Planar External Cavity Low Noise Narrow Linewidth Lasers

Lew Stolpner

Redfern Integrated Optics Inc. Santa Clara, CA 95054, USA

Outline

- 1550 nm narrow linewidth lasers for fiber optic sensing
- Planar External Cavity PLANEX Laser Design
- Phase noise and linewidth reduction in the external cavity
- PLANEX phase noise and linewidth
- Wavelength and power stability
- Wavelength tunability
- Direct frequency modulation
- Direct power modulation/pulsing
- Phase locking
- RIO laser products

Optical Sensing and Metrology

Applications

Military/security

Perimeter intrusion detection

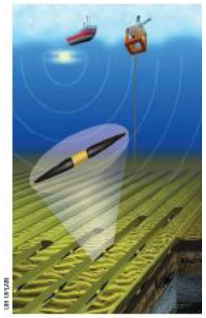
Navy acoustic detection

Oil and Gas

Seismic Reservoir Monitoring

Down well and SAGD

Pipeline Intrusion and Leakage Detection



Avionics/Space

LIDAR

RFOG

Wind Metrology

Wind energy

Air traffic control

Sensing Technologies

Interferometric

Coherent Rayleigh

C-OTDR

Lasers

Low Noise

Narrow

Linewidth

Coherent

Doppler LIDAR

Brillouin

DTSS

BOTDA/R

Photonic Doppler

Velocimetry /Vibrometery

Structural Monitoring

Static strain detection

Dynamic strain/vibration detection

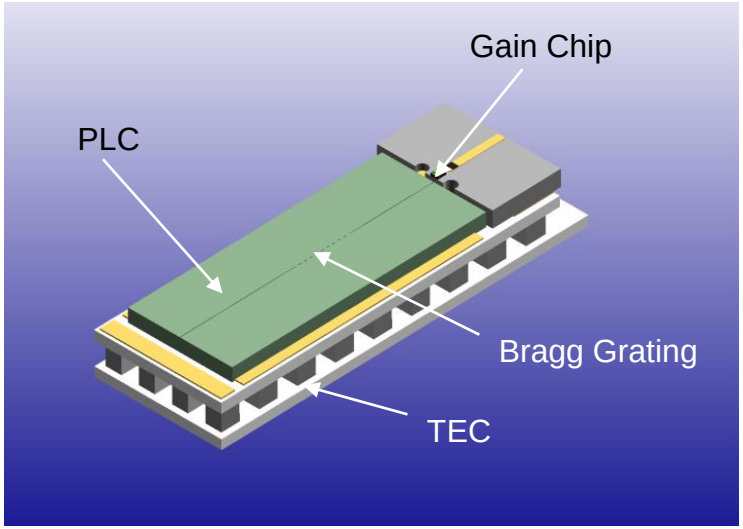
R&D/ Industrial/ Military,

metrology and process control

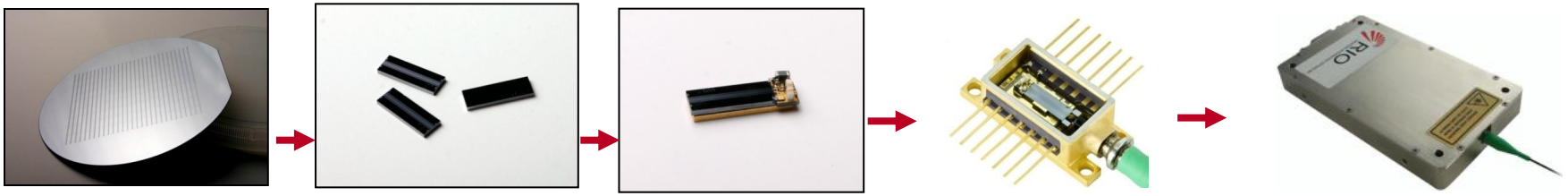
Laser for Sensing: Key Requirements

- Optical sensing market challenges for laser business
  - Market size it relatively small
  - Requirements vary significantly for various sensing technologies
  - Critical to make laser source suitable for multiple applications
- Performance
  - 1550 nm wavelength range to utilize availability of other Telco solutions
  - Low Phase/ Frequency Noise, Narrow linewidth, low RIN
- Features
  - Small size, suitable for large multi-laser system integration
  - Frequency modulation and wavelength tunability
- Field deployable
  - Stability in harsh environmental conditions
  - Reliability qualification to industry standards (Telcordia, MIL, Space)

