum computing community as the requirements for successful quantum computing continue to evolve and become better defined.