CMI5

Terahertz-Comb-Referenced Spectrum Analyzer

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Collaborations

Mode-locked Er-doped fiber laser THz clock and synthesizer

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Photomixing of two CW lasers with UTC-PD

Prof. Tadao Nagatsuma
Osaka University, Japan

Background

Frequency is a fundamental physical quantity of electromagnetic wave

Maintenance of THz frequency metrology is required for various THz applications

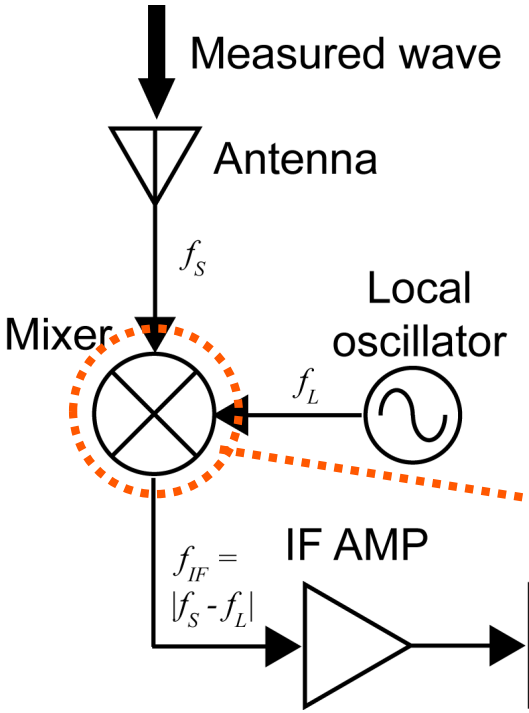
Advent of practical CW-THz sources (THz-QCL, photomixing with UTC-PD, RTD etc)

Precise frequency measurement of CW-THz wave is required!

However, techniques of frequency measurement in THz region are still lacking.

Conventional method

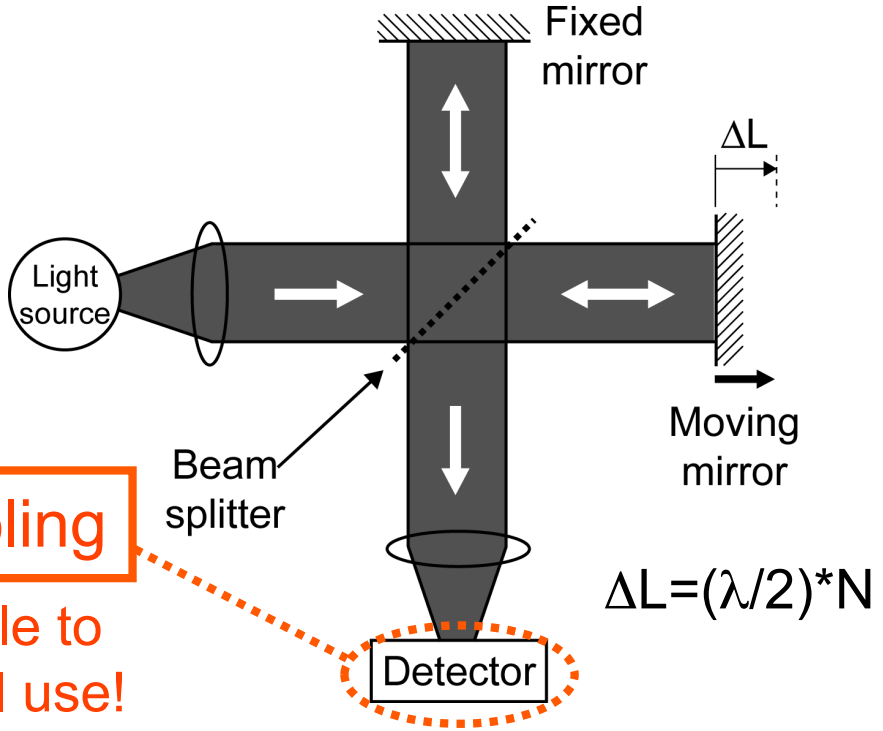
Electrical heterodyned method



Cryogenic cooling

Obstacle to practical use!

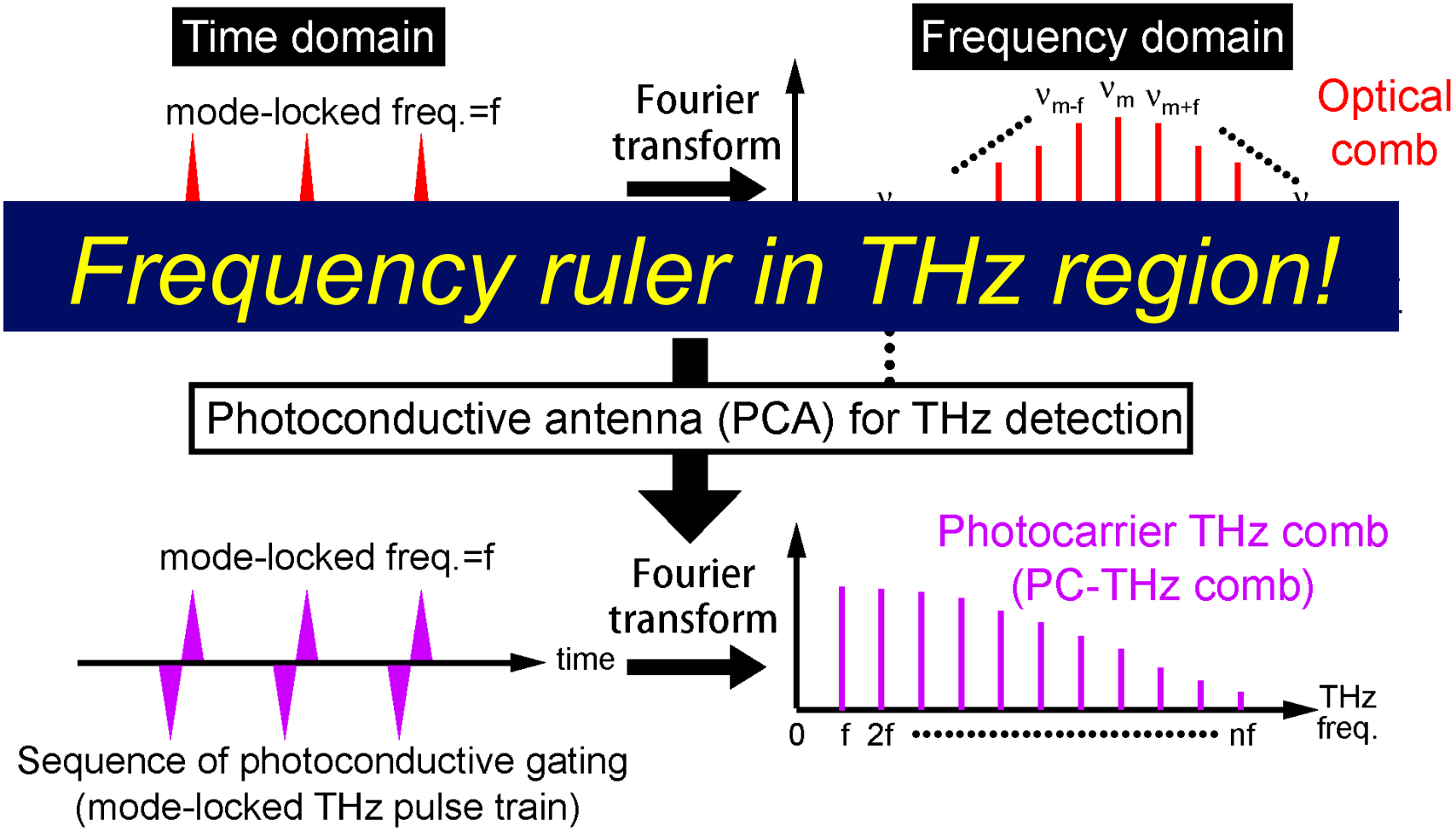
Optical interferometric method



Difficult to cover all frequency region of THz wave (0.1~10THz)

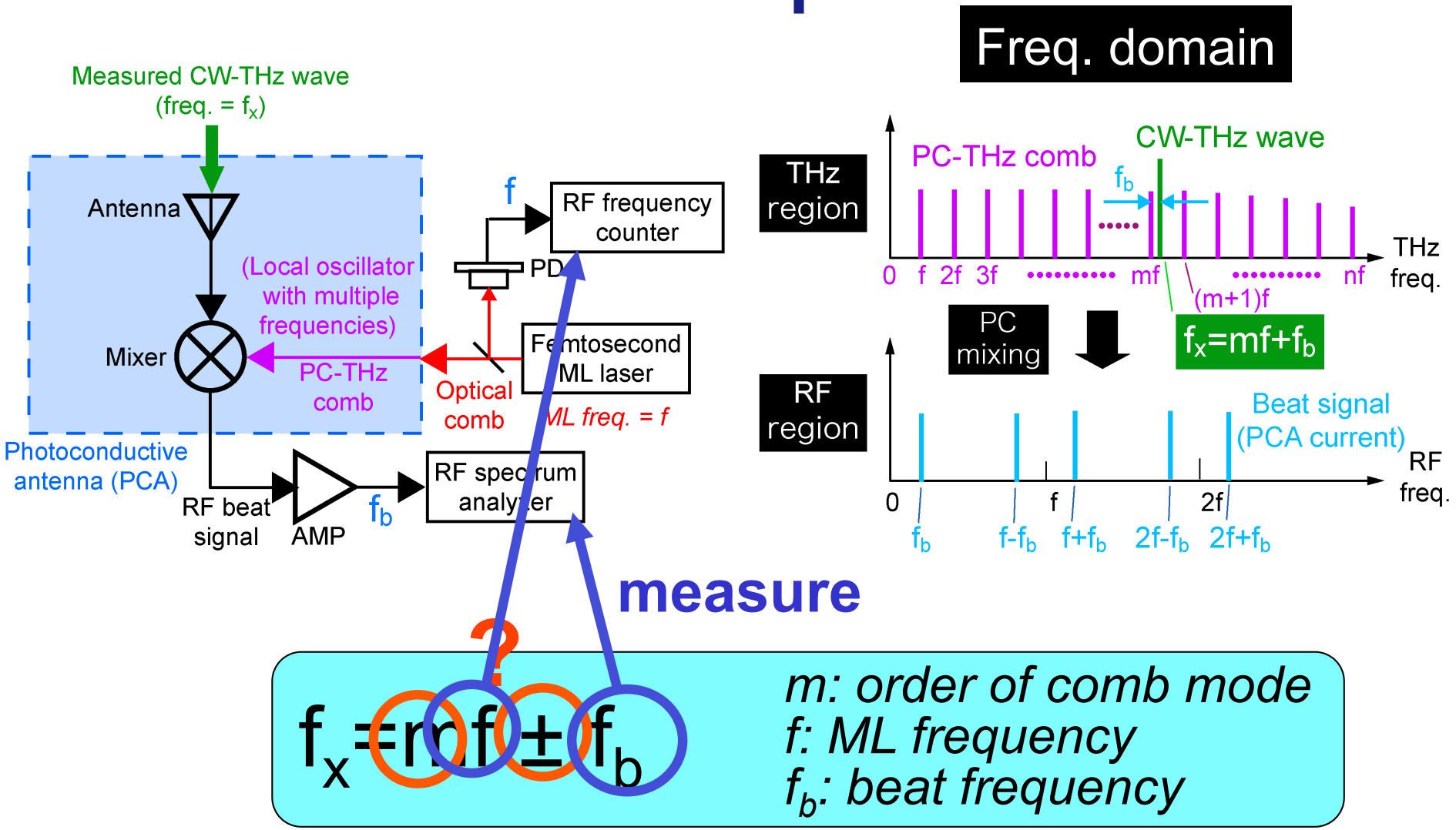
→Requirement of new method optimized for THz wave!

