

THz frequency synthesizer based on dual optical comb

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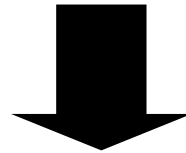
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Optical Comb Symposium @ Tsukuba (2011.9.26)

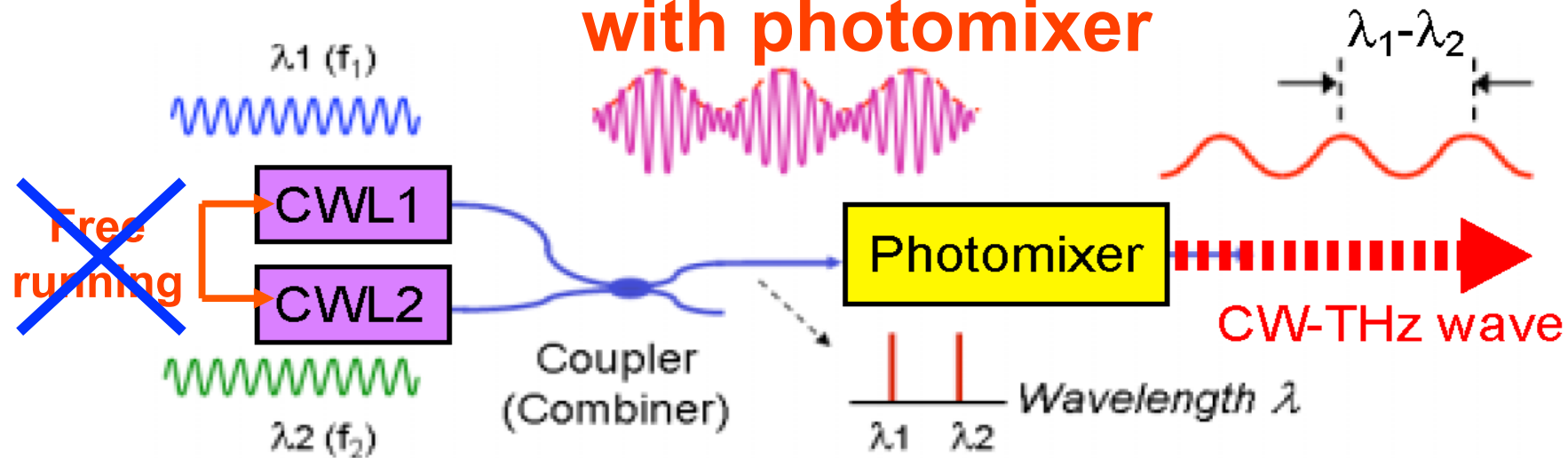
Background

Accurate, stable, tunable CW-THz source (THz clock and synthesizer)

(freq. metrology, high-resolution spectroscopy, local oscillator for heterodyne receiver, carrier wave for wireless communications, etc)



Photomixing of two CW NIR lasers with photomixer



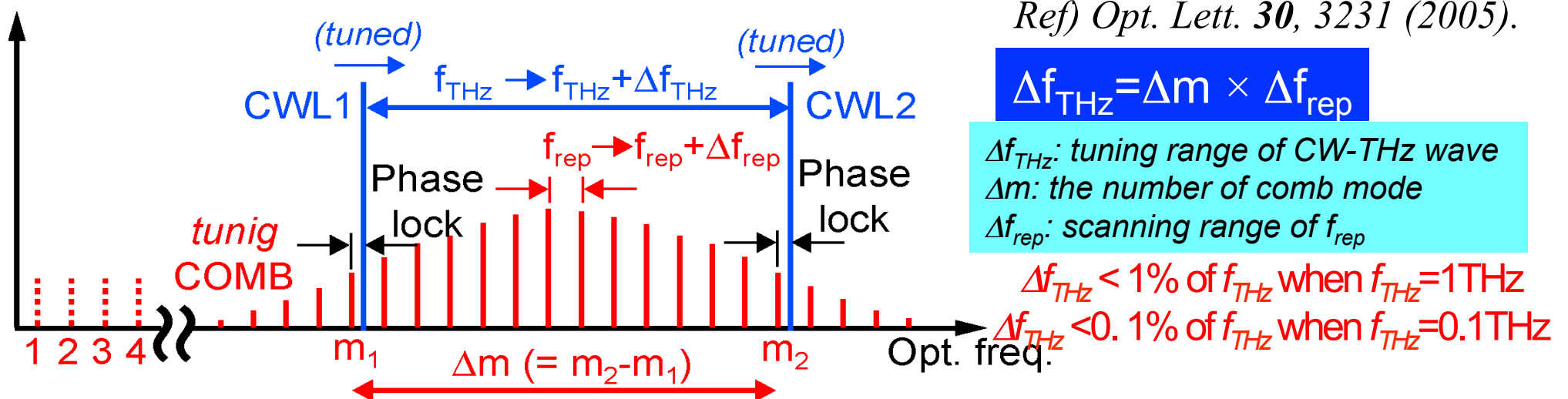
Ref) *Laser&Photon. Rev.* 3, 123 (2009).

