ED5-1-INV

Current Progress in Adiabatic Quantum Flux Parametron

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It is estimated that the power consumption of an exascale supercomputer will exceed 100 MW, if we continue using semiconductor technology. Therefore, superconductor logic is attracting much attention due to its high energy efficiency, and multiple types of superconductor logic are extensively investigated to realize an energy-efficient superconductor supercomputer [1]. We have been investigating adiabatic quantum-flux-parametron (AQFP) [2], which is an adiabatic superconductor logic based on quantum-flux-parametron (QFP) [3]. The switching energy of a single AQFP gate can be arbitrarily reduced via adiabatic switching [4,5], where potential energy evolves gradually between a single-well shape and a double-well shape. In previous studies [6,7], we demonstrated a 10-zJ switching energy in experiments and an even smaller switching energy in numerical calculations. In order to realize a low-power AQFP microprocessor, recently we have designed and demonstrated several data paths and memories, which include an 8-bit carry look-ahead adder [8] and a register file [9], by using customized cell libraries [10] and design tools [11]. In this paper, we will report the detail of these progresses towards an AQFP microprocessor. Moreover, we will also briefly introduce our recent work on an AQFP interface for superconducting single photon detector (SSPD) arrays.

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Keywords: Adiabatic superconductor logic, QFP, microprocessor, detector

ED5-2-INV

Cryogenic signal processing based on superconducting logic circuits for multi-pixel superconducting nanowire single-photon detectors

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Superconducting nanowire single-photon detectors (SSPDs) implemented in compact Gifford-McMahon (GM) cryocooler are used in a wide range of areas, such as quantum information, quantum optics, deep-space optical communication, fluorescence observation, and so on. The system detection efficiency (SDE) of SSPD reaches 90% at the optical wavelength of 1550 nm, which can never achievable in semiconductor photon detectors. However, in many applications, not only high SDE but also total performance including low dark count rate (DCR), high maximum count rate (MCR) and/or low timing jitter are important to determine the system performance. A multi-pixel SSPD is one of promising approaches to realize higher MCR without reducing the SDE and/or larger detection area without reducing the MCR. A multi-pixel SSPD also enables pseudo photon-number resolution also spatial resolution, which will provide a new functionality to SSPD. We have developed multi-pixel SSPDs combined with cryogenic signal processors based on single-flux-quantum (SFQ) circuits. By employing cryogenic signal processing using SFQ circuit, the number of readout cables can be reduced, resulting in reduction of the heat load to the refrigerator [1]. In this talk, we will review our recent progress in multi-pixel SSPDs combined with cryogenic signal processors based on SFQ circuit technology.
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Keywords: SSPD, SFQ circuit, cryogenic signal processing

ED5-3

A single-flux-quantum based event-driven encoder toward a 1024-pixel single-photon imaging system

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We report on the demonstration of an event-driven encoder using a single-flux-quantum (SFQ) circuit for a 1024-pixel single photon imaging system based on superconducting nanowire single-photon detectors (SSPDs). SSPDs are key elements in various applications such as quantum information systems, diagnostics of semiconductor integrated circuits and fluorescent observation due to their high quantum efficiency, low timing jitter, and so on. A multi-pixel SSPD system has been developed to improve maximum count rate and realize an ultra-high-sensitive imaging system. In a single-photon imaging system using SSPDs, spatial and timing information are important. We already demonstrated a 64-ch SFQ event-driven encoder in a 0.1-W GM cryocooler, which is driven by output signals of an SSPD and encode both spatial and timing information. The 64-ch encoder can handle 64-pixel SSPDs by one-to-one readout method. In order to extend the number of input channels of the system, we designed a 32 x 32-ch SFQ event-driven encoder, which can handle 1024-pixel SSPD based on the 2N readout method. The total number of Josephson Junctions (JJs) of the designed 32 x 32-ch SFQ encoder is 2900. In order to reduce the DC bias currents for the SFQ encoder, we designed the circuits with half critical currents (Ic) of JJs compared to the conventional design. The total required bias currents are 190 mA. The address data, which is spatial information, of SSPDs in each row and column is converted to the number of SFQ pulses. The output data of the encoder are transmitted to room-temperature electronics through the parallel-to-serial converter with the data rate of 100 Mbps. The fabricated 32 x 32-ch SFQ event-driven encoder operated successfully. We report on the detail in the presentation.

Keywords: single flux quantum circuit, SSPD, imaging system

ED5-4

Demonstration of picosecond time resolution of double-oscillator time-to-digital converters using single-flux-quantum circuits

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Detection of high-mass molecules, which is difficult to detect with a conventional detector, has been realized by using superconducting detectors [1]. The purpose of this research is to develop an imaging system for intracellular molecules. In the proposed system, imaging is performed based on the time information of the detection signal. To realize the imaging system with high spatial resolution, we focused on a double oscillator type time-to-digital converter (TDC) with single-flux-quantum (SFQ) circuits [2] that can realize high temporal resolution. The TDC consists of two sets of ring oscillators and binary counters, and a coincidence detector (CD), which detects the coincidence of the arrival of two SFQ pulses from two ring oscillators. The time resolution of the TDC is limited by the resolution of the CD. In this study, we have developed a dynamic AND (DAND) gate, which can detect two simultaneous SFQ signal inputs with high accuracy, and realized high time resolution of 2 ps or less. By adjusting the period of both oscillators, we also reduced the jitter accumulated in the oscillators and increased the dynamic range. We conducted 1,000 measurements under the same conditions and demonstrated the picosecond time resolution of the improved TDC. We have estimated that when the TDC is used in the imaging system, the spatial resolution of the order of hundreds of nm is expected.
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