Beam pattern measurements of a quasi-optical HEB mixer at 2 THz

Yoshihisa Irimajiri[1*], Alvaro Gonzalez[2], Satoshi Ochiai[1], Akira Kawakami[1], and Yoshinori Uzawa[1]

[1] National Institute of Information and Communications Technology (NICT), Koganei, Tokyo, 184-0015 Japan
[2] National Astronomical Observatory of Japan (NAOJ), Mitaka, Tokyo, 181-8588, Japan
*Contact: irimaji@nict.go.jp

***Abstract*— We plan to measure beam patterns of a quasi-optical NbN HEB mixer in the 2 THz-band. A 2 THz AMC (Amplifier Multiplier Chain) is used as the test RF source. A THz-QCL is phase-locked using a SLH mixer (super-lattice harmonic) mixer with 12th harmonic multiplication. A beat note is measured by a heterodyne receiver system with the phase-locked THz-QCL as a local oscillator. The amplitude and the phase of the antenna beam patterns are measured using a lock-in amplifier. If successful, this will be the first time that beam patterns are measured in amplitude and phase at frequencies as high as 2 THz.**

I. Introduction

Low noise heterodyne receivers at terahertz frequency are widely used for radio astronomical observations and atmospheric spectroscopy. Beam pattern of a receiver system is one of the important basic performances for these observations. Optics of an HEB mixer for the ASTE telescope was characterized at 900 GHz [1], and reconfigurable beam pattern measurement system for different frequency band of ALMA was reported, and beam pattern measurements were performed at 1.37 THz, 1.47 THz, and 900 GHz [2]. Experimental characterization of the HIFI FM model was described and measurements were performed at 480 GHz, 802 GHz, 1.1 THz, and 1.6 THz in [3].

We are developing an HEB mixer for the measurement of atomic oxygen line at 2.06 THz for SMILES-2 [4]. We plan to measure beam patterns of the quasi-optical HEB mixer in the 2 THz-band. The measurement set up is based on a near-field beam pattern measurement system at 0.03 to 1.6 THz [2]. If successful, this will be the first time that beam patterns are measured in amplitude and phase at frequencies as high as 2 THz.

II. Experiment setup

A quasi-optical NbN HEB mixer device was fabricated in NICT. Figure 1 shows photographs of the HEB mixer device with a log-spiral antenna, the quasi-optical mixer mount with an AR-coated hyper-hemispherical HRFZ Si lens, and the receiver setup with a parabolic focusing mirror in a 4 K cryostat. (The focusing parabolic mirror may be replaced to an ellipsoidal mirror to narrow the measurement area and shorten the observation time.)

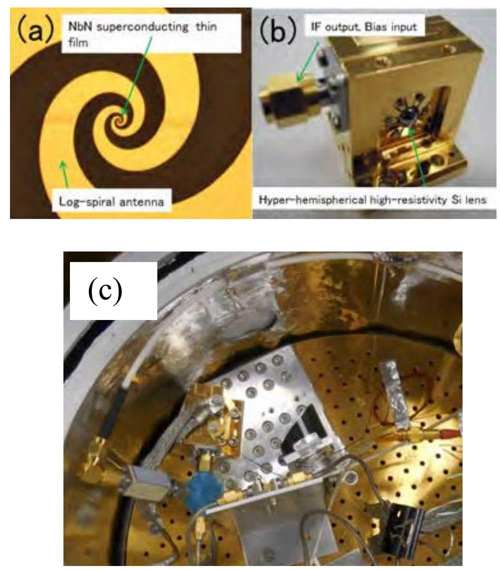

Fig. 1. (a) A quasi-optical NbN HEB mixer device with a log-spiral antenna. The device was fabricated in NICT. (b) A quasi-optical mixer block with an AR-coated hyper-hemispherical HRFZ Si lens. (c) Receiver setup with a parabolic focusing mirror in a 4 K cryostat.

A 2 THz AMC source with a diagonal horn output is used as a test RF source. The AMC source consists of a microwave synthesizer, amplifiers, four doublers, and two triplers. The multiplication factor is 144. The output frequency of the AMC source and the THz-QCL are set to be 2066.4 GHz and 2067.44 GHz, respectively so that the IF frequency goes into the IF band of the HEB mixer. The beat note of 1.04 GHz is detected by the HEB mixer with the THz-QCL as a local oscillator. A 3rd order antenna-coupled DFB QCL array at 2 THz-band provided by MIT group is cooled using a cryotel (CT) cooler. A THz-QCL with lasing frequency of ~2067 GHz is used. The THz-QCL is operated in CW-mode with an output power of ~600 μW at 45 K. The power consumption of THz-QCL is about 1.9 W. The THz-QCL is phase-locked using a SLH mixer (super-lattice harmonic) mixer with 12th harmonic multiplication. A D-band (110-170 GHz) AMC source is used as a LO for the SLH mixer at 172.32 GHz. The multiplication factor of the LO is 12, therefore, the total multiplication factor is 144 which is same as that of the 2 THz AMC source. The amplitude and the phase of the antenna beam patterns are measured using a lock-in amplifier. All oscillators are connected to a same 10 MHz reference. The AMC source is scanned by a XYZ stage. The source is rotated 90 degrees to measure co- and cross-polarization characteristics. Figure 2 shows a block diagram of the measurement setup. The far field beam pattern is calculated from near field measurements. The beam pattern of the diagonal hon of the RF source should be corrected. If possible, a RF source with a waveguide output may be used.