Planar External Cavity Laser PLANEX™

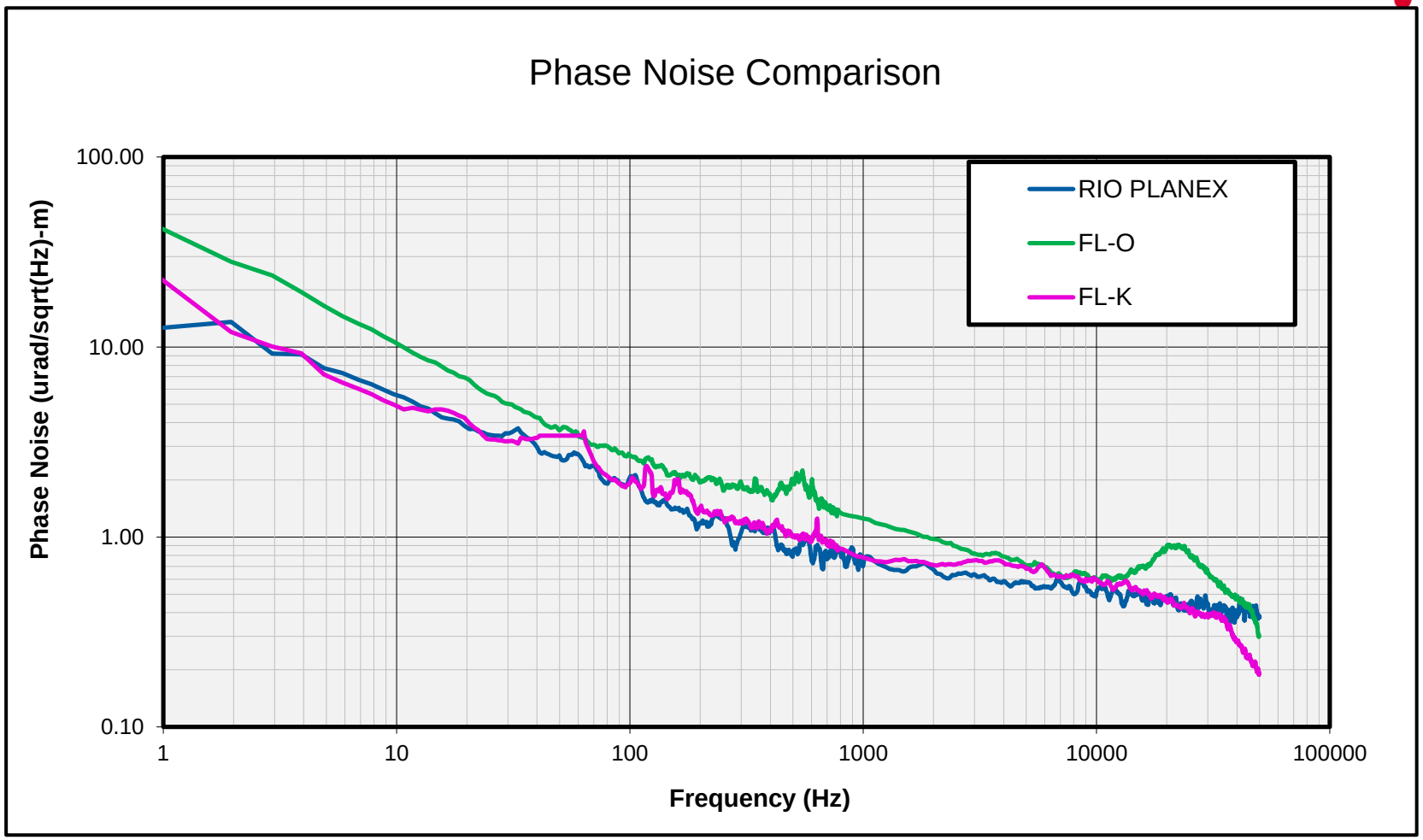


- PLC with Bragg grating on silicon wafers
- Gain: optimized InP MQW chip
- Packaging: 14-pin butterfly package, proven processes and materials



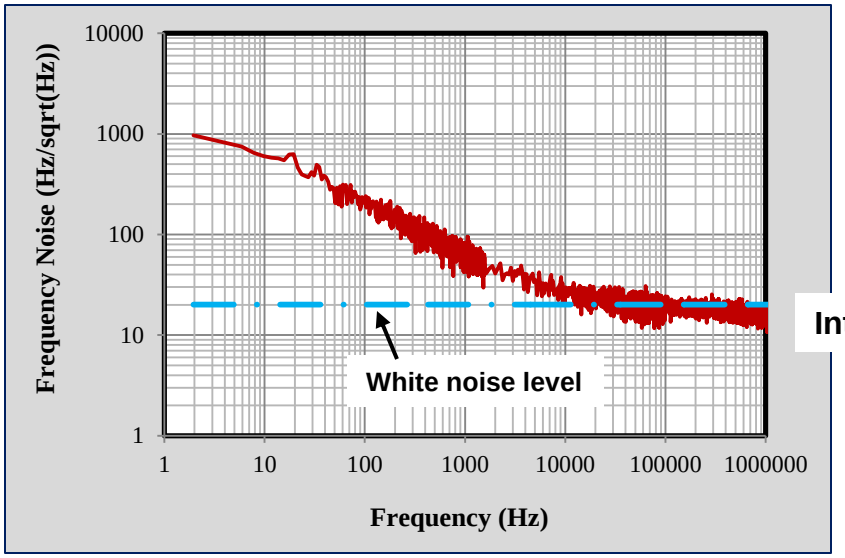
PLANEX **ORION**

PLANEX™ Laser Phase Noise



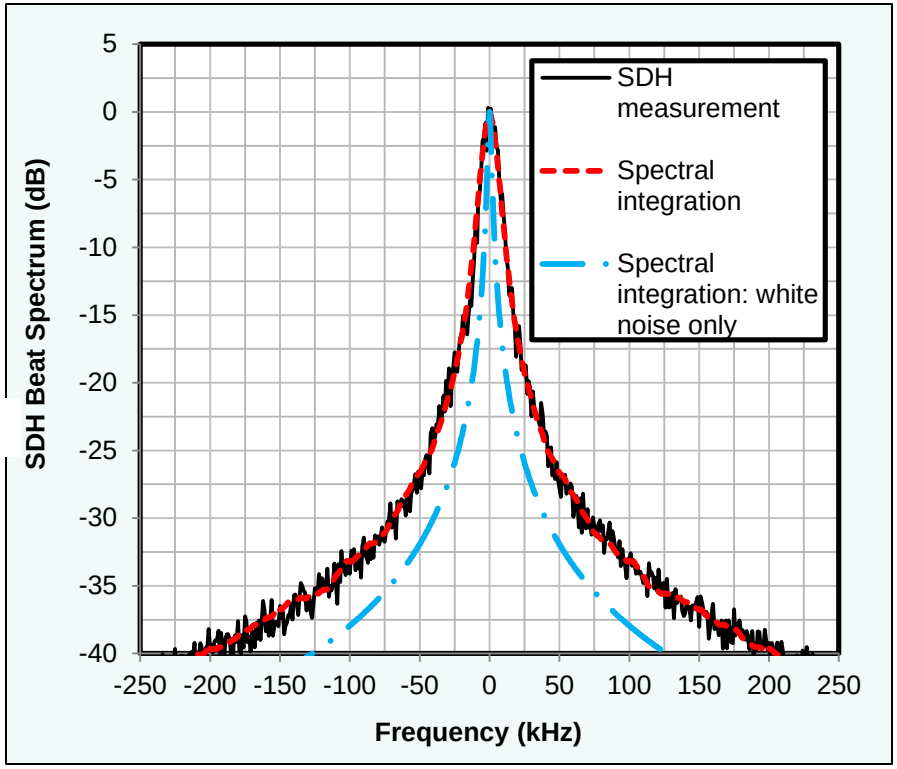
Linewidth Measurement vs. Spectral Integration