Photomixing of two *stabilized* CW lasers

Optical frequency comb is attractive frequency reference to control two CW lasers for photomixing

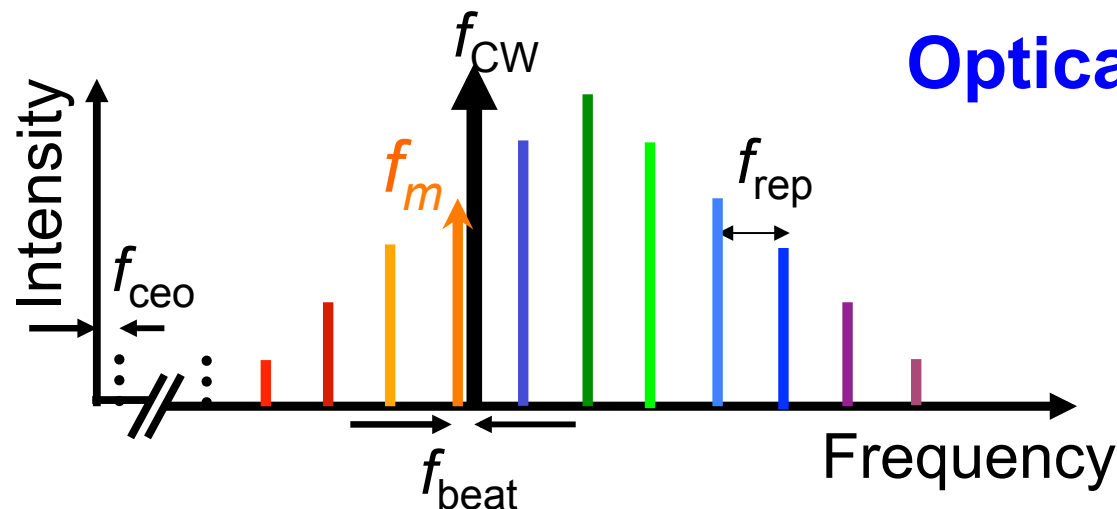
Conventional study

Photomixing of two CW lasers phase-locked to single optical comb



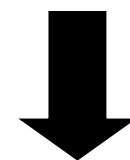
Common-mode change of CWL1 and CWL2 cancels most of optical frequency change!

Optical Frequency Synthesizer (OFS)



