研究報告

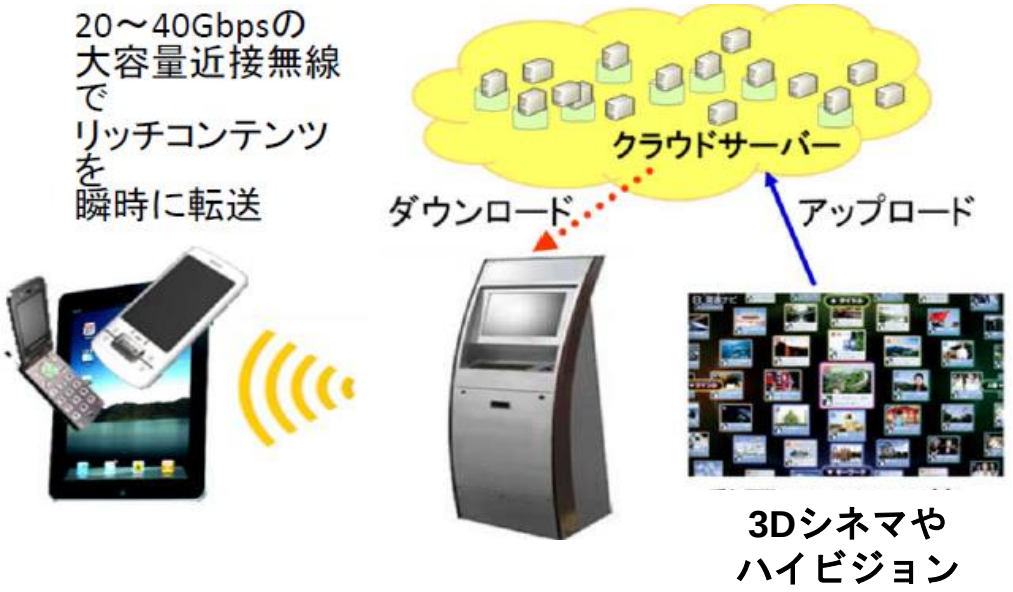
Real-Time Absolute Frequency Measurement of CW-THz Wave Based on THz Combs

H26/8/4　M2　Kenta Hayashi

THz Radio Communication

Recently, THz wave has attracted attention as a new tool for high capacity radio communication

Alternative lines and backup lines for emergency

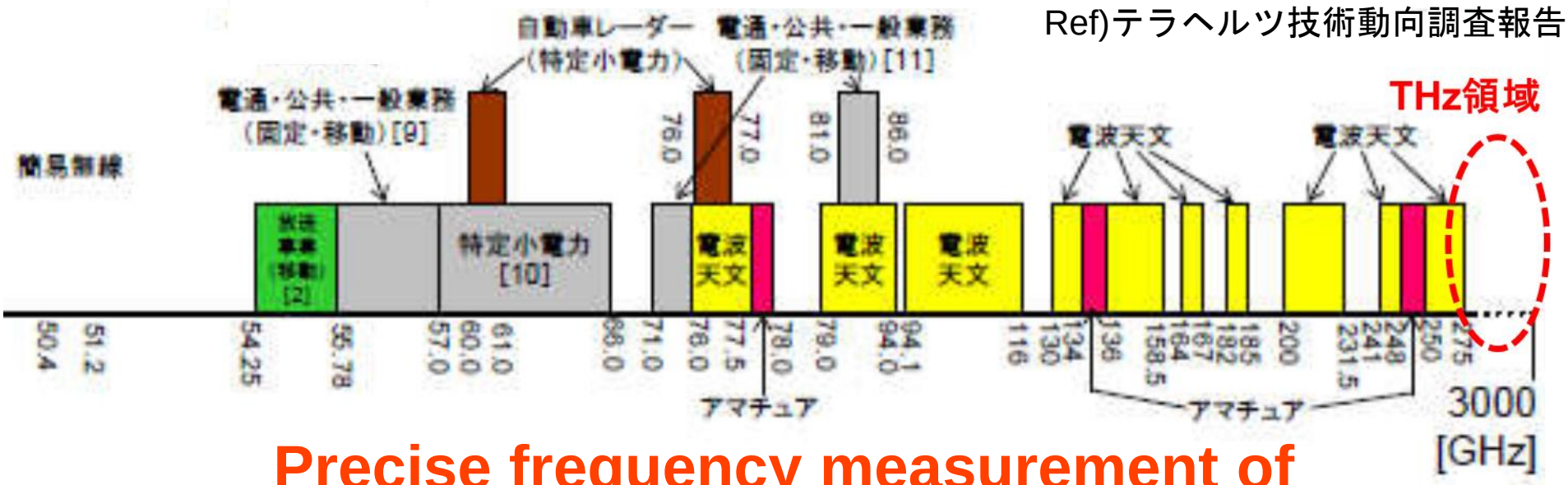


Instantaneous wireless data transfer

Ref)テラヘルツ波帯の情報通信利用に関する調査報告書

Frequency allocation of radio communication

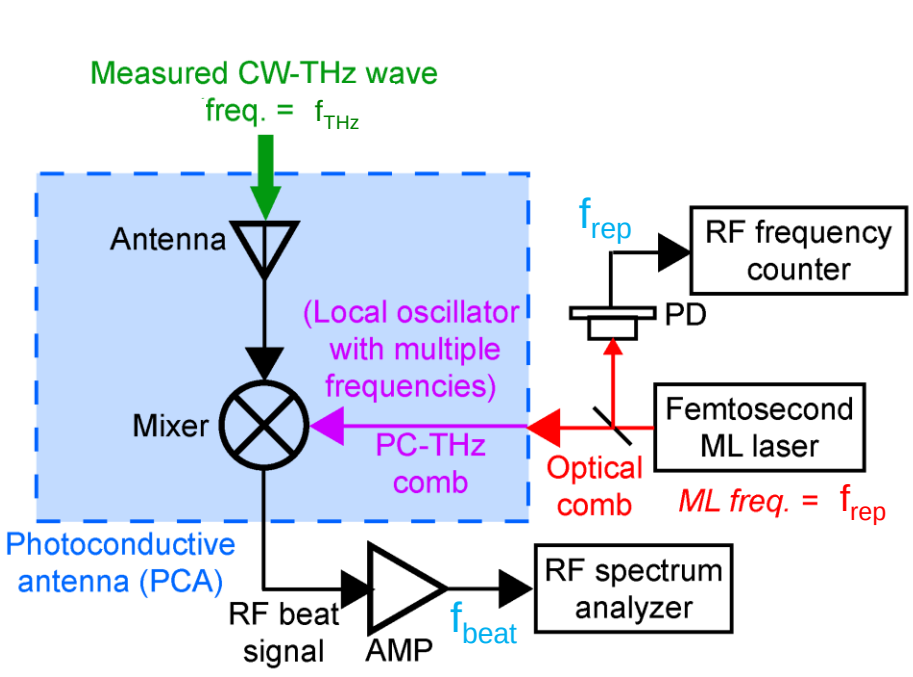
Ref)テラヘルツ技術動向調査報告

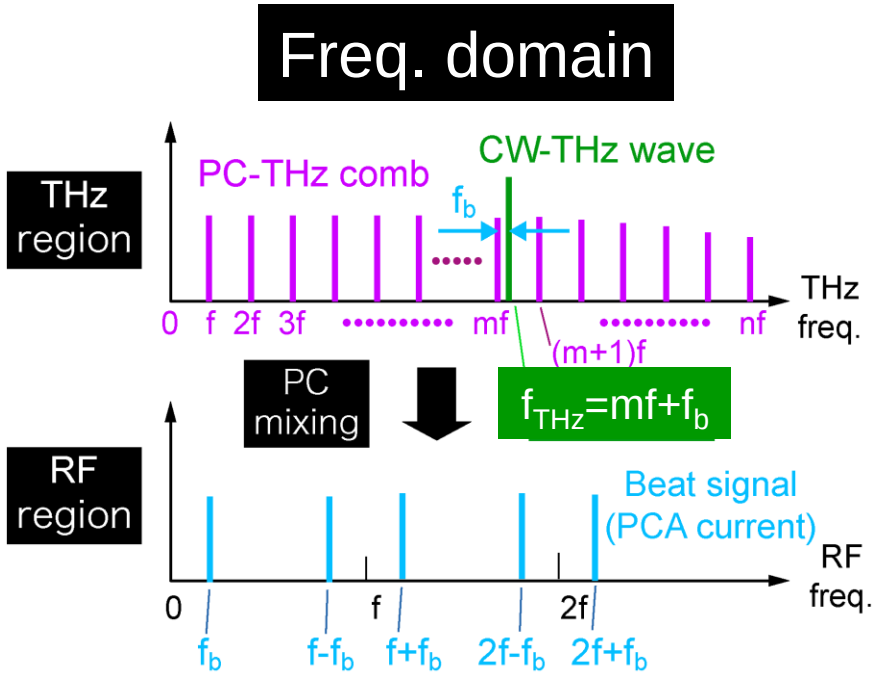


Precise frequency measurement of CW-THz wave is required

However, techniques of absolute frequency measurement of CW-THz wave are still immature!