ORION Laser Frequency Noise



Integration

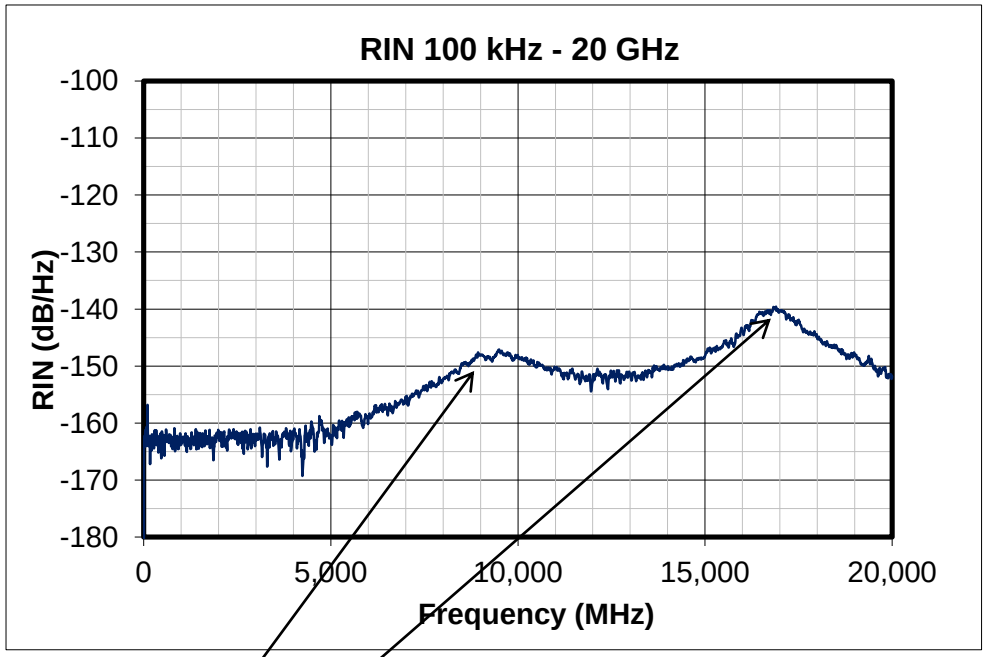
Laser Linewidth SDH Beat Spectrum

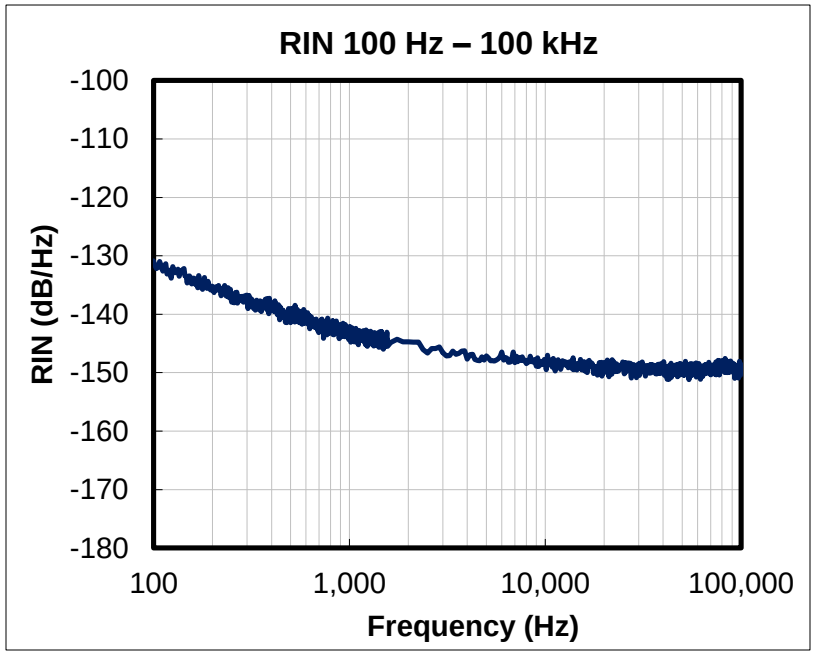


- Observation time on SI: 30 msec.
- SI for white noise only is done with fiber delay 400 km.

- ❑ Both measurement and spectral integration match well down to -40 dB level on Linewidth (LW) spectrum. (LW ~ 2.7 kHz @ -20 dB)
- ❑ When only white noise level is integrated, SI provides pure Lorentzian LW ~ 1.2 kHz.

