# A Photonic Local Oscillator for an SIS Mixer in the 100 GHz Band

T. Noguchi, A. Ueda, H.Iwashita, Y. Sekimoto, M. Ishiguro,
T. Ishibashi[†,1], H. Ito[†], and T. Nagatsuma[††]

*Nobeyama Radio Observatory*
[†]*NTT Photonics Laboratories, NTT Corporation*
[††]*NTT Telecommunications Energy Laboratories, NTT Corporation*

## Abstract

We have developed a waveguide-mounted photomixer in the 75-115 GHz band with a uni-traveling carrier photodiode which is optically-pumped by two 1.55-$\mu$m lasers. We have successfully demonstrated to produce an output power of $\sim$2 mW at 100 GHz with an input laser power of $\sim$100 mW. An SIS mixer has been pumped by the photomixer as a local oscillator. It is found that in this configuration the photomixer can provide a sufficient local oscillator power required for optimum operation of the SIS mixer in the frequency band from 85 to 110 GHz. We have carried out similar experiment using a Gunn-diode local oscillator source and carefully compared the receiver noise temperature of the SIS mixer with those pumped by the photomixer. It is found that the receiver noise temperatures of the SIS mixer pumped by the photomixer is a little higher than those pumped by the Gunn oscillator.

## Introduction

Millimeter- and submillimeter-wave heterodyne mixers based on the Superconductor-Insulator-Superconductor (SIS) junctions have used a local oscillator (LO) source which is a combination of a Gunn diode and multipliers. Since the LO source with the combination of a Gunn diode and multipliers has a mechanical complexity and poor frequency coverage especially at submillimeter wavelength, a compact and mechanically-simple LO source with broad frequency coverage is highly required for submillimeter-wave SIS receivers in the radio telescopes. Photomixers, which generate a difference frequency of two diode lasers at millimeter and submillimeter wavelength by photoconductive mixing, have been alternatively developed. Photomixers are so compact solid-state sources with broad frequency tunability that they can meet the requirement for the LO source of the SIS receivers at millimeter and submillimeter wavelengths.

It has been recently shown that photomixers using a uni-traveling carrier photodiode (UTC-PD) have a great potential for generation of millimeter-wave radiation with a bandwidth as high as 220 GHz [1]. Based on a simple analysis, it is expected that a 3-dB falloff bandwidth of the UTC-PD determined by carrier traveling time can be in a THz range [2]. The UTC-PD photomixer has emerged as one of the promising candidates to generate the millimeter- and submillimeter-wave radiation.

[1]Present affiliation: NTT Electronics Corporation

We have designed a new photomixer using the UTC-PD for generation of W-band radiation and successfully demonstrated to generate output power of $\sim$1 mW at 100 GHz by the photomixer.[3] Although the output power of the photomixer is thought to be enough to pump the SIS mixers as an LO of the usual receivers in this frequency band, noise characteristics of the photomixer have not been fully understood. At present, it is especially important to know the noise level of the photomixer when it is used to pump a low-noise SIS mixer as an LO. We have systematically measured noise temperature of an SIS mixer pumped by the photomixer as well as a Gunn diode as an LO. The measured noise temperature of those two cases are carefully compared to estimate the noise level of the photomixer in reference to that of Gunn diode.

In this paper, design and performance of the photomixer using the UTC-PD in the W band is briefly described. Then experimental results of measurement on noise temperature of SIS mixers using the photomixer as well as the Gunn diode as an LO are presented.

## UTC-PD Photomixer

We have made a waveguide photomixer in the W-band using the UTC-PD. Detailed design of the UTC-PD and photomixer is described in Ref.[3]. A cross section of the photomixer mount is schematically shown in Fig. 1. Photographs of the mixer mount and the diode chip are also shown in Fig. 1.

Lasers ($\lambda = 1.5\mu$m) provided by two distributed-feedback (DFB) semiconductor laser-diodes are combined by a coupler into an optical fiber and then amplified by an optical fiber amplifier. The amplified lasers are focused onto the UTC-PD by a lens located in the photomixer mount. Schematic diagram of the photomixer experiment is shown in Fig. 2. The position of the lens is precisely aligned against the photodiode so that maximum power of millimeter-wave radiation is available at the output port of the photomixer mount. The output millimeter-wave radiation from the photomixer is detected by a spectrum analyzer with a harmonic mixer (HP11970) or a Schottky-diode detector.

