Amplitude Noise in a Photomixer Using a UTC-PD in the 100 GHz Band

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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-μm 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 (Superconductor-Insulator-Superconductor) mixer has been pumped by the photomixer as a local oscillator (LO). We have made similar experiment using a Gunn-diode LO 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 as low as those pumped by the Gunn oscillator. The photomixer was employed as an LO in an SIS receiver used in the 45-m telescope at Nobeyama Radio Observatory and we have successfully observed an interstellar molecular spectral line with the receiver for the rst time.

1. Introduction

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 [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.

We have designed a new photomixer using the UTC-PD and successfully demonstrated to generate output power of $\sim$1 mW at 100 GHz by the photomixer. Although the output power of the photomixer is thought to be enough to pump SIS mixers as an LO of the usual receivers in this frequency band, noise characteristics of the photomixer have not been fully understood yet. 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.

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In this paper, performance of the photomixer using the UTC-PD in the W band is brie y described. Then an experimental setup and results of measurement on noise temperature of SIS mixers using the photomixer as well as the Gunn diode as an LO are presented. Finally, we present preliminary results of radio astronomical observation of an interstellar molecular spectral line of a carbon mono-sul de (CS) at 97.98 GHz with an SIS receiver in which the photomixer is used as an LO.

2. Photomixer Performance

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]. Schematic diagram of the photomixer oscillator at the W band is shown in Fig. 1. Millimeter-wave output power from the photomixer measured by a Schottky-diode detector is plotted as a function of photocurrent of the UTC-PD in Fig. 2. 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 previous 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. The output power reaches $\sim$2 mW at the photocurrent of 20 mA where laser power of $\sim$100 mW each is applied to the photomixer [5, 6]. It is noted that as far as we know, the power achieved in this experiment is one or two orders of magnitude higher than those generated by photomixers in this frequency band [7].

A typical spectrum of photomixer output near 100 GHz is shown in Fig. 3. Frequency width of the output spectrum of the photomixer is less than 10 MHz, which is mainly governed by uctuation of frequencies of the lasers, since freely-running lasers are used in the experiment. It should be noted that no serious spurious peaks are not found in this frequency range. Frequency dependence of output power of the photomixer is plotted in Fig. 4. It is found that relative variation of the photomixer output power is less than 3 dB over the entire range of W-band (75 – 115 GHz) without any mechanical tuning mechanisms usually used in Gunn-diode oscillators.

3. Photomixer LO for SIS Mixers

The photomixer was used as an LO source for SIS mixers in the 100 GHz band. The photomixer output as an LO and an RF signal are combined by a cross-guide coupler with a coupling ef cienc y of $<$ -20 dB placed on a 4-K stage in a dewar and then coupled into the SIS mixer. It is noted here that 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 temperature of the SIS mixer pumped by the photomixer with those pumped by the Gunn-diode oscillator. Pumped and unpumped I-V curves of an SIS mixer by the Gunn-diode oscillator and photomixer at 100 GHz are shown in Fig. 6(a) and (b), respectively. Total IF power response to hot (295 K) and cold (80 K) loads are also shown in those gures. We have found that the photomixer is able to provide suf cient LO power required to pump the SIS mixer in the frequency band from 85 GHz, 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 measured receiver noise temperature for the Gunn-diode LO as well as the photomixer LO are shown in Fig. 7. No signi cant difference between the noise temperatures of the SIS mixer pumped with the Gunn diode and phtomixer was found in this experiment.

The estimated noise in the photomixer output from the measured receiver noise temperature is as high as $\sim$10 K/μW, which is much smaller than that expected by Shillue including relative intensity noise (RIN) of lasers [8], if the noise in the Gunn diode output of 1 K/μW is assumed. It is demonstrated by this experiment that the noise in the photomixer is suf ciently low and that the photomixer is quite adequate for supplying the LO to SIS mixers in the 100 GHz band.

Radioastronomical Observation Using Photomixer LO

As a next step, the photomixer was applied to an LO source of an SIS receiver used in the 45-m telescope at Nobeyama Radio Observatory and we carried out actual radioastronomical observations using the SIS receiver with the photomixer LO [9]. The laser system employed here generates an optical comb, which enables stable and precise production of the beat signal from the photomixer [10]. A block diagram of the laser system is shown in the left side of Fig. 8. The output of a laser at about 1.55 μm is amplitude-modulated by a radio frequency (RF) and consequently the optical comb is generated. Two appropriate emission lines of this comb are selected with tunable optical lters and ampli ed, and then transmitted to the photomixer with an optical ber .