PLANEX RIN – Shot noise limited up to 5GHz

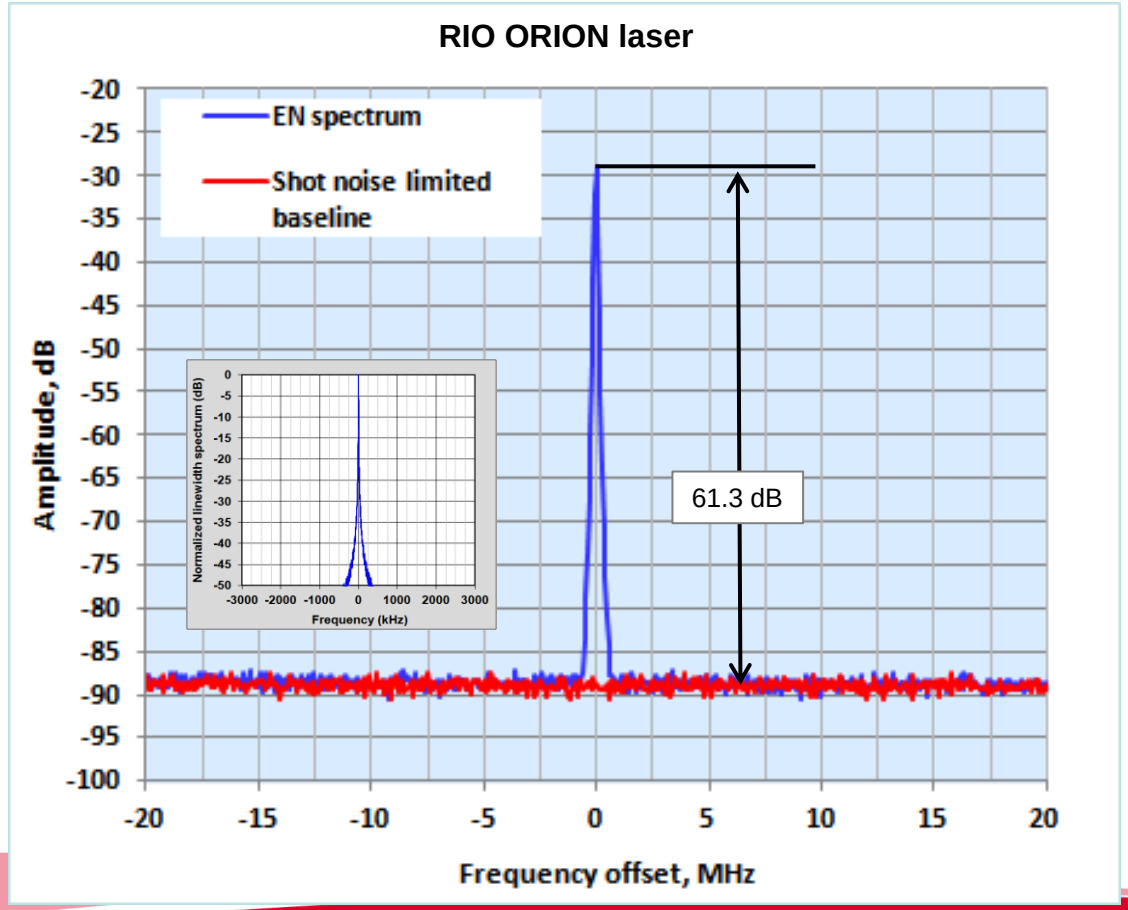




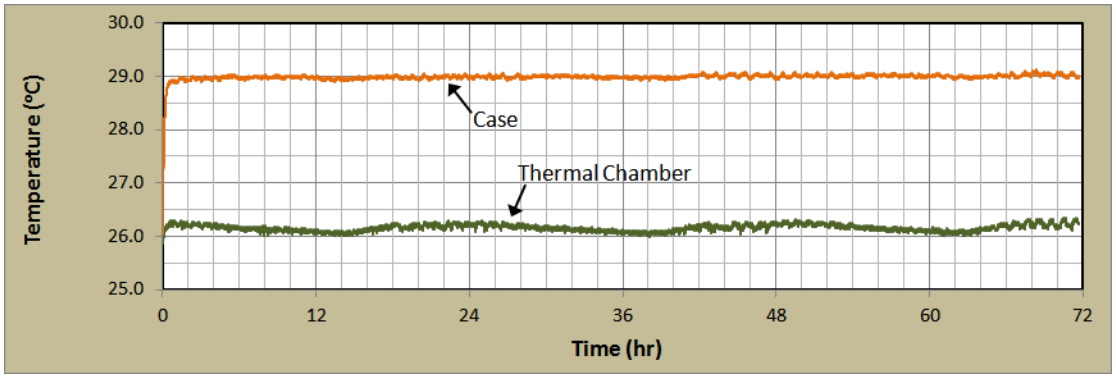
- High frequencies of relaxation oscillations
  - Electron – Photon resonance
  - Photon-photon resonance (cavity round-trip)
- RIN
  - <– 140 dB/Hz at frequency > 2 kHz.
  - Shot noise limited up to 5 GHz

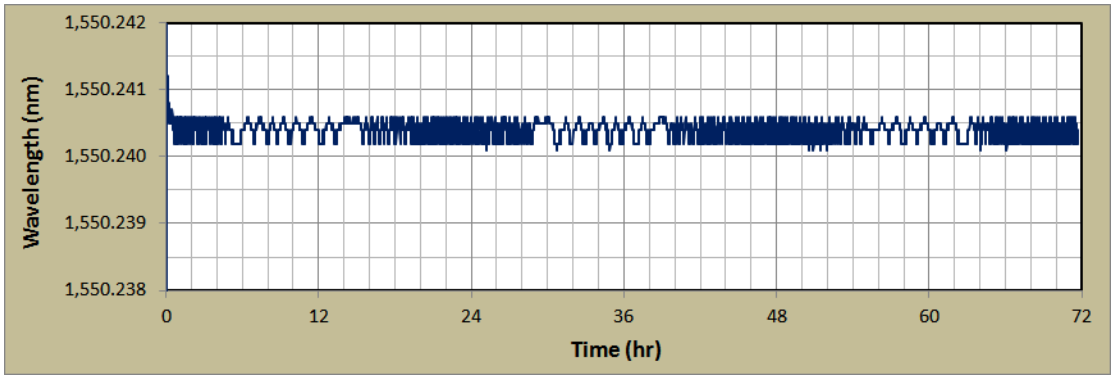
Excess Noise

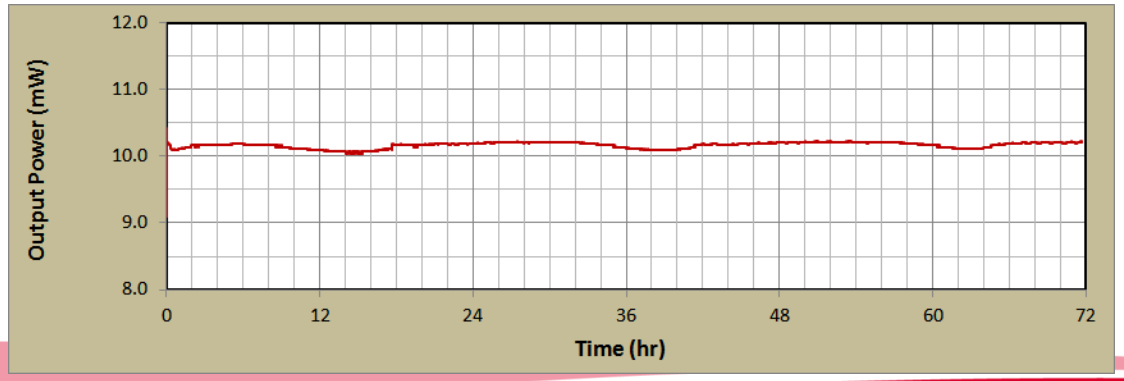
- Lorentzian linewidth as a parameter is not sufficient for
- RIO developed special test to provide all information for Doppler metrology applications
- Excess noise < 0.2 dB for RIO laser with Lorentzian linewidth of 1.6 kHz



Power and Wavelength Stability







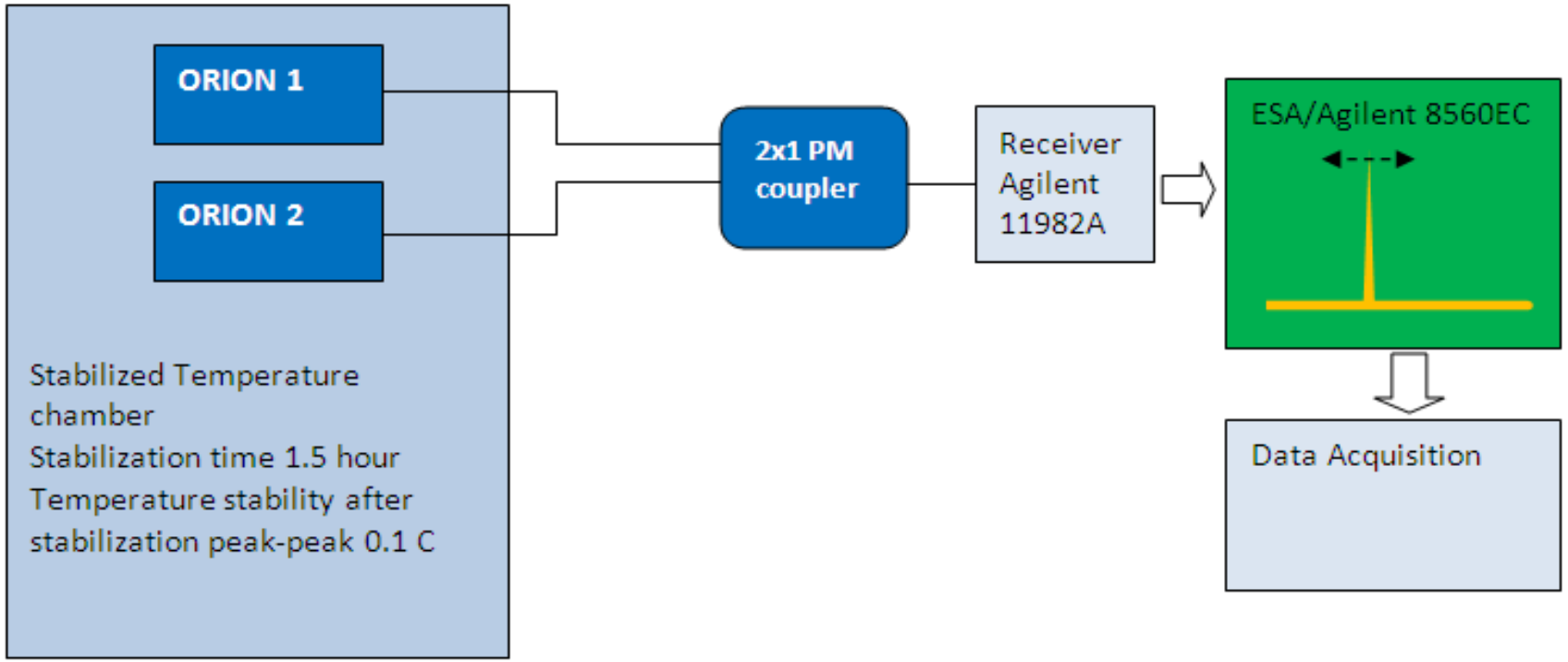
- Tested w. 10 mW ORION laser
- ORION laser is stabilized in thermal chamber over 3 days
- ORION case reaches near const. case temp. after 30 min. of power-up