THz-comb-referenced frequency measurement



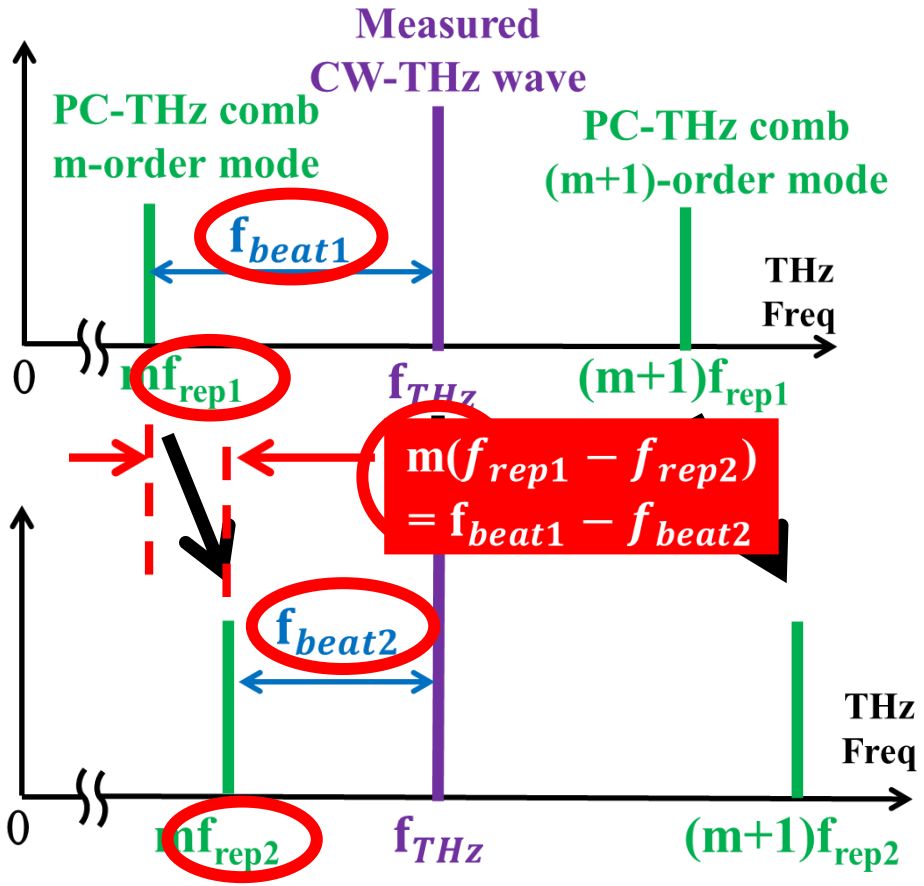


$$f_{THz} = mf_{rep} \pm f_{beat}$$

m: order of comb mode
f_{rep}: ML frequency
f_{beat}: beat frequency

*Ref) S. Yokoyama et al, Opt. Express **16**, 13052-13061 (2008).*
*T. Yasui et al. Opt. Express **17**, 17034-17043 (2009).*

Determination of m and sign of f_{beat}



Measurement of f_{rep1} and f_{beat1}

$$m = \frac{\left| f_{beat1} - f_{beat2} \right|}{\left| f_{rep1} - f_{rep2} \right|}$$

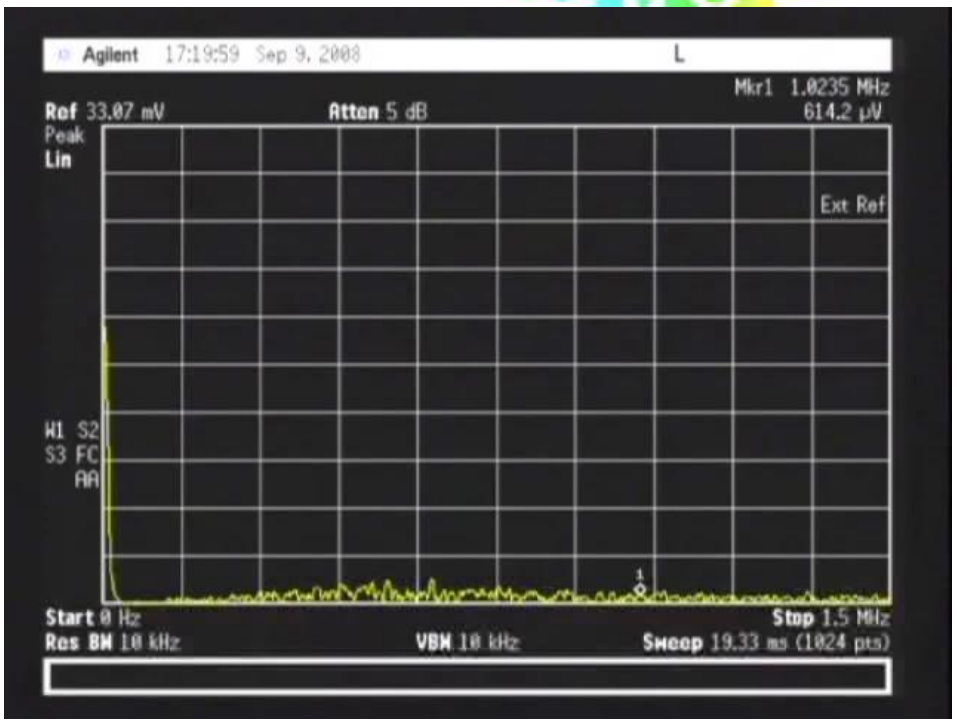
Measurement of f_{rep2} and f_{beat2}

Assumption : f_{THz} is sufficiently stable during measurements of f_{beat1} and f_{beat2}

For example

CW-THz source (UTC-PD)

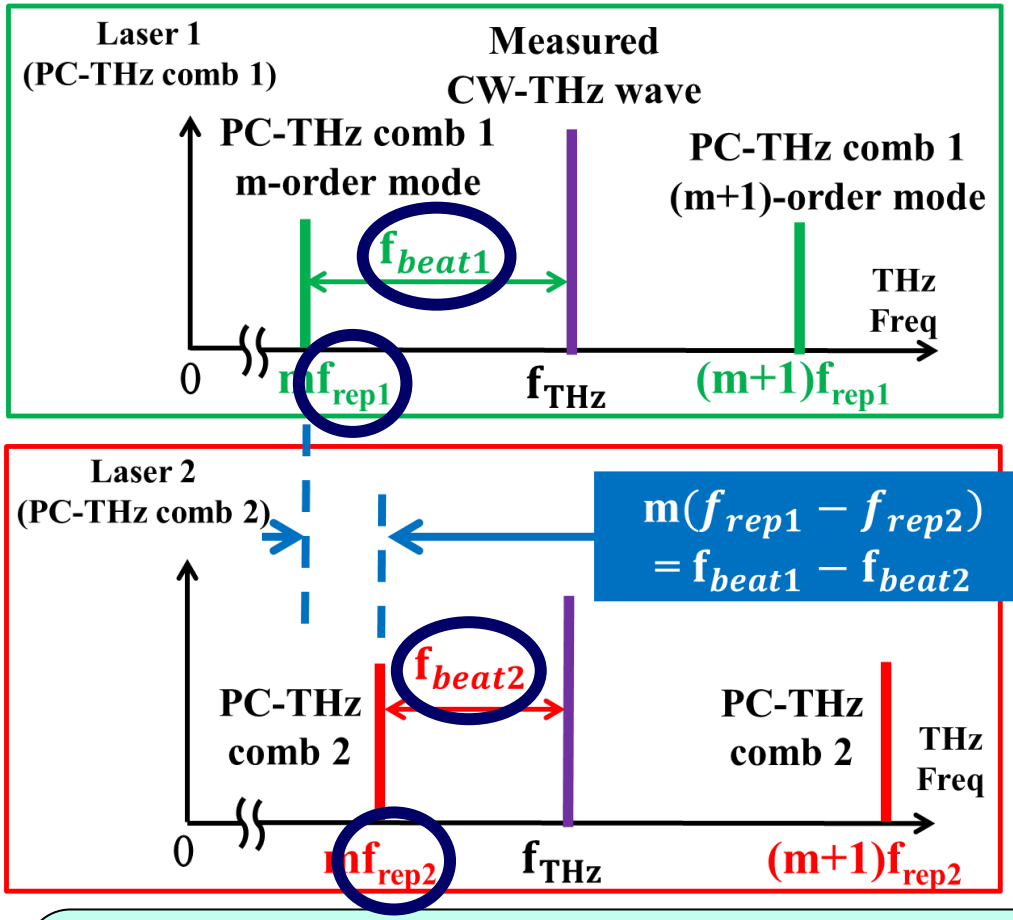
- fast frequency fluctuation
- large frequency fluctuation (mode hopping)



Present talk

Real-time determination of the fast or largely fluctuating CW-THz frequency using dual PC-THz combs .

Real-time determination of CW-THz frequency



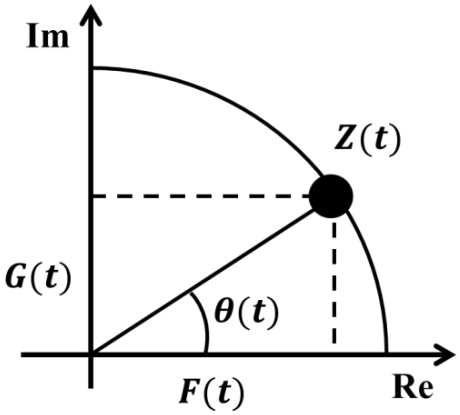
parallel measurement using dual PC-THz combs !

$$m = \frac{\left| f_{beat1} - f_{beat2} \right|}{\left| f_{rep1} - f_{rep2} \right|}$$

$$f_{THz} = mf_{rep1} - f_{beat1} \qquad [(f_{beat1} - f_{beat2})/(f_{rep1} - f_{rep2}) > 0]$$

$$f_{THz} = mf_{rep1} + f_{beat1} \qquad [(f_{beat1} - f_{beat2})/(f_{rep1} - f_{rep2}) < 0]$$

