ALMA memo 449

Noise Evaluation of Hybrid Photonic Local Oscillator at 500 GHz

Yutaro Sekimoto[*], Akitoshi Ueda[*], Takeshi Okuda[*,†], Eric Bryerton[‡],
Masahiro Sugimoto[*,†], Hiroshi Matsuo[*], Sozo Yokogawa[*], Takashi Noguchi[*],
Masato Ishiguro[*], Hiroshi Ito[§], Tadao Nagatsuma[¶],
Akihiro Hirata[¶], and John M. Payne[‖]

March 20, 2003

Abstract

A hybrid photonic local oscillator, which consists of a multiplier, a W-band power amplifier, a W-band photomixer, and a laser system, has been demonstrated to be sufficiently powerful to pump a superconducting-insulator-superconducting tunneling junction (SIS) mixer at 490 GHz. The noise temperature at 490 GHz was 135 K, which is comparable with that pumped by Gunn oscillator + multipliers. Wideband spectrum of the multiplier is also measured.

[*]National Astronomical Observatory of Japan (NAOJ), 2-21-1 Osawa Mitaka 181-8588, Japan

[†]Institute of Astronomy, University of Tokyo, Osawa Mitaka Tokyo 181-0015, Japan

[‡]National Radio Astronomy Observatory, Charlottesville, VA 22903, USA

[§]NTT Photonics Laboratories, NTT Corporation, 3-1, Morinosato Wakamiya, Atsugi, Kanagawa, 243-0198, Japan

[¶]NTT Microsystem Integration Laboratories, NTT Corporation, 3-1, Morinosato Wakamiya, Atsugi, Kanagawa, 243-0198, Japan

[‖]National Radio Astronomy Observatory, Tucson, AZ 85721-0655, USA

1 Introduction

A photomixer is a promising local oscillator (LO) source for submillimeter and terahertz wavelength because of its wide tuning range, small package, and spectral purity due to no multiplication. An NAOJ and NTT Laboratories joint research group has developed a high power W-band photomixer (~ 2 mW) using a uni-traveling-carrier photodiode (UTC-PD) sensitive for 1.55 μm [1]. The direct photonic LO with a UTC-PD photomixer has succeeded in driving a low noise superconducting-insulator-superconducting (SIS) tunnel junction mixer at 100 GHz. Amplitude noise of the photonic LO was reduced to that of a Gunn diode oscillator at 100 GHz [2]. Amplitude noise of a photonic LO has been calculated by Shillue [3]. An experiment of the photomixer with a log-periodic antenna showed that at least 10μW is available at 800 GHz [4]. Thus, the prospect of developing a direct photonic LO up to ALMA band 7 ($275 - 370$ GHz) is very high.

To make the best use of a direct photonic LO and to solve the difficulty in getting the required power at submillimeter wavelengths, we have proposed a ”hybrid option” for the first LOs using direct photonic LO driver instead of the warm multiplier assembly (WMA) [5]. This approach could make the first LO system very simple and would facilitate future extension to the direct photonic LO for all frequency bands.

The noise temperature of a heterodyne receiver of millimeter and submillimeter wavelengths is mainly determined by the mixer performance. However, for the more popular configurations amplitude noise on the LO signal appears as a degradation in the noise performance of the receiver. Thus, we have measured the amplitude noise of a hybrid photonic LO, which is a combination of a W-band photomixer, a W-band power amplifier and multipliers and a laser system, at 490 GHz with an existing SIS cartridge-type receiver at NAOJ. We also measured broad-band spectrum of the multiplier with a fourier transform spectrometer.