Optical frequency comb

$$f_m = m \cdot f_{rep} + f_{ceo}$$



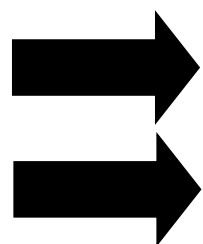
f_{rep} and f_{ceo} are
phase-locked

**Precise freq. ruler
in optical region**

Phase-locking single-mode CW laser to optical comb

$$f_{ofs} = m \cdot \boxed{f_{rep}} + \boxed{f_{ceo}} + \boxed{f_{beat}}$$

Phase-locked to microwave
freq. standard

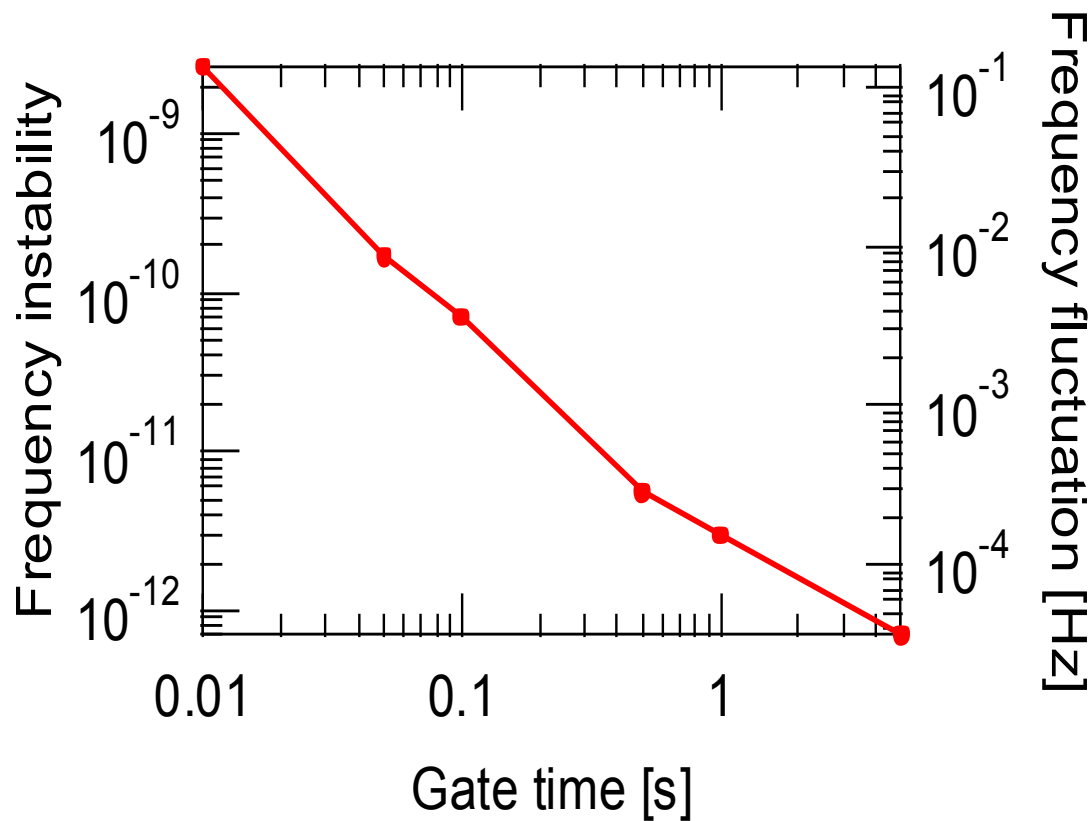


