【Grant-in-Aid for Scientific Research (S)】

Realization of innovative non-reciprocal integrated-circuit devices using SIS mixers

Principal Investigator	National Astronomical Observatory of Japan, Advanced Technology Center, Professor UZAWA Yoshinori Researcher Number:00359093
Project Information	Project Number : 22H04955 Project Period (FY) : 2022-2026 Keywords : SIS mixer, nonreciprocal integrated circuit, quantum computer

Purpose and Background of the Research

●Outline of the Research

Superconductor-insulator-superconductor (SIS) mixers, which have shown the quantum limited sensitivities, are widely used in receivers for radio telescopes (Fig. 1, upper left). In order to dramatically increase observation efficiency, SIS mixer arrays in a large-scale, like camera pixels (Fig. 1, upper right), are being developed in the world. Among the receiver components, nonreciprocal circuit elements such as isolators using magnetic materials (bottom left of Fig. 1) are cm-sizes, which prevents to realize large-scale SIS mixer arrays. Similar issues exist in quantum computing, etc.

In this research, we propose a novel nonreciprocal integrated circuit device using SIS mixers (bottom right of Fig. 1). Several SIS mixers are used as frequency up- and down-converters, and the Josephson millimeter-wave local oscillator (LO), phase shifters, etc. are integrated in the device to miniaturize nonreciprocal circuits. Following experiments using waveguide modules to seek the nonreciprocity, innovative integrated circuit device with monolithic integration of the Josephson oscillator and SIS mixers will be fabricated and tested to demonstrate the performance.

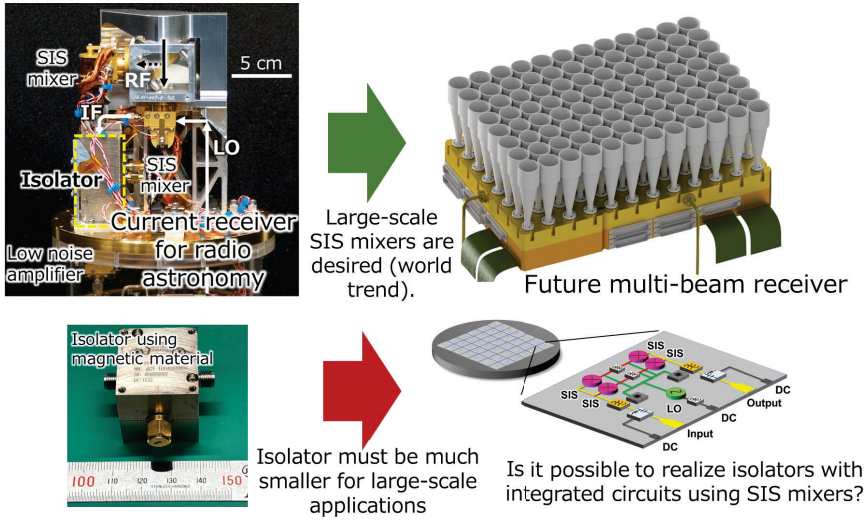

Figure 1. Outline of this research showing the scientific background (upper) and question (bottom).

●Research Plan and Method

The gyrator plays an important role to realize the nonreciprocity by electric circuits, which is basically a two-port device to obtain 180 deg. phase shift, as shown in Fig. 2 (a). As shown in Fig. 2(b), gyrators can be realized by using up- and down-converters and 90 deg. phase shifters. We propose to use SIS mixers for both converters, which can also provide quantum noise performance and frequency conversion gain.

We have shown the up-conversion gain in SIS mixers and low noise amplification in combination with SIS down-converter under KAKENHI Kiban A (18H03881) for the first time (Fig. 3 left). Based on this, gyrators and isolators will be demonstrated by adding phase shifters and other components including the Josephson oscillator developed in parallel, as the LO source (Fig. 3 center). A fabrication process for monolithically integrating the Josephson oscillator and SIS mixers will be developed in the clean room of our institute, with this research goal of realizing a non-reciprocal integrated circuit device, as shown in Fig. 3 right.

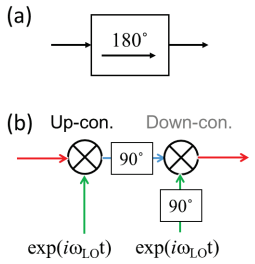

Figure 2. A gyrator. (a) symbol and (b) a circuit using mixers.

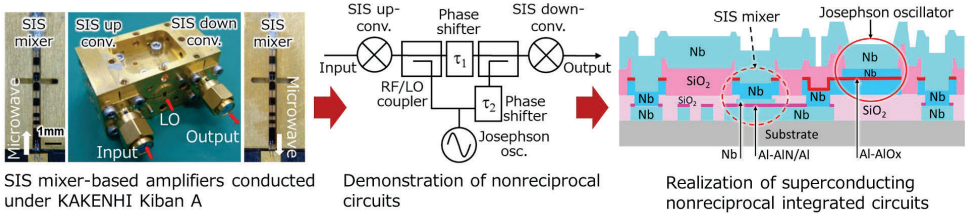

Figure 3. Steps from superconducting amplifiers to nonreciprocal integrated circuit using SIS mixers.

Expected Research Achievements

●Achievements

1. To develop nonreciprocity by means of electric circuits using SIS mixers.
2. To operate the Josephson oscillator as the LO source of the nonreciprocal circuits.
3. To realize superconducting nonreciprocal circuits by monolithically integrating the SIS mixers and oscillator.

●Broader Impacts, etc.

The proposed nonreciprocal integrated circuit is expected to fundamentally solve the problem of large scale in superconducting electronics and accelerate the development of fault-tolerant quantum computers and SIS mixer arrays in Japan. As a result, it is expected to contribute not only to scientific fields such as astronomy, but also to solving social issues such as energy problems using quantum computers (Fig. 4).

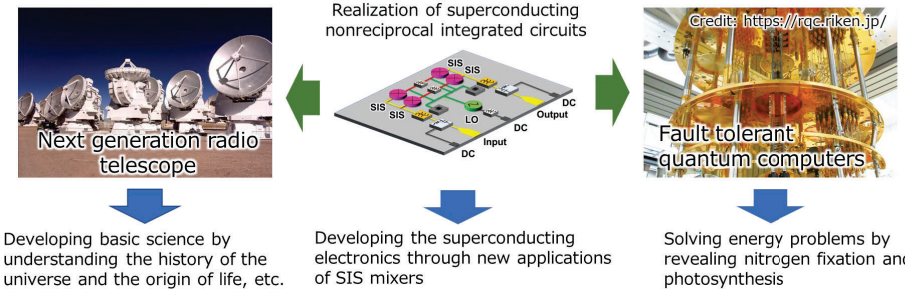

Figure 4. Expected ripple effects of this research.

Homepage Address, etc.	http://atc.mtk.nao.ac.jp/ Contact: y.uzawa@nao.ac.jp