100 GHz Wide-Band HTS Mixer Antenna with Phase Control

Katsumi Suzuki, Masahito Ban, Seiichi Tokunaga, Masashi Ohtsuka, Kunihiko Hayashi and Youichi Enomoto

Tamachi Laboratory, Superconductivity Research Laboratory, ISTEC
1-16-25, Shibaura, Minato-ku, Tokyo 105 Japan,
TEL:03-3454-7679, FAX:03-3454-9287

ABSTRACT

Here we report on a millimeter-wave performance of high-Tc superconducting (HTS) Josephson junctions on MgO substrates using a focused Ga ion beam (FIB). The 6 junctions with 1.5μm space apart from each other occupied 7.5μm. The 6 junctions can modulate even the 1000GHz electromagnetic wave with nearly equal phase. We applied the YBCO series junction to millimeter wave mixer with a log-periodic antenna. The HTS junction mixer and the log-periodic antenna are expected to have a function of flat frequency response up to THz. First, we measure wide frequency band responsibility for mixing function below 100 GHz. Next, we observe the HTS mixer-antenna performance as fundamental and harmonic mixers in the wide frequency range up to 100 GHz. Finally, the IF output phases can be changed within 1dB of IF output power differences.

INTRODUCTION

High temperature superconducting (HTS) can provide high sensitive Josephson junctions for nonlinear HTS for active circuits at 77K. The HTS junction has been studying its advantages in mixers compared with Schottky diode mixers. D.Terpstra et al. reported the HTS advantages by observing of AC Josephson effect up to THz frequencies in Y-Ba-Cu-O / Pr-Ba-Cu-O / Y-Ba-Cu-O ramp-type Josephson junctions [1]. Our previous experiments demonstrated a superiority of the HTS junction to Schottky diodes [2,3]. The HTS mixer required a local (LO) power of -25dBm for optimum operation, which was -30dB (1000 times) lower than that of the Schottky diode mixer. This paper describes a 100GHz HTS mixer antenna without LO feeding connector, but with an LO feeding log-periodic antenna. We developed a YBCO Josephson junction on MgO substrates fabricated by a focused Ga ion beam (FIB) with its narrow (>50 nm) diameter [4]. The junction shunted resistance, *Rn*, depends on the number of junctions in series, which is nearly proportional to the junction input impedance. Cross-sectional TEM images showed that the junctions with more than 1 μm spaces and flat & lateral structure were independent each other for the crystallization process [5]. The YBCO junction mixer and the log-periodic antenna are expected to have a

0-7803-3246-6/96/$5.00 © IEEE

function of flat frequency response up to THz.

First, we measure wide frequency band responsibility for mixing function below 100 GHz. Next, we observe the HTS mixer-antenna performance as fundamental / harmonic mixers in the wide frequency range up to 100 GHz. Finally, the IF output phases can be changed within 1dB of IF output power differences.

EXPERIMENTAL

We fabricated 6 junctions with 1.5μm space apart from each other, which occupied 7.5μm as shown in Fig.1. The 6 junctions can modulate the 1000GHz electromagnetic wave with nearly equal phase. The equal phase is the fundamental condition or high activities of high speed devices with phase control, such as tera-Hertz array mixer antennas and tera-Hertz optical modulators. Figure 2 shows the log-periodic antenna with the YBCO 6 junctions in the center, DC bias circuit lines and IF output lines. They are monolithically mounted on a 20 mm x 20 mm MgO substrate. The MgO substrate thickness was 0.5mm. This mixer antenna might be active from 10GHz to 1000GHz. Our expectation about the 6 junctions experimentally proved right in mixing from 10GHz to 100GHz and in Shapiro step corresponding to 700GHz. In order to eliminate the surface wave loss and to enhance the antenna gain, J.Konopka et al. [6] used LaAlO3 semi-spherical lens, and H.Shimakage et al. [7] used quartz hyperhemisherical lens. We did not adopt these lens with which an array antenna with several log-periodic antennas could not be designed.

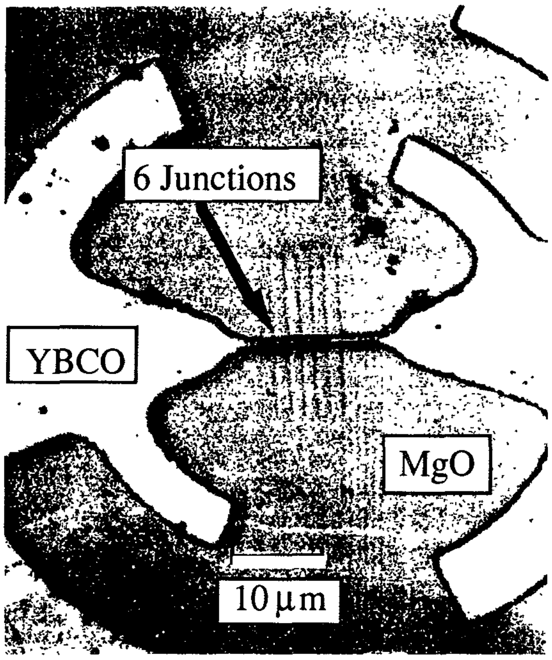

Fig.1 The 6 junctions with 1.5μm space apart from each other, which are located in the center of log-periodic antenna.

