NOISE FIGURE of HTS JJ MMIC DOWNCONVERTER at 12GHz

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ABSTRACT

We report here the first deliberately made high temperature superconductivity (HTS) monolithic microwave integrated circuit (MMIC) for down-cnverting direct broadcast satellite (DBS) signals. A $YBa_2Cu_3O_{7-\delta}$(YBCO) step-edge microbridge Josephson junction (JJ), two 12GHz YBCO microstrip bandpass filters, a 1GHz YBCO filter, and current bias and voltage monitor circuits are successfully combined into a 20mm x 20mm MgO substrate and integrated into a frequency downconverter. The YBCO downconverter and a GaAs low noise amplifier(LNA) for intermediate frequency (IF=1GHz) are combined into a microwave cryostat and characterized by receiving direct broadcast satellite (DBS) signals. The noise figure has been first measured for such YBCO JJ MMIC downconverter as a subsystem. The dependence of noise figure and IF output on temperature, bias voltage and LO power has been studied. We have successfully demonstrated clear pictures of DBS bellow 40K.

INTRODUCTION

HTS can provide high quality films for passive microwave devices [1], but nonlinear superconducting Josephson elements for active circuits have been difficult to fabricate. In recent years researchers have focused on $YBa_2Cu_3O_{7-\delta}$(YBCO) step-edge Josephson junctions (JJs) fabricated on (100) $LaAlO_3$ substrates with higher angle step-edges than the 45 degree [2]. A monolithic HTS phase shifter with 2000 step-edge Josephson junction was reported [3]. Due to the uncertainties in coupling the microwave power into the junctions, little quntitative information about the conversion gain of HTS mixers exists [4],[5]. Only a few measurements of the noise figure of the HTS mixer have been reported [6]. We have developed high quality nonlinear YBCO microbridge Josephson junctions of for such an active circuit as a mixer [7], which were fabricated on (100) MgO substrates with the relatively low angle step-edges (i. e. lower than the 40 degrees) [8] and with flat surfaces lightly damaged by focused Ga-ion-beam [9]. A much higher $IcRn$ product, where Ic and Rn are the critical current and the normal resistance for the measured Josephson junction, respectively, has been obtained by I-V characteristics in qualitative agreement with the good present results of mixer conversion gains and noise figures. We have successfully fabricated and tested a monolithic HTS frequency downconverter for direct broadcast satellite (DBS). A YBCO step-edge microbridge Josephson junction, three YBCO microstrip filters, and current bias and voltage monitor circuits were combined into a 20mm x 20mm MgO substrate. The monolithic YBCO downconverter circuits were simulated by using the Touchstone microwave circuit analysis by EEsof, Inc. The monolithic YBCO downconverter and a GaAs low noise amplifier(LNA) for intermediate frequency (IF=1GHz) were combined into a microwave cryostat with 9 Watt closed-cycle helium refrigerator [1], and characterized by receiving DBS signals with 33cm diameter-disk antenna.

EXPERIMENTAL

Step edges substrates were fabricated by Ar ion milling, using a resist mask [8] and which coated one half of a 20mm x 20mm MgO substrate with OFPR-800 resist layer. Both side polished MgO(100) single crystals with 0.5mm thickness were used. Epitaxial, c-axis oriented YBCO films were deposited onto these substrates with step edges by pulsed laser deposition (PLD) [1]. MgO has an adequate dielectric constant of 9.7 and a smaller dielectric loss tangent than 10^{-5}. Therefore, the width of the YBCO microstrip with 50Ω characteristic impedance is 0.45mm, which is easily obtained by conventional photolithograpy. Microbridges with 5μm width, 0.5μm

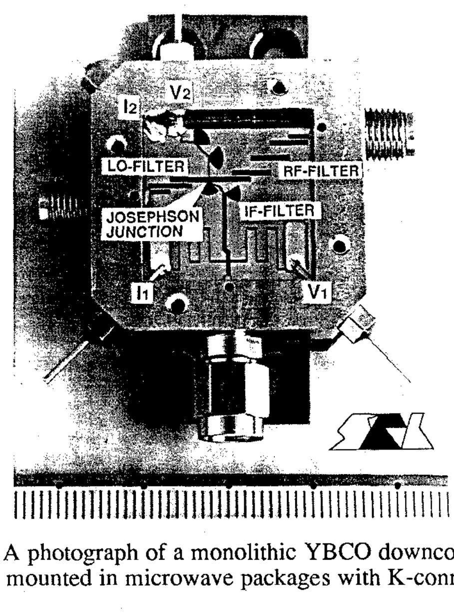

Fig.1 A photograph of a monolithic YBCO downconverter circuit mounted in microwave packages with K-connectors.