Optical comb and THz comb



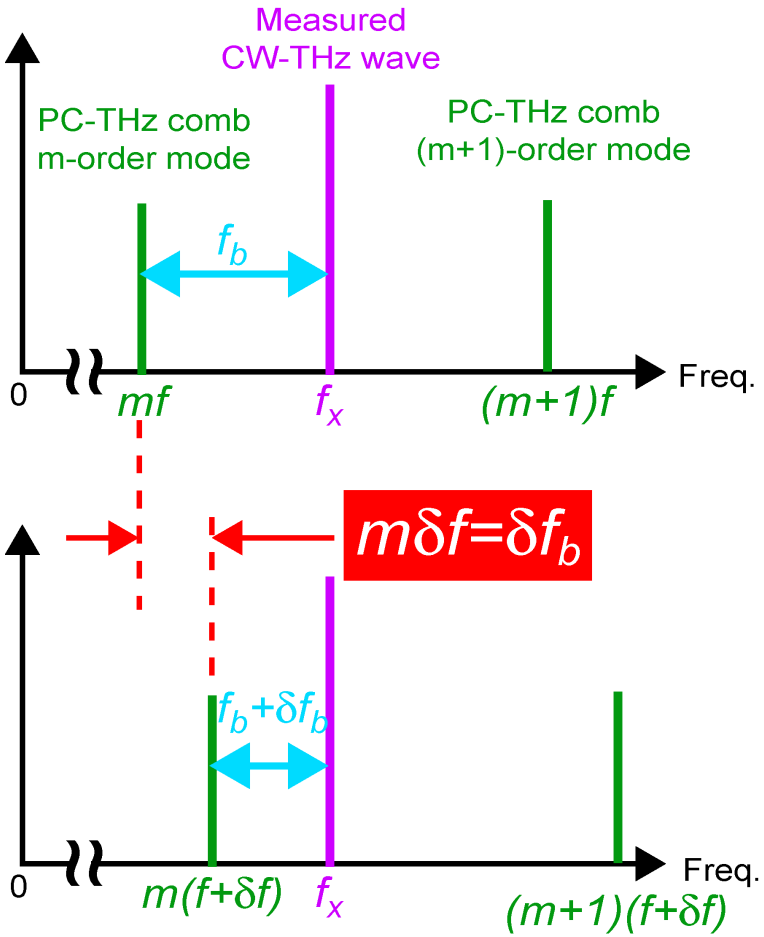
Simple, broadband selectivity, high spectral purity, offset free, and absolute frequency calibration

Principle



*Ref) Yokoyama et al, "Terahertz spectrum analyzer based on a terahertz frequency comb", Opt. Express **16**, pp. 13052-13061 (2008).*

Determination of m and sign of f_b



Shift of ML freq. by δf
(f → f+δf)

$$m = \frac{|\delta f_b|}{|\delta f|}$$

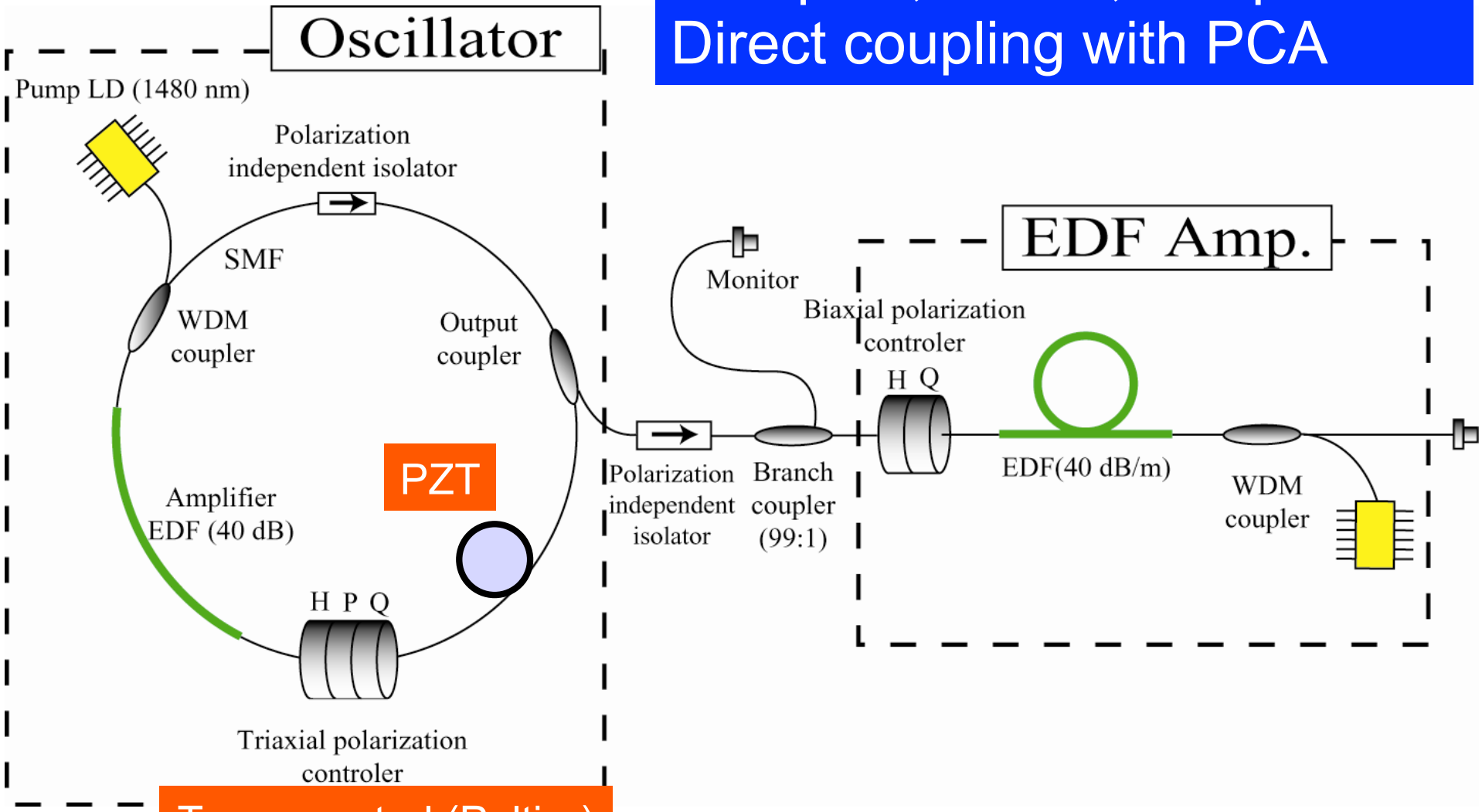
Change of beat freq. by δf_b
($f_b \rightarrow f_b+\delta f_b$)

$$f_x = mf - f_b \qquad (\delta f_b/\delta f > 0)$$

$$f_x = mf + f_b \qquad (\delta f_b/\delta f < 0)$$

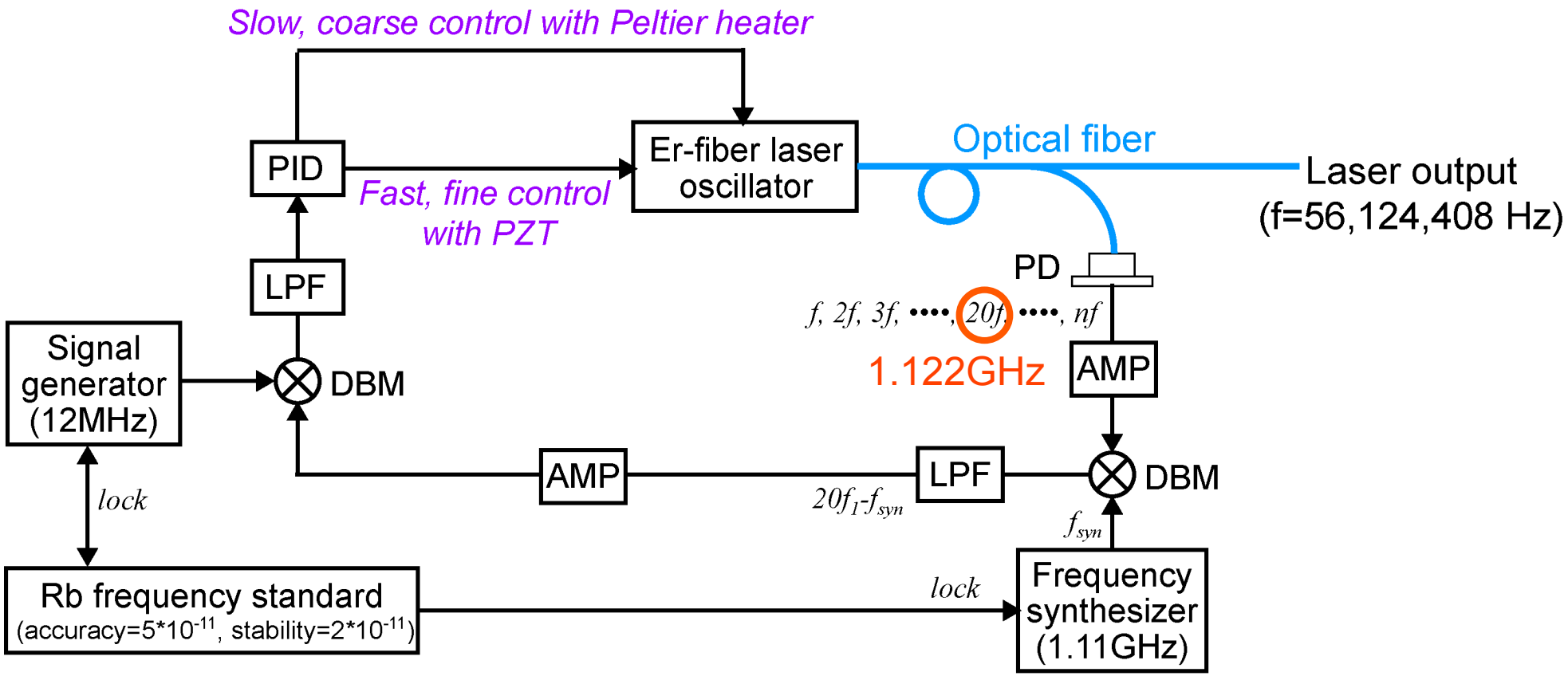
ML-freq.-stabilized fs Er-doped fiber laser