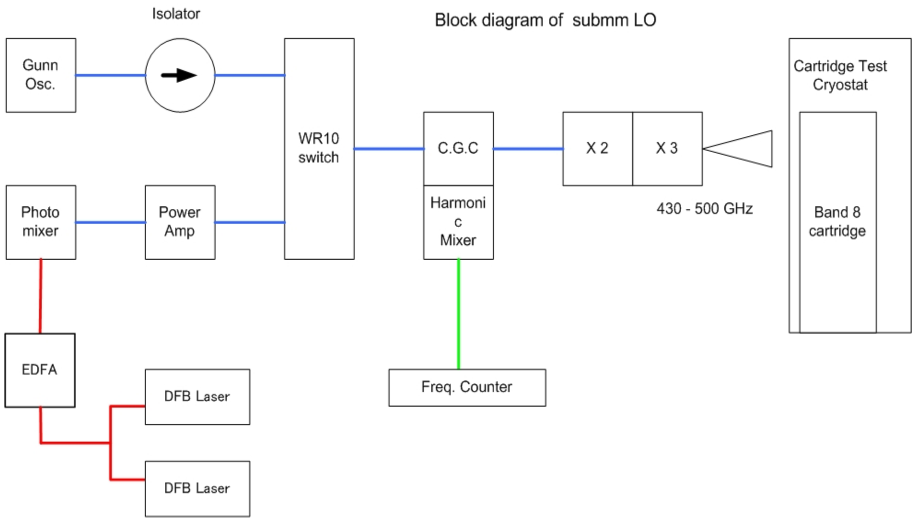

Figure 1: Block diagram of this experiment.

2 Experiments

A block diagram of this experiment is shown in Figure 1. The 500 GHz receiver is a cartridge-type and an engineering model of ALMA band 8. This cartridge structure has a diameter of 170 mm and a height of 280 mm. The receiver is installed on a cartridge test cryostat which houses an ALMA cartridge receiver (Figure 2) [6]. This cryogenic system has been modified from a three-cartridge cryostat for ASTE [7]. It uses a simple and efficient thermal link developed by NAOJ [8]. The SIS mixer is a parallel connected twin junction (PCTJ) [9]. The current density of the junction is ~ 7 kW cm^{-2} and the normal resistance of R_N is 13 Ω. Two permanent magnets are used to cancel the Josephson current of the mixer.

Cooled optics is mounted on the 4 K stage of a column-like cartridge. The LO optics is designed to use a warm LO attached to the side wall of the cryostat, which is a Gunn oscillator/multipliers system or hybrid photonic LO system. For LO coupling to the RF signal, a polyimide (Kapton) of 12 μm thickness is used.

A multiplier composed of a tripler and a doubler were manufactured by Radiometer Physics GmbH (RPG). This multiplier has four mechanical tuners and covers the frequency