Determined at uncertainty of frequency standard

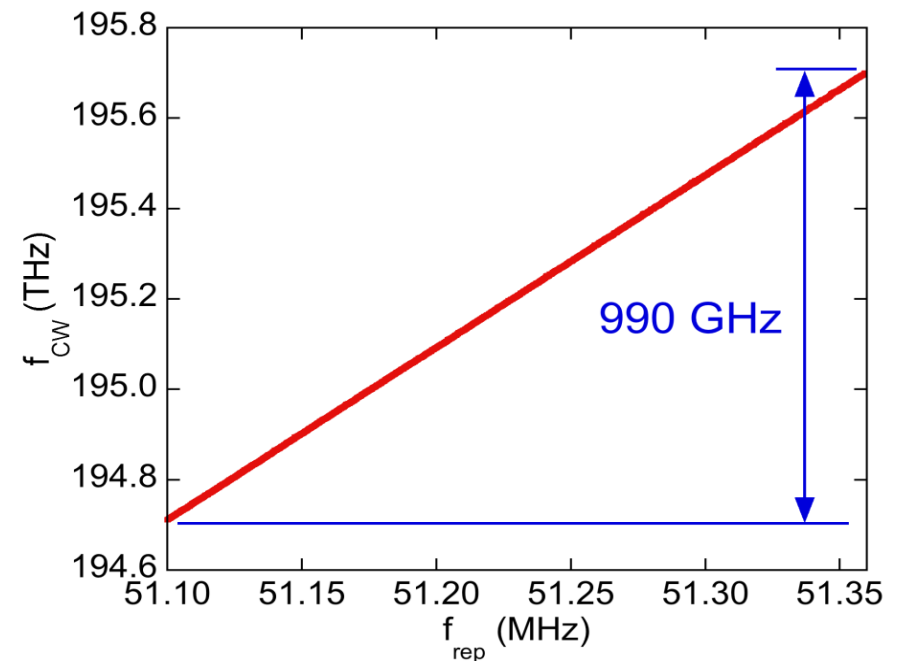
Continuous tuning by scanning f_{rep}

Performance of OFS

Stability of f_{opt}



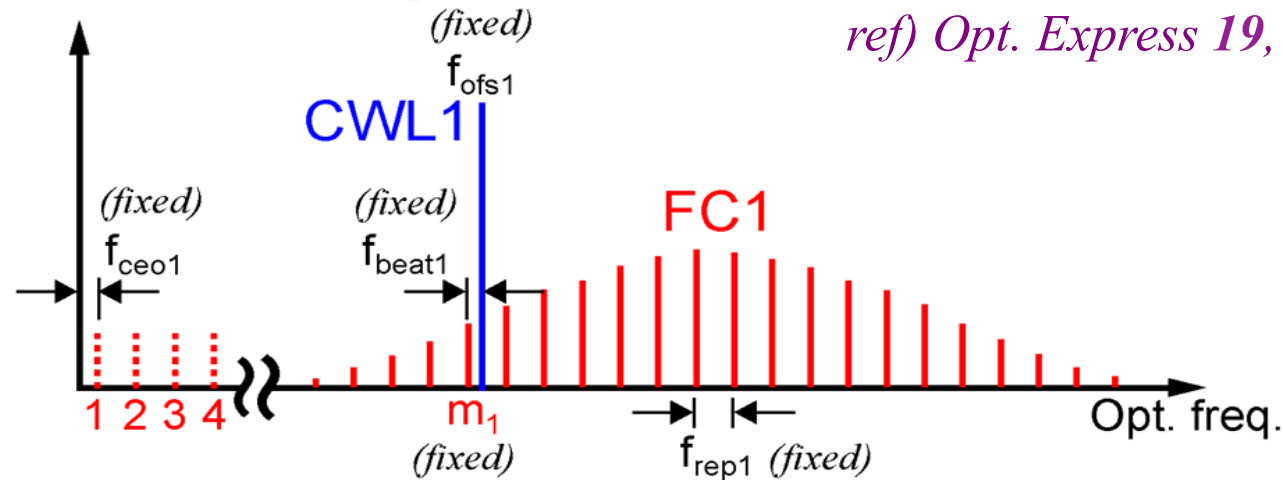
Tuning characteristic



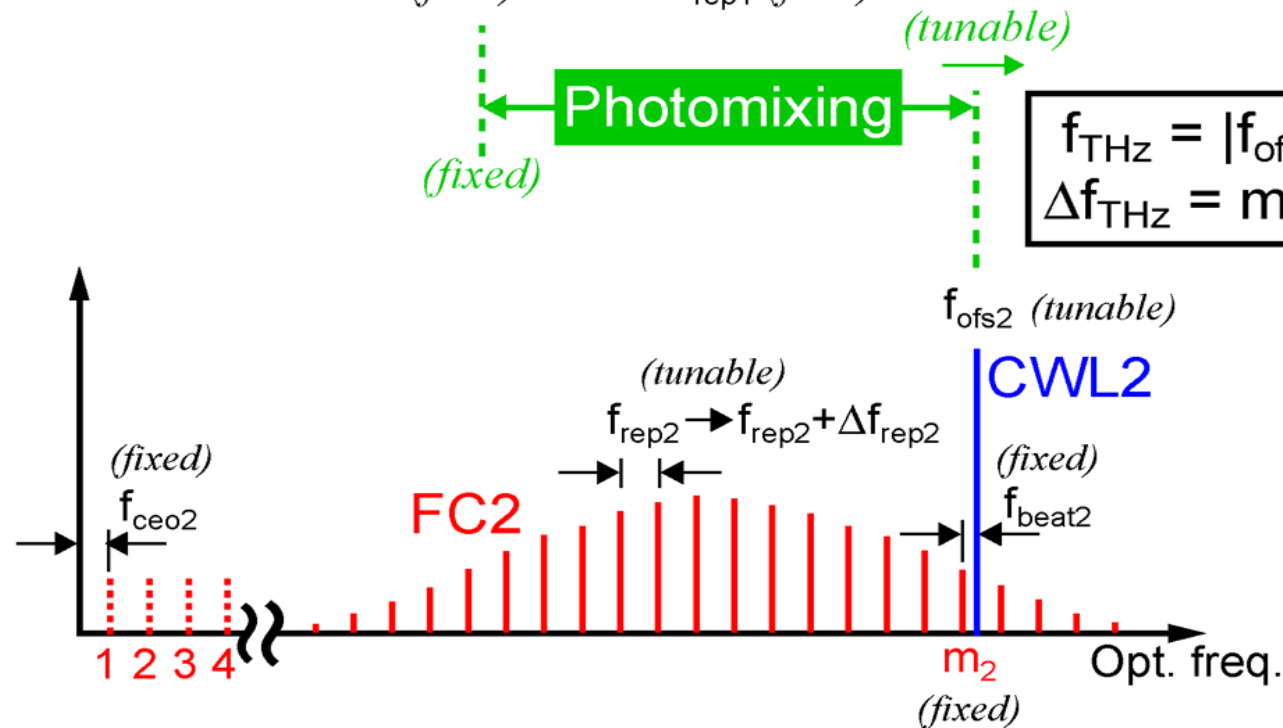
THz synthesizer based on photomixing of two independent OFSs

ref) Opt. Express 19, 4428 (2011)

Fixed OFS
(OFS1)



Tunable OFS
(OFS2)