We have used two nearly identical SIS receivers simultaneously. One (called S80) is pumped by a conventional Gunn-diode LO system, while the other (called S100) is pumped by the photomixer LO as schematically shown in Fig. 8. The radio signal was divided into two by a polarization grid placed in front of the receivers and they are coupled to the respective SIS receivers. In order to make a direct comparison, data were simultaneously obtained by the two SIS receivers. The intermediate frequency (IF) of 1.375 GHz was used in those two receivers. As the performance of the SIS receiver strongly depends on the LO power applied to the SIS mixer, output of power of the photomixer was carefully optimized by adjusting gain of optical ampli er and by adjusting an RF attenuator. Acousto-optic spectrometer (AOS), with a bandwidth of 40 MHz and frequency resolution of 37 kHz, were used as radio spectrometer.

The observed spectral line was the $J = 2 - 1$ rotational transition of a CS at 97.98 GHz, which is one of strong observable lines near 100 GHz in many kinds of astronomical sources. The observed source was W51, which is a famous high-mass star-forming region in our galaxy. The CS $J = 2 - 1$ spectra simultaneously observed with the receiver pumped by the photomixer LO and with that pumped by the conventional Gunn-diode LO are shown at the top and middle in Fig. 9, respectively. The integration time on source was 260 seconds. At the bottom in Fig. 9, a difference between those two spectra is shown for comparison. It is clear that both spectra are approximately identical. This result indicates that useful spectral data for radioastronomical research can be obtained by using the photomixer LO.

We carried out a small mapping observation toward the central region of W51 using the receiver with photomixer LO for further demonstration. The CS $J = 2 - 1$ line was mapped at 9 positions with a 3×3 grid as shown in Fig. 10. The integration time of each spectrum on source was 140 –160 seconds. The variation of the CS intensity is clearly found , which is in consistent with the result reported previously using receivers with the conventional Gunn-diode LO.

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 suf- cient power to drive the SIS mixer. It is found that the noise added to the SIS mixer by the photomixer is as low as that by a Gunn oscillator.The photomixer was employed as an LO in an SIS receiver used in a telescope and we have successfully observed an interstellar molecular spectral line with the receiver for the rst time.

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 Scienti c Research from the Ministry of Education, Culture, Sports, Science and Technology.

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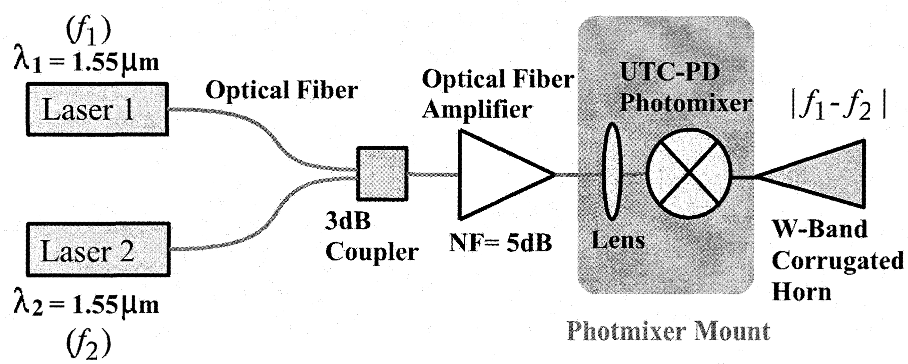

Fig. 1 Schematic diagram of a photomixer.

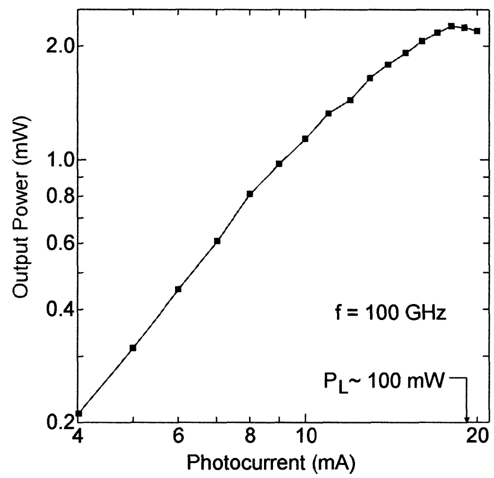

Fig. 2 Output power of the photomixer as a function of photocurrent.

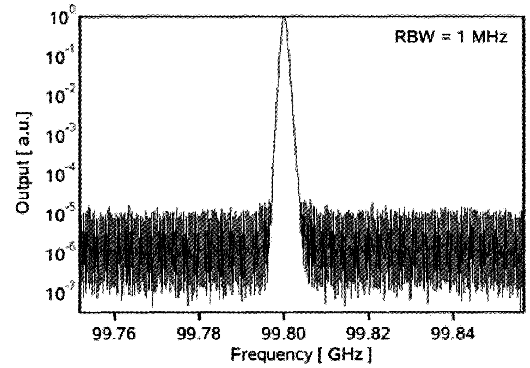

Fig. 3 Typical spectrum of photomixer output.