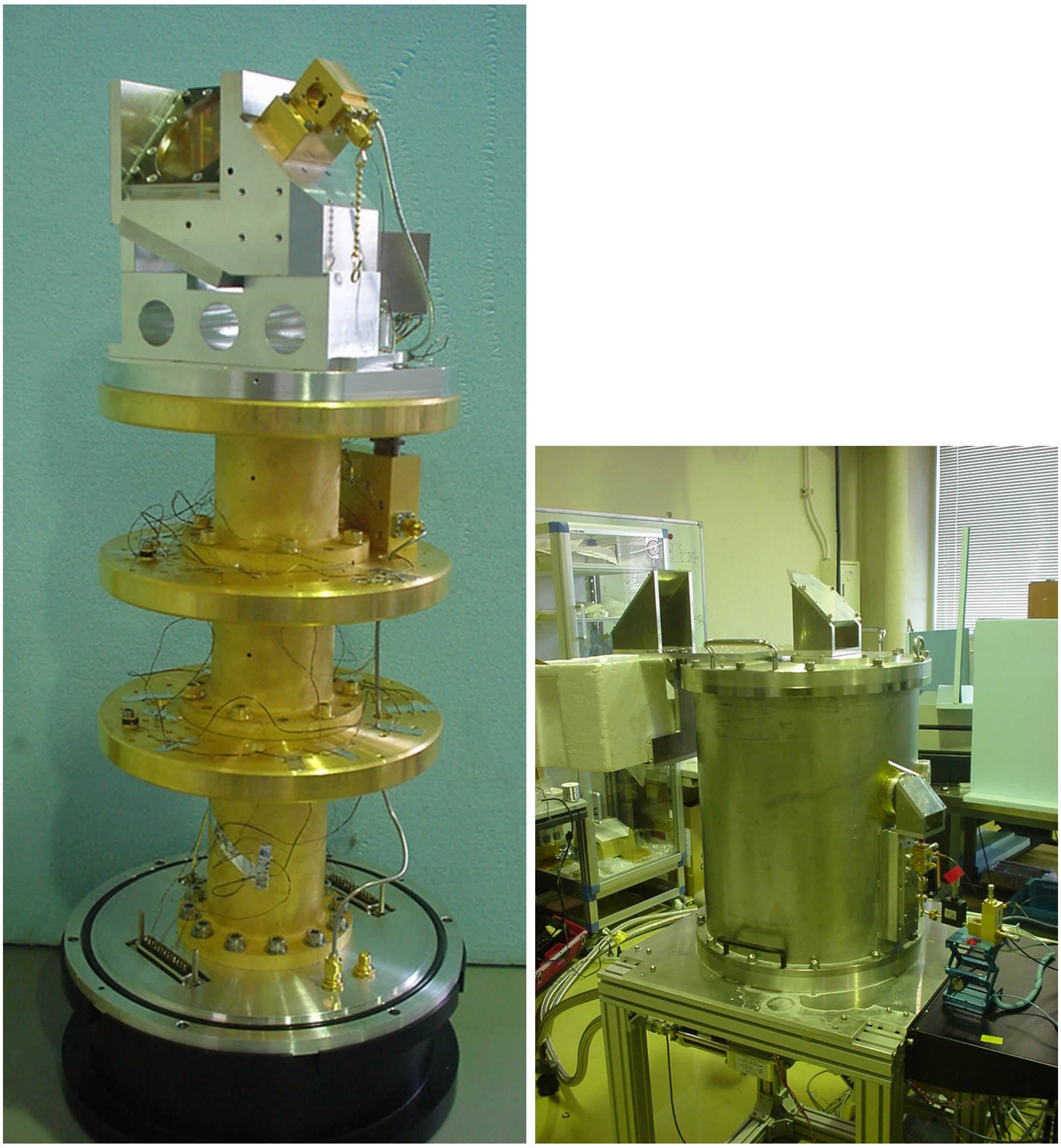

Figure 2: The left picture shows the engineering model of band 8 cartridge and the right shows a cartridge test cryostat.

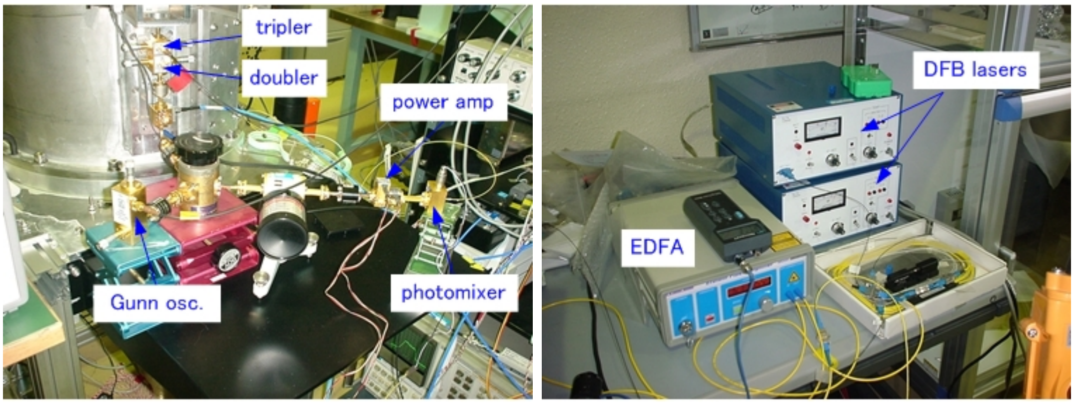

Figure 3: The left picture shows photonic and Gunn local oscillators and the right picture shows DFB lasers.

range from 430 GHz to 500 GHz with an efficiency of ~ 1 %. A dual-mode horn is attached at the output of the multiplier. With a W-band cross guide coupler, the base frequency from the photomixer or a Gunn oscillator is monitored by a frequency counter. A spectrum of this multiplier was obtained by a fourier transform spectrometer (FTS) [10] is shown in Figure 4. There are spurious emission at 647.2 GHz ($\times 8$) and 972 GHz ($\times 12$).

A waveguide switch selects the input for multipliers from a Gun oscillator or a hybrid of a W-band power amplifier and a photomixer (see Figure 3).

W-band/F-band power amplifiers have been assembled at NRAO Central Development Laboratory using an HRL InP MMIC [11]. It has a gain of 13 dB. The noise was reported to be 2000 K [12].