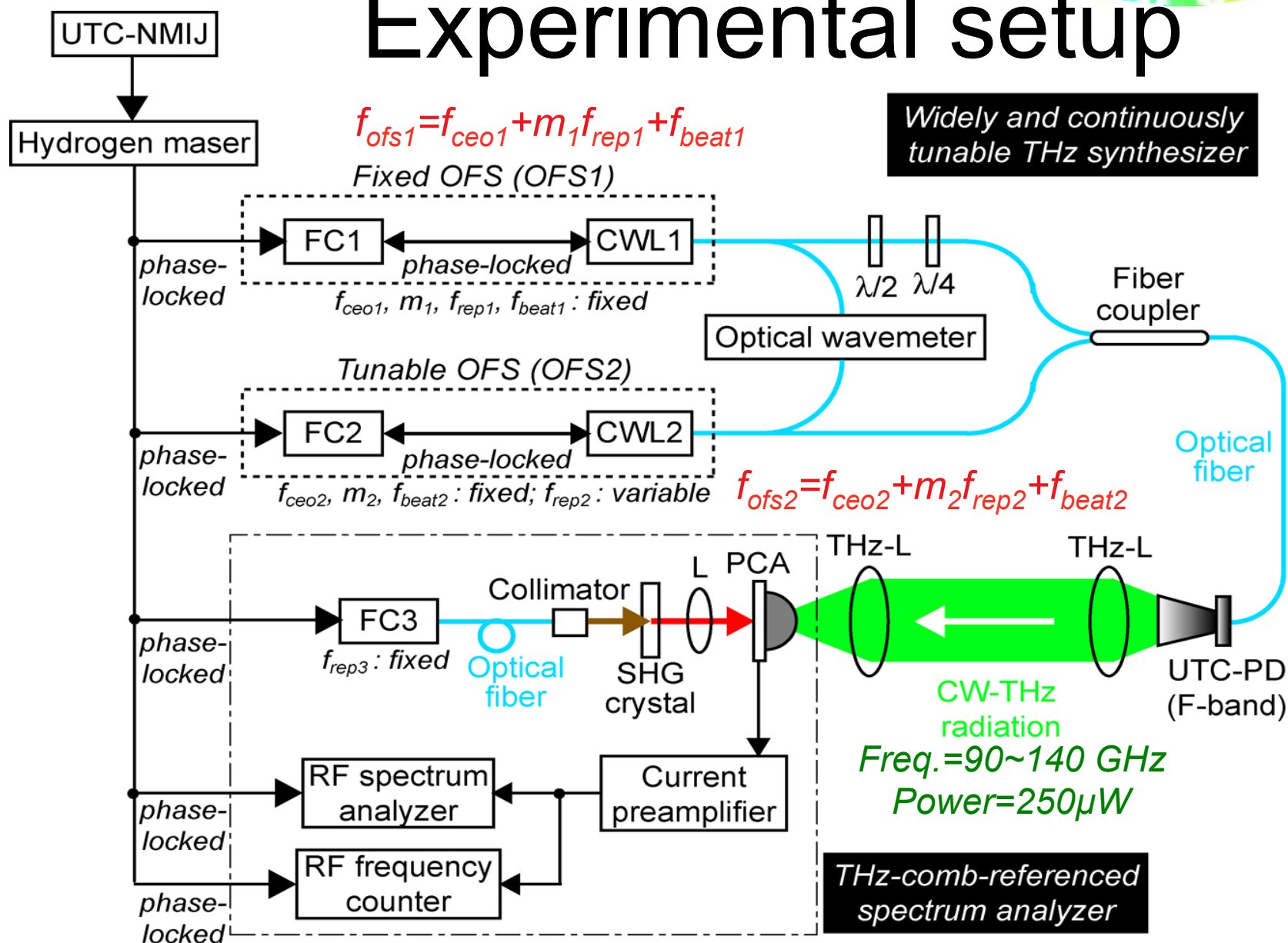


Photomixing

$$f_{\text{THz}} = |f_{\text{ofs2}} - f_{\text{ofs1}}|$$

$$\Delta f_{\text{THz}} = m_2 \times \Delta f_{\text{rep2}}$$

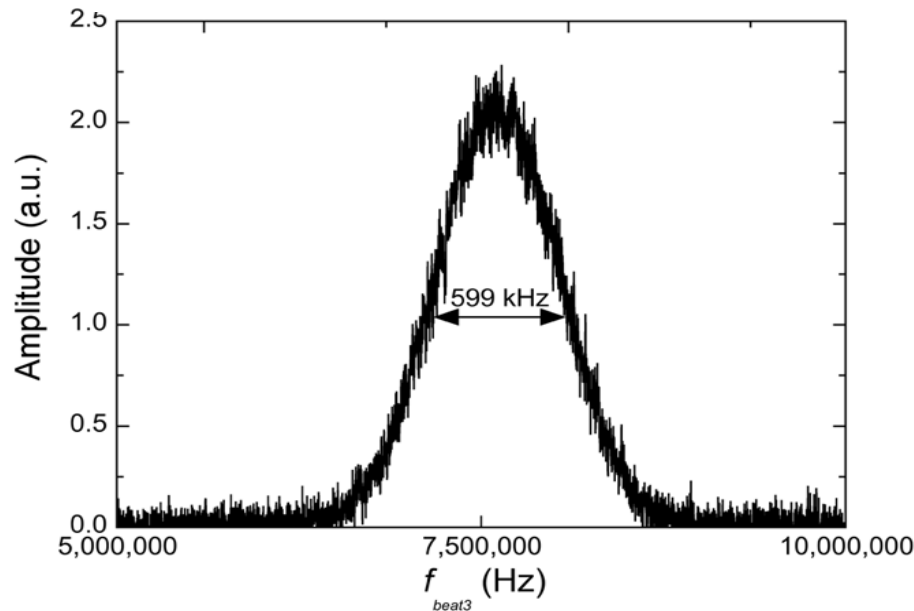
Experimental setup



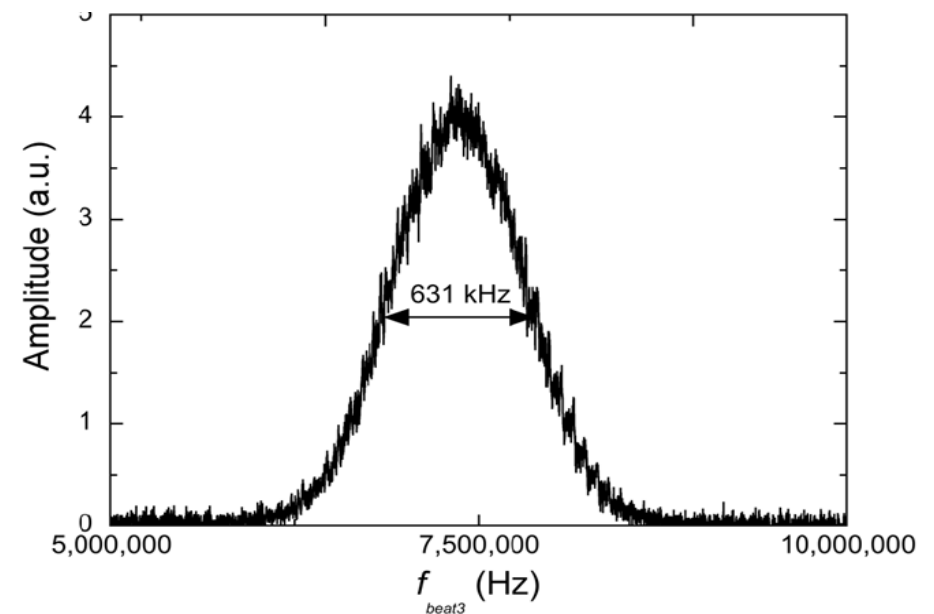
ref) Opt. Express 16, 13052 (2008); Opt. Express 17, 17034 (2009)