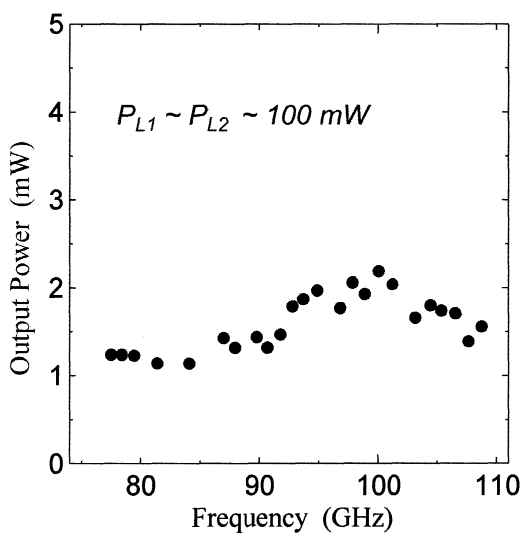

Fig. 4 Output power of the photomixer as a function of frequency.

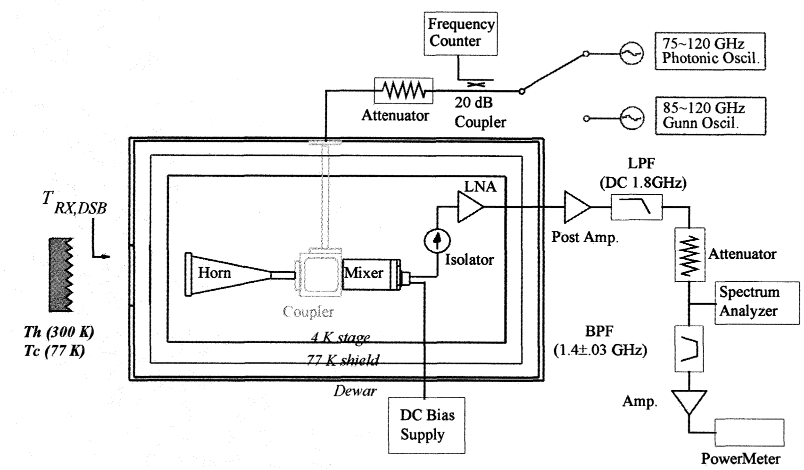

Fig. 5 Measurement setup of photomixer LO experiment using a low-noise SIS mixer.

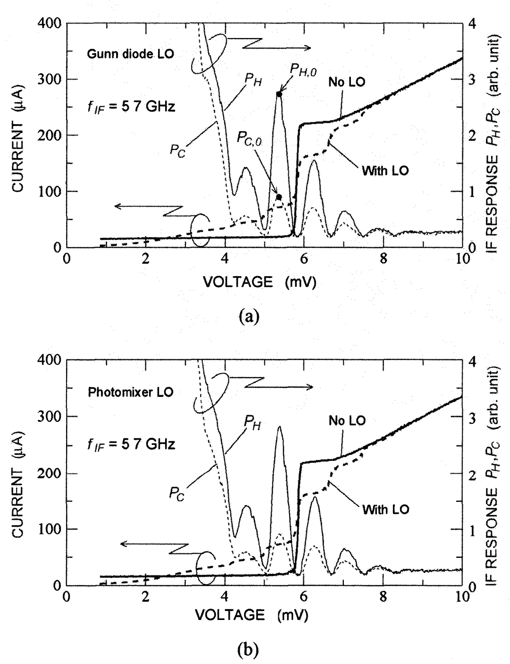

Fig. 6 dc I-V curves and IF response pumped by (a) Gunn-diode and (b) photomixer LO.

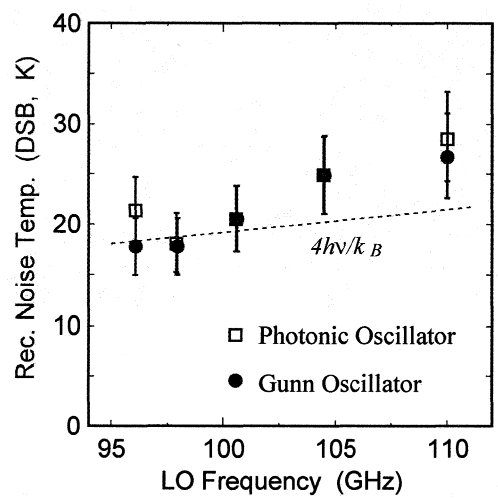

Fig. 7 Receiver noise temperature of SIS mixers pumped by the photomixer and Gunn-diode LO.