Compact, robust, inexpensive
Direct coupling with PCA



*ref) H. Inaba et al, Opt. Express **14**, 5223 (2006)*

Control system of ML frequency



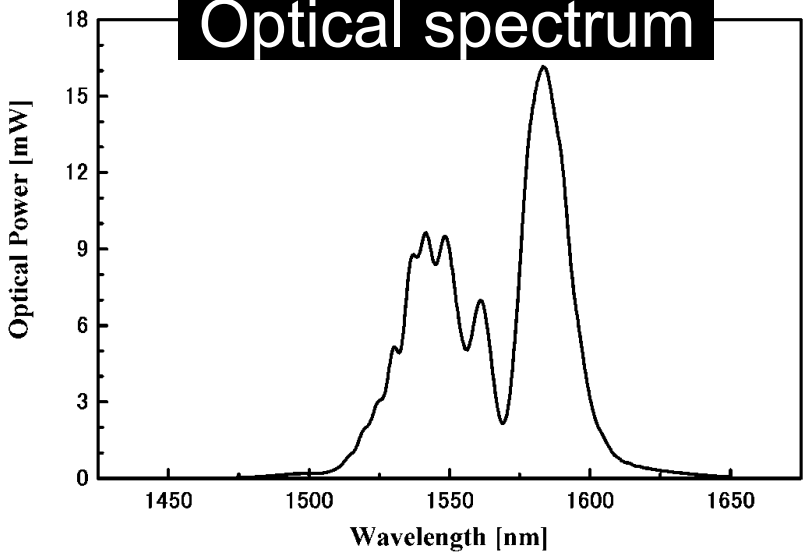
Photograph and basic performance

EDFA

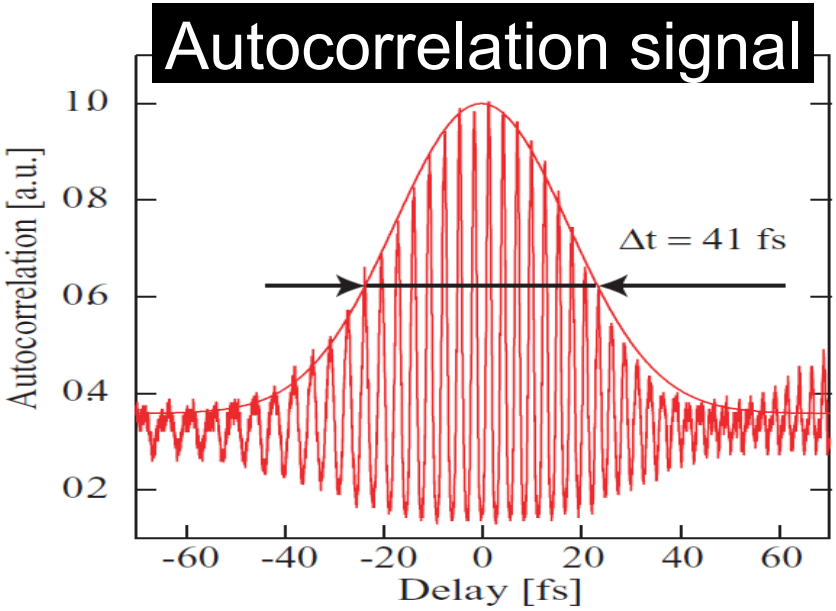
P_{avg} = 90 mW
λ_c = 1550nm
Δt = 41 fs

OSC

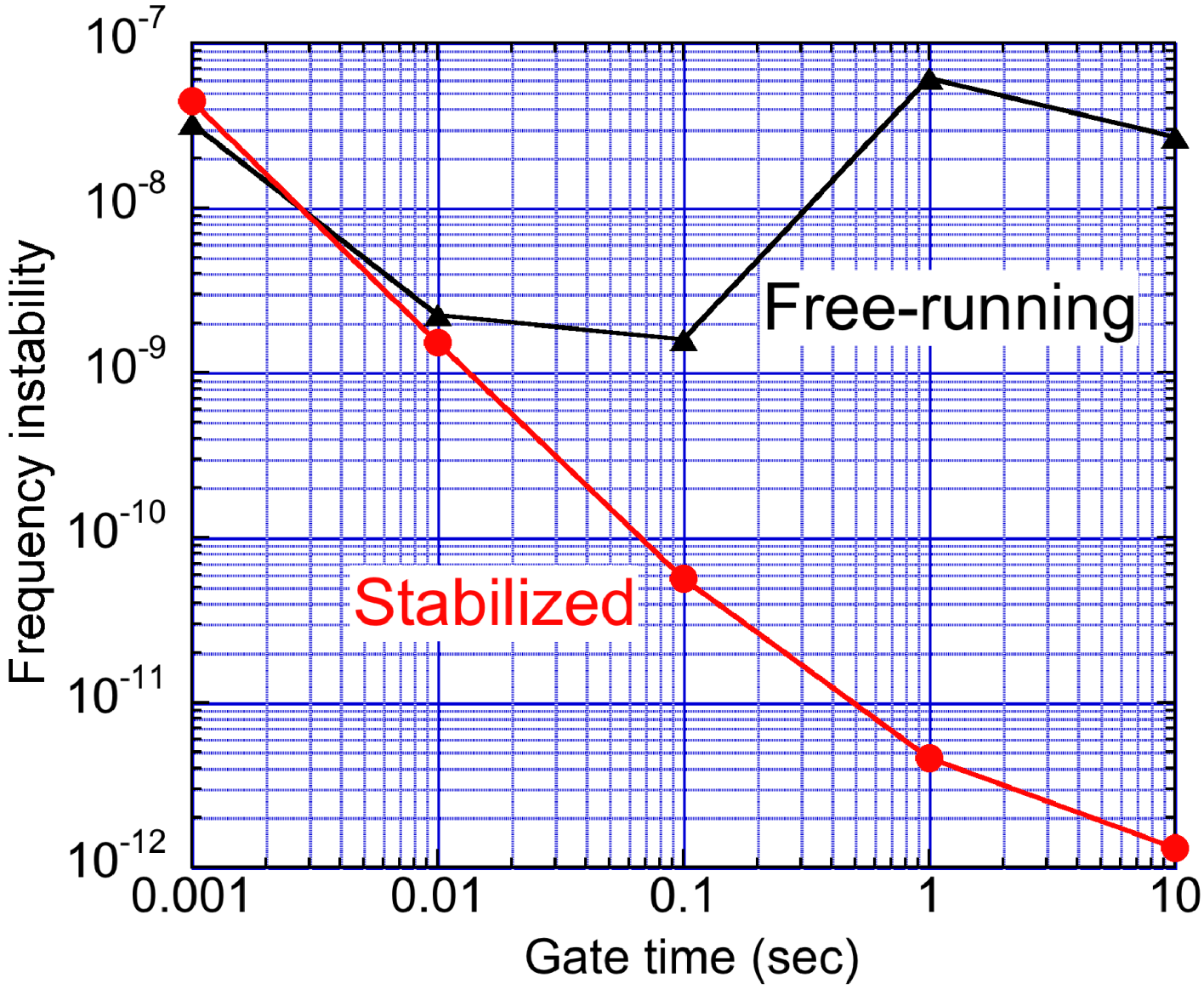
Optical spectrum



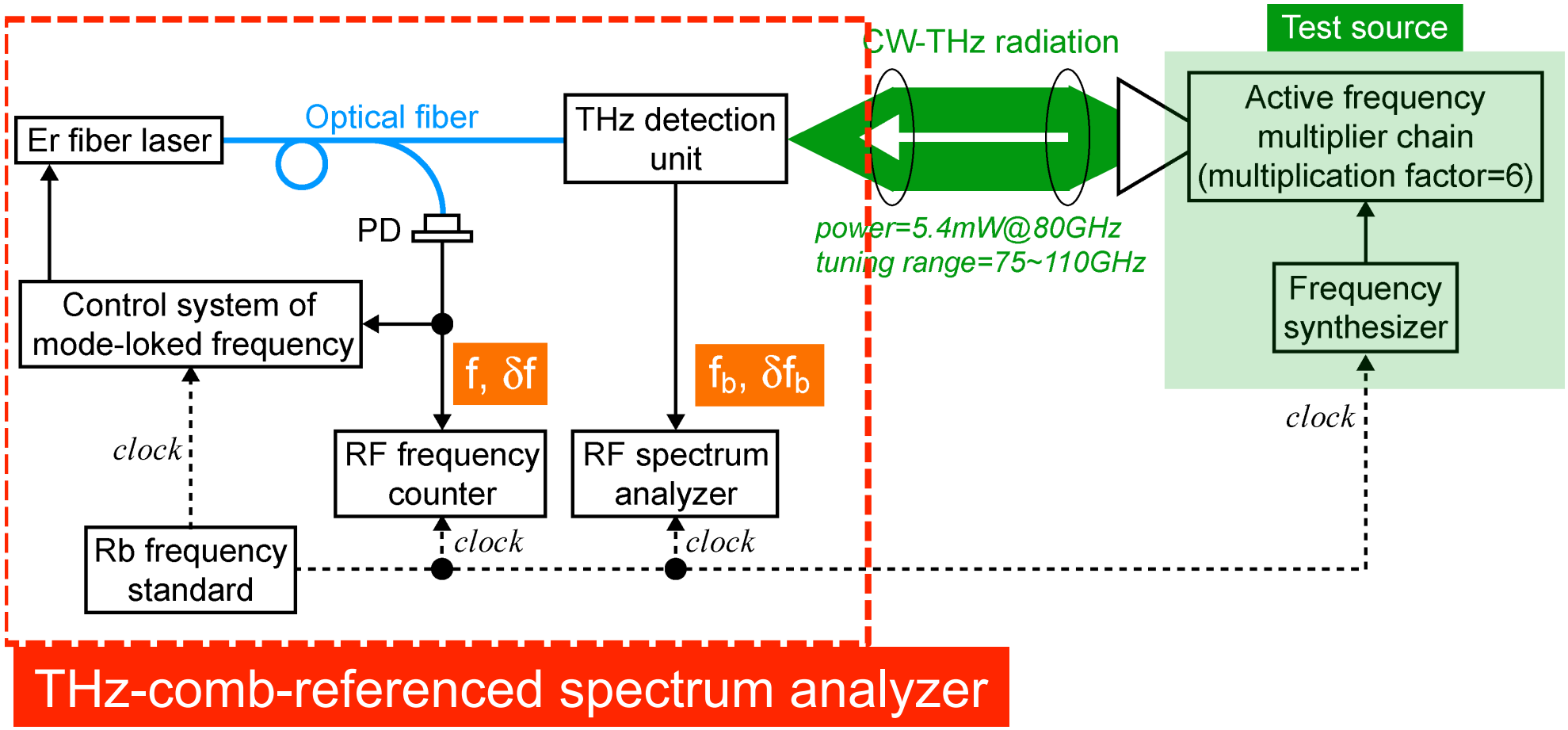
Autocorrelation signal



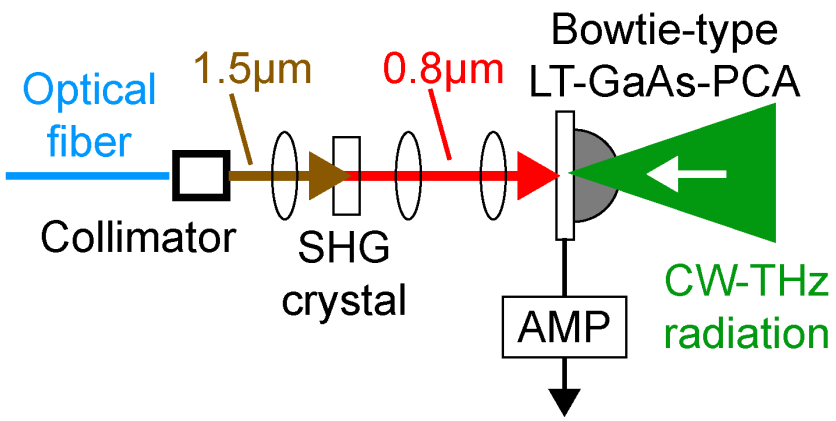
Instability of ML frequency of fiber laser



