Simultaneous phase-locking of two THz-QCLs using an HEBM and a comb generator

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Abstract**—** We have demonstrated simultaneous phase-locking of two THz-QCLs using an HEB mixer and a comb generator. We have also demonstrated the simultaneous phase-locking using an AMC (Amplifier/Multiplier Chain) as a THz reference. This system can be applicable for a THz radar system etc.

I. Introduction

Phase-locking of THz-QCL [1] is important for some applications such as astronomical/atmospheric observations and communications. We have demonstrated simultaneous phase-locking of two THz-QCLs using an HEBM [2] and a comb generator [3]. Two THz-QCLs with different lasing frequencies at the 3 THz band were fabricated in our laboratory, and they were cooler by different coolers, a 45 K mechanical cooler and a LHe flow-type cryostat, respectively. A Mach-Zehnder type flat optical (1.55 μm)-comb with a UTC-PD (Uni-Traveling Carrier Photodiode) was used as a THz reference. In order to generate two THz reference signals with different frequencies for each THz-QCL, three modes of the comb were selected using a programmable bandpass filters. THz waves from the THz reference and the THz-QCLs were fed into an HEBM using beam splitters. Two beat notes were detected simultaneously by an HEBM and they were put into an each PLL system for the phase-locking of the THz-QCLs.

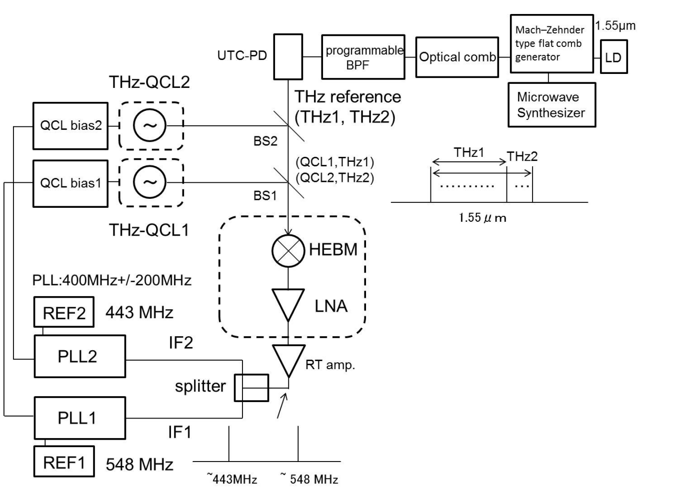

Fig. 1. A system block diagram of simultaneous phase-locking of two THz-QCLs using an HEBM and an optical comb generator followed by a UTC-PD.

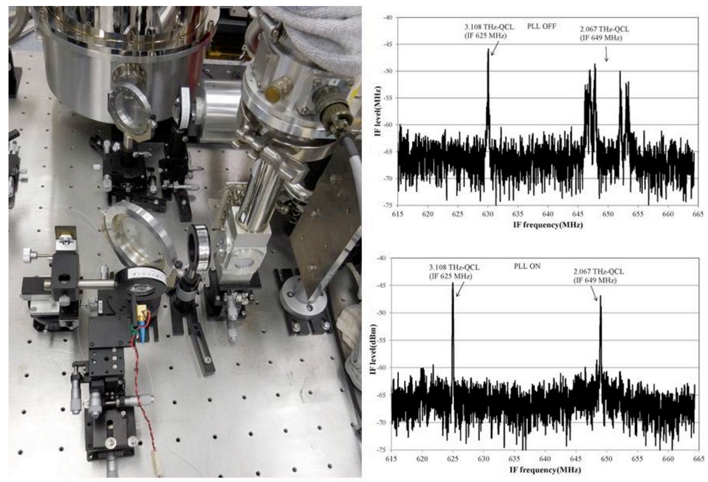

Fig. 2. A photograph of setup for the simultaneous phase-locking of two THz-QCLs (left). Each THz-QCL was cooled by different cooler, 45 K mechanical cooer and a LHe flow-type cryostat. THz reference was generated by a comb generator followed by a UTC-PD. Mylar beam splitters were used for LO injection to an HEB mixer. The detected spectrum show beat signals of PLL OFF(upper right)/ON(lower right) for 2 THz and 3 THz-QCLs.