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thickness and 30μm length were patterned so as to cross the step-edge on the substrate. Finally, Au contact metal was deposited on the YBCO as electrodes for microwave launching and I-V characterization, and on the backside of the MgO substrate as a ground plane, respectively [1].

A photograph of a monolithic YBCO downconverter circuit mounted in microwave packages with K-connectors is shown in Fig.1. On the 20mm x 20mm chip, the RF and the LO are 3-stage and 1-stage Chebysheff bandpass filter, respectively, the IF is microstrip-radial-stub LO signal rejection filter, and the current bias and the voltage monitor circuits are designed as microstrip line open circuits with microstrip line short circuit of EMI suppression filters. Excepting the EMI suppression filters, all these filters and the nonlinear microbridge Josephson junction on the MgO chip are made of YBCO.

The monolithic YBCO downconverter and a GaAs low noise amplifier(LNA) for IF (1GHz) are combined as a microwave downconveter subsystem into a microwave cryostat with 9 Watt closed-cycle helium refrigerator [7]. The gain of the 1GHz IF-LNA is 23.7dB at 800MHz and 15K. The dependence of frequency mixing characteristics such as a noise figure, a conversion gain and C/N (carrier/noise) ratio were measured using HP 8970B noise figure meter and HP 8563A spectrum analyzer, as shown in Fig.2. The microwave cryostat is distinguished by small drifts of insertion and return losses between 300K and 15K using shortest possible CuNi coaxial cable lengths to minimize effects due to temperature. The sample temperature in the package can be determined within 1 degree accuracy by the helium exchange gases. The sliding vacuum feedthroughs of CuNi coaxial cables are useful to easily accommodate devices and calibration standards of differing lengths.

RESULTS AND DISCUSSIONS

Figures 3(a) and 3(b) show I-V characteristics of the YBCO step edge junction at 15K without and with -14dBm irradiation of f=11.7GHz microwave, respectively. The $IcRn$ =52mV of the junction is estimated from the I-V characteristics (Ic=1.3mA (Jc=1.3x10^5A/cm^2) and Rn=40Ω). This extremely high Rn value, which may cause an easy impedance match between junction and RF input circuit, can be explained by assuming that it consists of a series of several Josephson junctions. Figure 4 shows the zero bias current amplitude, Ic, as a function of the square root of the input microwave LO power. The normalized frequency $\Omega=(hf/2e)(1/IcRn)$ = 4.6x10^{-4} is so small that the Ic shows linear dependence on the square root of the input microwave LO power, and that no Shapiro step is resolved above the noise intensity, as P.Russer [10] and the authors [8,9] suggested. Conversion gains from RF=11.735GHz to IF=800MHz and 900MHz at 15K as a function of LO input powers are shown in Fig.5. Total and JJ conversion gains were obtained at 15K by measuring the total system in which the monolithic YBCO downconverter and the GaAs-IF-LNA were combined, and by subtracting the GaAs-IF-LNA gain from the total gain, respectively. The maximum gains of total and JJ are 9.0dB and -14.5dB, respectively, at IF=800MHz in the wide range of LO power (-28dBm and -14dBm). This figure of -14.5dB might be improved by optimizing the YBCO circuit layout shown in Fig.1, because of mismatches between RF input port and Josephson junction.

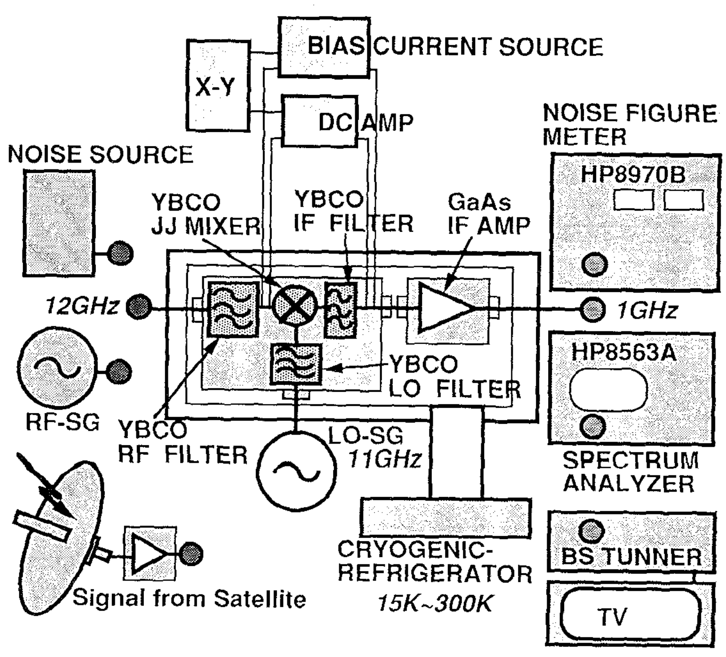

Fig.2 Schematic block diagram of the 12GHz HTS downconverter experiments.

