Terahertz Communication Demonstration by using a High-Tc Superconducting Josephson Receiver Integrated with a Miniature Cryocooler

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***Abstract*—This paper presents the terahertz communication demonstration by using a quasi-optically coupled high-T_c superconducting (HTS) Josephson receiver. The receiver consists of a broadband HTS Josephson-junction mixer integrated with a cryogenic low noise amplifier inside a miniature cryocooler. The noise and conversion properties of the broadband HTS mixer versus the bias current and local oscillator (LO) power, are thoroughly investigated for different operating temperatures and frequencies. Based on such HTS receiver frontend, a 320-GHz wireless communication link was established at the UTS laboratory and demonstrated by using the QPSK and 16QAM modulations, respectively.**

Keywords*—*Terahertz communication, high-T_c superconducting receiver, Josephson junction mixer, miniature cryocooler

I. Introduction

The considerably large bandwidth of Terahertz (THz) waves facilitates potential ultrahigh speed communications at data-rates up to terabits per second [1]. However, there exists challenges such as the path loss resulting from atmospheric absorption, which poses a major constraint on the communication distances. To exploit the great potential of THz communication systems, ultrasensitive receiver frontends are very much desired.

High-T_c superconducting (HTS) Josephson receivers are promising candidates for THz communication frontends due to the advantages of superior sensitivity, low local oscillator (LO) power, high frequency operation (due to high energy band-gap) and large IF bandwidth. In particular, HTS receivers can operate at higher temperature ranges than the low-T_c superconducting ones, thus significantly reduce the cryogenic costs. Smaller and cheaper commercial single-stage cryocoolers can be used for cooling the HTS receivers, which is very attractive for THz wireless communication applications. Research progress in HTS THz receivers has been reported in the open literature [2]-[6]. However, a THz communication demonstration by using the HTS Josephson receiver has never been reported so far.

This paper presents the design and demonstration of a THz wireless communication link that employs a quasi-optically coupled HTS Josephson receiver. The specific design details, simulation analyses, experimental measurement and demonstration are discussed in this work.

II. Design, Simulation and Experiment

A. System Design of a THz Communication Link using the HTS Josephson Receiver

Fig. 1 illustrates the schematic design of a THz wireless communication link that uses the HTS Josephson receiver. The output of a microwave source is separated (via a 3-dB power splitter) into two signals for driving the THz LO source and the THz transmitter, respectively. After power amplifications and frequency multiplications (×12) inside the THz LO source, the driving signal frequency is converted to 325.2 GHz for offering LO pumping for the HTS receiver frontend. To guarantee sufficient LO power coupled into the HTS mixer module, a horn antenna together with a parabolic mirror are utilized to generate and collimate the THz radiation beam. On the other hand, another microwave driving signal, after power amplifications and frequency multiplications (×6), is mixed with a modulated IF signal centered at 15.65 GHz via a second harmonic mixer inside the THz transmitter, which results in a double-sideband (DSB) modulated THz signal. A waveguide filter is then followed to reject one sideband for image interference suppression. A horn antenna combined with a lens are used to generate and collimate the RF THz radiation centered at 309.55 GHz. Those two THz signals (RF and LO) are combined via a beam splitter and then refocused by another parabolic mirror onto a broadband HTS mixer module mounted in a mini-cryocooler. Two variable waveguide attenuators are added in the LO and RF links to adjust the LO power for optimum mixer pumping and to produce a certain link propagation loss, respectively.

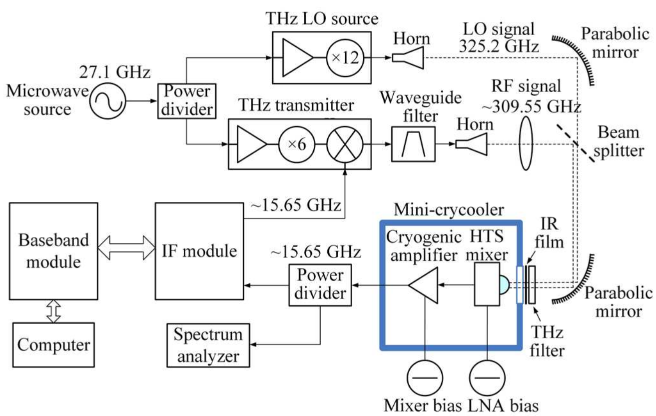


Fig. 1. Schematic design of a THz communication link using a HTS Josephson receiver.

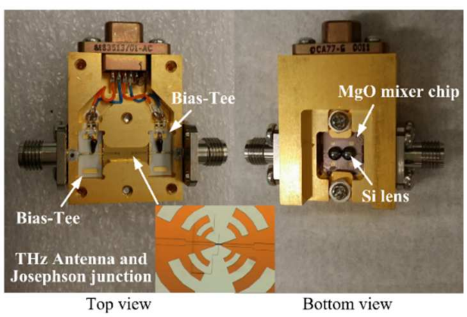


Fig. 2. Photographs of the broadband HTS Josephson THz mixer module [5].