Spectrum of CW-THz wave measured by THz-comb-referenced spectrum analyzer

$$f_{\text{THz}} = 92 \text{ GHz}$$



$$f_{\text{THz}} = 140 \text{ GHz}$$

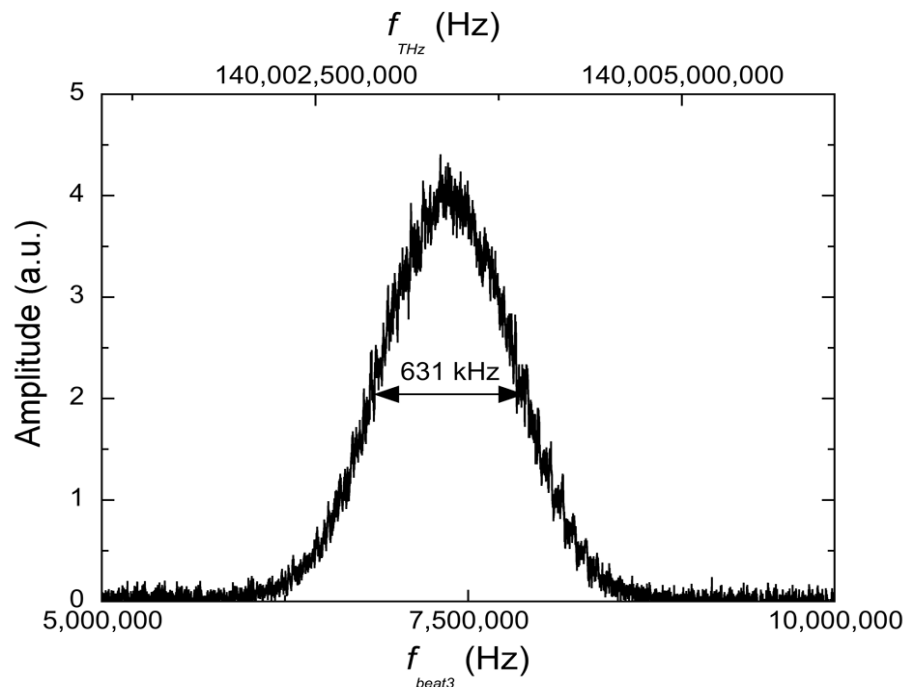


OFS1: $\Delta f_{\text{ofs1}} = 280 \text{ kHz}$ OFS2: $\Delta f_{\text{ofs2}} = 600 \text{ kHz}$

Assignment of absolute frequency to CW-THz spectrum around 140 GHz

Parameters of OFSs

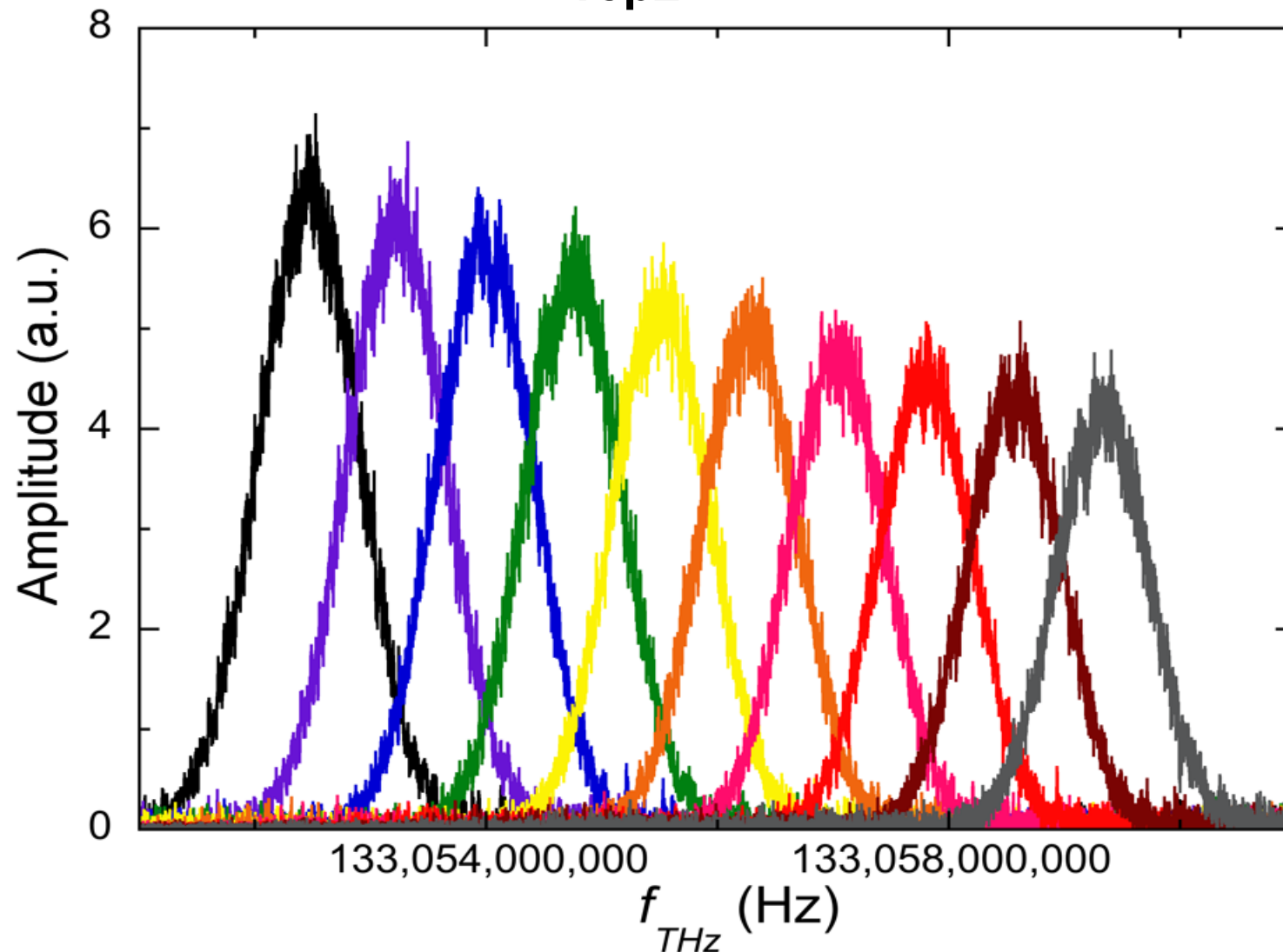
	f_{ceo} (Hz)	m	f_{rep} (Hz)	f_{beat} (Hz)	f_{ofs} (Hz)
OFS1	10,683,000	3,889,264	49,985,129.0	-21,384,000	194,405,352,054,056
OFS2	10,683,000	3,811,224	50,971,884.1	69,960,000	194,265,348,650,138