- Pk-Pk wavelength change over 3 days: 0.6 pm
  (NOTE: measured with Agilent 86122A WM, WL differential accuracy: +/- 0.4 pm)

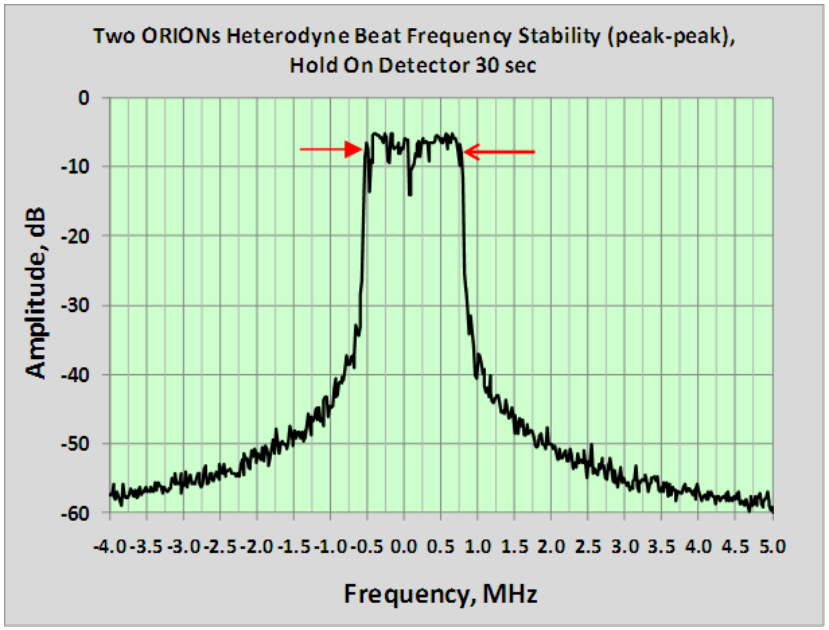
- Pk-Pk output power change over 3 days: 0.19 mW
  (NOTE: measured with Agilent 86122A WM, P calibration accuracy: +/- 0.5 dB)

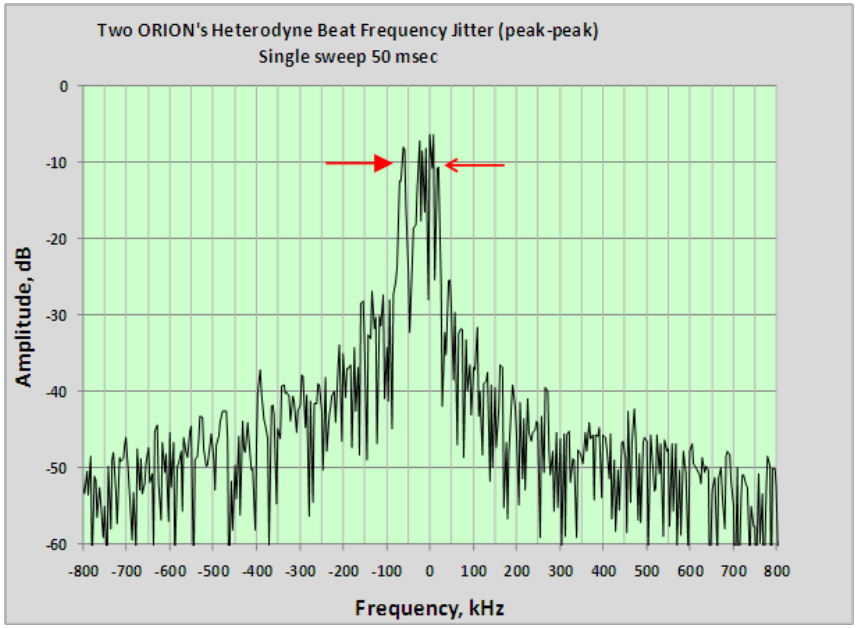
Frequency Stability Test

- ORION lasers modules (free running) frequency stability measured with heterodyne mixing of two lasers
- Laser stabilization time <1 s after turn on or re-tuning