In Fig. 3 output of the photomixer power measured by a Schottky-diode detector is plotted as a function of the photocurrent of the UTC-PD. It is noted here that the photocurrent of the UTC-PD induced by lasers is approximately proportional to the amount of laser power coupled to the diode in the experiment at lower frequency[4]. It is clear that the output power increases approximately in proportion to the photocurrent (or the input laser power) at lower photocurrent. At the photocurrent of 20 mA the output power reaches $\sim$2 mW, which is, as far as we know, one or two orders of magnitude higher than those generated by photomixers in this frequency band.[5]

In Fig. 4 a typical spectrum near 100 GHz of photomixer output is shown. Width of the output spectrum of the photomixer is less than 10 MHz, which is mainly governed by fluctuation of frequencies of the two lasers, since freely-running lasers are used in the experiment. It should be noted that no serious spurious peaks are found in this frequency range.

## SIS Mixer Experiment

The photomixer was used as an LO source for SIS mixers in the 100 GHz band. The photomixer output and an RF signal are combined by a cross-guide coupler with a coupling efficiency of < -20 dB placed on the 4-K stage in the dewar and then coupled into the SIS mixer. This LO coupling scheme is popularly used in low-noise receivers at millimeter wavelengths. Schematic diagram of a low-noise receiver employing SIS mixer associated with an LO source of the photomixer is shown in Fig. 5.

In order to compare noise of the photomixer with that of Gunn-diode oscillator, we have carried out similar experiment using a Gunn-diode LO source. Then, we carefully compared receiver noise temperatures of the SIS mixer pumped by the photomixer with those pumped by the Gunn-diode oscillator.

## Results and Discussion

Pumped and unpumped I-V curves of an SIS mixer by the Gunn-diode oscillator and photomixer at 100 GHz as well as the hot (295 K) and cold (80 K) total IF power response are shown in Fig. 6(a) and (b), respectively. We have found that the photomixer is able to provide a sufficient LO power required to pump the SIS mixer in the frequency band from 85, which approximately corresponds to a cut-off frequency of the waveguide in the cross-guide coupler and mixer block, to 120 GHz. The frequency dependence of the achieved receiver noise temperature for the Gunn-diode LO as well as for the photomixer LO are shown in Fig. 7. It is found that no significant difference between the noise temperatures of the SIS mixer pumped with the Gunn diode and phtomixer is observed in this measurement. However, it is noted here that magnitude of the noise temperature of the SIS mixer is higher than those of usual SIS mixers in this frequency band. Since we suspected that the small amount of LO noise is deafened by the mixer noise, we carried out the same experiment using an SIS mixer with much lower noise temperature.

In Fig. 8, the receiver noise temperatures of the lower noise SIS mixer pumped with the photomixer LO and Gunn-diode LO are shown. In this case, the receiver noise temperature for the photomixer LO is systematically higher than that for the Gunn-diode LO. This result indicates that the photomixer has an “excess noise” with equivalent temperature from 15 to 25 K compared to the Gunn-diode oscillator.

It should be noted that photocurrent in the photomixer used in the second experiment is approximately half of that in the first experiment, when the same amount of laser power as that in the first experiment is applied. This is due to degradation of the photo-diode and/or poor alignment of optical system. As a result, output power of the photomixer was approximately 40 % of that in the first experiment.

We found that the “excess noise” increases as the laser power is decreased keeping the input power to the photomixer constant. We confirmed that noise figure (NF) of the optical fiber amplifier is approximately constant and independent on its gain. These results indicate that the “excess noise” is mainly dominated by the amplifier noise. It is expected that the “excess noise” can be suppressed by the increase of output power of the photomixer. We think the fact that the “excess noise” obtained in the first experiment is quite small is achieved by high output power of the photomixer.

Another noise source is harmonic oscillations generated in the photomixer, because sideband noise of the harmonic oscillations might be down-converted to the IF frequency in the SIS mixer. A recent experiment of an open-structured photomixer carried out by Hirata *et al.* [6] and indicates that significant amount of harmonic oscillations are excited in the photomixer. It is possible to eliminate the harmonic oscillations penetrating into the SIS mixer by adopting an adequate low-pass filter in the output port of the photomixer. Although reason of the "excess noise" of the photomixer has not been fully understood yet, we are now studying the noise issue in the photomixer.