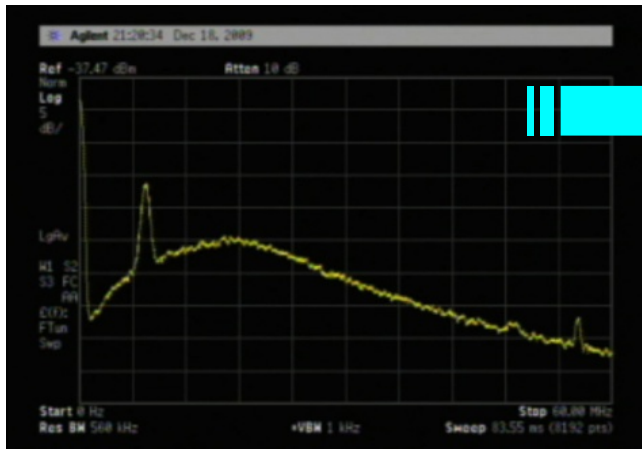
Center frequency of CW-THz wave (f_{THz})

140,003,403,918 Hz
(uncertainty = 10^{-12})

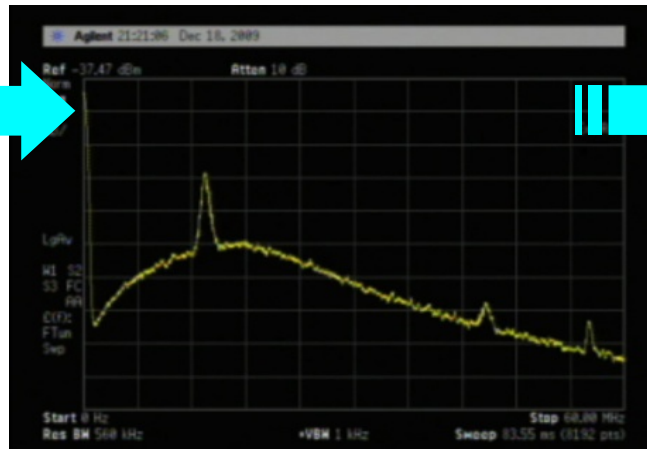
Incremental tuning of CW-THz wave around 133 GHz by scanning $f_{\text{rep}2}$ at 0.2 Hz intervals



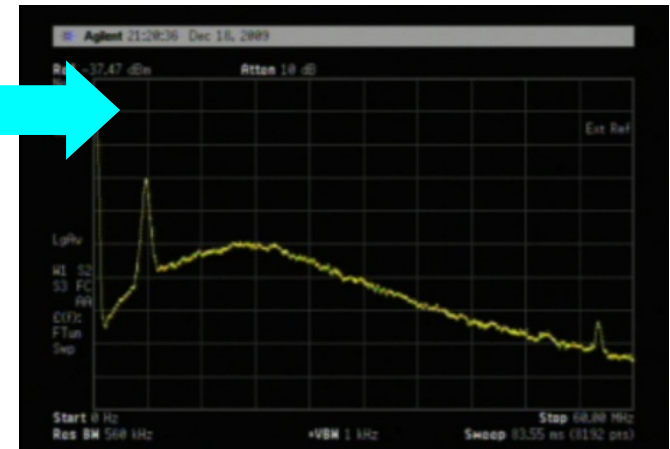
Consecutive tuning of f_{THz} over range of 1GHz around 131.71GHz