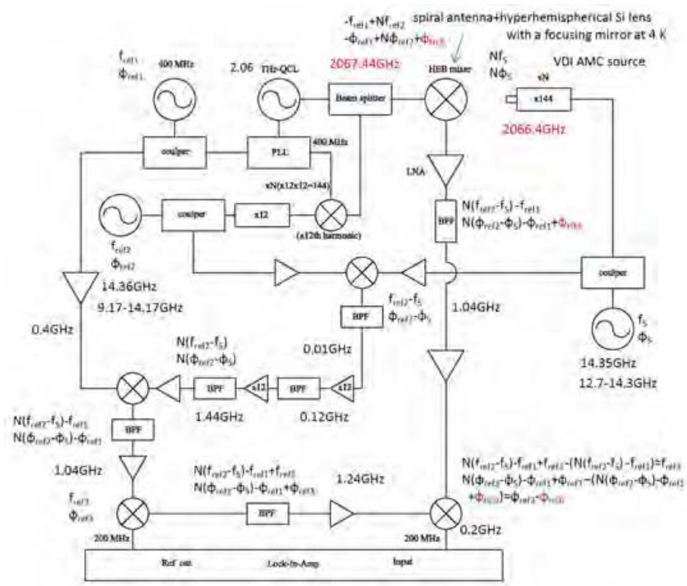

Fig. 2. Setup of beam pattern measurements of a quasi-optical 2-THz HEB mixer. A 2 THz AMC source with a diagonal horn is used for a RF source. The multiplication factor is 144. The output frequency of the AMC source and the THz-QCL are set to be 2066.4 GHz and 2067.44 GHz, respectively so that the IF frequency goes into the IF band of the HEB mixer. The beat note of 1.04 GHz is detected by the HEB mixer with the THz-QCL as a local oscillator. The THz-QCL is phase-locked using a SLH mixer with 12^{th} harmonic multiplication. A D-band AMC source is used as a LO for the SLH mixer at 172.32 GHz. The multiplication factor of the LO is 12, therefore, the total multiplication factor is 144 which is same as that of the 2 THz AMC source. The amplitude and the phase of the antenna beam patterns are measured using a lock-in amplifier. All oscillators are connected to a same 10 MHz reference. The AMC source is scanned by a XYZ stage. The source is rotated 90 degrees to measure co- and cross-polarization characteristics. The far field beam pattern is calculated from near field measurements. The beam pattern of the diagonal hon of the RF source should be corrected.

The setup of the characterization of the amplitude and the phase of the beam pattern is based on the previous work [2, 3]. The measurement set up is designed so that the phases of each microwave oscillators other than that of an HEB mixer (φ_{HEB}) are canceled out. The phase at an IF signal is described as

$$(\varphi_{HEB}+N\varphi_{ref2} - \varphi_{ref1})-N\varphi_S= N(\varphi_{ref2} - \varphi_S) - \varphi_{ref1}+\varphi_{HEB} \quad (1)$$

, where
N: harmonic number
φ_{HEB} : phase of the HEB mixer
φ_S : phase of the RF source
φ_{ref1} : phase of reference (400 MHz) for phase-locking of the THz-QCL
φ_{ref2} : phase of reference (14.36 GHz) for the LO of the SLH mixer.

In order to measure φ_{HEB}, $N(\Phi_{ref2}-\varphi_S)-\varphi_{ref1}$ should be canceled out. The phase differences between the source oscillator of the RF source and that of LO for the SLH mixer ($\Phi_{ref2}-\varphi_S$) is multiplied by 144 using two 12 times frequency multipliers. By mixing this signal with reference source for PLL (400 MHz) and reference of the lock-in amplifier (200 MHz), a phase of $N(\varphi_{ref2}-\varphi_S)-\varphi_{ref1}+\varphi_{ref3}$ is detected. Subtracting equation (1) from this, we can measure φ_{HEB} as follows

$$N(\varphi_{ref2}-\varphi_S)-\varphi_{ref1}+\varphi_{ref3}-(N(\varphi_{ref2}-\varphi_S)-\varphi_{ref1}+\varphi_{HEB})=\varphi_{HEB}+\varphi_{ref3} \quad (2)$$

, where
φ_{ref3} : phase of reference (200 MHz) of the lock-in amplifier.

