Science and Technology Trends

No. 21, December 2002.

A publication of the "Science and Technology Foresight Center" of
the National Institute of Science and Technology Policy (NISTEP).
Ministry of Education, Culture, Science and Technology. Japan

Information Technology Sector

RIKEN Proposes a New Type of Superconducting Quantum Computer

Aiming toward the realization of a quantum computer, a goal that has received much attention in recent years, Franco Nori (also a Professor at the University of Michigan), Jaw-Shen Tsai (also a senior researcher at the NEC Fundamental Research Institute), and J.Q. You (all affiliated with the RIKEN Frontier Research System's Single Quantum Dynamics Research Group) have designed a superconducting circuit able to integrate several hundred quantum bits. An article about it has been published in the November 4, 2002 issue of Physical Review Letters.

Unlike conventional computers, in a quantum computer each bit operates according to quantum mechanics, and a quantum computer should be able to work out in seconds problems that computers today would find impossible to complete (e.g., factoring large numbers) in a realistic time frame, which makes their development very attractive.

Regarding the methodology by which the quantum bit, the basic element of the quantum computer, may be realized, numerous ways have been proposed, though no single one has yet become the overall favorite. The effort is yet at the stage of studying methods that are able to maintain coherence (and quantum mechanical interactions between qubits) over a long period of time, while also allowing expansion to larger numbers of bits.

Superconducting qubits are able to maintain coherence over relatively long distances. This is known as the macroscopic quantum effect, and represents one of the major advantages of superconductors over other quantum elements, and it is thought that this may enable the creation of a quantum computer that combines a large number of elements.

Superconducting qubits may be generally divided into charged qubits, with the charge enclosed in an "electron box", and flux qubits using flux trapped in a SQUID. The one proposed by the RIKEN research group is based on charge qubits. Previous proposals involving integrated circuits using charged qubits were limited in their ability to expand to multiple bits, and were unable to control any one desired bit, which meant that they lacked the ability to integrate hundreds of qubits, indispensable to quantum computing.

This proposal connects two superconductor loops on either side of the qubit, the electron box. The superconductor loops are cut by the two Josephson junctions, altogether forming two DC SQUIDs. This provides a control gate in the proximity of the electron box.

Multiple qubits are connected in parallel via the two SQUIDs, in addition to which the inductance (coils) supplied to all the qubits are connected in parallel. The qubits themselves are joined by the DC-SQUIDs. The qubits are controlled by a gate voltage and the electromagnetic field exerted on the SQUIDs, as well as the electromagnetic field exerted on the supply coils. With this method not only can the qubits which are not adjacent to each other be coupled through interaction, but the operation of the control NOT gate and the control phase gates, basic to quantum calculation, can all be manipulated with a single action.

The article published in Physical Review Letters was published at the completion of the theoretical verification of the proposal; we now look forward to its experimental implementation.