## Summary

We have exploited a photomixer for generation of millimeter wave at W band using a UTC-PD and successfully demonstrated to generate millimeter-wave radiation with a power as high as 2 mW in the 100 GHz band. As far as we know, this is the highest output power ever generated by any kind of photomixers in this frequency band. An SIS mixer was pumped by the photomixer as an LO and we found that the photomixer can provide a sufficient power to drive the SIS mixer. It is found that the noise added to the SIS mixer by the photomixer is a little higher than that by a Gunn oscillator. Although origin of the additional noise of the photomixer has not been fully understood yet, we are studying to find the origin of the additional noise experimentally as well as theoretically.

## Acknowledgment

The authors would like to thank S. Matsuura of Institute of Space and Astronautical Sciences (ISAS) for stimulative discussion. This work was supported by a Grant-in-Aid for Scientific Research from the Ministry of Education, Culture, Sports, Science and Technology.

## References

[1] H. Ito, T. Furuta, S. Kodama, N. Watanabe, and T. Ishibashi, "InP/InGaAs Uni-Traveling-Carrier Photodiode with 220 GHz Bandwidth", *Electron. Lett.*, **35**, 1556–1557, 1999.

[2] T. Ishibashi, H. Fushimi, T. Furuta, and H. Ito, "Uni-Traveling-Carrier Photodiodes for Electromagnetic Wave Generation", *Proc. IEEE 7th Int. Conference on Terahertz Electron.*, pp. 36–39, Nara, Japan, Nov. 1999.

[3] T. Noguchi, A. Ueda, H. Iwashita, S. Takano, Y. Sekimoto, M. Ishiguro, T. Ishibashi, H. Ito, and T. Nagatsuma, 12th Int. Symp. Space Terahertz Technology, 3.2, San Diego, Feb. 14-16, 2001, Millimeter Wave Generation Using A Uni-Traveling-Carrier Photodiode.

[4] H. Ito, T. Ohno, H. Fushimi, T. Furuta, S. Kodama, and T. Ishibashi, "60 GHz high output power uni-traveling-carrier photodiodes with integrated bias circuit", *Electron. Lett.*, **36**, 747–748, 2000.

[5] P. G. Huggard, B. N. Ellison, P. Shen, N. J. Gomes, P. A. Davies, W. P. Shillue, A. Vaccari, W. Grammer, and J. M. Payne, ALMA Memo #396, "A Photonic MM-Wave Reference and Local Oscillator Source".

[6] A. Hirata, T. Nagatsuma, R. Yano, H. Ito, T. Furuta, Y. Hirota, T. Ishibashi, H. Matsuo, A. Ueda, T. Noguchi, Y. Sekimoto, M. Ishiguro, and S. Matsuura, "Output Power Measurement of Wide-band Photonic Local Oscillator at 100-800 GHz", *preprint*.

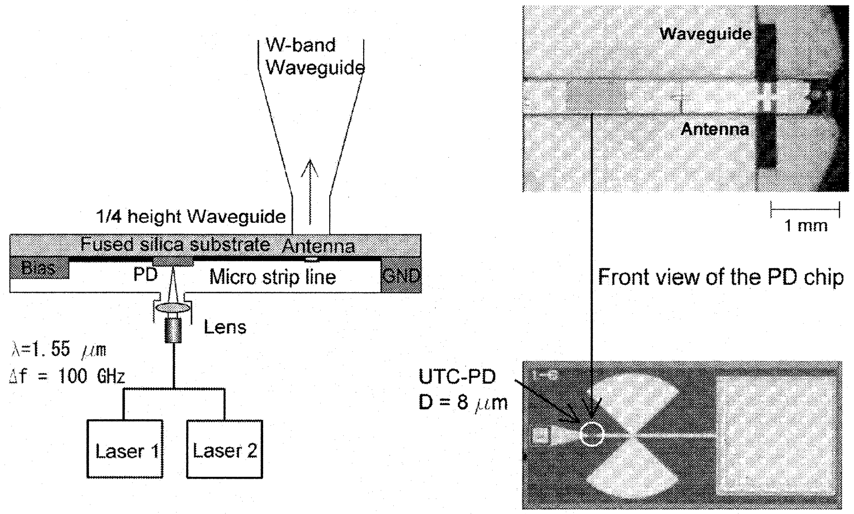



Fig. 1 Cross section of the photomixer mount (left), photographs of phtomixer mount (top right) and a UTC-PD chip (bottom left).