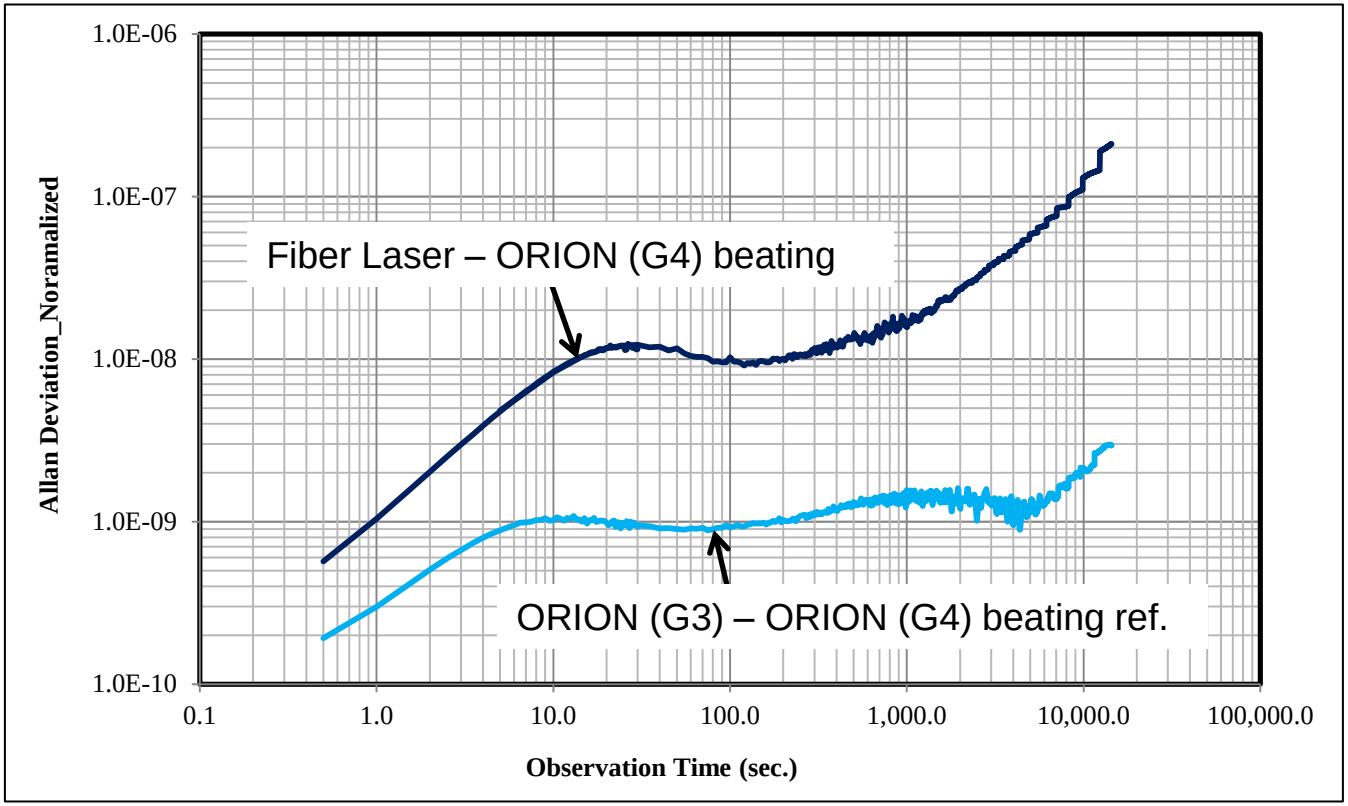
ORION Laser Module Frequency Stability





Measurement Time	Frequency stability
50 msec	150 kHz p-p
30 sec	1.5 MHz p-p
1 hour	4 MHz p-p
12 hours	20 MHz p-p

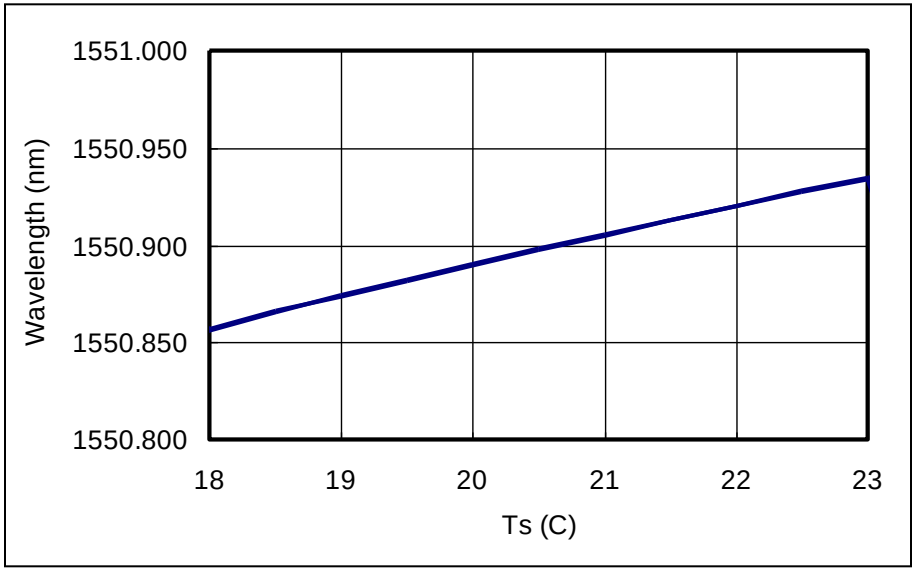
ORION Laser Allan Deviation

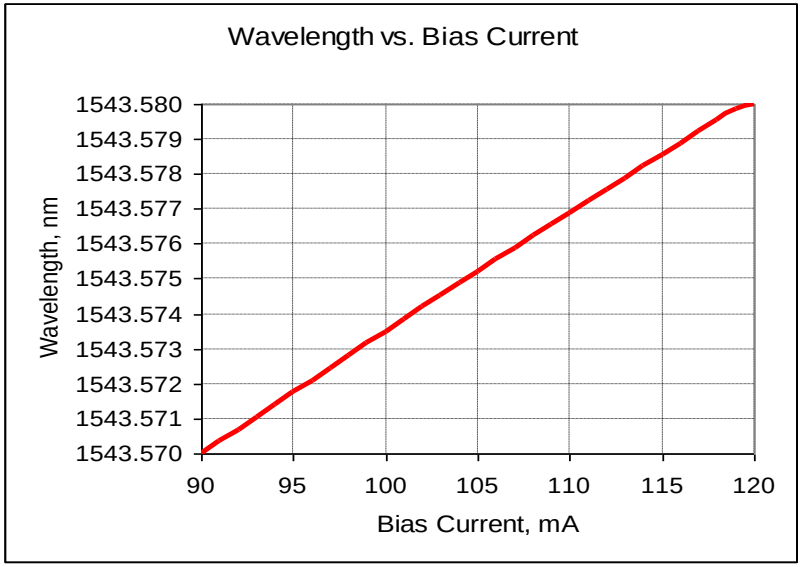


- Free-running. Case temperature stabilized : <0.2ºC over 3 h

Wavelength Tunability

- Wavelength vs. TEC temperature: ~15 pm/ºC
- Wavelength vs. bias current, CW: 0.4 -0.5 pm/mA (40-60 MHz/mA)