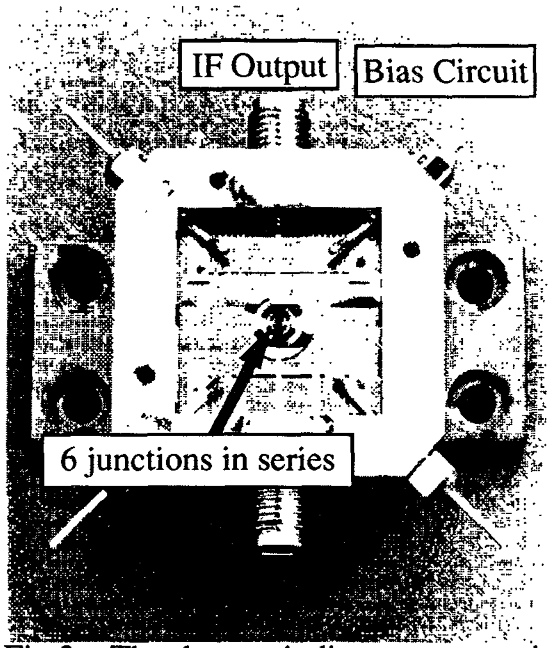

Fig.2 The log-periodic antenna with the YBCO 6 junctions in the center, DC bias circuit lines and IF output lines.

RESULTS AND DISCUSSIONS

Figure 3 shows the IF output as a function of temperature. LO of 99GHz were fed into the YBCO junctions through the same log-periodic antenna as that RF of 100GHz used. The antenna was a log-periodic microstrip and was linearly polarized. We obtained a cross-polarization level of -10 dB at RF=100 GHz and LO=99GHz. This value might be depend on the frequency. The wide-band performance of the log-periodic antenna and absence of a narrow-band RF or LO matching networks assure that our mixer antenna can have nearly identical performance over 10GHz to 1000GHz frequency range with both the fundamental and harmonic mixing modes.

Table 1 shows the measured harmonic mixings with LO= 99GHz, 99/4GHz, 99/5GHz, 99/6GHz, 99/7GHz. The S/N of IF output is nearly identical performance from 14GHz to 99GHz of LO power under different optimum bias currents.

Finally, we have investigated the IF phase shift and then obtained good results of more than 90 degrees controlled under RF=59.34GHz, as shown in Fig.4. Figure 4 shows the IF output power(upper half) and the IF output phase(lower half) versus the junction bias current at RF=59.34GHz and 26K. The IF output peaks, mark 1 and mark 2 that correspond to different bias currents, have the nearly same values, -31.896dB and -31.719 but the large difference of their output phases, such as 143.71 and -49.57 degrees, respectively. Phsed array antenna can be made by using the number of our mixer antenna.

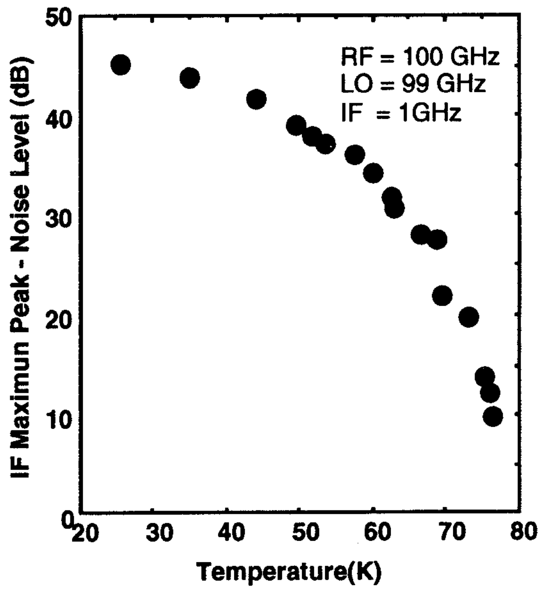

Fig.3 Temperature dependence of IF output of fundamental mixing with RF=100GHz and LO=99GHz.

Table 1 Harmonic mixing performances at RF=100GHz at 26K

LO (GHz)	IF S/N(dB)	Bias (μA)
99	45	125
99 / 4	44	30
99 / 5	40	170
99 / 6	40	1000
99 / 7	40	80

ACKNOWLEDGMENT

The authors thank Prof.S.Tanaka for his continuous encouragement in this study. This work was supported by NEDO for the R&D of Industrial Science and Technology Frontier Program.