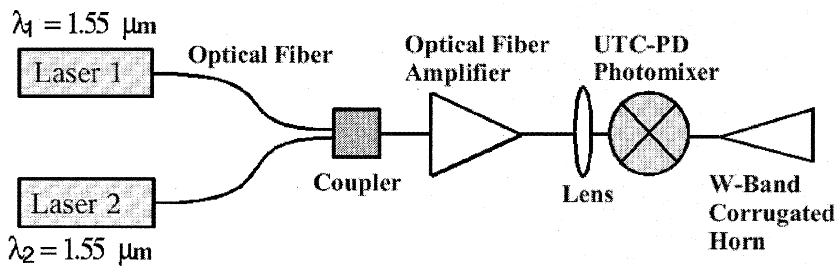



Fig. 2 Schematic layout of a photomixer oscillator.

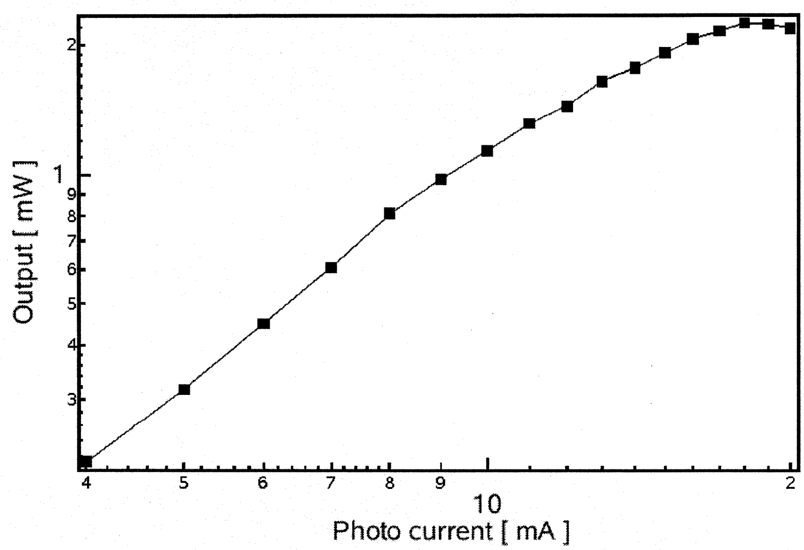



Fig. 3 Output power of the photomixer as a function of photocurrent induced in the photodiode by the laser irradiation.

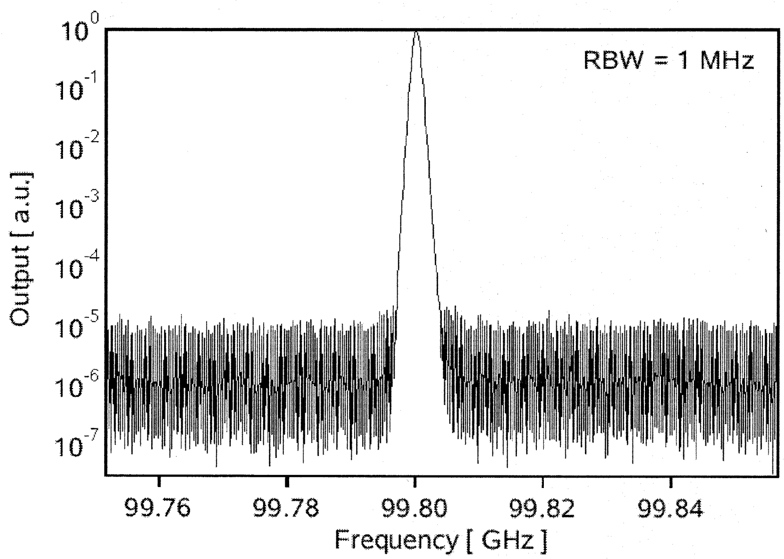



Fig. 4 Typical measured spectrum of the photomixer output.