A W-band photomixer using a UTC-PD [1] is used in this experiment. The UTC-PD is sensitive to a wavelength of 1.55 μm and has a high saturation output while maintaining its fast response when compared to other types of photodiode, e.g. Si-PIN, InGaAs-PIN photodiodes [13]. Photo-generated holes in this photodiode do not dominate the response speed, and only electrons play the role of active carriers. Ito et al. [14] reported a pulse response for the InP/InGaAs UTC-PD of 0.97 ps (FWHM), which corresponds to a 3-dB bandwidth of 310 GHz. A simple cross-shaped microstrip waveguide transition formed on the quartz substrate is designed to couple the output power into the waveguide [15]. A

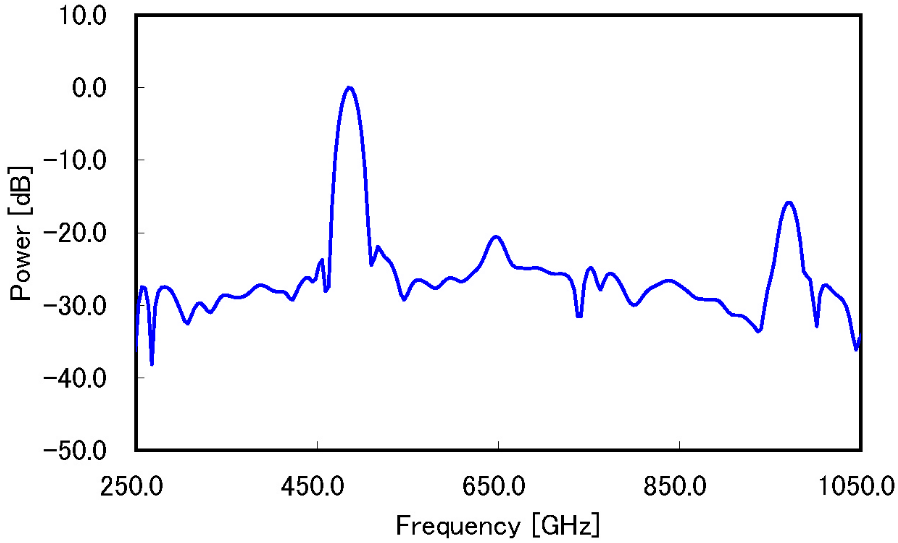

Figure 4: Fourier transform spectrometer (FTS) spectra for a multiplier manufactured by Radiometer Physics (RPG). The RPG multiplier composed of a doubler and a tripler is driven by a Gunn oscillator at a frequency of 80.8 GHz. The dual-mode horn is attached for the RPG multiplier.

return loss between micro-strip channel and the quarter-height waveguide is calculated to be about -15 dB for the frequency range of $75-110$ GHz with High Frequency Structure Simulator (Agilent technologies: HFSS) [16]. The diameter of the UTC-PD in this experiment was 8 μm.

The photomixer is driven by the heterodyne beatnote of the combined output of two DFB lasers whose emission wavelengths are around 1.55 μm (Figure 3). The line width of the lasers is a few hundred kHz in free running operation. The lasers were operated by batteries. Relative intensity noises of these lasers are estimated to be -155 dBc/Hz. The output of the fiber-coupled DFB lasers, whose total optical power is 20 mW, is amplified up to 180 mW using an Er-doped fiber amplifier (EDFA) with a noise figure of 5 dB. A polarization controller is inserted in an optical path in order to improve contrast of the interference. Output of the fiber coupled semiconductor laser diodes is combined with a single-mode fiber using a 3 dB coupler. The beam from the single-mode fiber through