Instantaneous frequency measurement using Hilbert transformation



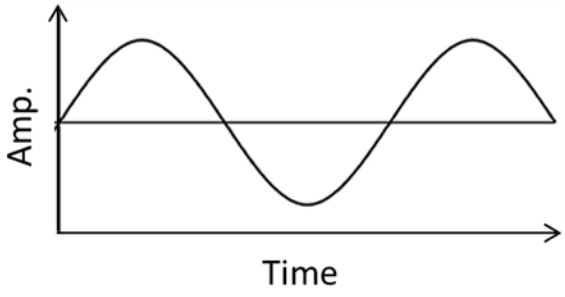
Ref) H. Füser et al, Appl. Phys. Lett. ***99****, 121111 (2011).*

$$Z(t) = F(t) + iG(t)$$

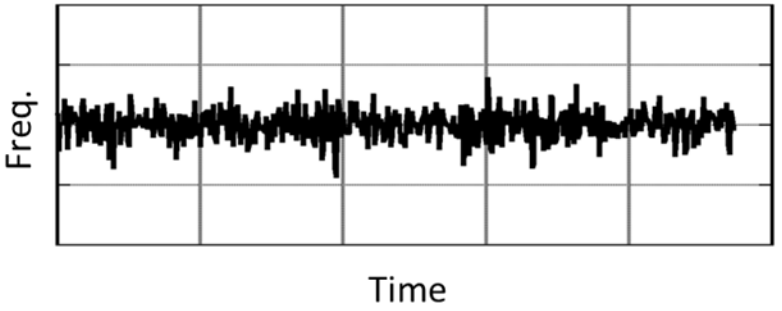
***Z(t)*: analytic signal** $F(t)$: **measurement signal** $G(t)$: **signal after Hilbert transform**