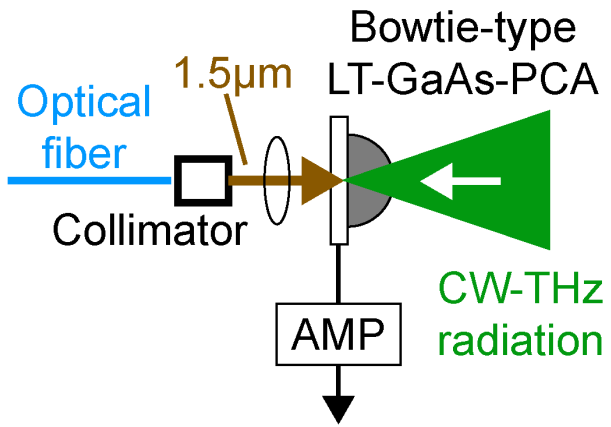
Experimental setup



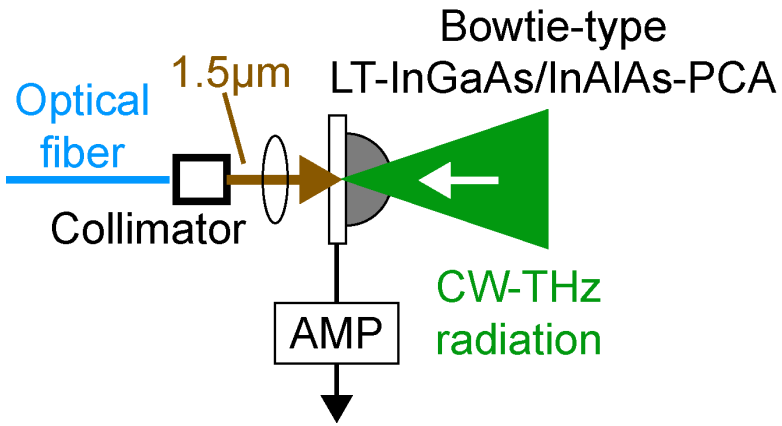
THz detection unit



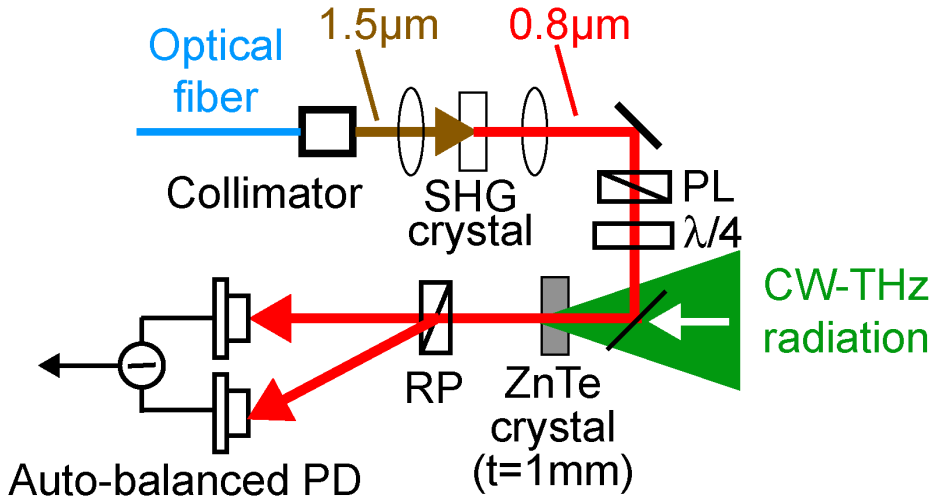
1 Bowtie-type LT-GaAs-PCA (0.8μm@6mW)



2 Bowtie-type LT-GaAs-PCA (1.5μm@20mW)



3 Bowtie-type LT-InGaAs-PCA (1.5μm@30mW)

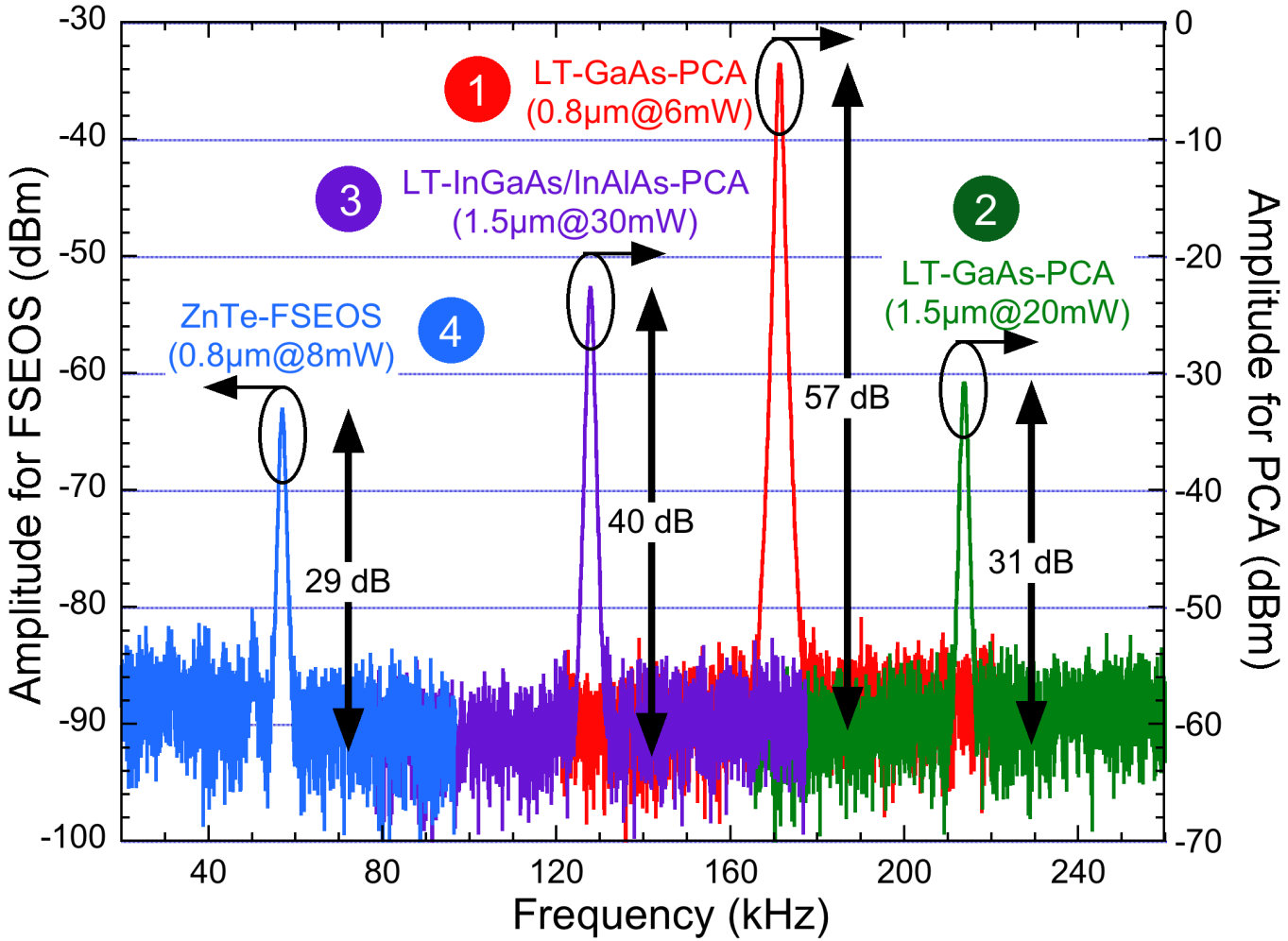


4 1mm-ZnTe-FSEOS (0.8μm@8mW)