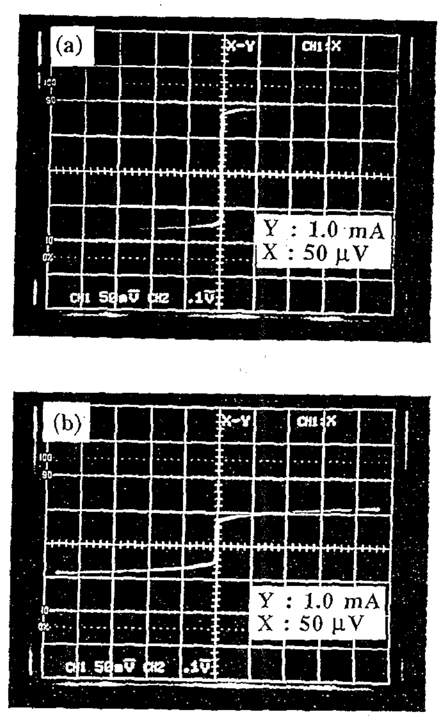

Fig.3 I-V characteristics at 15K of an YBCO step edge junction under LO=11.7GHz microwave, (a) without irradiation and (b) with -14dBm irradiation.

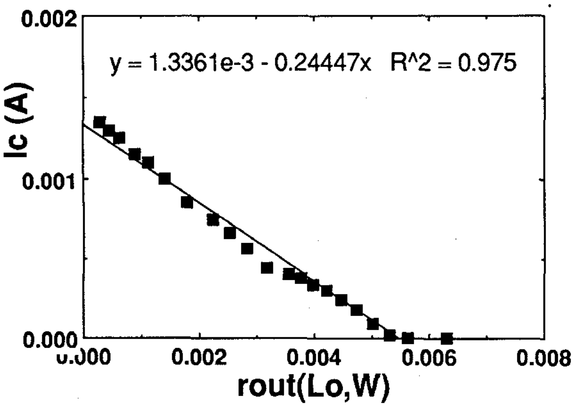

Fig.4 The zero bias current amplitude, Ic, as a function of the square root of the input microwave LO power.

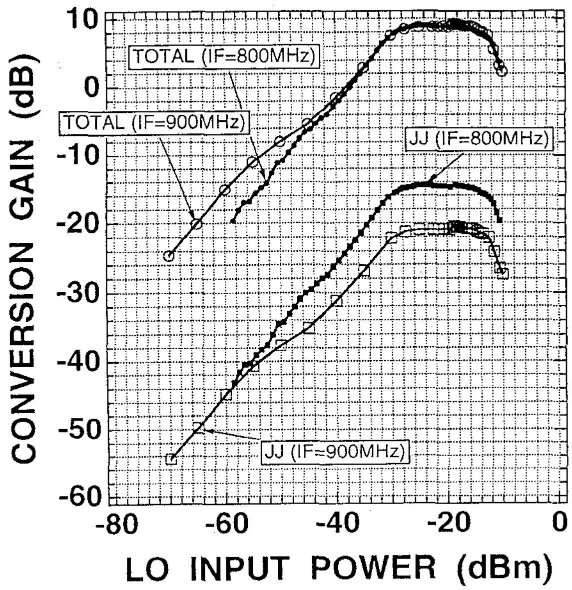

Fig.5 Conversion gains from RF=11.735GHz to IF=800MHz and 900MHz at 15K as a function of LO input power.

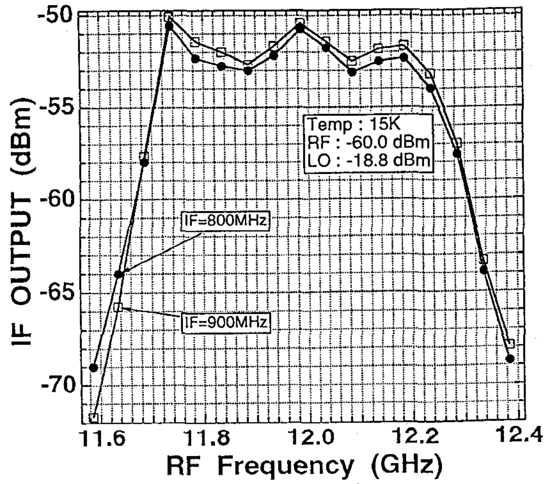

Fig.6 RF filter transmission measured at 15K.

