Scalable Self-Adaptive Synchronous Triggering System in Superconducting Quantum Computing

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Abstract—Superconducting quantum computing (SQC) can solve some specific problems which are deeply believed to be intractable for classical computers. Synchronizing trigger is essential for SQC where the control and measurement of qubits can’t go on without the synchronous operation of digital to analog converter array and the controlled sampling of analog to digital converter. In this paper, a scalable self-adaptive synchronous triggering system is proposed to ensure synchronized operation among different qubits of SQC.

Introduction

As a distributed data converters array, superconducting quantum computing needs to solve the problem of synchronous operation of multiple qubits. Meanwhile, because the state of qubit is very sensitive to its microwave control signal, the signal must be stable and controllable, that is to say, the phase noise should be as small as possible.

Control and Measurement System of SQC

A quantum processor chip made from superconducting qubits works at an ambient temperature below 10 mK provided by dilution refrigerator. The modulating signal from room temperature is transmitted to the chip after multistage refrigeration, attenuation and filtering. These modulating signals can be obtained by mixing up the microwave signals generated by the DAC-based arbitrary waveform generator (AWG) with the RF signals provided by the microwave sources.

In the process of reading, a modulating signal is first input into the resonant cavity coupled with the qubits. Different states of qubits correspond to the different amplitudes and phases of the modulating microwave signal on the resonator. The state information is deduced from the demodulated results of ADC after collecting the feedback microwave signal from the resonator.

The Design of Synchronizing Trigger System

A. The High-preformance Clock System

We design a scalable clock tree system in which a 10 MHz Rubidium clock is deployed as the root of the clock tree. The rubidium clock has multiple coherent 10 MHz outputs, which are mainly used in three aspects: the first one is locked to 250 MHz by a clock generator HMC7044 and fan out to 56 by fan-out buffers HMC7043 to every AWG as the synchronous reference clock.

The second one is used as the reference clock of microwave source which is used to generate the 4-6 GHz RF signal. Similarly, the RF signal is divided into multiple channels as the local signal of IQ mixer through the power splitter of multi-level tree structure. The last one is used as the clock source of ADC acquisition board.

B. The Star-like Trigger Design

Control computer

Fan-out buffer HMC7043

IQ Mixer

Power splitter

IQ output

RF output

Fig. 4. The Star-like Ranning Out Structure

Test Results and Analysis

A. The Test of Clock System

We carry out a comparison test using the original ordinary clock design and the proposed high-performance clock solution, which is shown in figure 6. The current design can bring an improvement of about 15 dB in phase noise of DAC output and an improvement of about 6 dB in phase noise of RF signal in an offset range of 1 kHz to 2 MHz.

B. The Test of Self-adaption

We record the probability of metastable phenomena for each modification of the trigger output delay. The results show that traversing a 4 ns clock cycle needs a modification of about 215 times, of which 6 are accompanied by a high probability of metastability. Therefore, there are about 111 ps unstable interval in this system.

C. The Test of Synchronization

A synchronization test with 10 AWGs is present in figure 8. Results show that a synchronization of less than 25 ps is achieved without addition delay adjustment.

Conclusion

In this paper, a scalable synchronous trigger system is proposed to ensure synchronized operation of qubits in SQC. First, a high-performance clock system is designed to serve as a physical structure of the proposed two-level trigger mechanism. This clock scheme can bring about a phase noise improvement of about 15 dB for AWG output and an improvement of about 6 dB for the RF control clock of qubits. Then a scalable master-slave star-like trigger method is proposed, which can realize the synchronization of dozens or hundreds of qubits with the synchronization precision less than 25 ps. Finally, an self-adaptive solution is proposed to detect and calibrate the metastability that ensure the synchronization of multiple AWGs.