Design and Measurement of a 36 GHz High-Gain HTS Josephson Mixer

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Abstract:

A high-gain Ka-band high-temperature superconducting (HTS) microwave monolithic integrated circuit (MMIC) mixer is presented. The mixer was designed and modeled using our previously developed modeling methodology to extract the junction's port impedance for optimal conversion performance, and the circuit was designed in EM simulator accordingly. The designed HTS MMIC mixer comprises a step-edge Josephson junction with passive devices, including filters, resonators and impedance matching circuits, all on a single chip to reduce the loss of interconnections. The MMIC mixer demonstrated a maximum conversion gain around -6 dB at an operating temperature of 40 K, and -1 dB at 20 K. The superior mixing performance makes it a competitive candidate for future mm-wave wireless receiver systems. Modeling, design consideration and measurement results are presented in the paper.

Introduction:

High temperature superconducting (HTS) materials have ultra-low surface resistance at the frequencies below 100 GHz, which has been applied to make filters and resonators with superior performance [1]. The low–noise and high non-linearity properties of the HTS Josephson junctions make them ideal for the key component of mixers [2]. A number of HTS MMIC Josephson mixers have been developed by the author's group, of which the $YBa_2Cu_3O_{7-x}$ (YBCO) step-edge Josephson junctions are integrated monolithically with a series of YBCO filters to achieve better performance [3,4].The impedance matching and optimization theory between passive devices and Josephson junctions have also been investigated through the development of HTS MMIC Josephson schematic circuit modeling [5,6], and a full EM design approach was proposed accordingly, and subsequently verified experimentally [7].

In this work, a high-gain Ka-band HTS MMIC mixer is presented. The mixer was firstly modelled using a schematic simulator to investigate the port impedance of the Josephson junction at various frequencies, and the MMIC circuit was then designed accordingly for optimized matching and isolation between relevant ports. The Josephson mixer was then fabricated, packaged and measured for comparison with the simulation results.

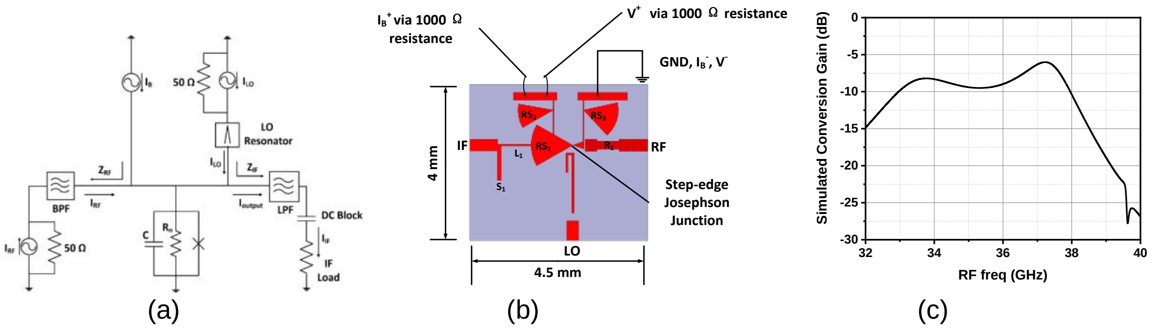


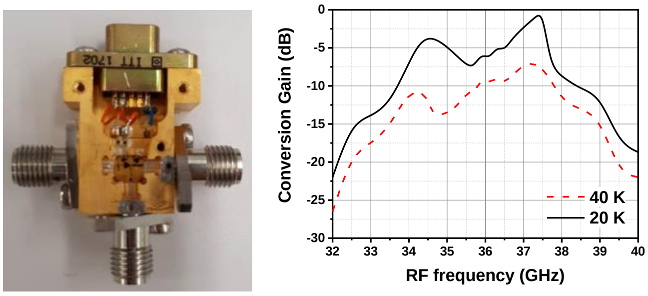
Fig. 1. (a) schematic model of the HTS MMIC Josephson mixer; (b) the circuit layout, and (c) its simulated frequency response of conversion gain.

Design and Simulation:

Fig. 1 (a) shows the schematic of the Josephson mixer simulation model. The junction critical current I_c and intrinsic resistance R_n were set to 300 μA and 5 Ω respectively, which were the typical measured junction characteristics at 40 K. Operation frequencies of RF and IF filters are set to be 34 to 38 GHz and 0 to 20 GHz, respectively. Detailed simulation approach to deriving port impedances has been described in [6], and further details of the simulation process will be presented at the conference. Following the theoretical modelling, the HTS MMIC mixer was designed using the EM simulation approach reported in [7]. The designed the MMIC mixer features a compact size of 4.5 × 4 × 0.3 mm^3, as shown in Fig. 1(b). Combining the simulation results of the theoretical modelling and EM modelling, the simulated conversion gain of the mixer was obtained and shown in Fig. 1 (c). The average conversion gain is -8 dB within the RF passband, and a maximum conversion gain is -6 dB at 37 GHz.

Module Packaging and Measurement Results:

The designed mixer was subsequently fabricated on a single-sided YBCO film on MgO substrate using the CSIRO established step-edge junction technology [4]. The mixer chip was packaged into a customized metal housing, along with other lumped elements of DC biasing networks as shown in Fig. 2 (a). The packaged module was cooled down to an operating temperature between 20 - 77 K in a two-stage pulse-tube cryocooler for measurement. The measured frequency response of the mixer's conversion gain is shown in Fig. 2 (b). The average conversion gain at 40 K is around -9 dB, and a maximum gain of -6 dB is observed at 37 GHz, which shows good consistency with the simulation result in Fig. 1 (c). The mixer demonstrates a conversion gain averaging at -5 dB at 20 K, with a peak of -1 dB around 37 GHz. This is the best result reported in HTS Josephson mixers at similar frequencies, and is close to the best result that has been achieved at 10-12 GHz [4]. The high conversion gain of the new mixer verifies the validity of the modelling and design methodology, and provides a guidance for future circuit and module designs.



(a) (b)

Fig. 2. (a) photo of the packaged mixer module, and (b) its measured conversion gain.

Conclusion:

In this paper, we have presented the simulation and measurement results of a 36 GHz high-gain HTS MMIC Josephson mixer. Theoretical modelling is established for impedance investigation, and a full EM modeling was performed for optimal circuit design. Measurement results showed a high conversion gain was obtained and it is in good agreement with simulation. The presented HTS mixer with high conversion gain should find its potential application in Ka-band high-sensitivity wireless systems.

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