Comparison of SNR of f_b beat signal

Output of test source = 5.4 mW @ 80 GHz

Detection limit	6,800nW	540nW	11nW	4,300nW

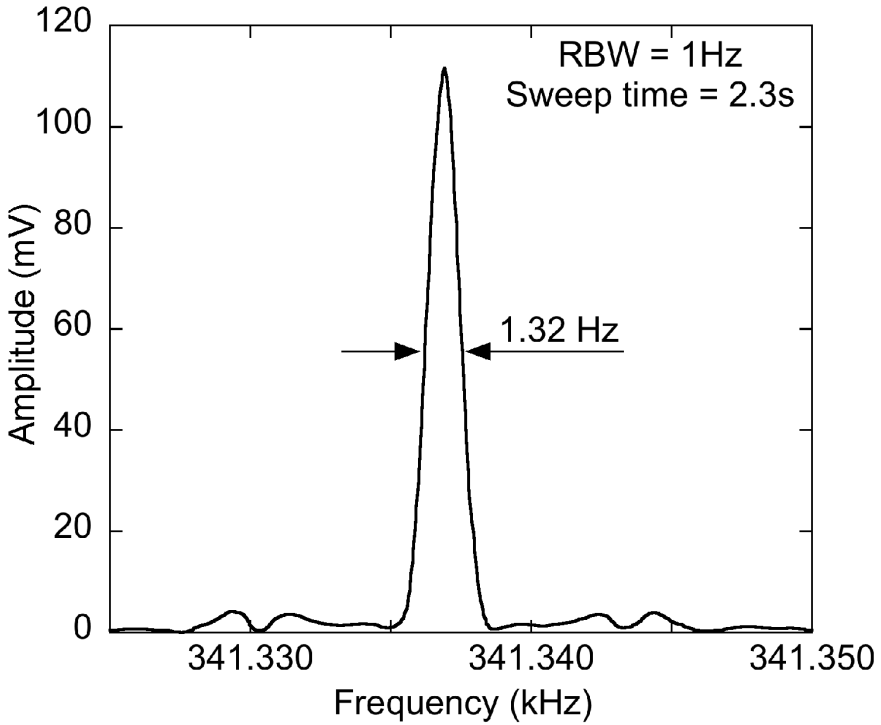


Detection sensitivity	0.22%	10%	100%	0.86%

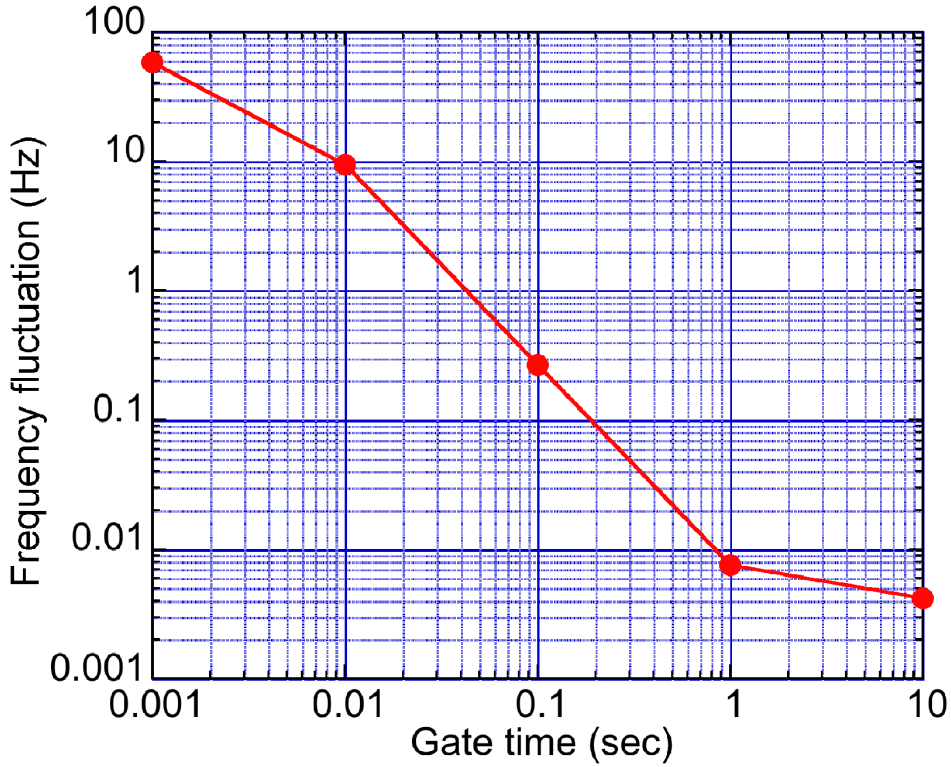
Linewidth of f_b beat signal

Output freq.=80 GHz

Linewidth



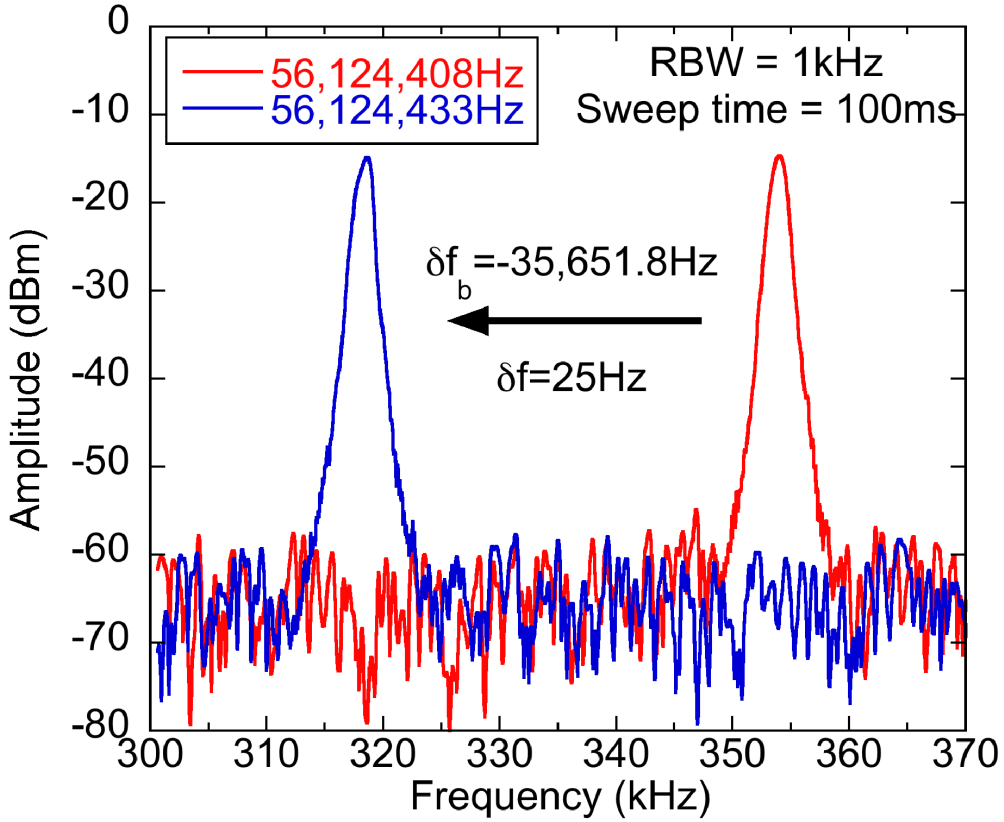
Frequency fluctuation



Linewidth = 10 mHz at 1 sec

Determination of absolute frequency

~Shift of ML frequency by 25Hz~



$$m = \frac{|\delta f_b|}{|\delta f|} = \frac{|-35{,}651.8|}{|25|} \approx 1426$$

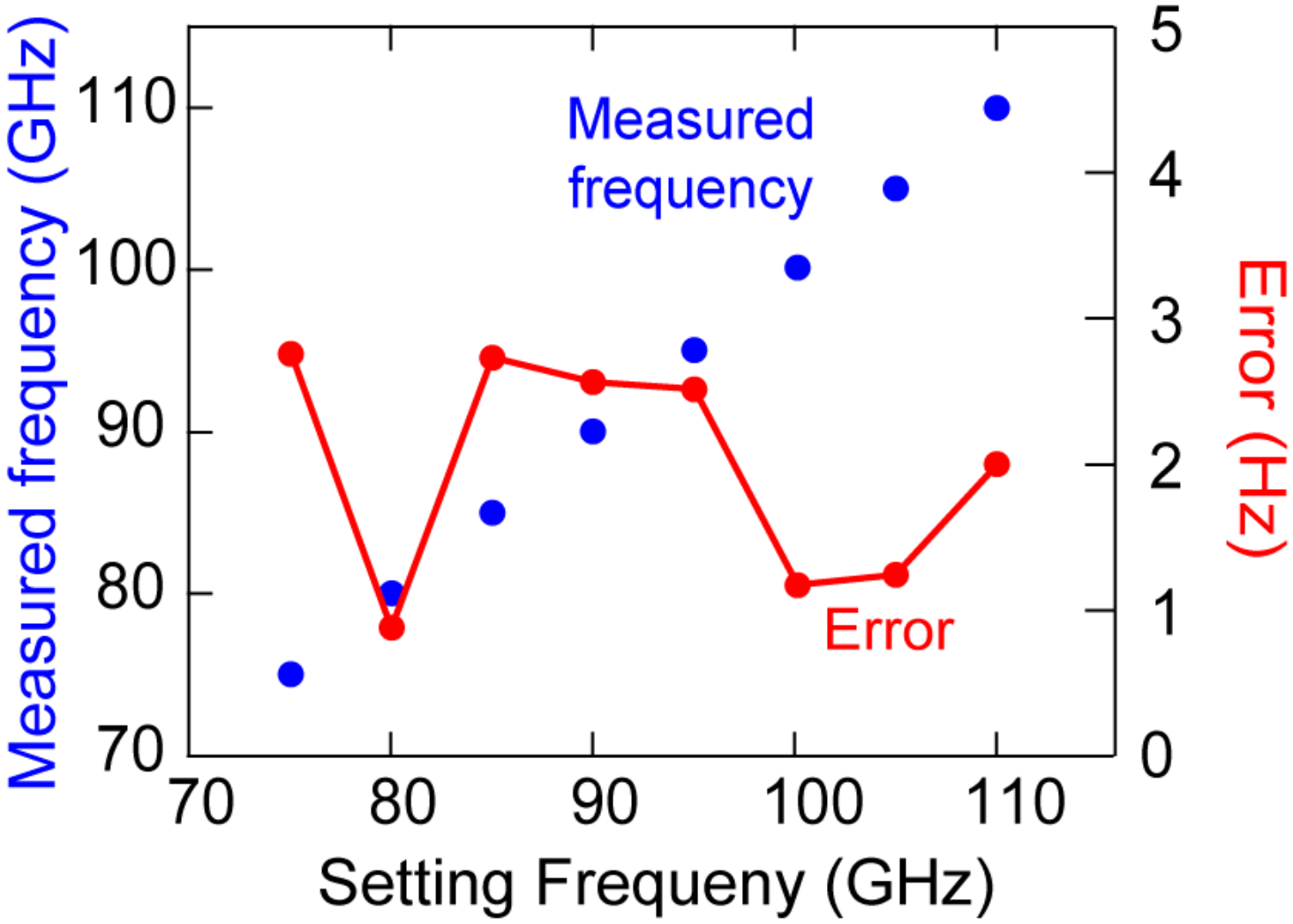
$$\frac{\delta f_b}{\delta f} = \frac{-35{,}651.8}{25} < 0$$

$$f_x = mf + f_b$$
$$= 1426 * 56{,}124{,}408 + 354{,}191.122$$
$$= 80{,}033{,}759{,}999.122\ Hz$$

error=0.878Hz

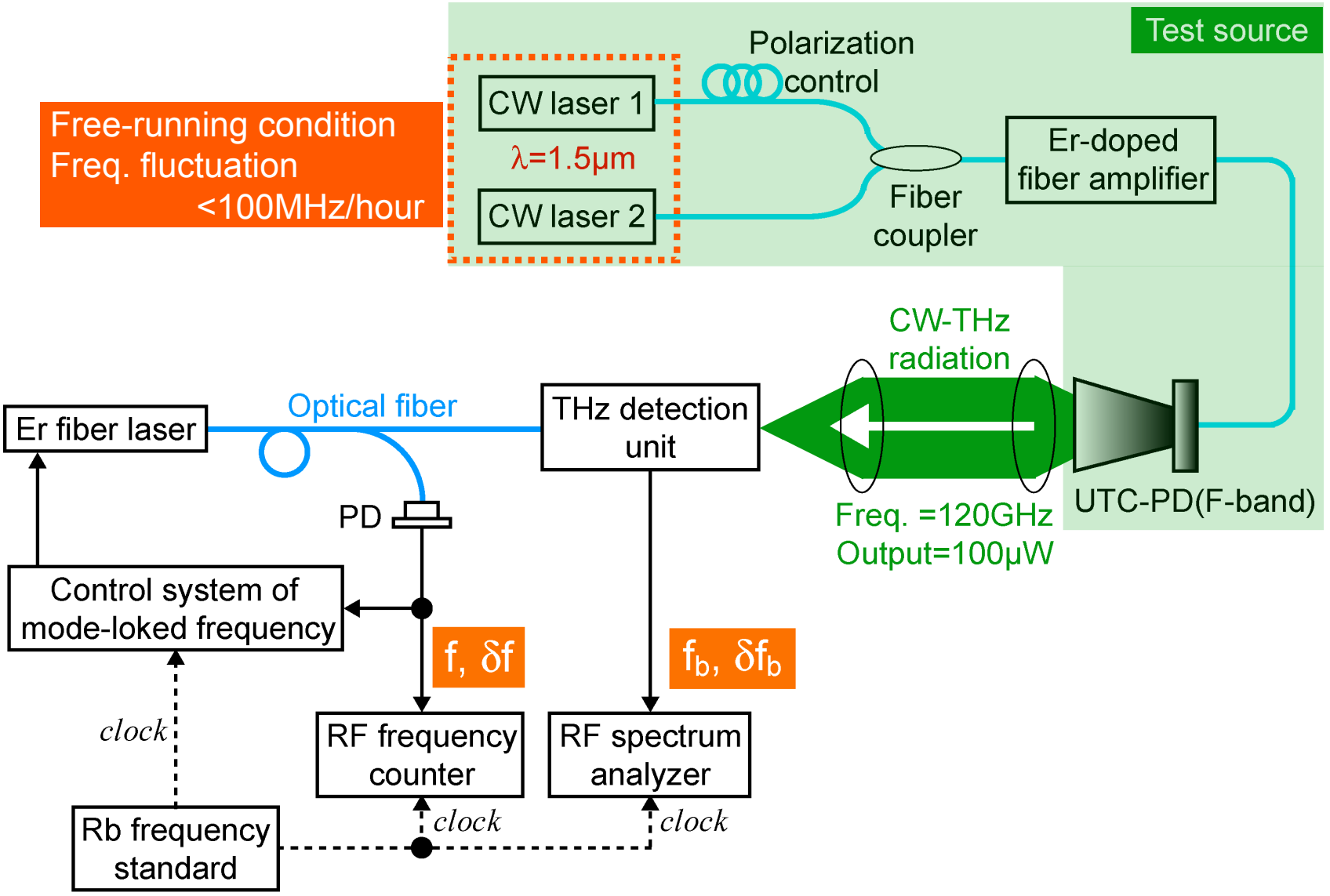
Setting freq. of test source=80,033,760,000 Hz