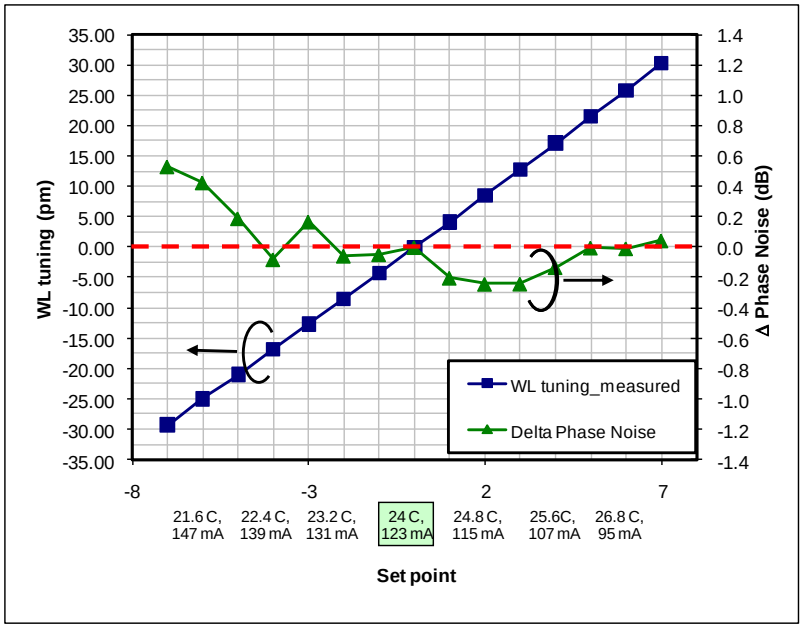


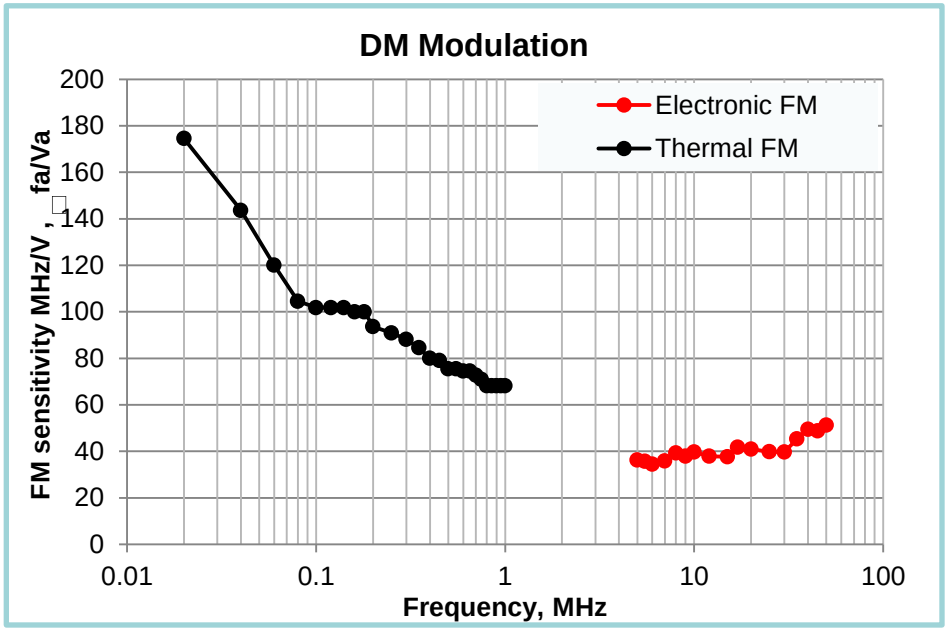


- Phase continuous temperature tuning range ± 30 pm (± 4 GHz)
- Fast wavelength tuning via bias current up to 4 pm (500 MHz)
- Frequency tuning via bias current leads to simultaneous power modulation

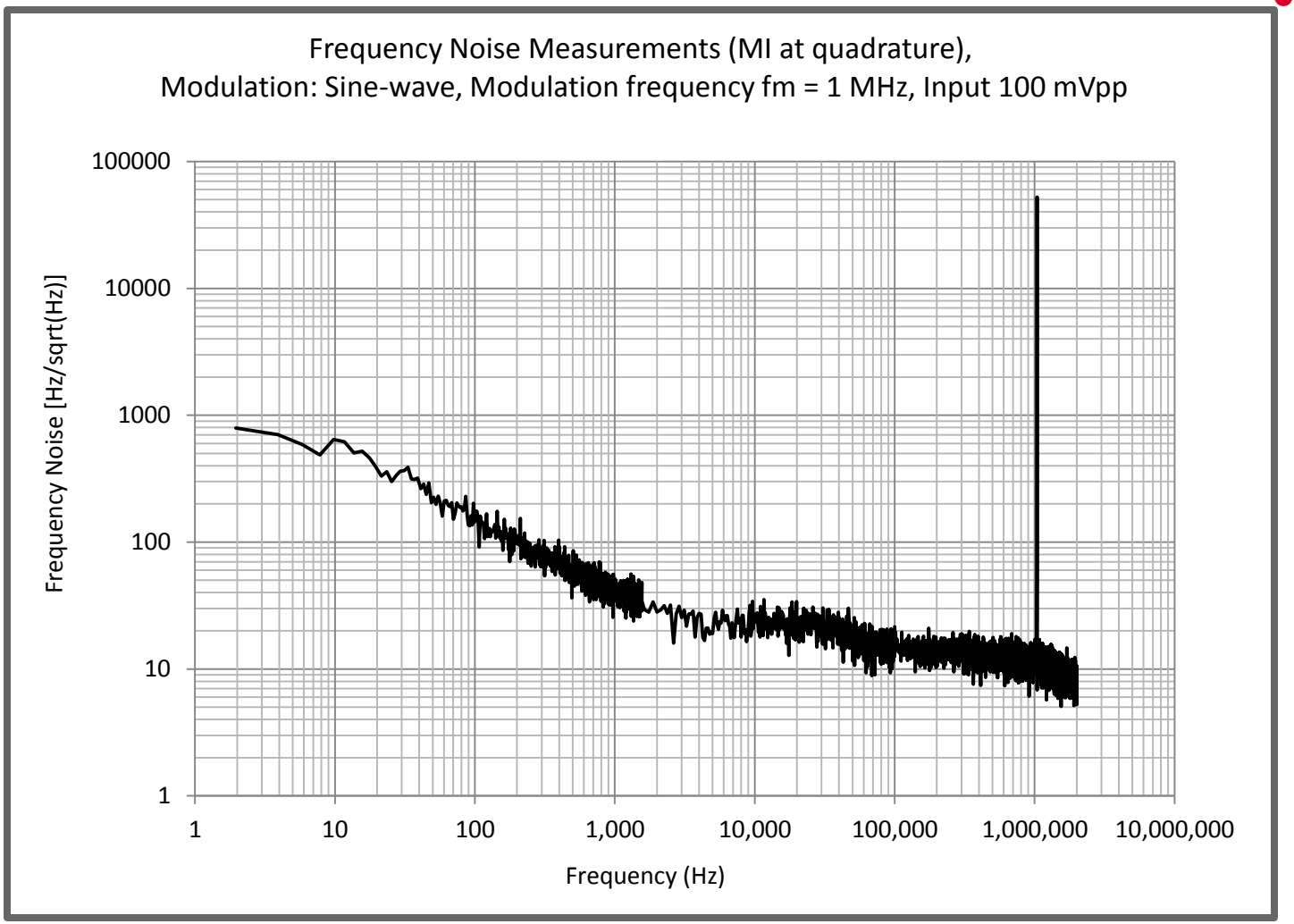
Wavelength Tuning and Direct FM

- Tuning TEC Temperature and Bias Current
  - Slow thermal tuning up to +/- 30 pm (+/- 4 GHz)
  - Fast direct frequency modulation efficiency
    - CW : 0.9 MHz/mV (~ 50 MHz/mA)
    - 10 kHz: 0.5MHz/mV