$$\theta(t) = \arg[Z(t)] = \tan^{-1}\left[\frac{G(t)}{F(t)}\right]$$

$$f = \frac{1}{2\pi} \times \frac{d\theta(t)}{dt}$$



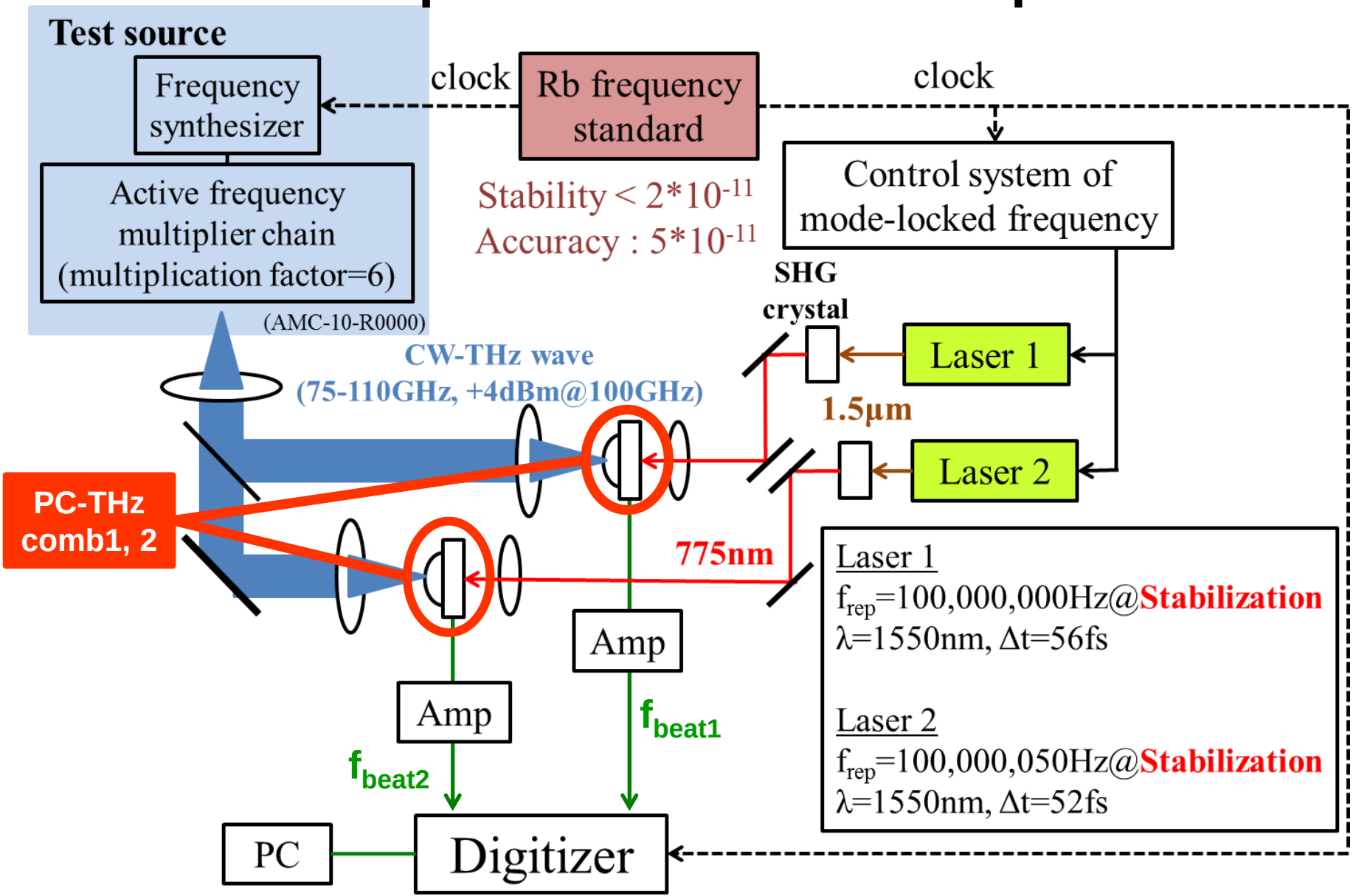
Hilbert transform



Temporal waveform of f_{beat}

Instantaneous frequency of f_{beat}

Experimental setup

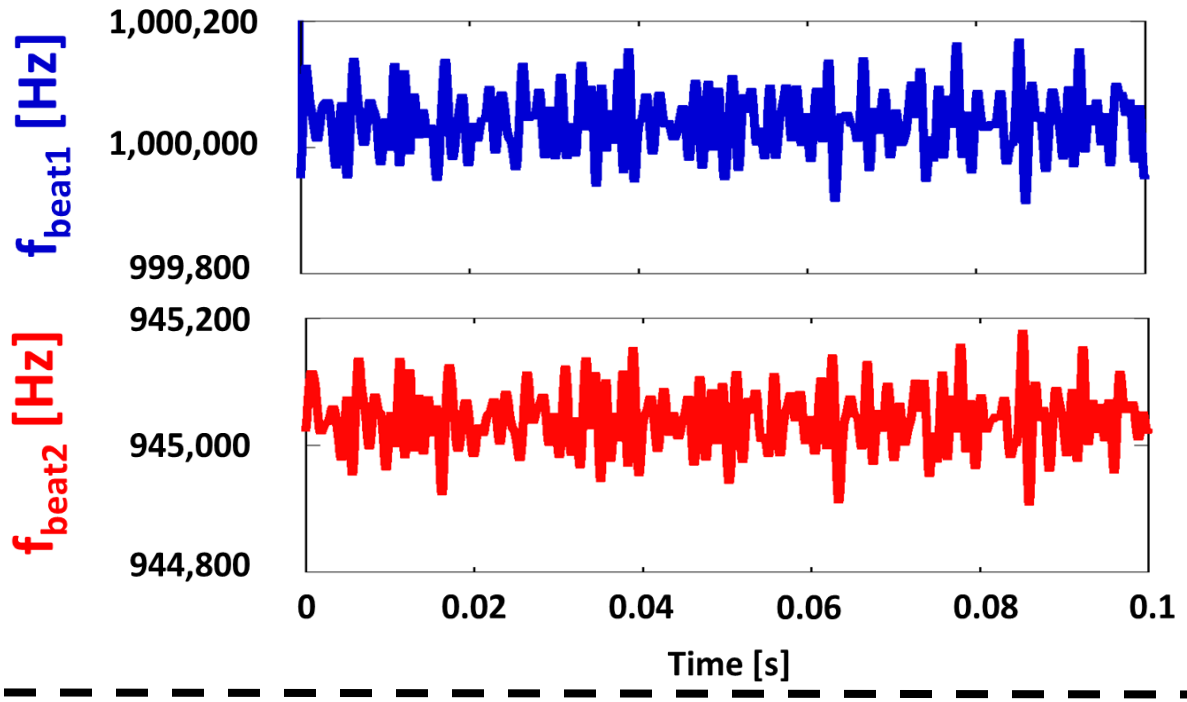


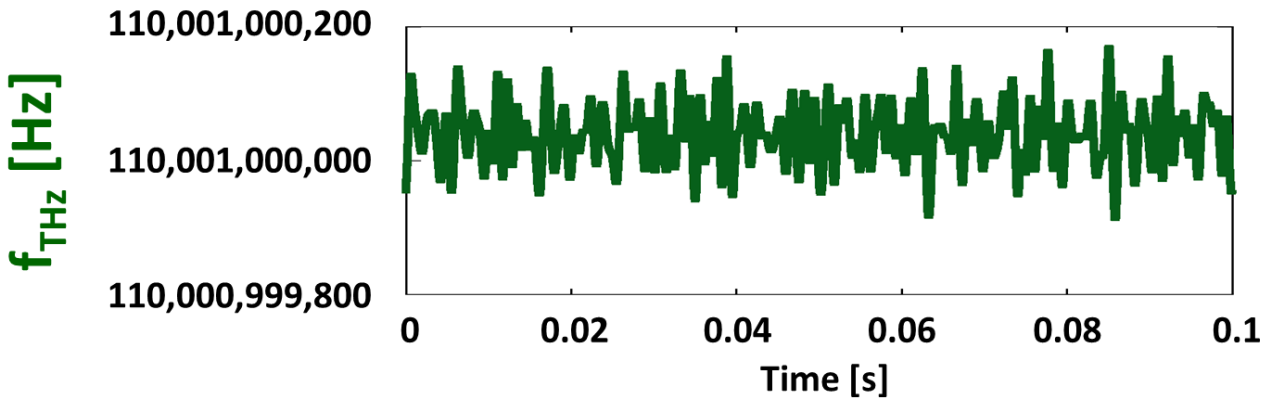
Real-time determination of f_{THz}

Sampling rate 10MHz

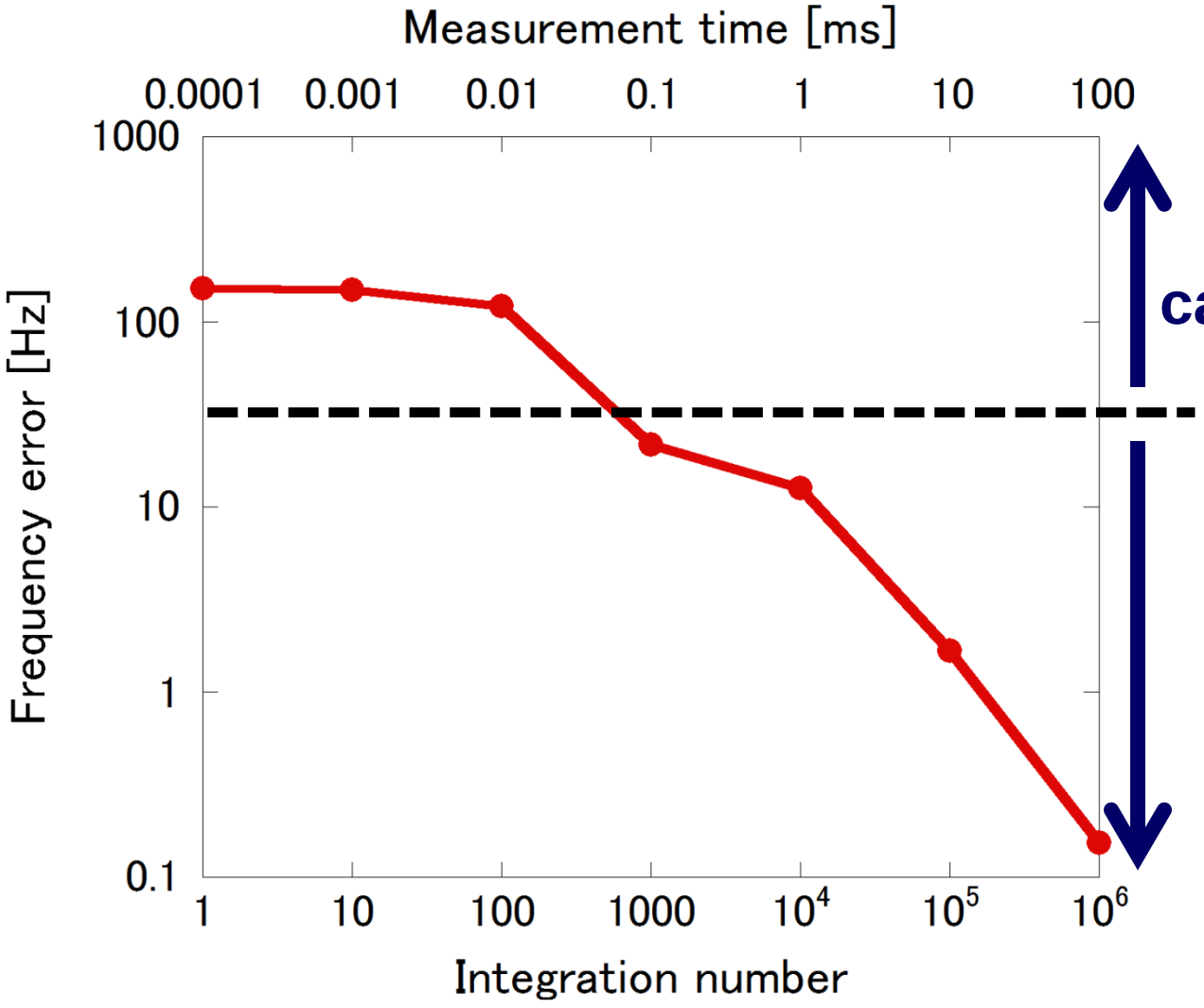
f_{rep1} = 100,000,000 Hz
f_{rep2} = 100,000,050 Hz

fixed





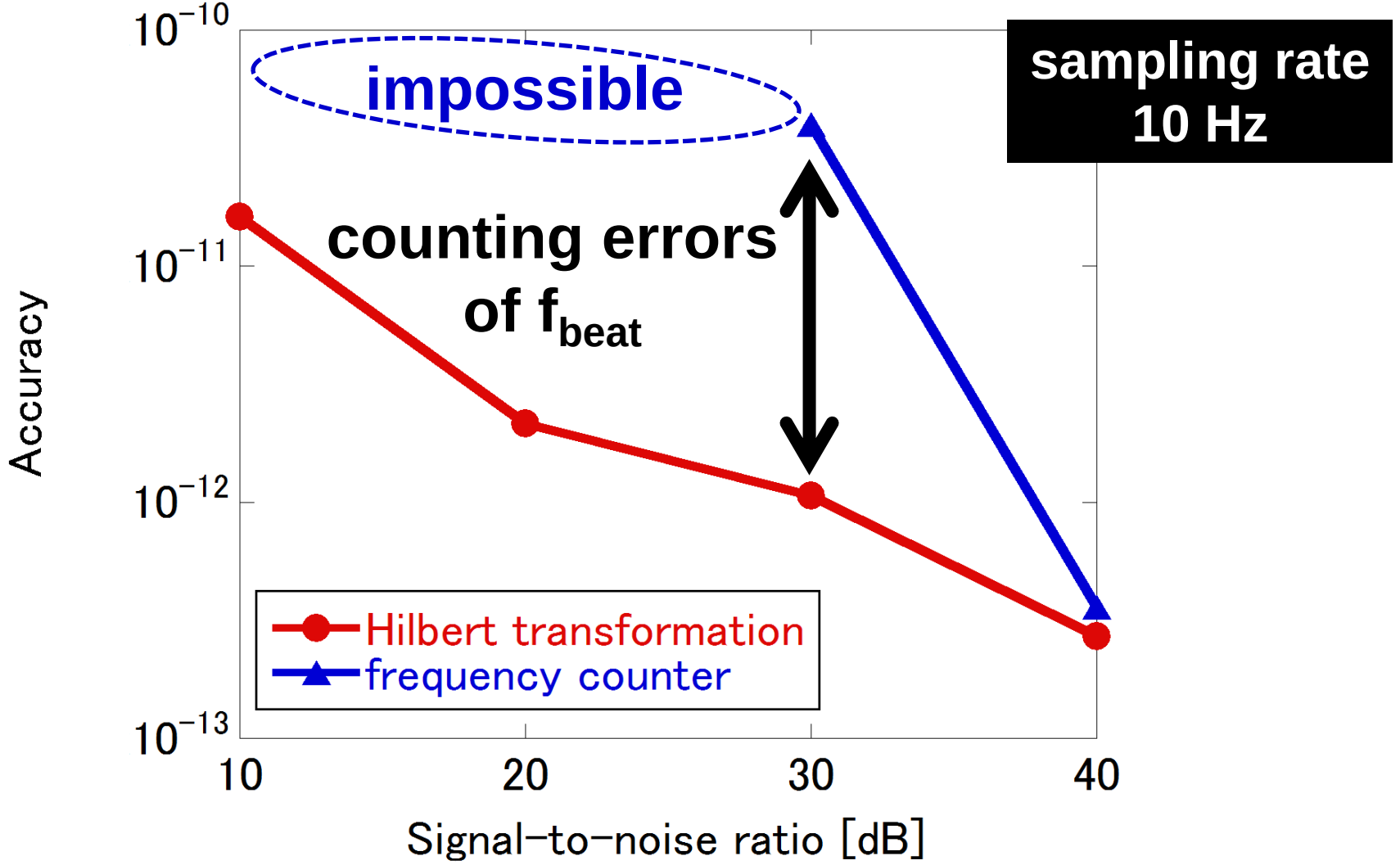
Frequency error with respect to a various integration number