TABLE I
FREQUENCY CONFIGULATION FOR SIMULTANEOUS PHASE-LOCKING OF TWO THz-QCLs AT 3-THz BAND USING A COMB GENERATOR AS A THz REFERENCE

Synth. Frq.(GHz)	Mode no.	UTC-PD(GHz)
17.991	172	THz1:3094.452
17.991	173	THz2:3112.443
THz-QCL device no.	QCL frq.(GHz)	IF(MHz)
QCL11dM(NICT)	QCL1:~3095	IF1:~548(THz1-QCL1)
QCL11kI(NICT)	QCL2:~3112	IF2:~443(THz2-QCL2)

TABLE II
FREQUENCY CONFIGULATION FOR SIMULTANEOUS PHASE-LOCKING OF TWO THz-QCLs AT 2-THz AND 3-THz BAND USING A COMB GENERATOR AS A THz REFERENCE

Synth. Frq.(GHz)	Mode no.	UTC-PD(GHz)
17.97241	115	THz1:2066.82715
17.97241	173	THz2:3109.22693
THz-QCL dvice no.	QCL frq.(GHz)	IF(MHz)
2THzQCL(Longwave)	QCL1:~2067.5	IF1:~649(THz1-QCL1)
QCL11lk(NICT)	QCL2:~3108.6	IF2:~625(THz2-QCL2)

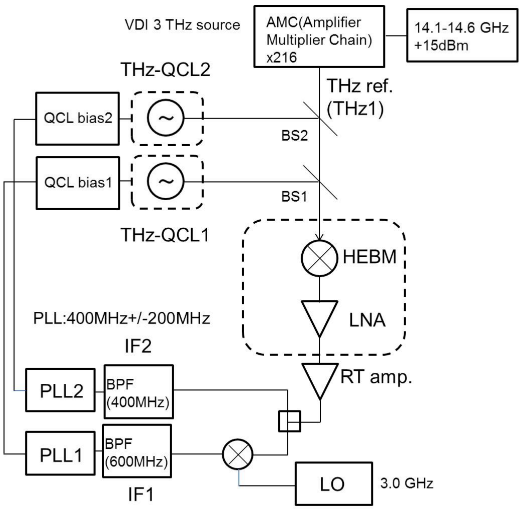

Fig. 3. Phase-locking system of two THz-QCLs using an AMC as a THz reference. In this case, we have a single THz reference signal. Therefore, the lasing frequency of two THz-QCLs should be within an IF bandwidth of an HEBM. Although, the gain IF bandwidth of the HEBM is around 3 GHz, the beat signal can be detected even at ~14 GHz if we use an appropriate LNA.

TABLE III
FREQUENCY CONFIGULATION FOR SIMULTANEOUS PHASE-LOCKING OF TWO THz-QCLs AT 3-THz BAND USING AN AMC AS A THz RFERENCE

THz reference	THz ref. frq.(GHz)	
AMC	THz1:3108.4	
THz-QCL device no.	QCL frq. (GHz)	IF(GHz)
QCL1:QCL11kI(NICT)	QCL1:~3112	IF1:~3.6(THz1-QCL1)
QCL2:QCL11lk(NICT)	QCL2:~3108	IF2:~0.4(THz1-QCL2)
		IF3:~4.0(QCL1-QCL2)

II. Measurement Setup and Result

Fig. 1 shows a setup for the simultaneous phase-locking of two THz-QCLs at 3 THz-band. Table I shows frequency configuration of two THz-QCLs at 3-THz band using a comb generator as a THz reference. The synthesizer frequency was set to 17.991 GHz. The mode number of 172 and 173 were selected from optical comb using a programmable filter and were put into a UTC-PD. Two THz reference signals of 3094.453 GHz (THz1) and 3112.443 GHz (THz2) were generated by a UTC-PD. THz waves from THz-QCL with lasing frequency of ~3095 GHz (THz-QCL1) and ~3112 GHz (THz-QCL2) were injected as a local oscillator for an HEB mixer. Both the THz waves from the THz-QCL1 and the THz-QCL2 were injected as a local signal for an HEBM, therefore, we should care about saturation of LO signal. The beat signal between THz1 and THz-QCL1 was ~548 MHz, and that between THz2 and THz-QCL2 was ~443 MHz. These signals were put into an each PLL circuit for phase-locking. We have also demonstrated simultaneous phase-locking of THz-QCLs at 2.067 THz (provided by Longwave photonics) and 3.108 THz (made in NICT) as shown in Fig. 2 and Table II.

We have also demonstrated the simultaneous phase-locking using an AMC (Amplifier/Multiplier Chain) as a THz reference. In this case, we have a single THz reference signal. Therefore, the lasing frequency of two THz-QCLs should be within an IF bandwidth of an HEBM. Although, the gain IF bandwidth of the HEBM is around 3 GHz, the beat signal can be detected even at ~14 GHz if we use an appropriate LNA. Two beat notes between THz-QCLs and the THz reference were used for phase-locking. A beat note between two THz-QCLs was also observed. We can use this beat note the phase-locking of the 2nd THz-QCL. The measurement setup and photograph are shown in Fig. 3 and Table III.