To minimize the noise of the HTS receiver frontend system, a THz quasi-optical filter and an infrared (IF) film are placed in front of the cryocooler window for external interference rejection, and a cryogenic low noise amplifier (LNA) is integrated with the broadband HTS mixer in the mini-cryocooler to minimize the noise from the IF link. A fundamental heterodyne mixing occurs at appropriate biasing, provided by a battery-operated current source. The down-converted IF signal is amplified and received by the IF module. The IF signal is also recorded by a spectrum analyzer via a power divider. A baseband module accounts for transmitting and receiving high-speed baseband signals to and from the IF module. A computer sends the control and command information and carries out communication data processing.

B. Performance Analyses of the Broadband HTS Josephson Mixer

The performance of whole HTS receiver frontend is mainly determined by that of the broadband HTS Josephson mixer. It is necessary to investigate the mixer noise and conversion properties versus the bias current and local oscillator (LO) power for different operating temperatures and frequencies. Fig. 2 shows the photographs of the broadband HTS Josephson THz mixer module. The details of the mixer had been reported in [5].

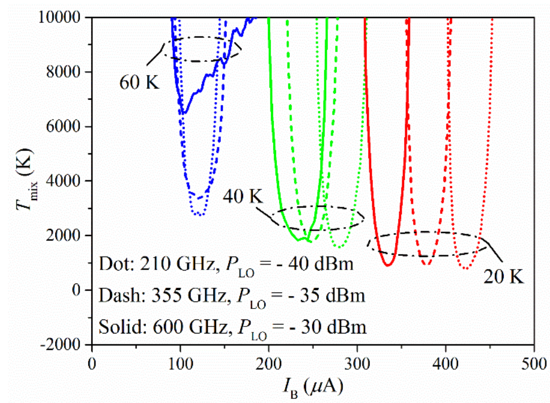


Fig. 3. Simulated T_{mix} versus I_B for different temperatures and frequencies.

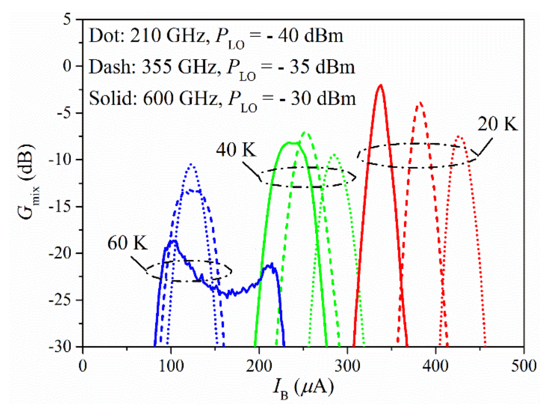


Fig. 4. Simulated G_{mix} versus I_B for different temperatures and frequencies.

Fig. 3 shows the simulated noise temperature T_{mix} versus the bias current I_B for the broadband HTS THz mixer. It can be found that, T_{mix} is strongly dependent on I_B and achieves its minimum at an optimal I_B, which is smaller for higher operating temperatures. This is because that the optimal bias current for heterodyne mixing generally locates about halfway between the zeroth and first Shapiro step of the pumped IV characteristics. As clearly shown in Fig. 3, the best T_{mix} deteriorates with increasing the operating temperature or frequency; more severe frequency-dependent performance deterioration is observed for a higher operating temperature T. Fig. 4 shows the simulated mixer conversion gain G_{mix} versus the bias current I_B for different operating temperatures and frequencies. Similar as T_{mix}, G_{mix} is also strongly dependent on I_B, and the optimal I_B for achieving the highest G_{mix} is in good consistency with that for lowest T_{mix}. Seen from Fig. 4, the best G_{mix} decreases monotonically as the operating temperature T rises from 20 K to 60 K. However, the relationship between G_{mix} and operating frequency is relatively complicated, showing a positive slope for T = 20 K but a negative one for T = 60 K. This phenomenon is believed to partly result from the discrepancy in dynamic resistance for different frequencies, which influences the impedance match between the Josephson junction and the IF readout network.

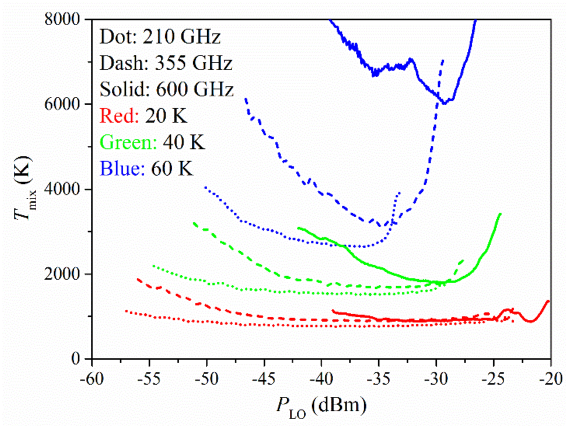


Fig. 5. Simulated T_{mix} versus P_{LO} for different temperatures and frequencies.