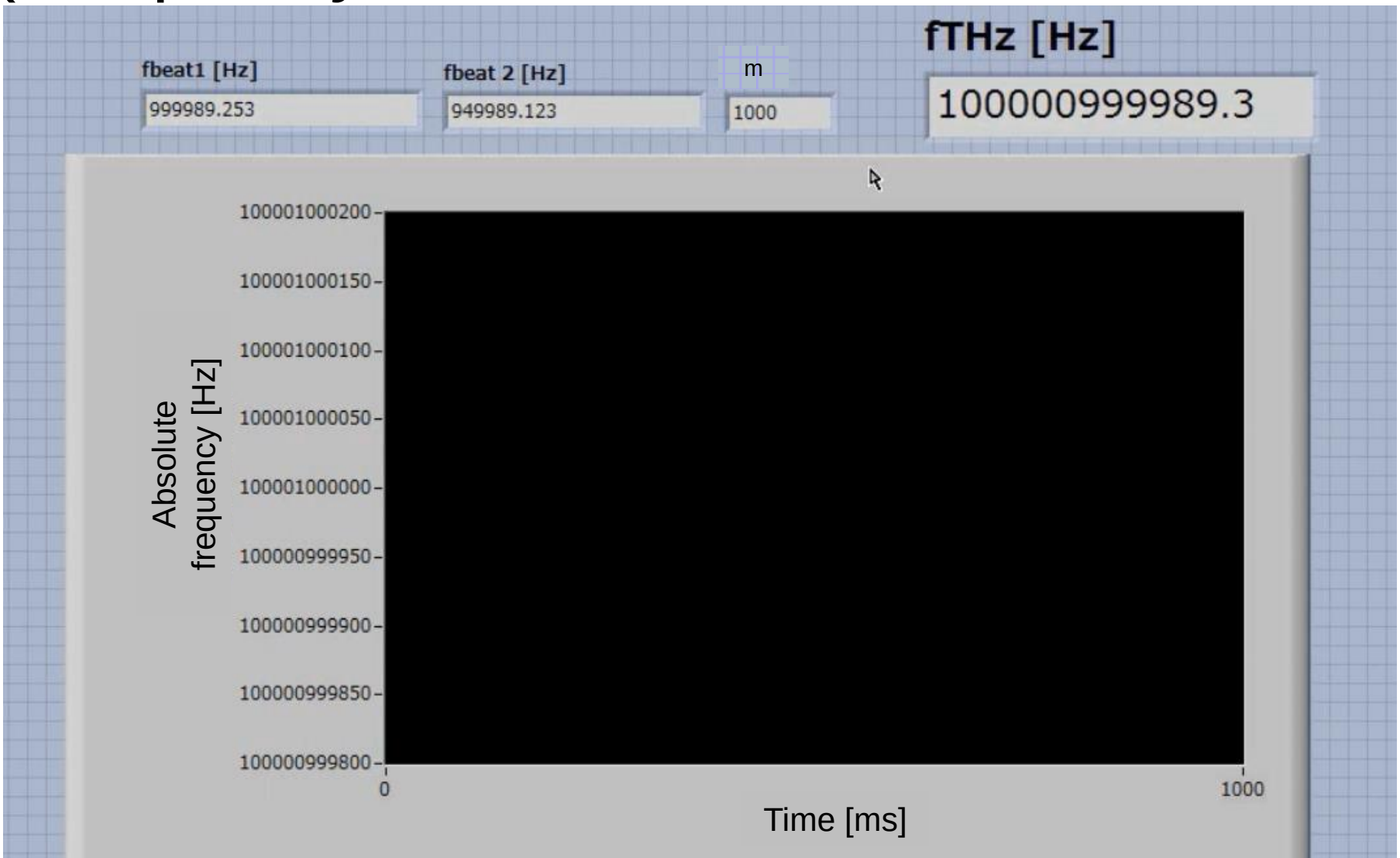
The comb mode cannot be determined

The comb mode can be determined

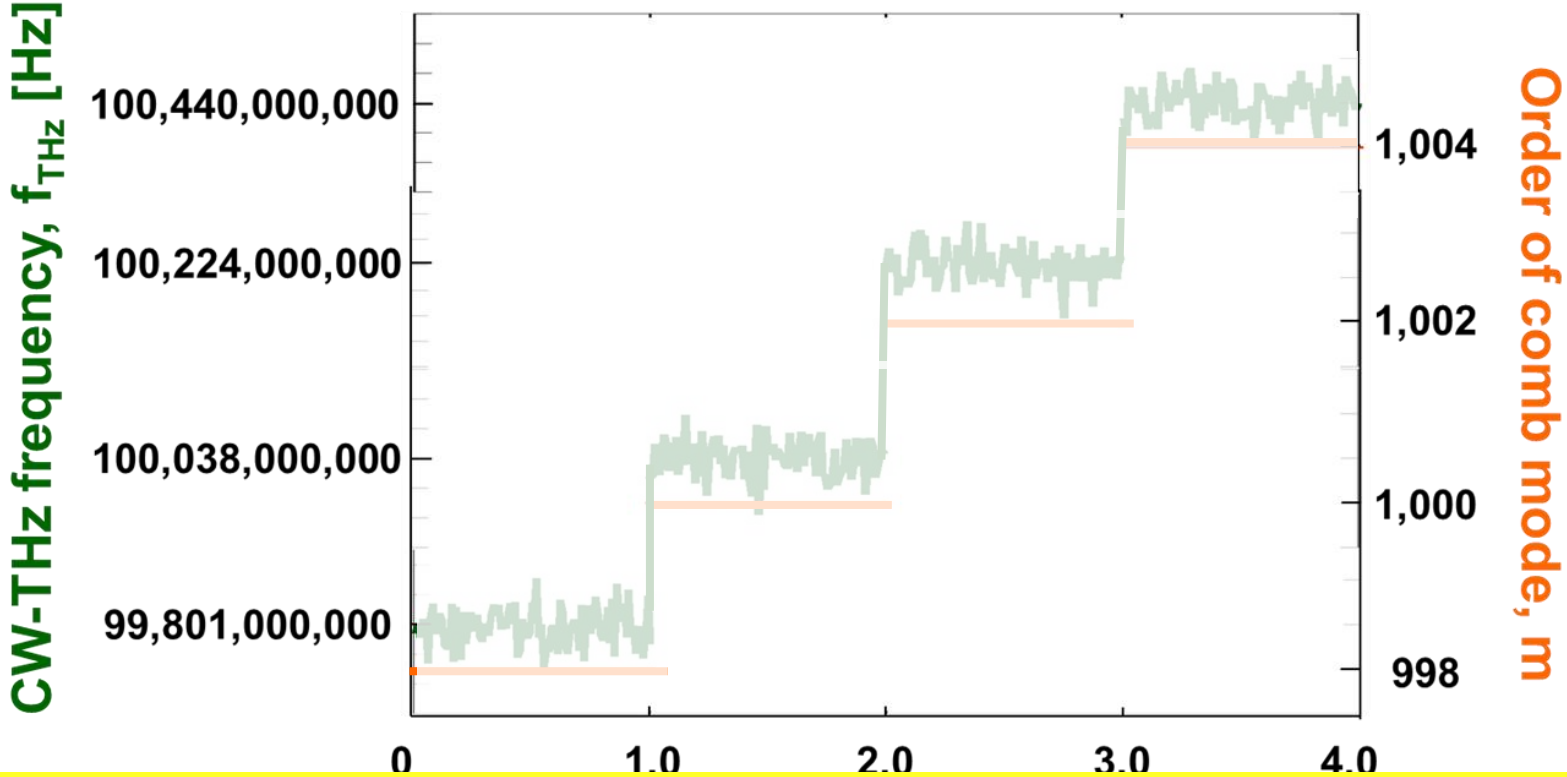
Comparison of accuracy between Hilbert transformation and frequency counter



Real-time monitoring of CW-THz wave ①
(Frequency fluctuation = 0.1 THz ±100 Hz)

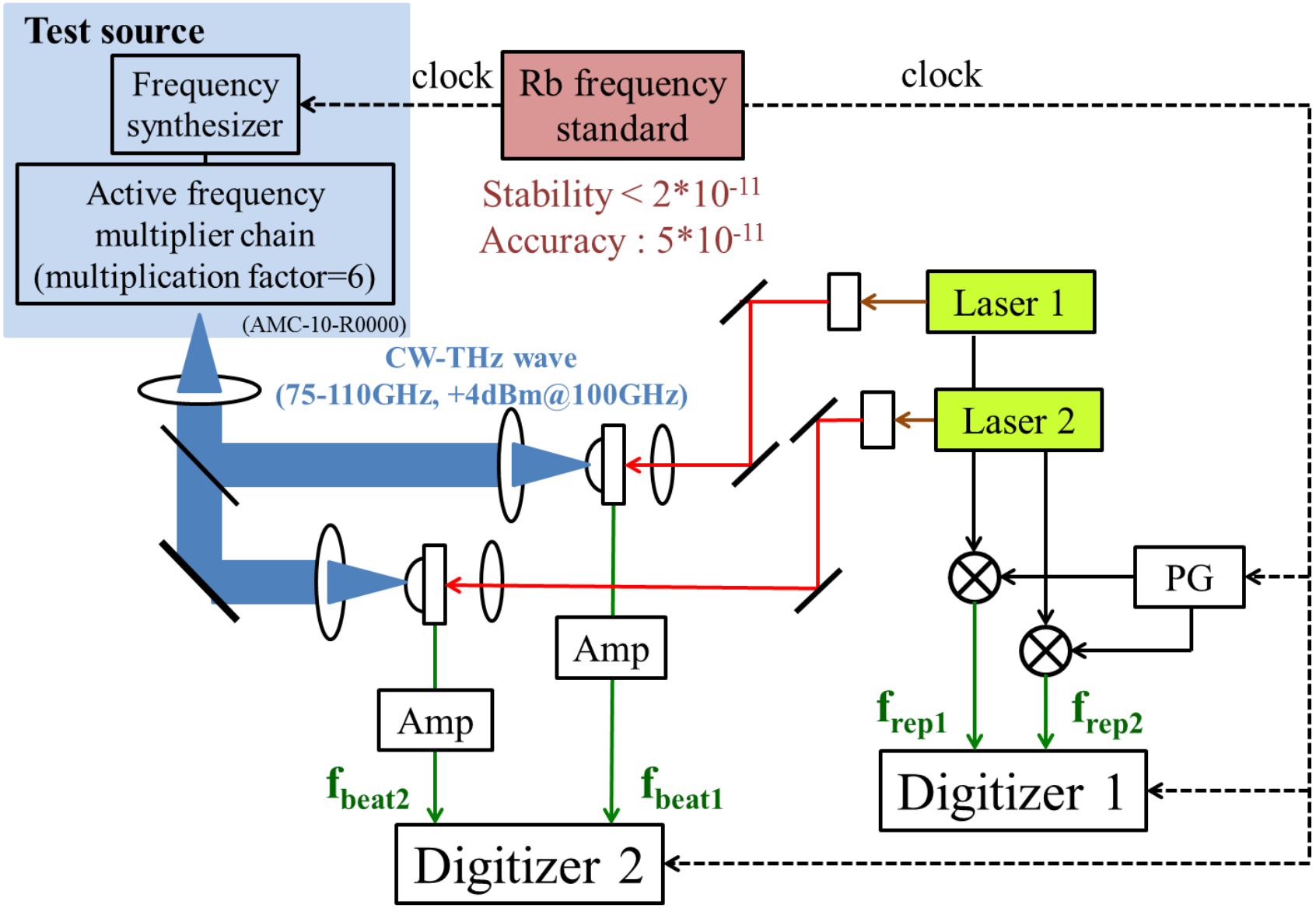


Real-time monitoring of CW-THz wave ②
(Frequency fluctuation = 0.1THz + 200MHz)



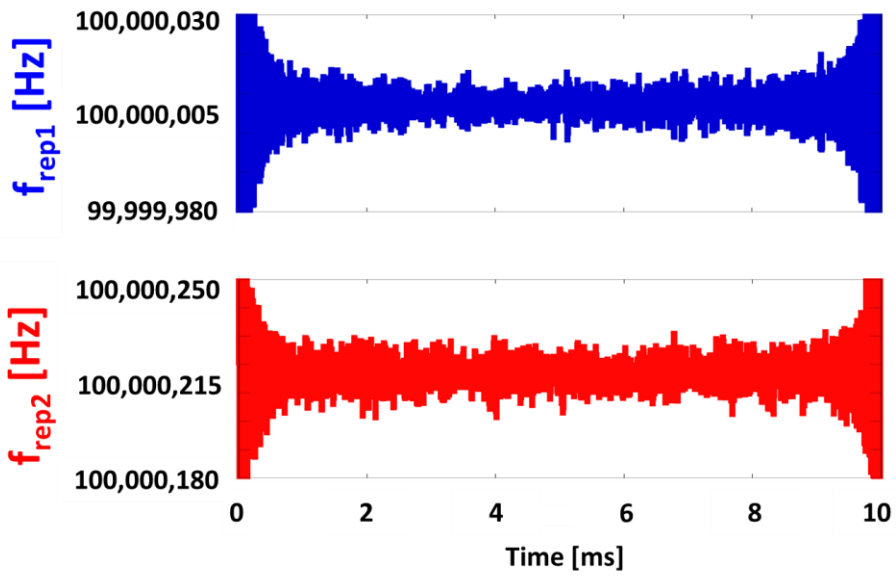
A high potential for real time monitoring of large fluctuation such as mode hopping in CW-THz sources!