The simultaneous phase-locking of THz-QCLs could be achieved using a superlattice harmonic mixer. We will also try gas cell measurement using an HEBM with two phase-locked THz-QCLs as LOs.

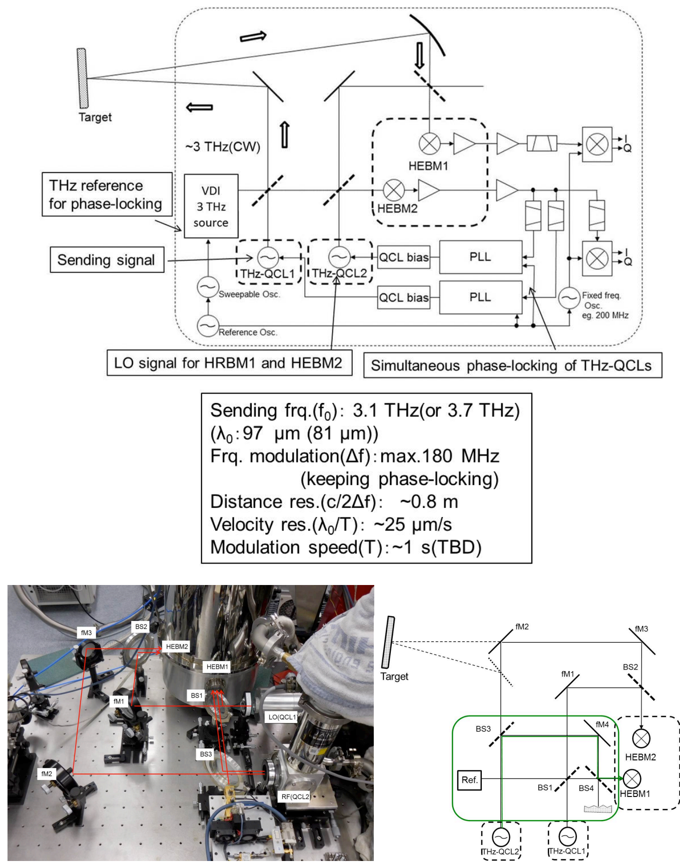

Fig. 4. System block diagram of a THz radar system (above), a photograph of an experimental setup (bottom left), and modified optics (bottom right).

One of an application of the simultaneous phase-locked THz-QCL is a THz radar system. Fig. 4 shows a system block diagram and an experimental setup of the THz radar (TeDar). We have successfully detected beat signals. However, we found the optics should be changed to avoid unnecessary beat signal. The modified optics is shown in Fig. 4 (bottom right).

We will make some demonstration experiments using this system by CW measurement which measures I, Q data of the signals.

1, Measure a metal target position in a few tens of micron from the phase measurement.

2, Measure another type of material such as a dielectric material.

3, Measure how far the target can be distant (ex. more than 1 m).

4, Measure through a dielectric material put in the path.

5, Measure environmental temperature and humidity change with fixed target (propagation delay, atmospheric attenuation).

III. Conclusions

We have demonstrated simultaneous phase-locking of two THz-QCLs using an HEB mixer at 2-3 THz band. An optical comb generator followed by a UTC-PD or an AMC were used as a THz reference. This system can be applicable for a THz radar system etc.

References

[1] Y. Irimajiri, M. Kumagai, I. Morohashi, A. Kawakami, N. Sekine, S. Nagano, S. Ochiai, S. Tanaka, Y. Hanado, Y. Uzawa, and I. Hosako, "Precise Evaluation of a Phase-Locked THz Quantum Cascade Laser," *IEEE Trans. THz Sci. Technol.,* vol. 6, Issue 1, pp.115-120, 2016.

[2] Y. Irimajiri, M. Kumagai, I. Morohashi, A. Kawakami, N. Sekine, S. Nagano, S. Ochiai, S. Tanaka, Y. Hanado, Y. Uzawa, and I. Hosako, "Development of a Superconducting Low-Noise 3.1-THz Hot Electron Bolometer Receiver," *IEEE Trans. THz Sci. Technol.,* vol. 5, no. 6, pp.1154-1159, Nov. 2015.

[3] I. Morohashi, Y. Irimajiri, T. Sakamoto, T. Kawanishi, M. Yasui, and I. Hosako, "Generation of millimeter waves with fine frequency tunability using Mach-Zehnder-modulator-based flat comb generator," *IEICE Trans. Electron.*, vol. E96-C, no. 2, pp. 192-196, 2013.