Frequency tuning of test source



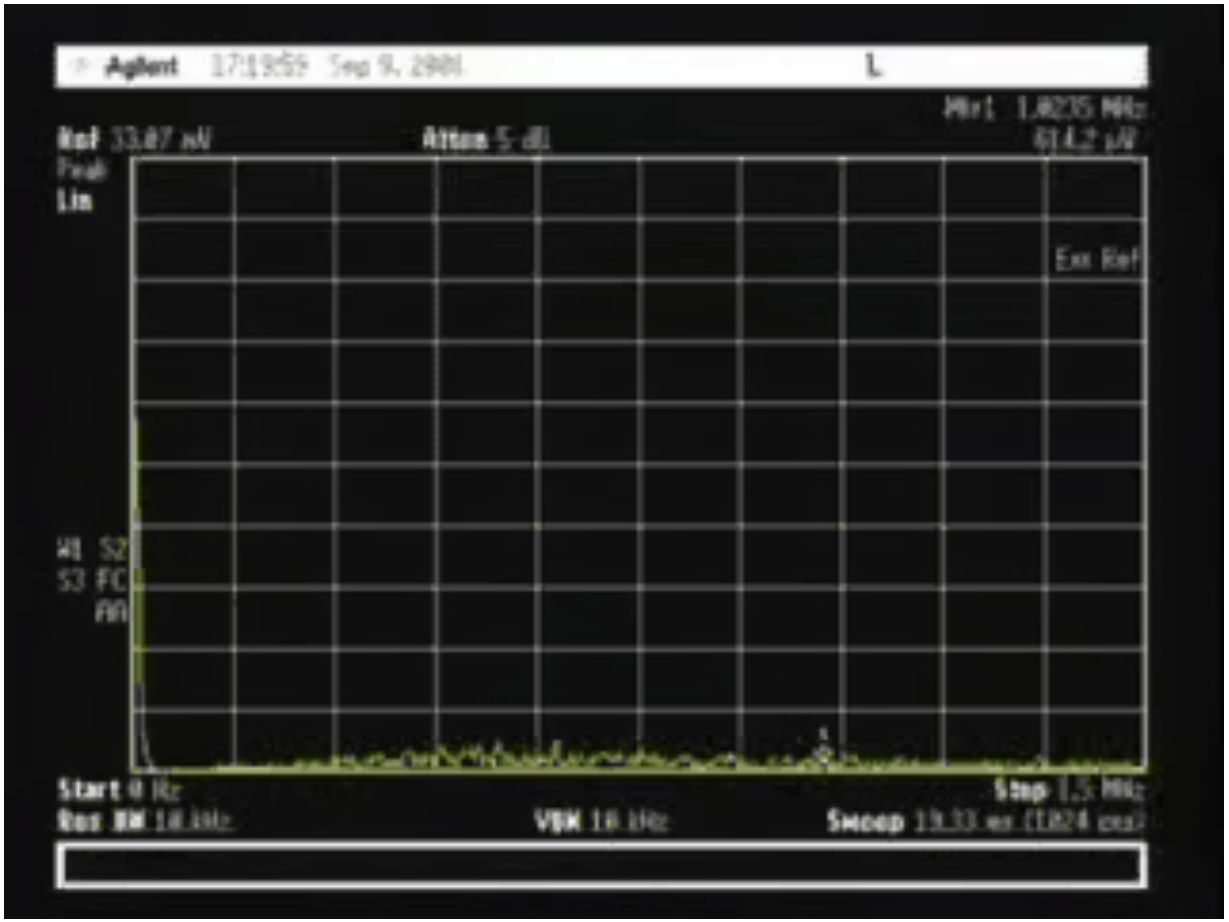
Mean precision=$2.2*10^{-11}$

Test source based on photomixing of two *free-running* CW lasers



Real-time monitoring of beat signal

←——Freq. span = 1.5 MHz——→

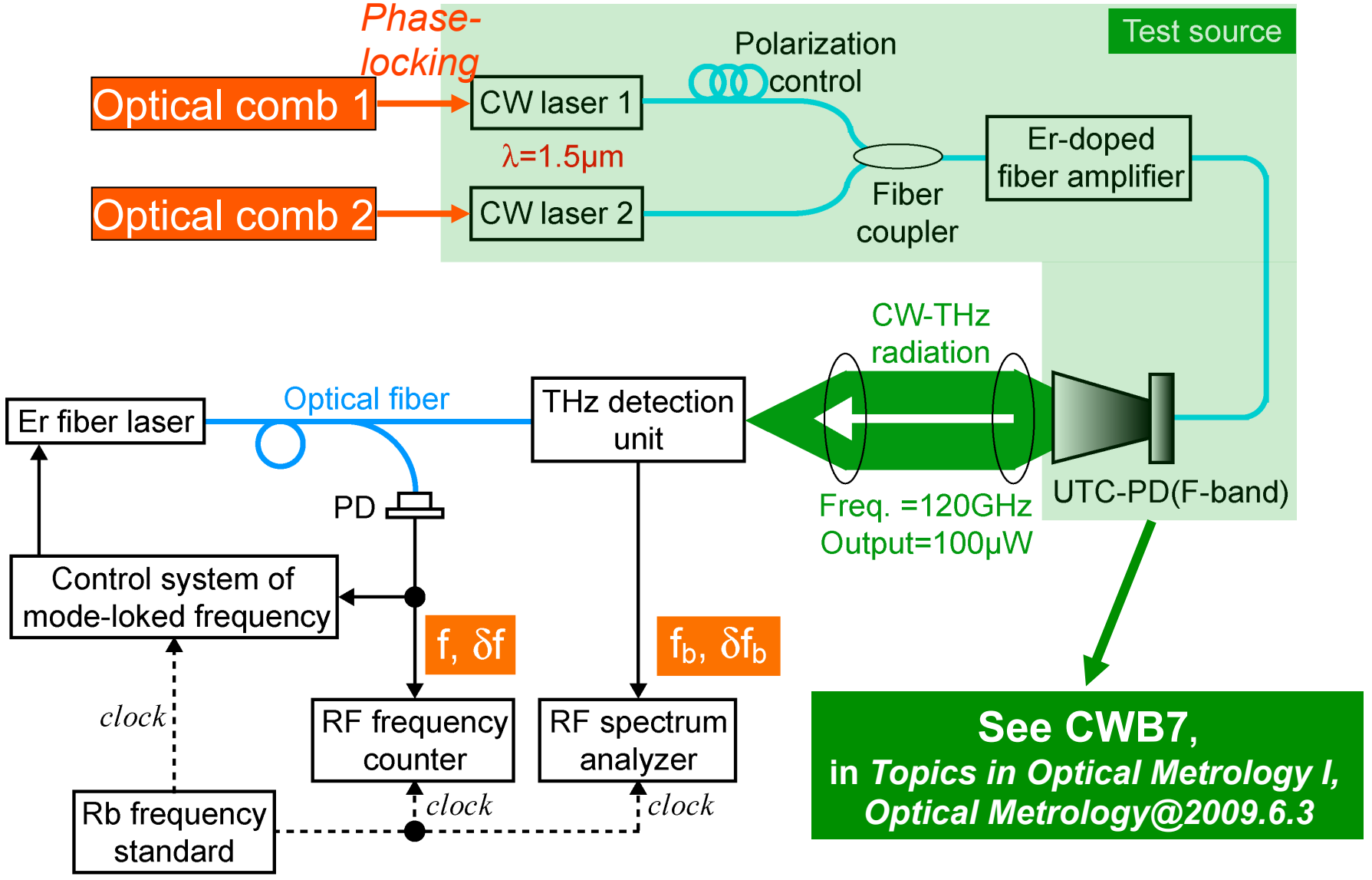


Output=100μW
Freq.=120GHz

Sweep time=20 ms
RBW=10 kHz

Large fluctuation of beat frequency caused by two fee-running CW lasers

Test source based on photomixing of two *stabilized* CW lasers