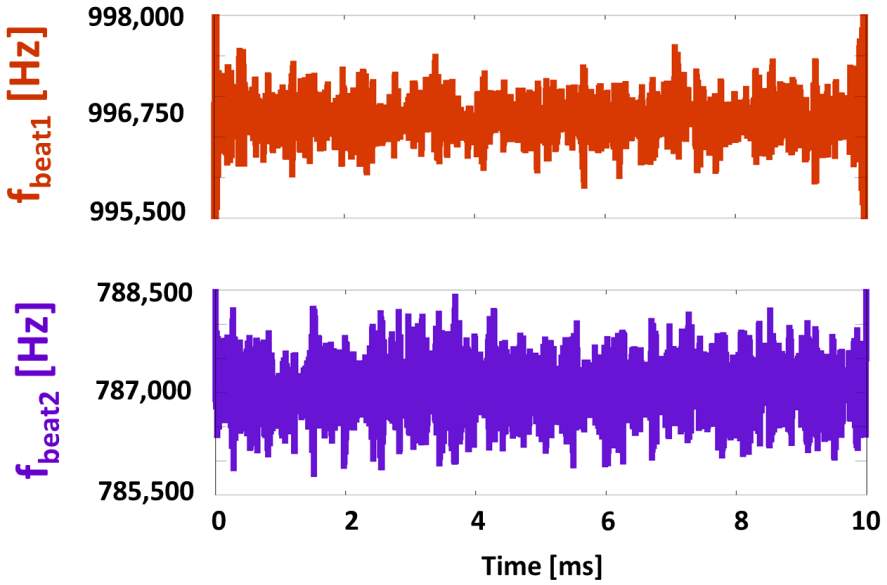
Experimental setup

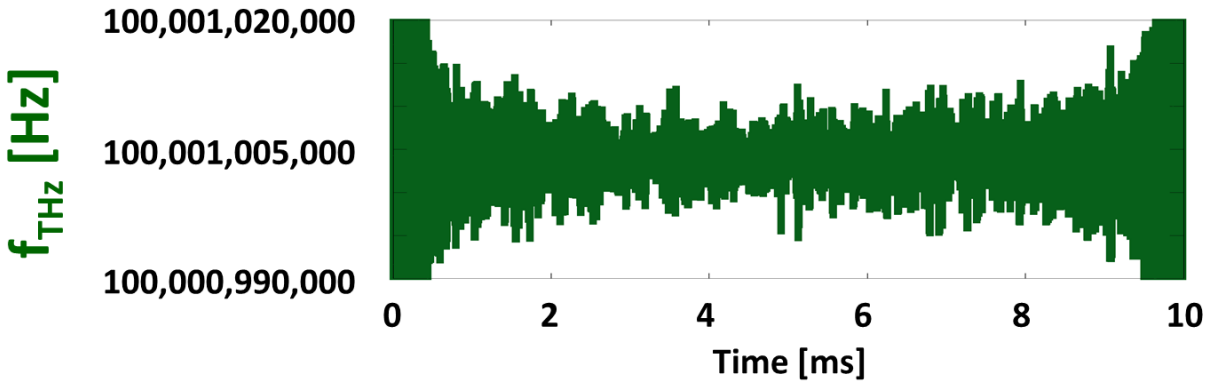


Real-time determination of f_{THz}

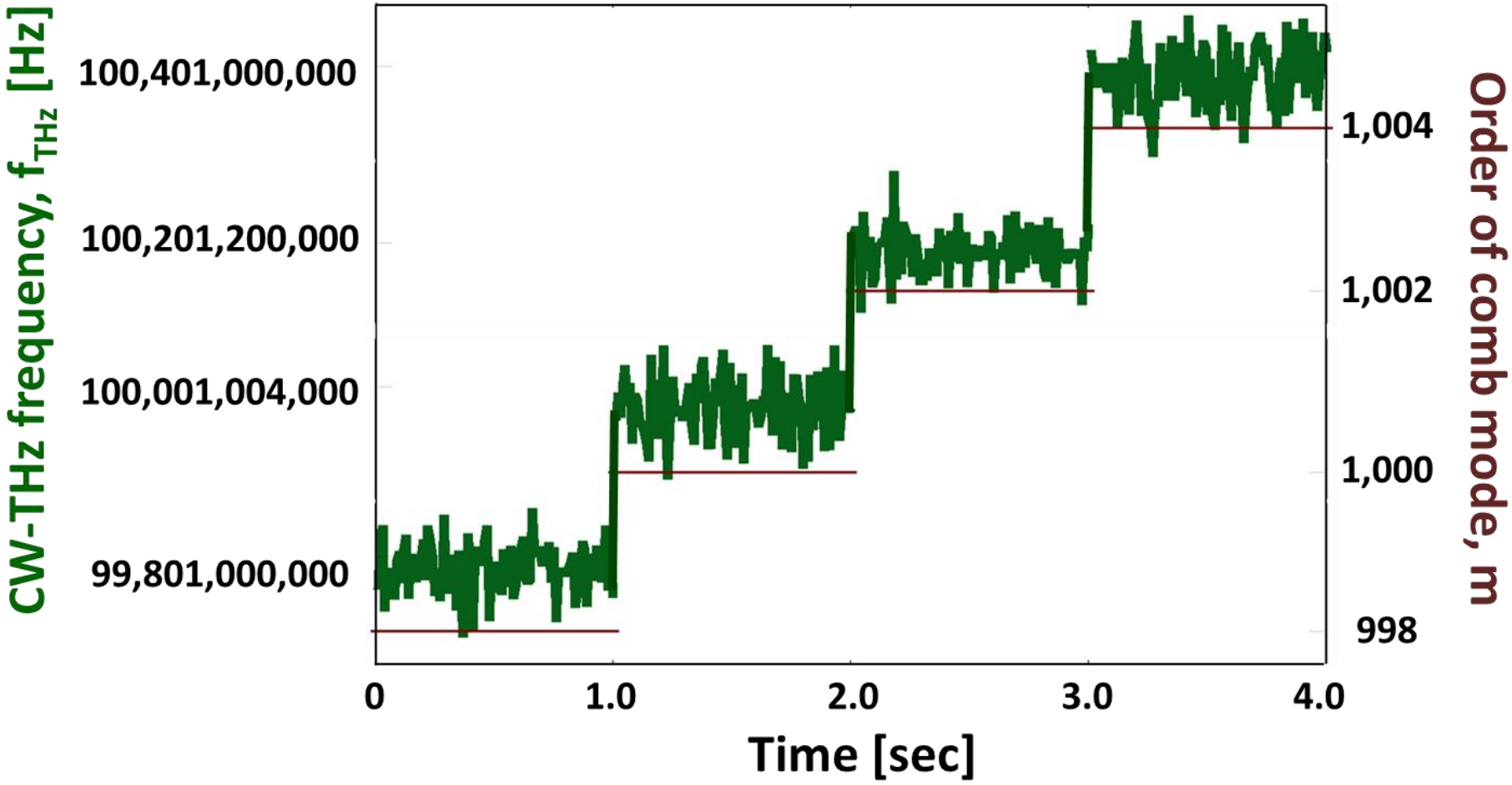
Sampling rate 10MHz



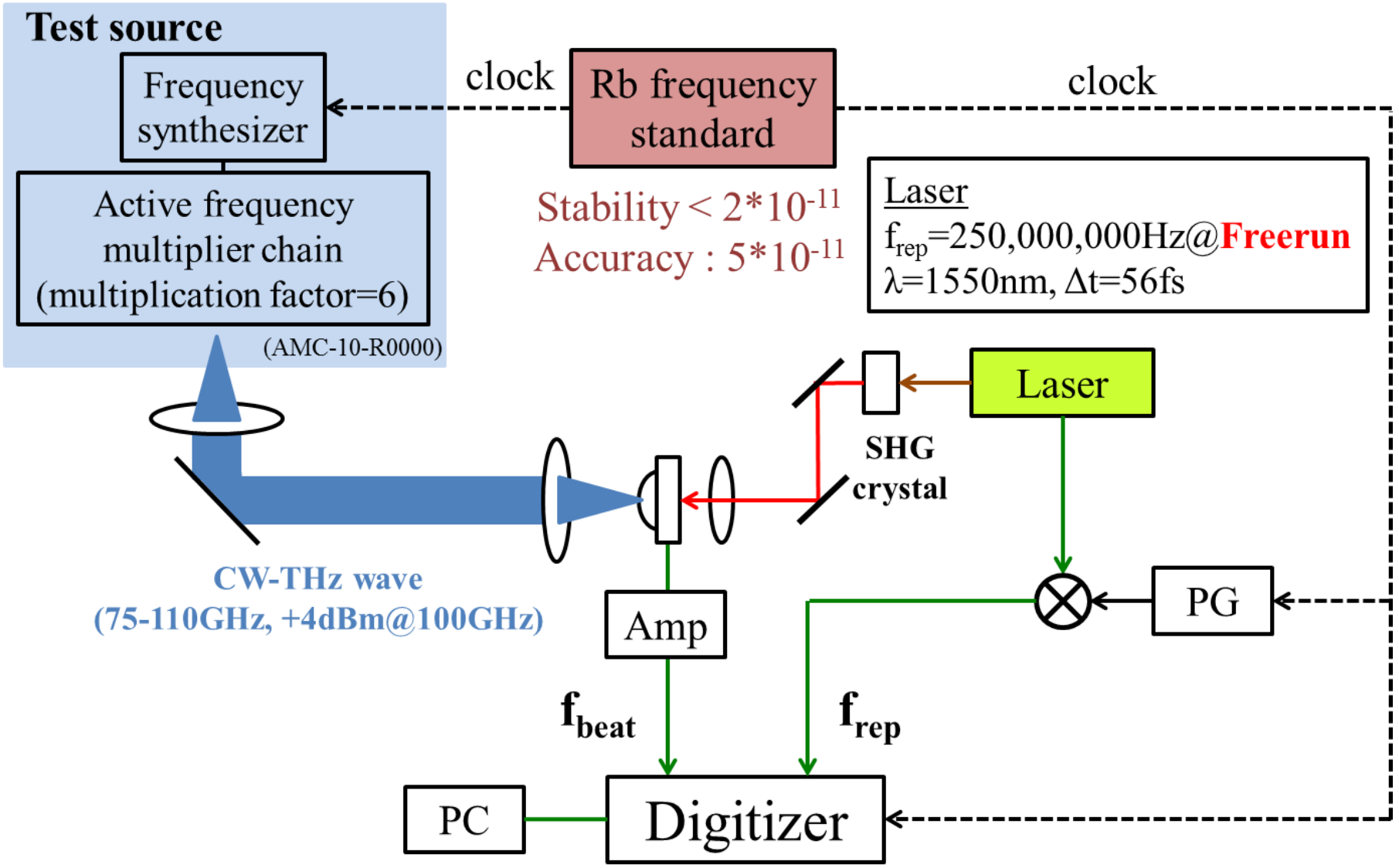




Real-time monitoring of CW-THz wave (Frequency fluctuation = 0.1THz + 200MHz)