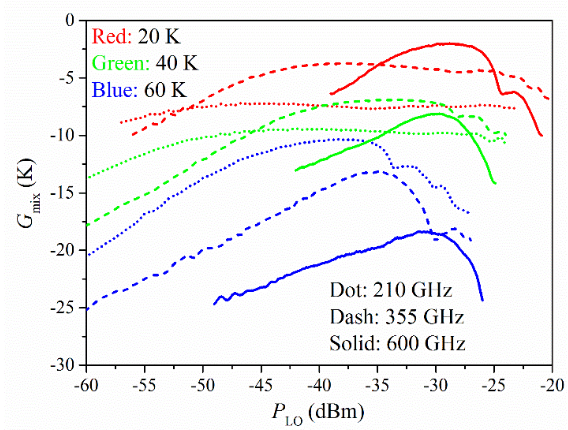


Fig. 6. Simulated G_{mix} versus P_{LO} for different temperatures and frequencies.

The relationship of T_{mix} and the LO pumping power P_{LO} is shown in Fig. 5. For each value of P_{LO}, a corresponding optimal bias current has been applied to the mixer. The simulation shows that the device performance is influenced by the LO power although the change is not as sharp as that of the bias (I_B) dependence, especially at lower operating temperatures. Seen from Fig. 5, the optimal P_{LO} is nearly independent on operating temperature but rises with increasing the operating frequency, which is around -40, -35 and -30 dBm for the frequencies of 210, 355 and 600 GHz, respectively. It can be found the LO pumping power is much lower than that required for Schottky diode mixers, which is one of the advantages of the Josephson-junction mixer. At the operating frequencies of 210, 355 and 600 GHz, the lowest T_{mix} (at optimal P_{LO} and I_B) is 760, 895 and 900 K at T = 20 K; 1515, 1667 and 1790 K at T = 40 K; 2645, 3104 and 6011 K at T = 60 K, respectively. Fig. 6 shows the simulated G_{mix} versus P_{LO} for different operating temperatures and frequencies. The dependence of G_{mix} on P_{LO} is similar as that for T_{mix} on P_{LO}. At the frequencies of 210, 355 and 600 GHz, the highest G_{mix} (at optimal P_{LO} and I_B) is -7.2, -3.7 and -2.0 dB at T = 20 K; -9.4, -6.9 and -8.1 dB at T = 40 K; -10.4, -13.1 and -18.4 dB at T = 60 K, respectively.

C. *Experimental Measurement and Demonstation*

The noise temperature and conversion gain of the HTS Josephson receiver were measured by using the Y-factor and U-factor methods [6]. In the operating temperature of 40 K, the measured noise temperature is around 1500 K at the 340-GHz band. Fig. 7 shows the photograph of a THz wireless communication link using the quasi-optically coupled HTS Josephson receiver, which was established at the laboratory of the University of Technology Sydney. All required components and instrument were placed on an optical platform. The THz transmitter and LO source were purchased from the Keysight company. Using a Lihan pulse-tube cryocooler, the miniature cryocooling system was integrated and developed in house. Fig. 8 shows the measured constellation diagram after demodulation processing. Due to the quasi-optic losses and alignment errors, the communication data-rate is limited to several Gbps.

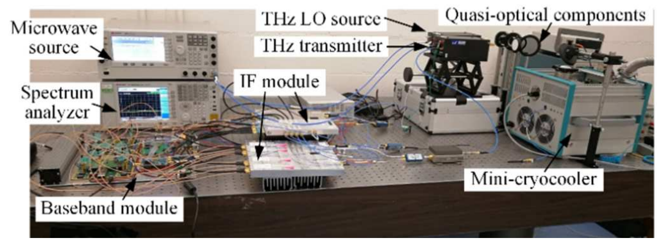
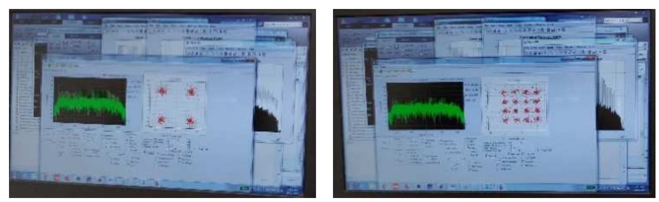


Fig. 7. Photograph of a THz wireless communication link using the quasi-optically coupled HTS Josephson receiver.



(a) (b)

Fig. 8. The measured constellation diagram after demodulation processing: (a) QPSK; (b) 16QAM.

III. Conclusions

This paper presents the terahertz communication demonstration by using a quasi-optically coupled HTS Josephson receiver. The system design, simulation analyses, experimental measurement and demonstration are discussed.

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