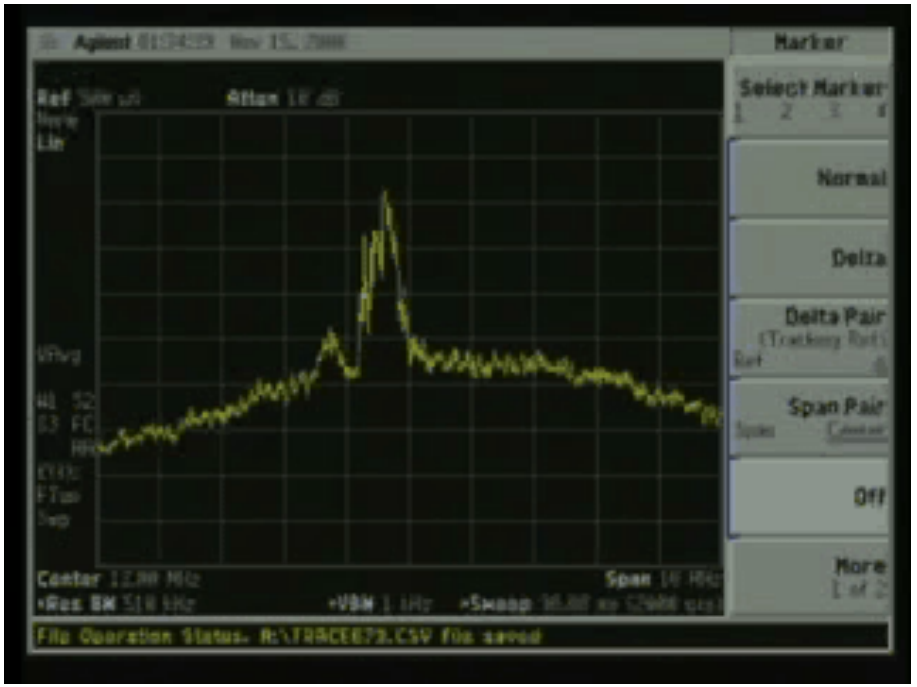


See CWB7,
in *Topics in Optical Metrology I, Optical Metrology@2009.6.3*

Real-time monitoring of beat signal

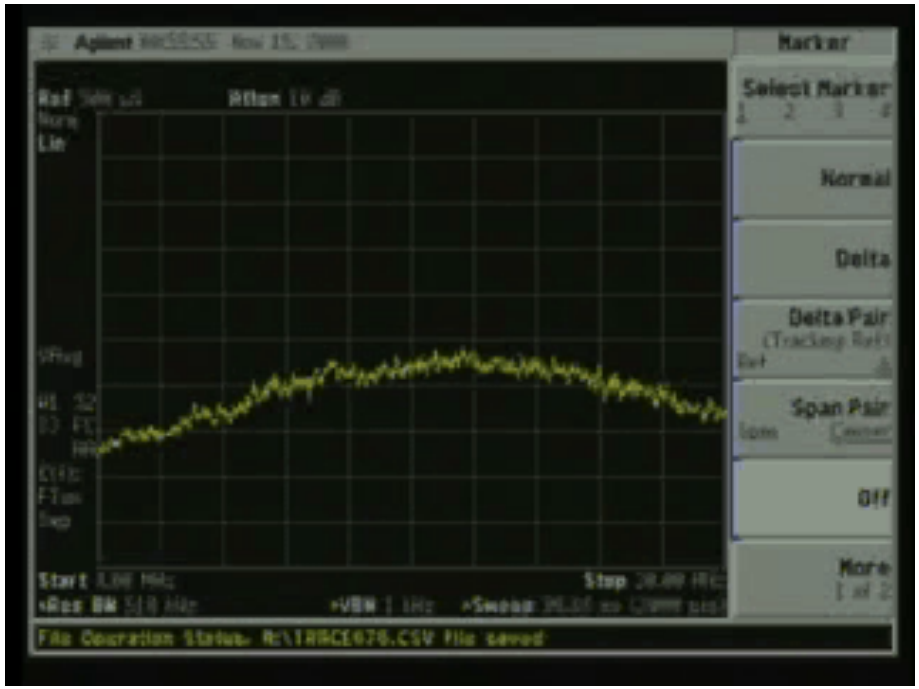
THz clock
(freq. =121,845,771,520 Hz)

←4MHz→



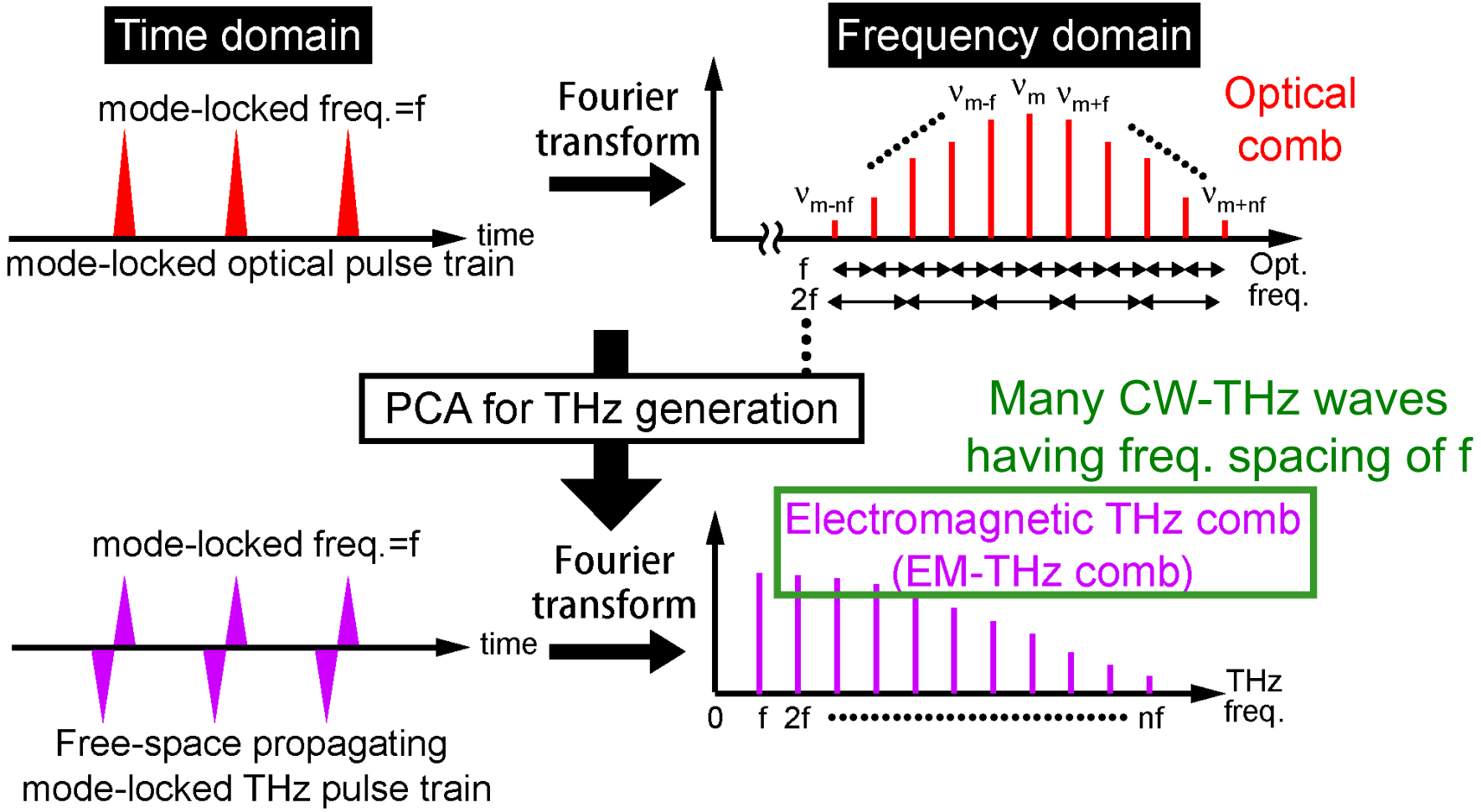
THz synthesizer
(tuning range = 90~140 GHz)

←16MHz→



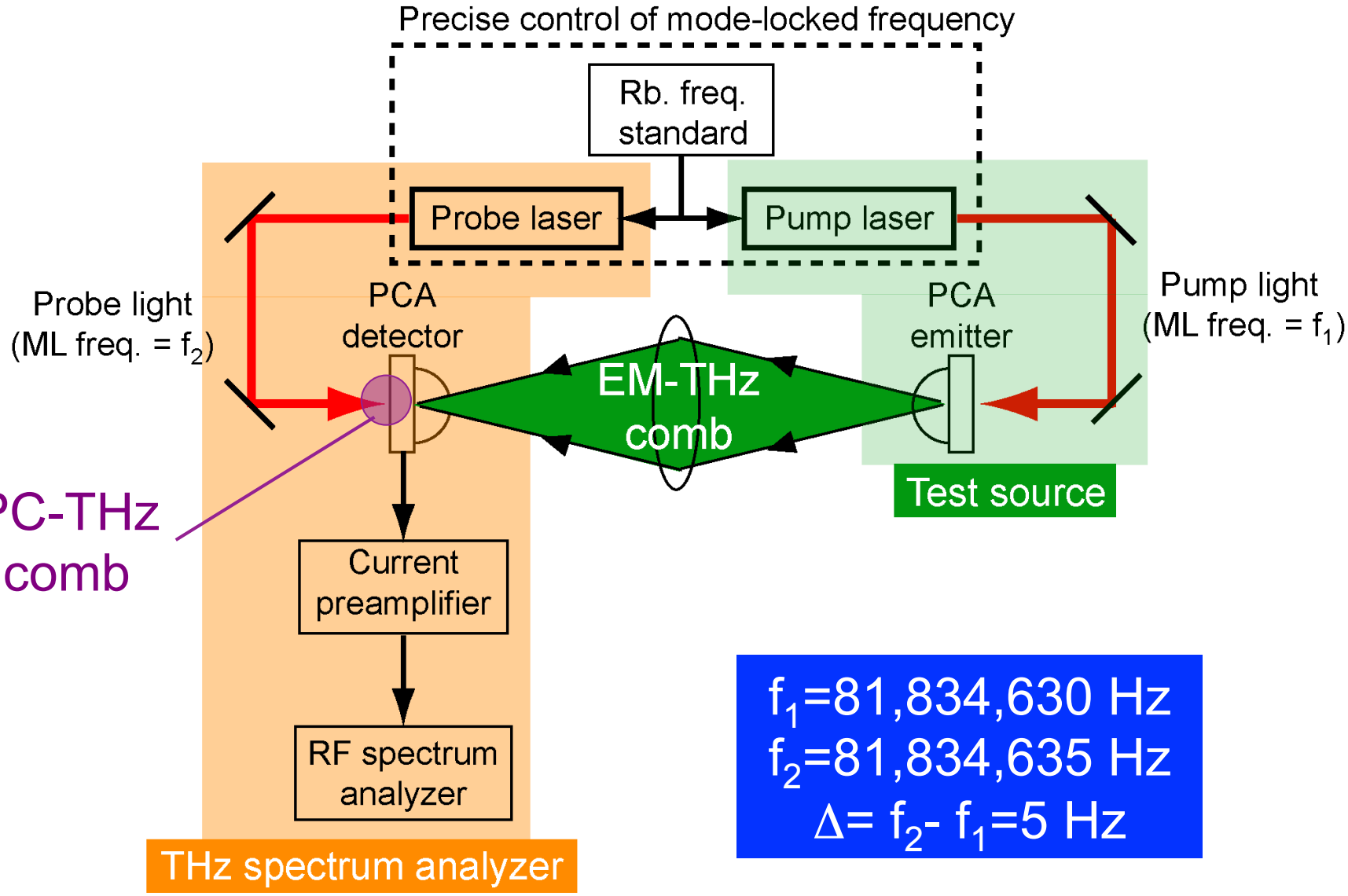
See CWB7, in ***Topics in Optical Metrology I, Optical Metrology@2009.6.3***