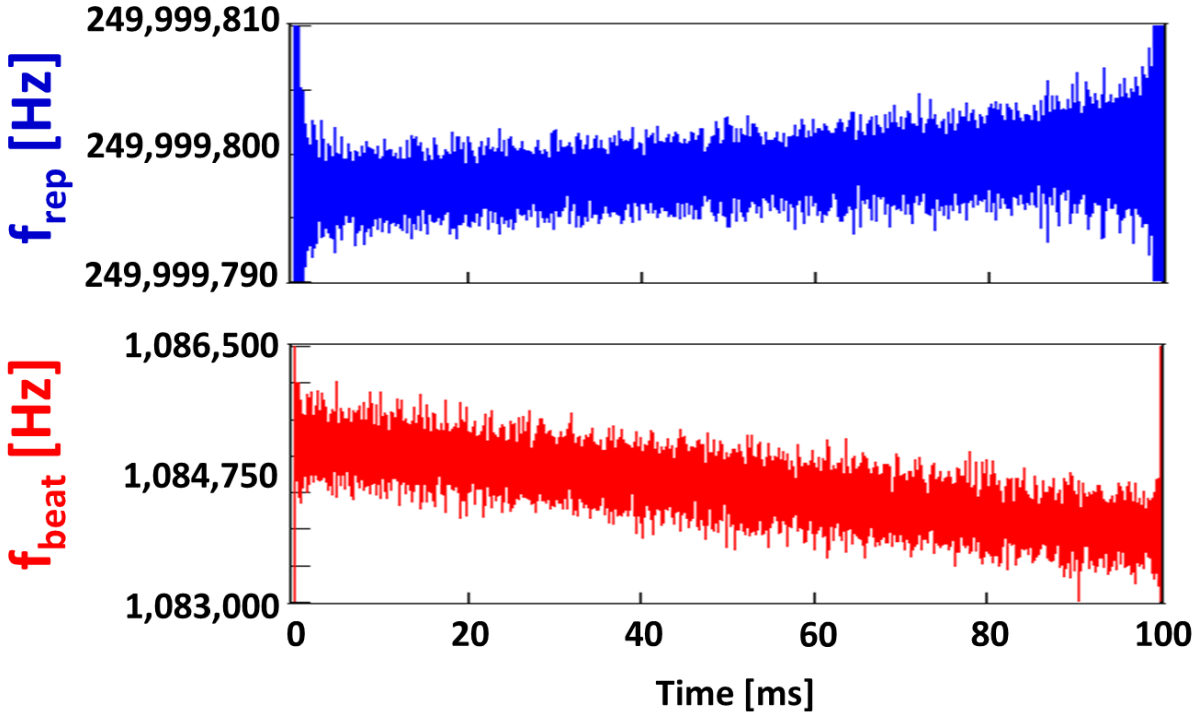
Experimental setup

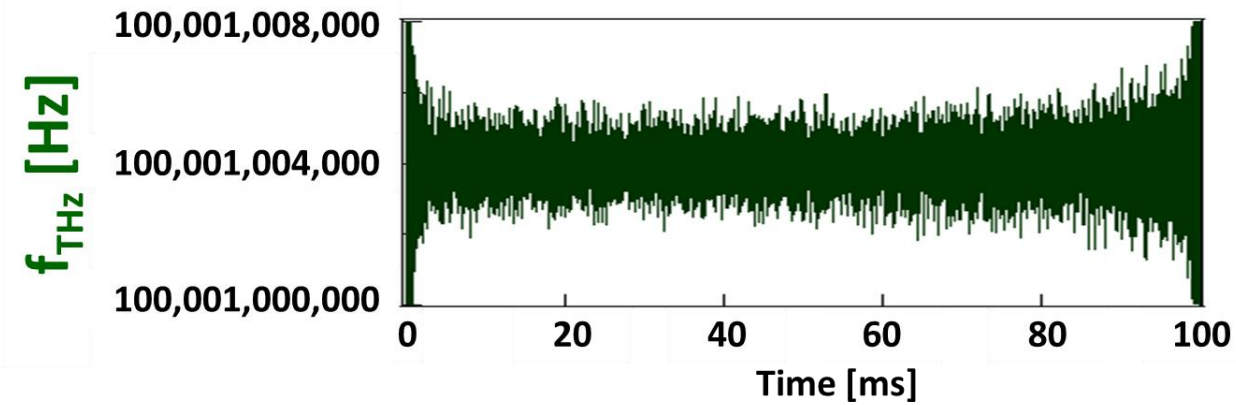


Real-time determination of f_{THz}

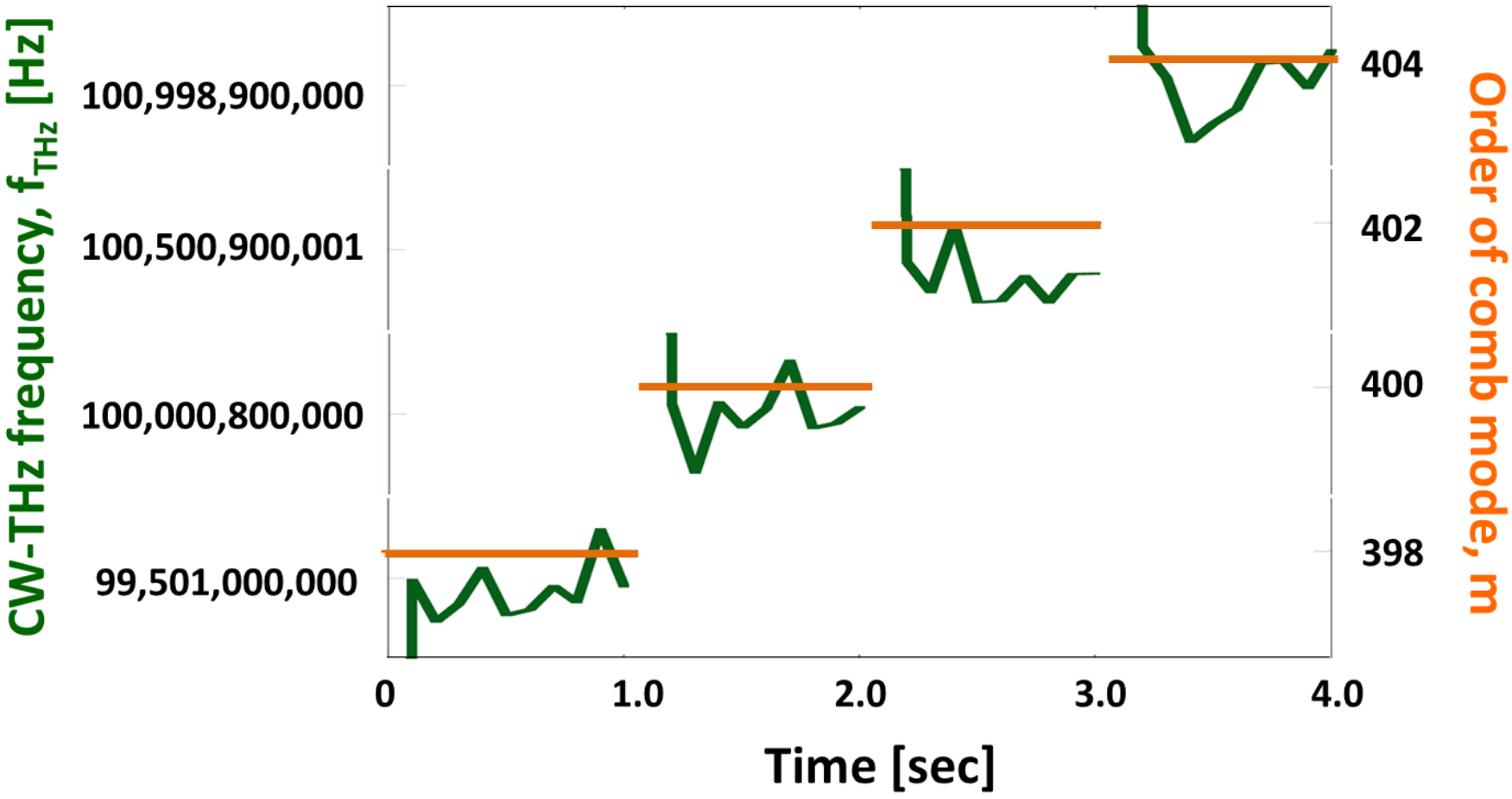
Sampling rate 10MHz

f_{rep} : freerun





Real-time monitoring of CW-THz wave (Frequency fluctuation = 0.1THz + 500MHz)