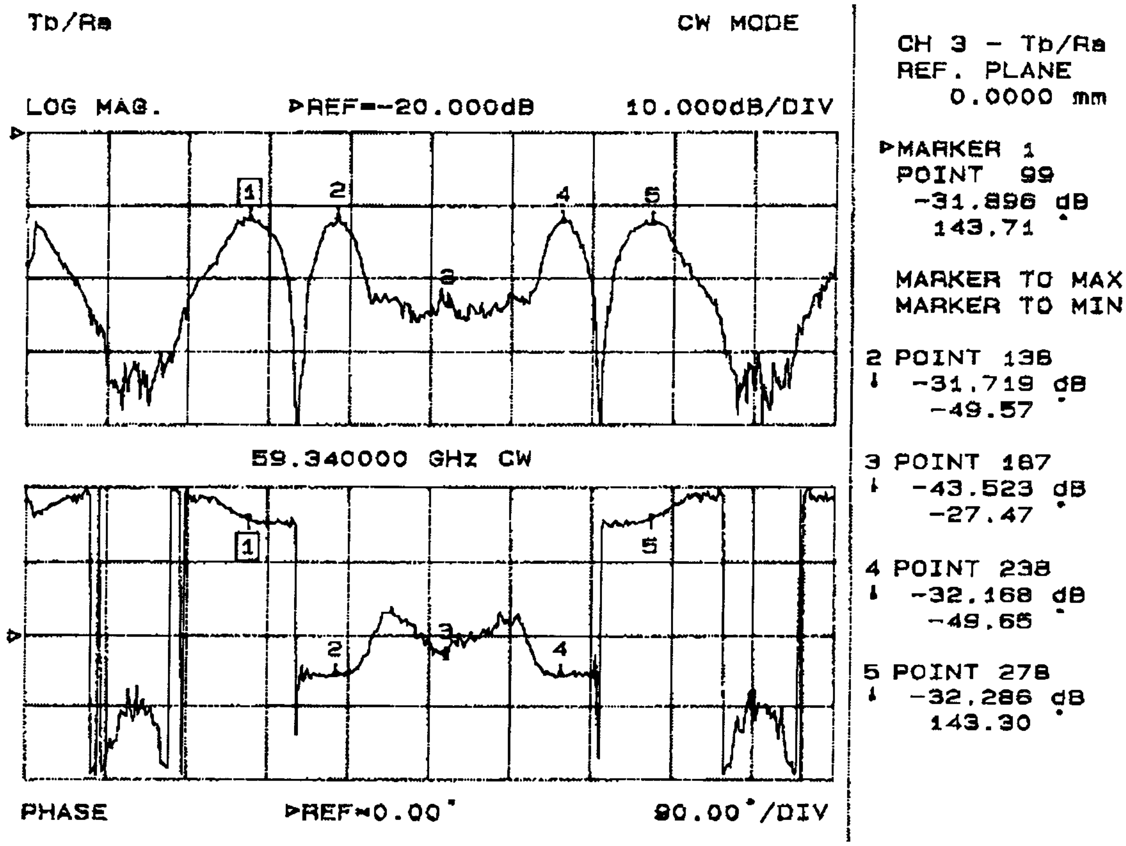

Fig.4 IF output power and IF output phase versus junction bias current at signal frequency of RF=59.34GHz and at device temperature of 26K. Mark 1 and mark 5 (mark 2 and mark 4) correspond to the same bias current.

REFERENCES

1. D.Terpstra, A.J.H.M.Rijinders, F.H.G.Roesthuis, D.H.A.Blank, G.J.Gerritsma and H.Rogalla, Physica C217(1993) 151-155.
2. K.Suzuki, S.Yoshikawa, K.Yamaguchi, K.Hayashi, S.Fujino, T.Takenaka, T.Mitsuzuka, Y.Enomoto, K.Imai, F.Suginoshita, N.Yazawa, 1993 IEEE MTT-S Digest, vol.3, 1429-1432.
3. K.Suzuki, K.Hayashi, A.T.Murphy, M.Fujimoto, S.Yoshikawa, K.Yamaguchi, Y.Enomoto, 1994 IEEE MTT-S Digest, vol.2, 1001-1004.
4. C.H.Neumann, K.Yamaguchi, K.Hayashi, K.Suzuki, Y.Enomoto and S.Tanaka, Pysica C 210 (1993) pp138-146.
5. K.Suzuki, K.Tokunaga, M.Ban, Y.Ishimaru, M.Fujimoto, K.Hayashi and Y.Enomoto, Extened Absts 1995 Int. Workshop on Superconductivity June 18-21,1995 Maui, Hawaii, U.S.A., 174-177.
6. J.Konopka, I.Wolf, S.Beuven and M.Siegel, Extended Abstracts of ISEC'95 Sept.18-21, 1995, Nagoya, Japan, 393-395.
7. H.Shimakage, Y.Uzawa, W.Chujo, Z.Wang, Extended Abstracts of ISEC'95 Sept.18-21, 1995, Nagoya, Japan, 429-430.