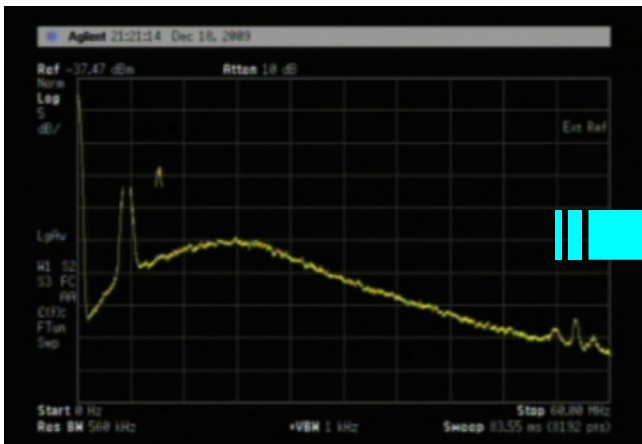
@@@ GHz



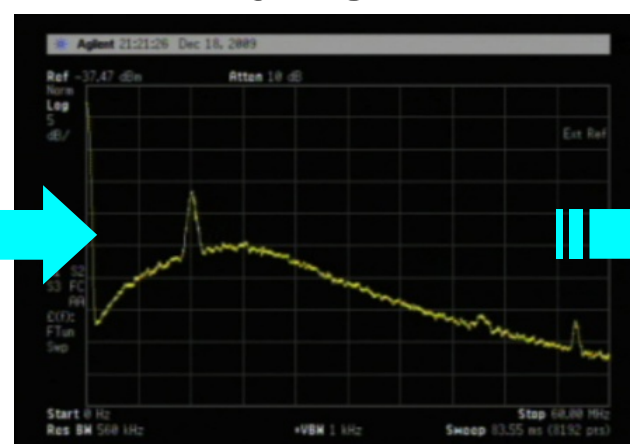
+0.2GHz



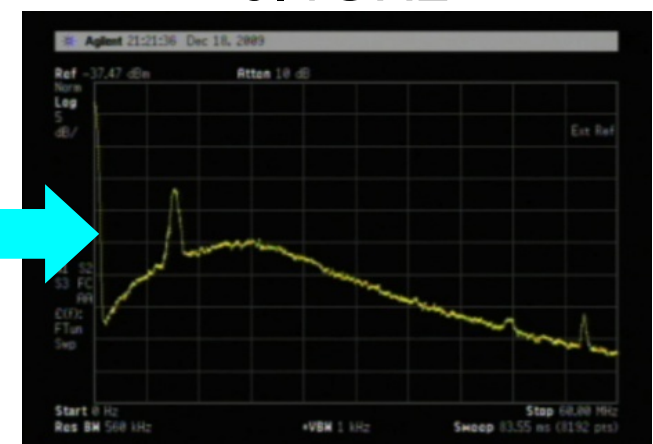
+0.4GHz



+0.6GHz



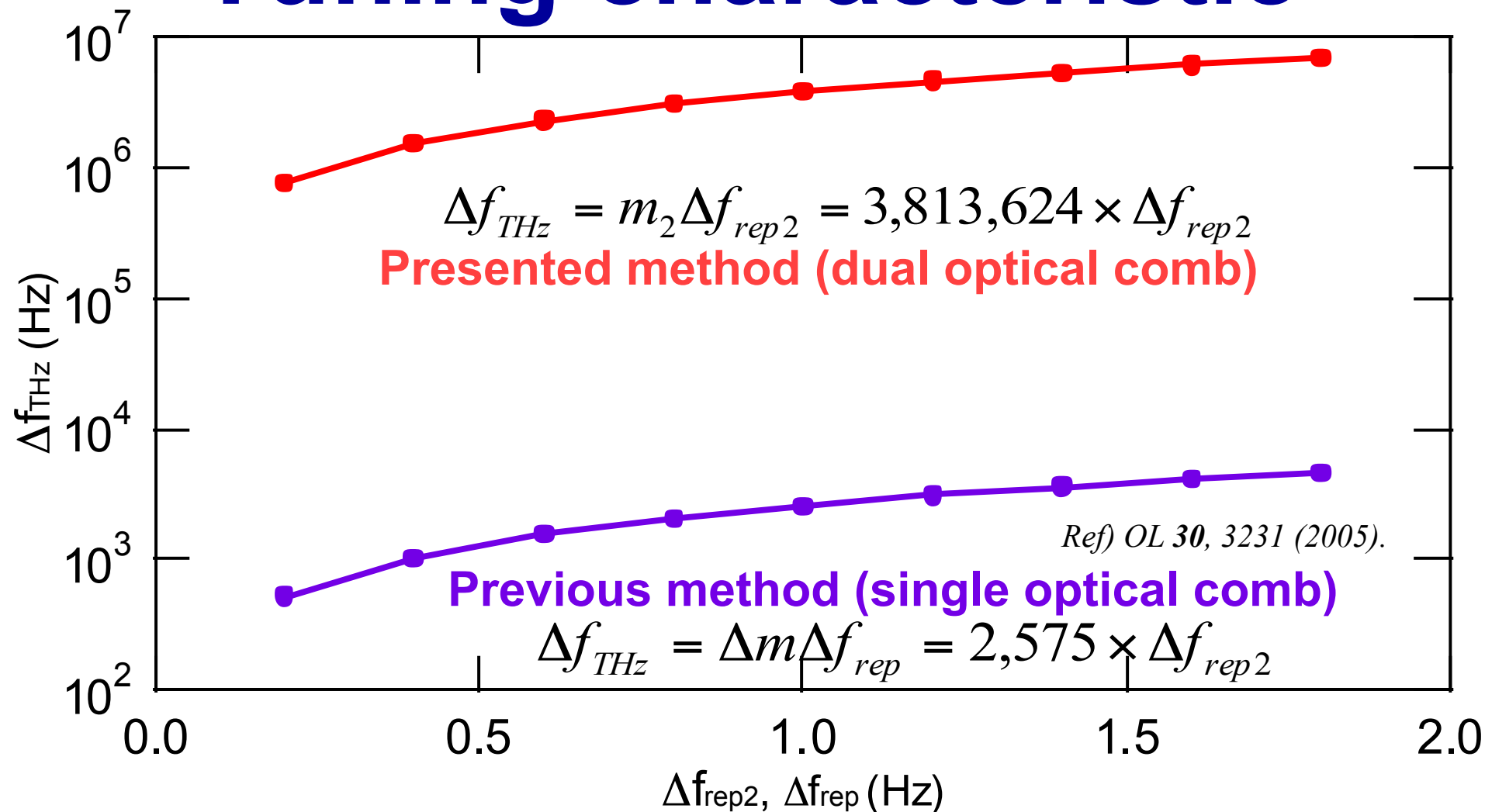
+0.8GHz



+1GHz

Tuning characteristic

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Δf_{THz} can achieve 1.7 THz when $\Delta f_{rep2} = 450$ kHz

Summary

Continuously tunable THz synthesizer traceable to hydrogen maser

- (1) Frequency uncertainty of 10^{-12}
- (2) Linewidth = 600 kHz
- (3) Discrete tuning = 50 GHz,
 limited by available BW of UTC-PD
- (4) Continuous tuning = 1.26 GHz
- (5) Maximum tuning range = 0.99 THz
 if broadband photomixer is used