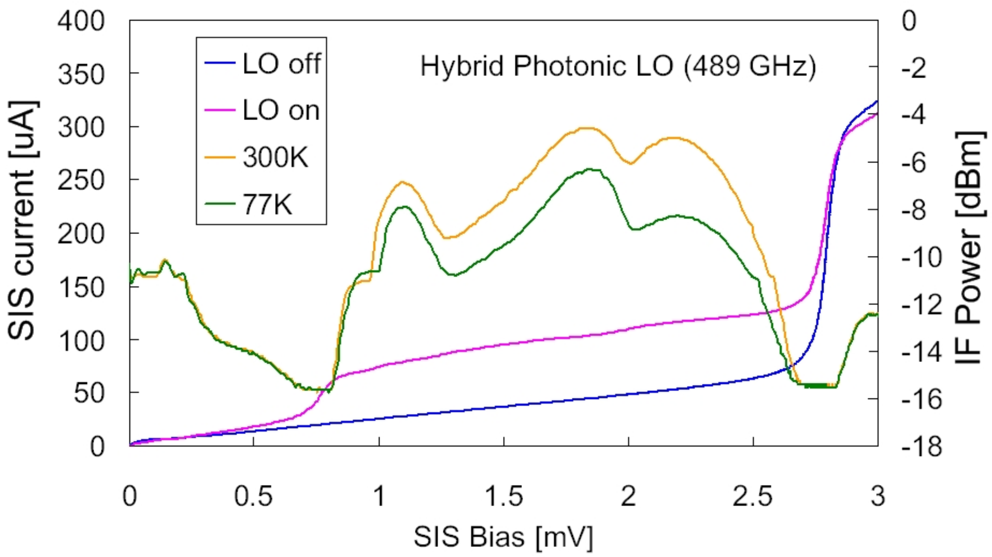

Figure 5: SIS mixer's I-V and IF-power bias-voltage curves pumped by a hybrid photonic LO at a frequency of 489 GHz. At a bias voltage of 2.2 mV, the Y-factor was 3.2 dB, which corresponds to a noise temperature of 135 K from the Plank formula. The dips at 1.0 and 2.0 mV on the IF-power curve are Shapiro steps ($hf/2e = 1.008$ mV).

relay-lenses of a self-focus and a plano-convex irradiates the UTC-PD. Estimated beam diameter on the device was about 10 μm.

3 Results

The noise temperature pumped by a hybrid photonic local oscillator at 489 GHz was around 135 K, which is comparable with that pumped by Gunn oscillator + multipliers. The SIS I-V and IF-power bias-voltage curves are shown in Figure 5. At a bias voltage of 2.2 mV, the Y-factor was 3.2 dB, which corresponds to the noise temperature of 135 K and 5.8 times quantum limit (hf/k_B). The photomixer bias voltage and current were 1.8 V and 18 mA. This photomixer produces 1 mW at 90 GHz for an optical input power of 180 mW. The output power of the hybrid photonic local oscillator is estimated to be 500 μW from the SIS I-V curve. The IF spectra with a hybrid photonic LO and a Gunn LO

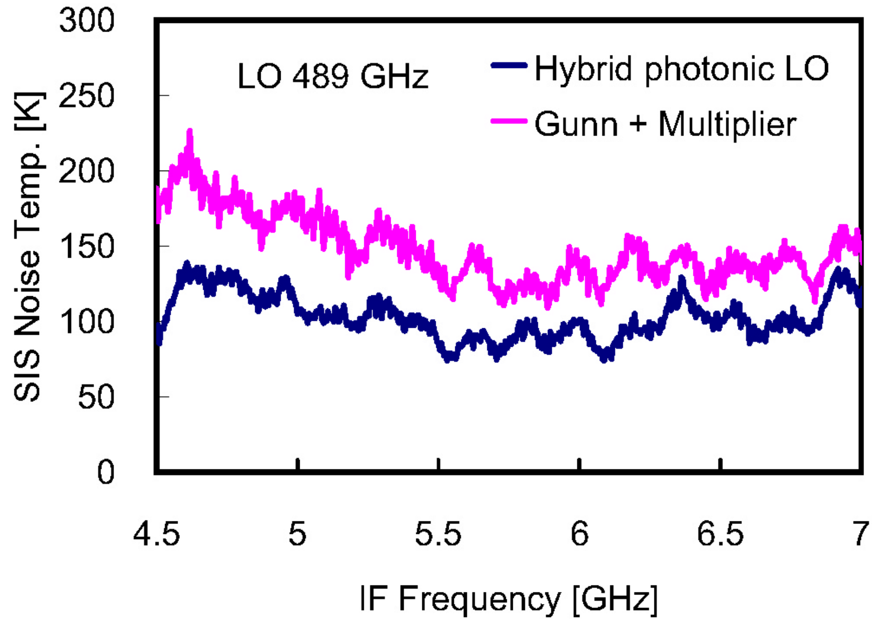

Figure 6: Noise temperatures of an SIS receiver pumped by a hybrid photonic LO and a Gunn LO with respect to IF frequency at an LO frequency of 489 GHz. The LO power for the SIS receiver by a Gunn LO is not optimum. Because the temperature scale was calculated from the Rayleigh Jeans approximation, the temperature is lower by 10 K than that from the Planck formula.

are shown in Figure 6. The IF LNA has a gain of 35 dB between 4.5 and 7.0 GHz.