The important thing is the harmonic number of the RF source (144) is same as that of the LO for the SLH mixer (144: x12x12) for this cancelation.

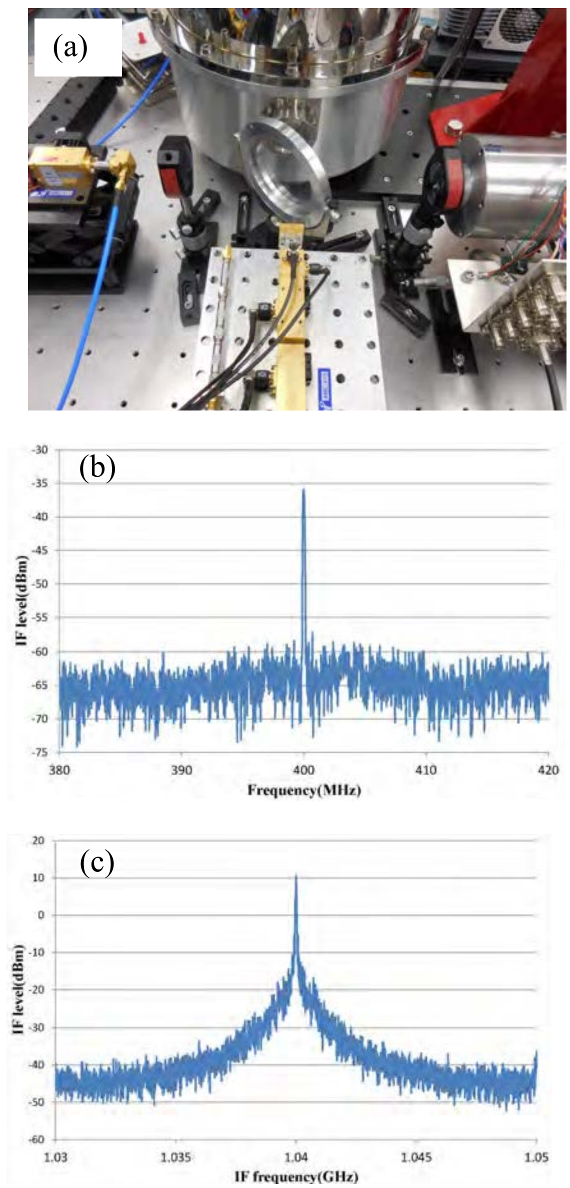

Fig. 3. (a) Photograph of a setup of test measurements. (b) A phase-locked beat note of the 2 THz-QCL detected by a SLH mixer. (c) A beat note between the phase-locked THz-QCL and an AMC source at 1.04 GHz.

III. Preliminary results

The measurement set up is under construction at the present. In order to confirm the setup can be operated at the designed frequency, we made some experiments (Figure 3 (a)). The THz-QCL is phase-locked at 2067.44 GHz using the SLH mixer. Figure 3 (b) shows the phase-locked beat note of the 2 THz-QCL. A beat note is detected at 1.04 GHz with a SN ratio of more than 50 dB at RBW of 100 kHz as shown in figure 3 (c). We will start the measurements from this spring. In the measurement, we have to pay attention to followings.

- Stability of the signal (We will use a LHe dewar for cooling of the HEB mixer to avoid mechanical vibration of a 4 K cooler. Any other vibrations, e.g. human movement, should be avoided as well. Vibration of a THz-QCL cooler and a vacuum pump would affect to the stability?)
- Calibration measurements are necessary. (Measure the same point at an each scan.)
- Scan range and measurement time should be optimized. (scan step is 75 µm (=λ/2).) (e.g. +/ 7.5 mm scan: 200 x 200(40,000 points)*0.3 sec/point=3.3 hours + calibration + 2 surfaces)
- Measure the beam patterns in as short a time as possible.
- Measure an area as small as possible, ex. at a beam waist using an ellipsoidal mirror.
- Purity of the signal (We need band-pass filters at any points.)
- Linearity of an HEB mixer regarding to an input RF signal.
- Linearity of microwave amplifiers.
- Bias point of an HEB mixer should be stable for RF input.
- Source beam pattern should be corrected. (RF source needs to be modified to a waveguide output?)
- Data processing to calculate a far filed pattern from two near filed patterns.

etc.

Conclusions

We plan to characterize the beam pattern of a quasi-optical HEB mixer at 2 THz. The measurement setup is not completed yet but we confirmed the setup works properly at the designed frequency.

We also plan to develop a waveguide-type HEB mixer with a corrugated feed horn to achieve good beam pattern and polarization characteristics. In order to avoid vibration from a mechanical cooler and a vacuum pump used for cooling a THz-QCL, an another 2 THz AMC source might be tested as a local oscillator of the HEB mixer.

References

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