Summary

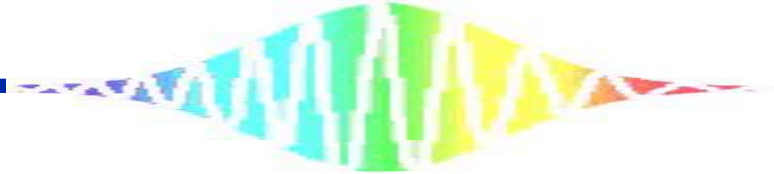
Real-time absolute frequency measurement of the fast or largely fluctuating CW-THz wave using dual PC-THz combs

(1) Frequency accuracy

- 2.2×10^{-10} at a sampling rate of 10 kHz
- 1.5×10^{-12} at a sampling rate of 10 Hz

(2) Possible to determine f_{THz} at lower SNR (~10)

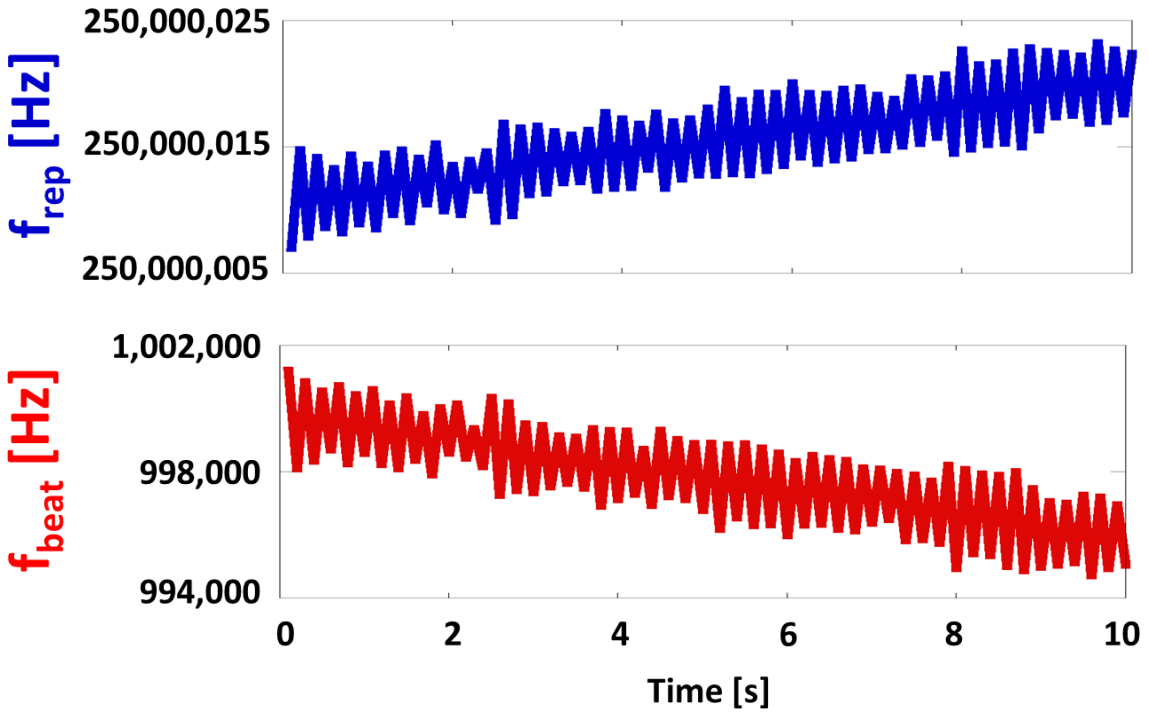
(3) Available for large change of f_{THz} across the comb mode

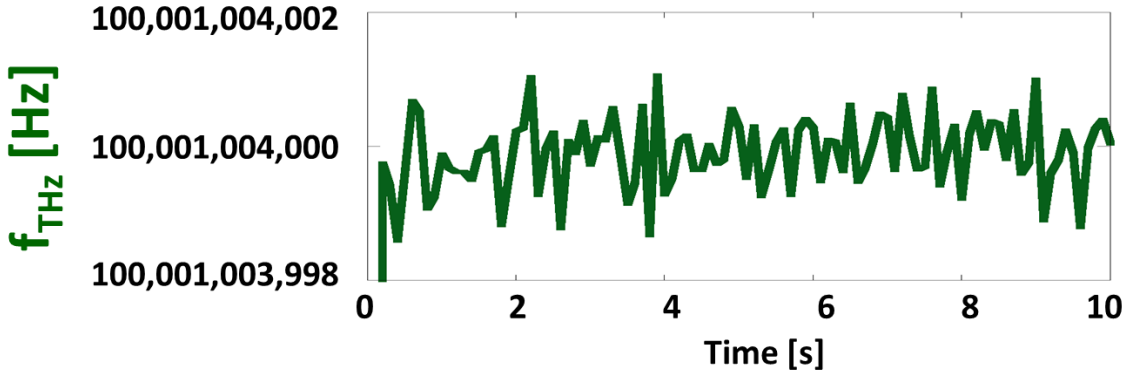


Real-time determination of f_{THz}

Sampling rate 10Hz

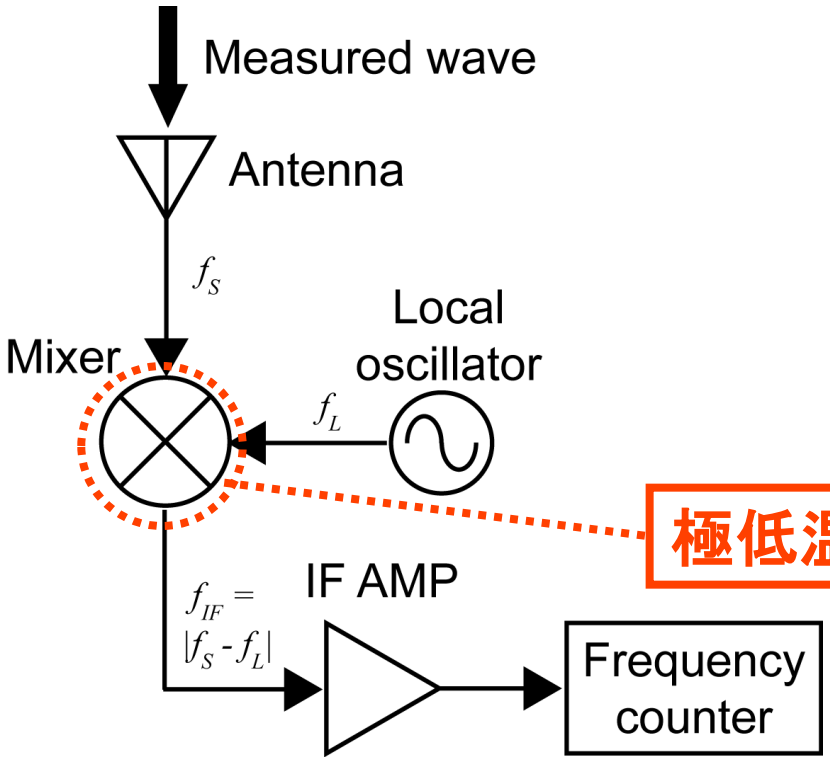
f_{rep} : freerun



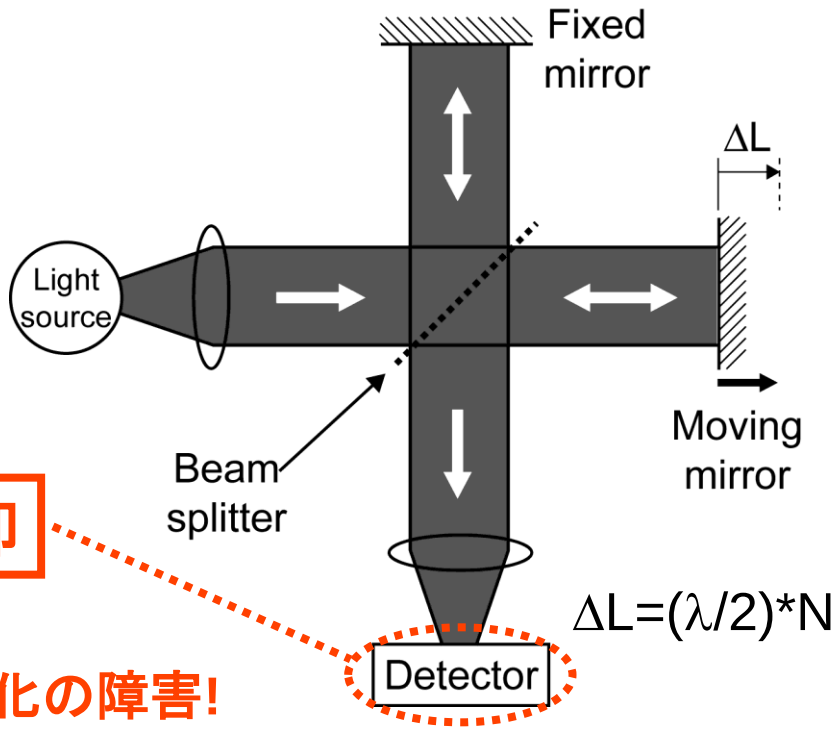


周波数計測の従来法

電気的手法 (ヘテロダイン)



光学的手法 (干渉計測)



極低温冷却

実用化の障害!

テラヘルツ領域 (0.1~10THz) をカバーすることは難しい

→THz領域をフルカバーできる新しい手法が必要!