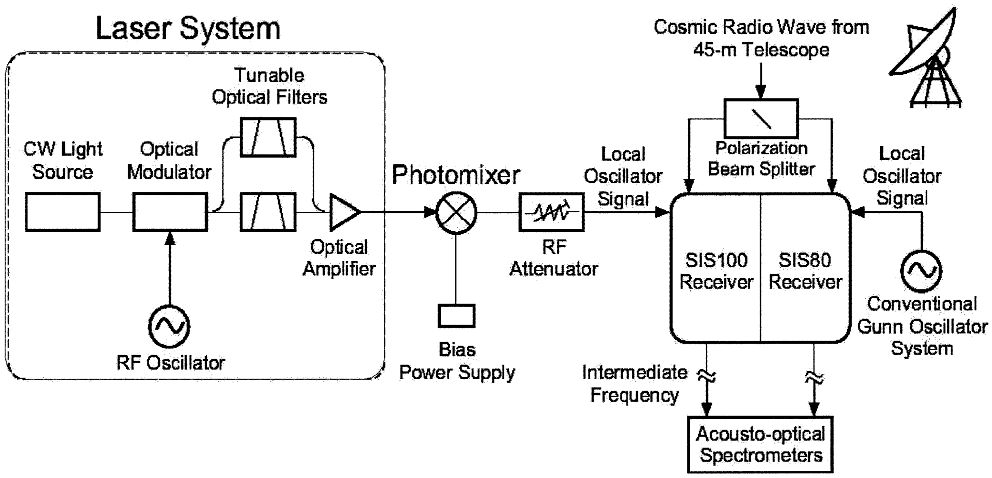

Fig. 8 Block diagram of the laser system, the photomixer and the SIS receivers used for radio-astronomical test observations.

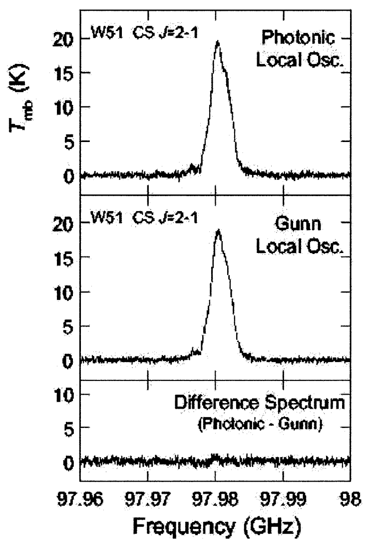

Fig. 9 CS ($J = 2 - 1$) spectra obtained with the Gunn-diode LO (top) and the photomixer LO (middle). A difference between both spectra (bottom) is also shown.

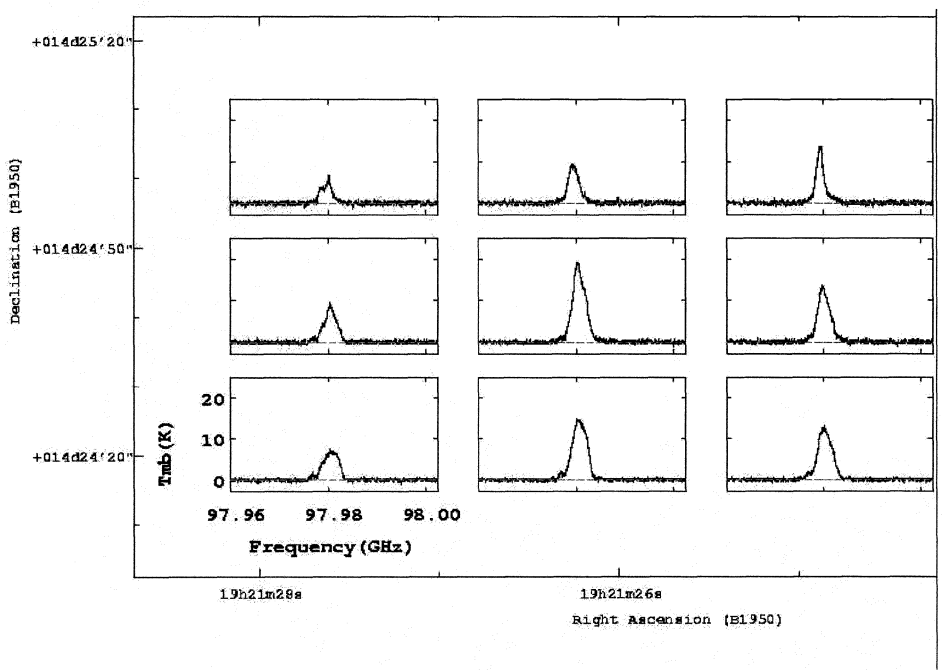

Fig. 10 Spatial map of CS ($J = 2 - 1$) spectrum.