Optical comb and THz comb



Test source with multiple frequencies ranging from sub-THz to THz

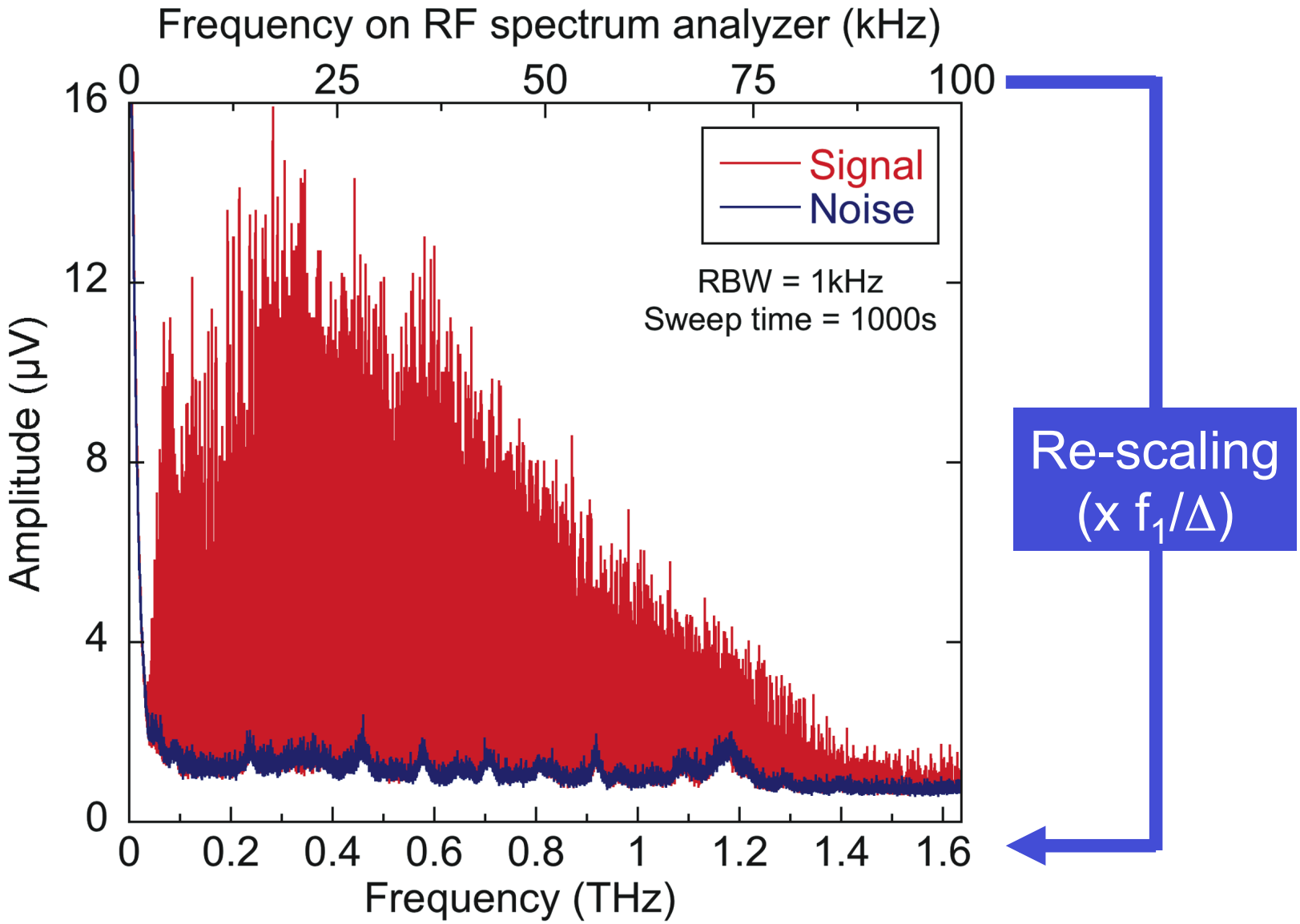
Experimental setup



f_1=81,834,630 Hz
f_2=81,834,635 Hz
$\Delta = f_2 - f_1$=5 Hz

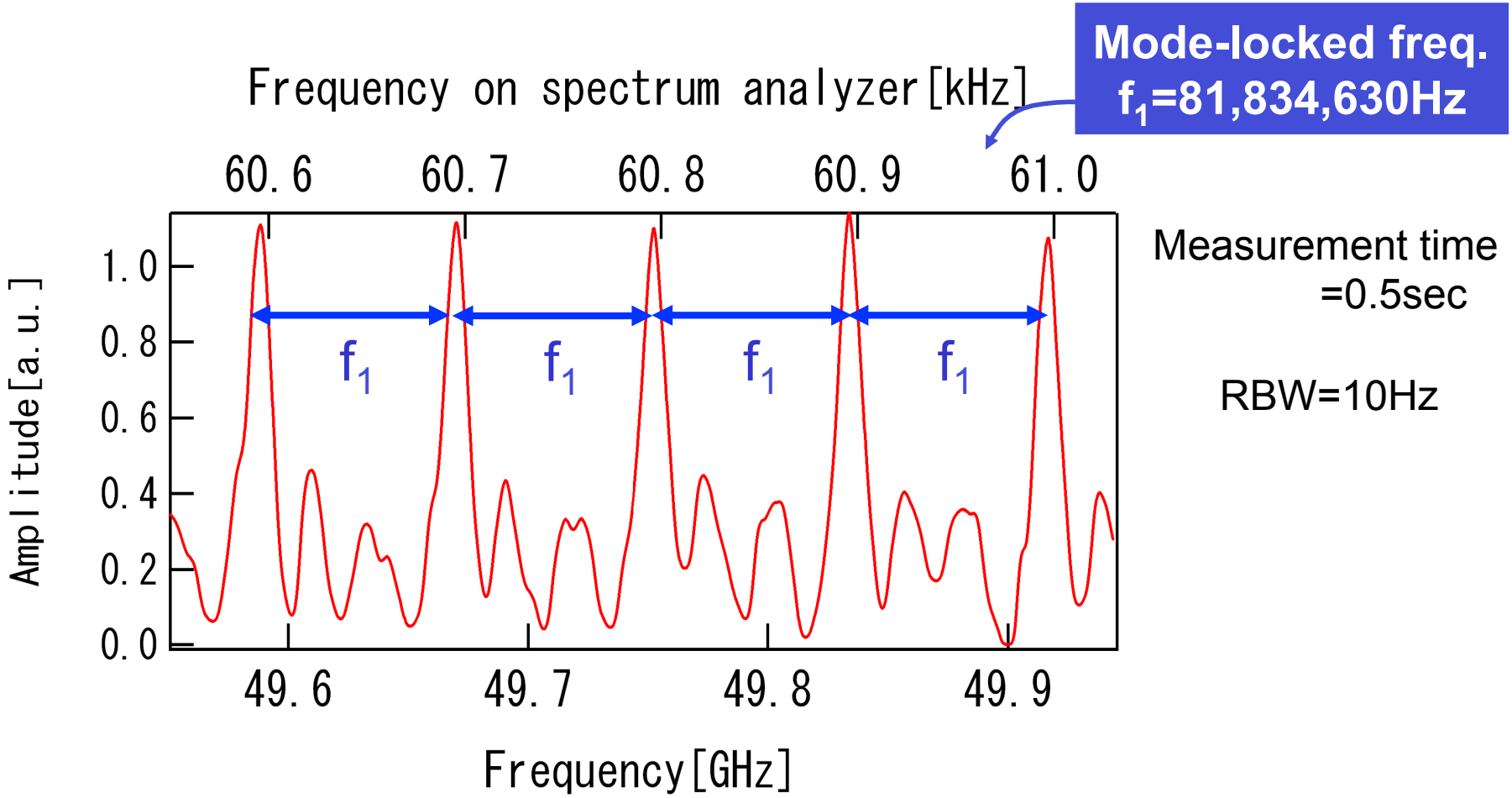
ref) Yasui, APL 88, 241104 (2006). Yokoyama, CMR5, CLEO2007.

Spectrum of EM-THz comb



Spectral range over 1THz !

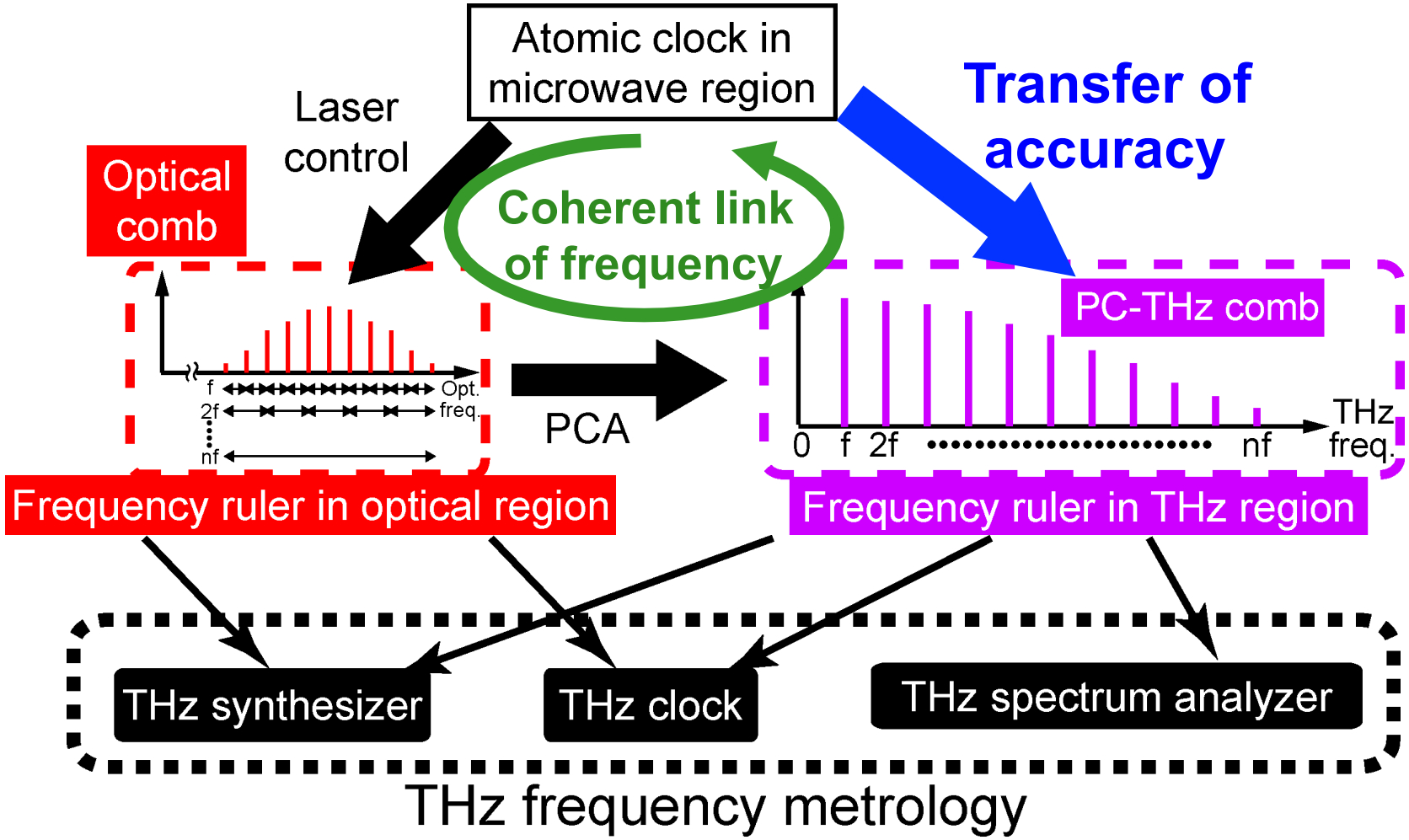
Observation of EM-THz comb mode



Average power of each mode < 1nW

High sensitivity in THz region

THz frequency metrology based on frequency comb techniques



Same accuracy as microwave and optical regions