Figure 6 shows the RF filter transmission measured at 15K. Because the LO filter characteristic is comparatively wide and smooth with the RF, the RF filter transmission could be obtained by sweeping input frequencies of RF and LO with keeping IF output frequency constant at 800MHz. Figures 7(a) and 7(b) show the measured conversion gains and noise figures of the total system at 15K and 30K, respectively. The temperature dependence of the conversion gain at IF=888MHz, RF=-60dBm and LO=-18dBm is shown in Fig.8. Noise figure minimums of 12.2dB and 15.2dB occur around 800MHz at 15K and 30K, respectively. On the other hand, the conversion gain is kept constant between 15K and 30K, and rapidly decreases near 83K. The critical temperature of 83K is mainly depend on that of YBCO microbridge in the monolithic YBCO converter. Two peaks at 62K and 78K reflecting the nonlinearity of junction, such as peaks of dynamic resistance Rd, are observed. Notice that the decreasing slowly from 15K to 83K is due to the change in phase velocity caused by kinetic inductance effects of the YBCO microstrip, and not to the GaAs-IF-LNA whose gain shifts by +3dB between 15K and 83K. Figure 2 shows the block diagram of the experiment of receiving BS signal when the RF signal generator or the RF

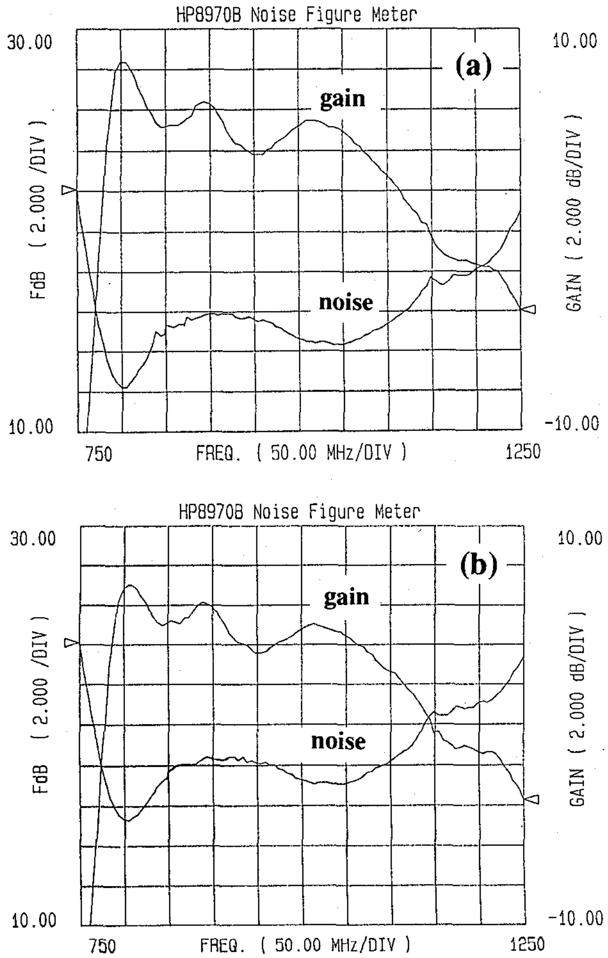

Fig.7 The measured conversion gains and noise figures of the total system at 15K(a) and 30K(b).

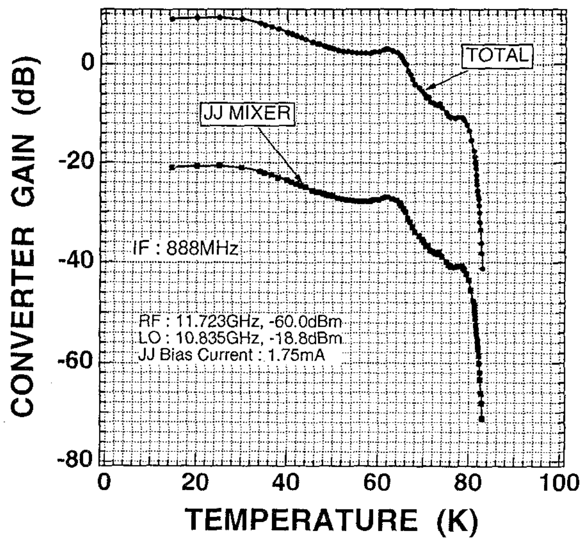

Fig.8 Temperature dependence of the total coversion gains at IF=888MHz, RF=-60dBm and LO=-18dBm.

noise source is exchanged for a 33cm diameter-disk antenna and a X-band preamplifier with 24dB gain operating at room temperature. C/N =12.5dB for BS-7 (27MHz bandwidth) have been obtained at 41K and LO =-19dBm. We have successfully demonstrated clear pictures of DBS bellow 40K.