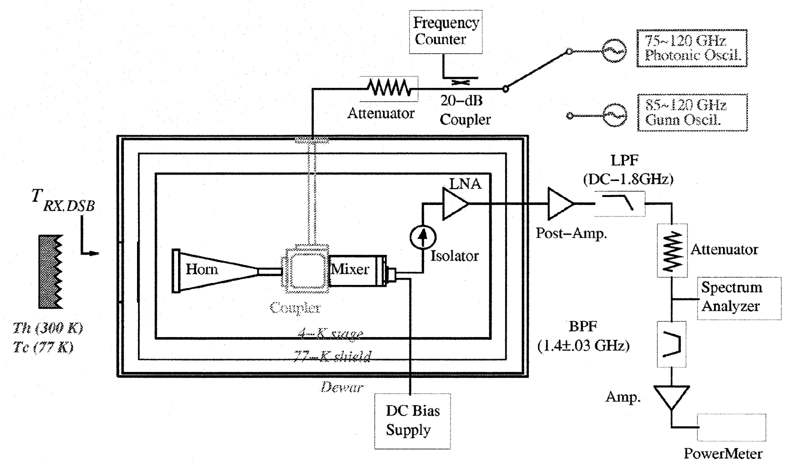
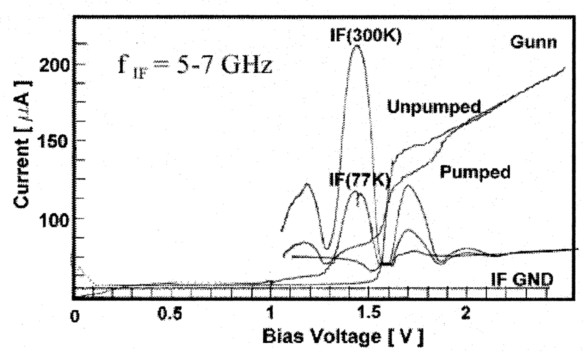
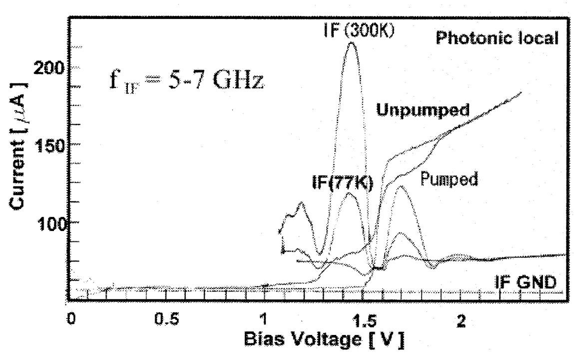



Fig. 5 Schematic layout of an low-noise SIS receiver with a phtomixer LO and Gunn-diode LO.




(a)




(b)

Fig. 6 Pumped and unpumped I-V curves and total IF power (a) by a Gunn oscillator and (b) by a photonic oscillator.

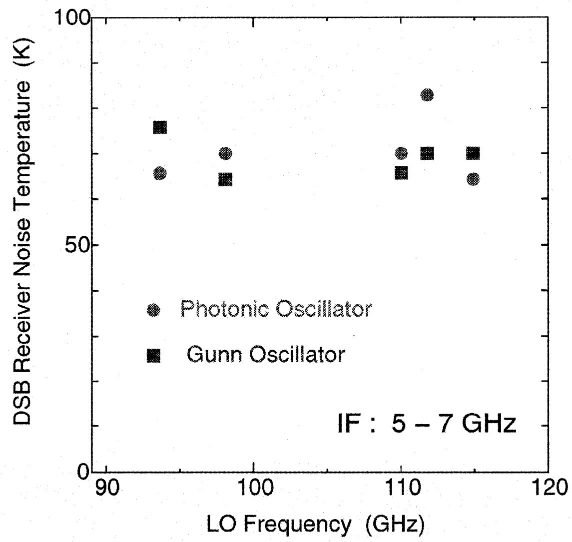



Fig. 7 Receiver noise temperature of an SIS mixer pumped with the photomixer and Gunn-diode oscillator as a function of frequency.

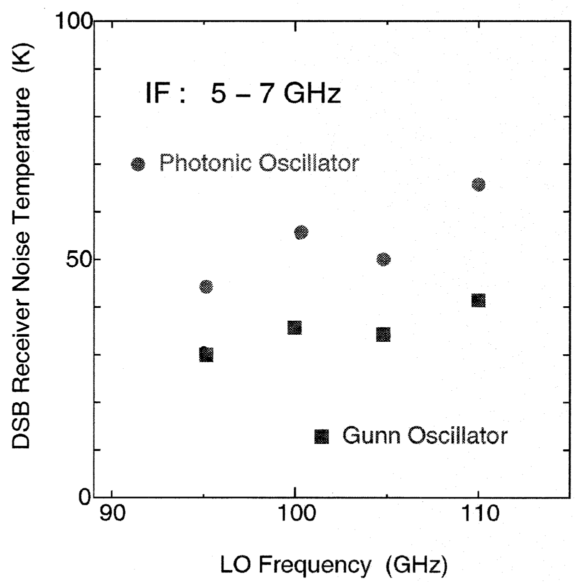



Fig. 8 Receiver noise temperature of an SIS mixer with good noise characteristics pumped with the photomixer and Gunn-diode oscillator as a function of frequency.