Because the two lasers for the photomixer were operated in a free run, it was difficult to make an accurate comparison of the noise temperature. The LO output from multipliers composed of a tripler and a doubler changed with the frequency drift. In addition, the power of the photonic and Gunn LO was not easy to adjust for the SIS mixer. However, SIS mixers pumped by the hybrid photonic LO have at least a noise temperature performance of $\sim$ 135 K at 490 GHz. This noise temperature is comparable with that pumped by a Gunn LO.

The LO power required for the PCTJ mixer at 489 GHz is 0.8 μW. If the specified level of LO amplitude noise is less than 10 K/μW, the LO noise of 8 K is added to the receiver. We confirmed from this experiment that the LO noise of the hybrid option is not much larger than the specified level at this frequency range if the spurious emission from multiplier is enough low.

References

[1] A. Ueda, T. Noguchi, H. Iwashita, Y. Sekimoto, M. Ishiguro, S. Takano, T. Nagatsuma, H. Ito, A. Hirata, and T. Ishibashi: IEEE Trans. Microwave Theory and Techniques, May (2003) in press.

[2] A. Ueda, T. Noguchi, S. Asayama, H, Iwashita,Y. Sekimoto, M. Ishiguro, H. Ito, T. Nagatsuma, A. Hirata and W. Shillue: “ Ultra-low noise photonic local oscillator at 100 GHz ” Submitted

[3] B. Schillue 2000 ALMA memo 319 “ Photonic Local Oscillators for Radio Astronomy: Signal-to-Noise issues ”

[4] 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 photonic millimeter-wave and sub-millimeter-wave emitter at 100-800 GHz”, Electron. Lett., 2002, in press.

[5] M. Ishiguro, Y. Sekimoto, A. Ueda, S. Iguchi, T. Noguchi, J. M. Payne, L. R. D’Addario, W. Shillue ”A Hybrid Option for the First Los using Direct Photonic LO Driver” ALMA Memo No. 435

[6] Y. Sekimoto et al. 2003 in preparation

[7] S. Yokogawa, Y. Sekimoto, M. Sugimoto, et al. 2003 PASJ in press ”Plug-In Cryogenic System for Cartridge-Type SIS receivers”

[8] M. Sugimoto, Y. Sekimoto, S. Yokogawa, et al. 2003 submitted

[9] S. C. Shi, T. Noguchi, and J. Inatani 1997 IEEE Trans. Applied Superconductivity, 7, 2587.

[10] H. Matsuo, A. Sakamoto and S. Matsushita 1998 PASJ 50, 359 ”FTS measurements of Submillimeter-wave atmospheric opacity at Pampa la Bola”

[11] L. Samoska and Y. C. Leong, ”65-145 GHz InP MMIC HEMT medium power amplifiers,” IEEE MTT-S Int. Microwave Symp. Dig., vol. 3, pp.1805-1808, May 2001.

[12] E. W. Bryerton, S. K. Pan, D. Thacker, and K. Saini 2002 ALMA memo 436 ”Band 6 Receiver noise measurements using a preprototype YIG-Tunable LO”

[13] T. Ishibashi, N. Shimizu, S. Kodama, H. Ito, T. Nagatsuma, and T. Furuta,” Uni-traveling-carrier photodiodes”, Tech. Dig. Ultrafast Electronics and Optoelectronics, 83-87, Mar. 1997.

[14] H. Ito, T. Furuta, S. Kodama, T. Ishibashi,” InP/InGaAs Uni-Traveling-Carrier photodiode with 310 GHz bandwidth”, Electron. Lett., 36, 1809, 2000.

[15] T. Noguchi, A. Ueda, H. Iwashita, S. Takano, Y. Sekimoto, M. Ishiguro, T. Ishibashi, H. Ito, and T. Nagatsuma," Millimeter Wave generation using a Uni-Travelling-Carrier Photodiode", Proc. 12th Int. Symp. Space Terahertz Technology, San Diego, USA, 73, 2001.

[16] T. Noguchi, A. Ueda, H. Iwashita, Y. Sekimoto, M. Ishiguro, T. Ishibashi, H. Ito, and T. Nagatsuma,"A Photonic Local Oscillator for an SIS Mixer in the 100 GHz Band", Proc. 13th Int. Symp. Space Terahertz Technology, USA, 2002