CONCLUSIONS

A $YBa_2Cu_3O_{7-\delta}$(YBCO) step-edge microbirdge Josephson junction, two 12GHz YBCO microstrip bandpass filters, a 1GHz YBCO filter, and current bias and voltage monitor circuits were successfully combined into a 20mm x 20mm MgO substrate and integrated into a frequency downconverter for receiving DBS signals. The YBCO downconverter and the GaAs low noise IF amplifier(IF-LNA) were combined into a microwave cryostat. The dependence of mixing signals on temperature and LO input power was measured. The conversion gain and the noise figure corresponding to the YBCO downconverter package were -14.5dB and 12.2dB, respectively, at 15K and small LO power (-25dBm). The first demonstration of the HTS subsystem, i.e., the monolithic YBCO downconverter, shows potential for applications in mobile radio communications and satellite broadcasting.

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REFERENCES

[1]. K.Suzuki, Y.Enomoto, T.Morishita and S.Tanaka, "High-Tc Superconducting Microwave Devices", Proceedings 11th Symposium on FED, Nov. 4-5, 1992 Chiba, Japan pp.165-172.

[2]. K.P.Daly, J.Burch, S.Coons, R.Hu, "YBa2Cu3O7 Step-edge RF SQUID Biased at 10 GHz", IEEE Transactions on Magnetics, MAG-27, pp.3066-3069, March 1991.

[3]. J.H.Takemoto-Kobayashi, C.M.Jackson, E.B.Guillory, C.P.Hall, J.F.Burch, "Monolithic High-Tc Superconducting Phase Shifter at 10 GHz", 1992 IEEE MTT-S Digest, vol.1 pp469-472.

[4]. D.P.Butler, W.Yang, J.Wang, A.Bhandrai, and Z.Celik-Butler, "Conversion loss of a $YBa_2Cu_3O_7$ grain boundary mixer at 20 GHz", Appl. Phys. Lett. Vol.61(3), 20 July 1992 pp.333-335.

[5]. T.Nozue, Y.Yauoka, J.Chen, H.Suzuki, and T.Yamashita, "Microwave Mixing Characteristics of Thin-Film YBCO Josephson Mixers at 77K", IEICE Trans. Electron, Vol.E/5-C, No.8 August 1992 pp.929-934.

[6]. J.P.Hong, T.W.Kim, H.R.Fettermann, A.H.Cardona and L.C.Bourne, "Millimeter wave mixing from deliberate grain-boundary weak links in epitaxial $Tl_2CaBa_2Cu_2O_8$ filma", Appl. Phys. Lett. Vol.59(8), 19 August 1991 pp.991-993.

[7]. K.Suzuki, S.Yoshikawa, K.Yamaguchi, K.Hayashi, S.Fujino, T.Takenaka, K.Imai, F.Suginoshita, N.Yazawa Y.Enomoto, "Performance of a Y-Ba-Cu-O Josephson Junction/Filter", To be published in Adv. in Superconductivity V Proc. ISS'92, Kobe, Japan 1992 (Springer, 1993), AD-07.

[8]. K.Yamaguchi, S.Yoshikawa, S.Fujino, T.Takenaka, and K.Suzuki, "YBCO Step-edge Josephson Junction by Pulsed Laser Deposition", To be published in Adv. in Superconductivity V Proc. ISS'92, Kobe, Japan 1992 (Springer, 1993), ADP-03.

[9]. C.H.Neumann, K.Yamaguchi, Y.Ando, K.Hayashi, S.Fujino, T.Takenaka, K.Suzuki, and Y.Enomoto, "YBCO-Josephson-Junctions on MgO Fabricated by A Focused Ion Beam", To be published in Adv. in Superconductivity V Proc. ISS'92, Kobe, Japan 1992 (Springer, 1993), ADP-14.

[10]. P.Russer, "Influence of Microwave Radiation on Current-Voltage Characteristic of Superconducting Weak Links", J. Appl. Phys., Vol.43, No.4, April 1972 pp.2008-2010.