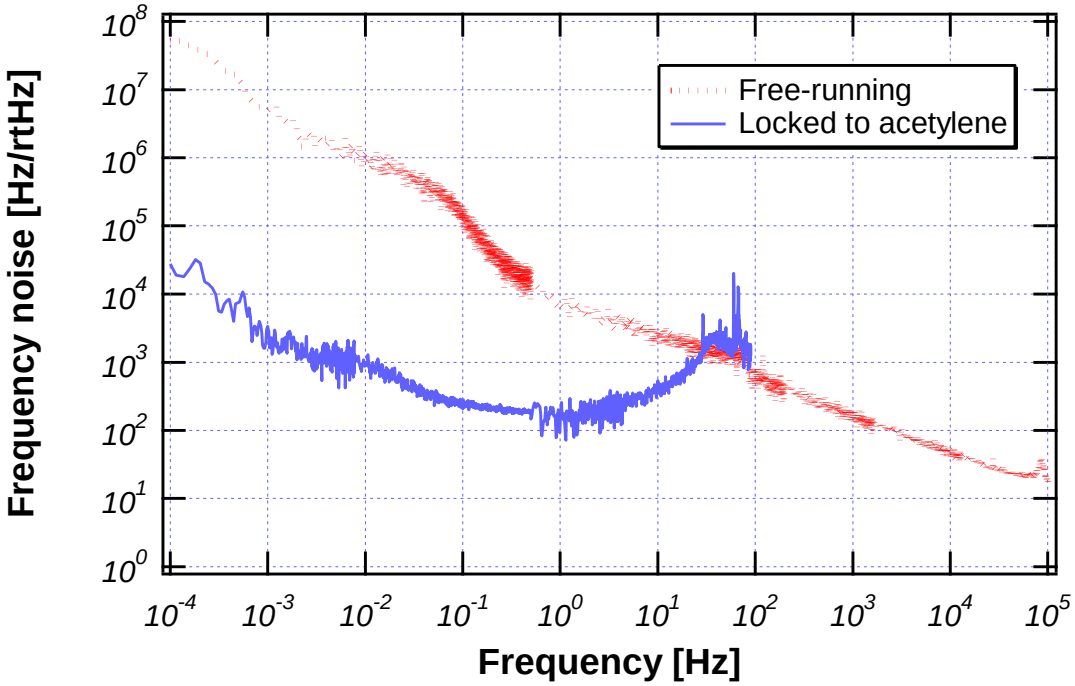




Low Frequency Noise with DM-FM



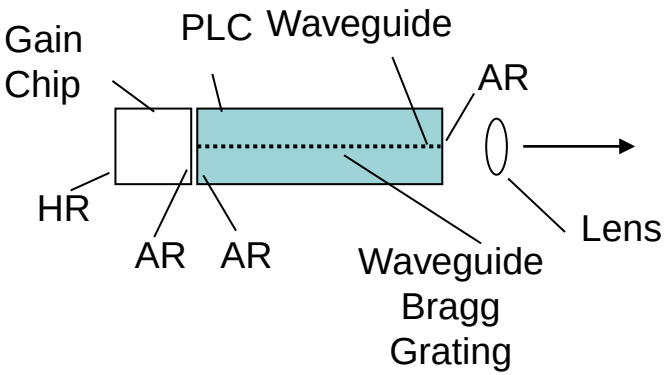
Reference Locking

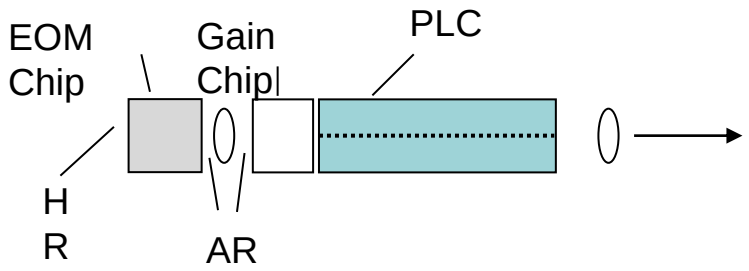


- Frequency noise spectrum of the PLANEX laser with (blue) and without (red) frequency stabilization.
- Within the control bandwidth of ~60 Hz, the noise was suppressed by a factor up to ~1000.

Performance of planar-waveguide external cavity laser for precision measurements.
Kenji Numata, Jordan Camp, Michael A. Krainak, and Lew Stolpner. October 2010 / Vol. 18, No. 22 / OPTICS EXPRESS

PLANEX- PLANEX FM



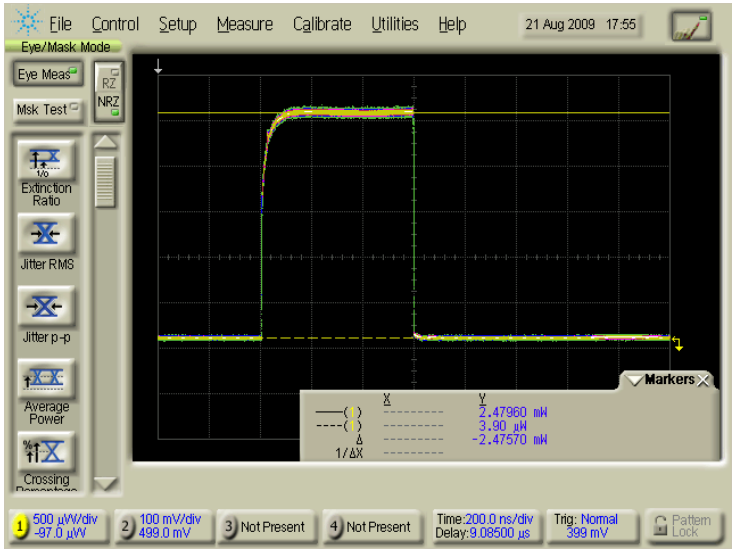


Parameter	PLANEX	PLANEX FM
Cavity	2 sections GC + WBG PLC	3 sections GC+ WBG PLC + LN FM
FM Modulation	Direct bias current	1. Direct bias current 2. LN FM voltage
Residual AM	Coupled with FM	Practically decoupled with FM
FM frequency	> 100 MHz Not flat with phase reverse	>50 MHz bulk LN FM >1 GHz with WG Flat phase possible

Direct Modulation/Pulsing of PLANEX laser

- ❑ PLANEX laser modulation bandwidth > 1 GHz
- ❑ 25 Ohms impedance input
- ❑ Unique direct modulation/pulsing while mountings narrow linewidth performance
- ❑ Minimal pulse shape distortion

Pulse Width	> 5 nsec
Pulse Repetition Frequency	up to 10 MHz
Extinction Ratio	25-32 dB
Linewidth	< 15 kHz at pulse plateau
Pulse shape distortion	Minimum or none
RMS Jitter	150 ps max



RIO Product Offering

- Wavelength
  - ITU DWDM or custom wavelength
- 4 Grades of linewidth/phase noise performance
- PMF and SMF options

PLANEX™ and ORION™

- > 10 mW
- > 20 mW

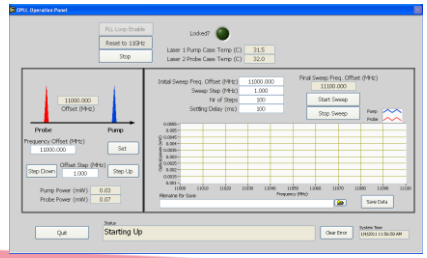
RIO COLORADO

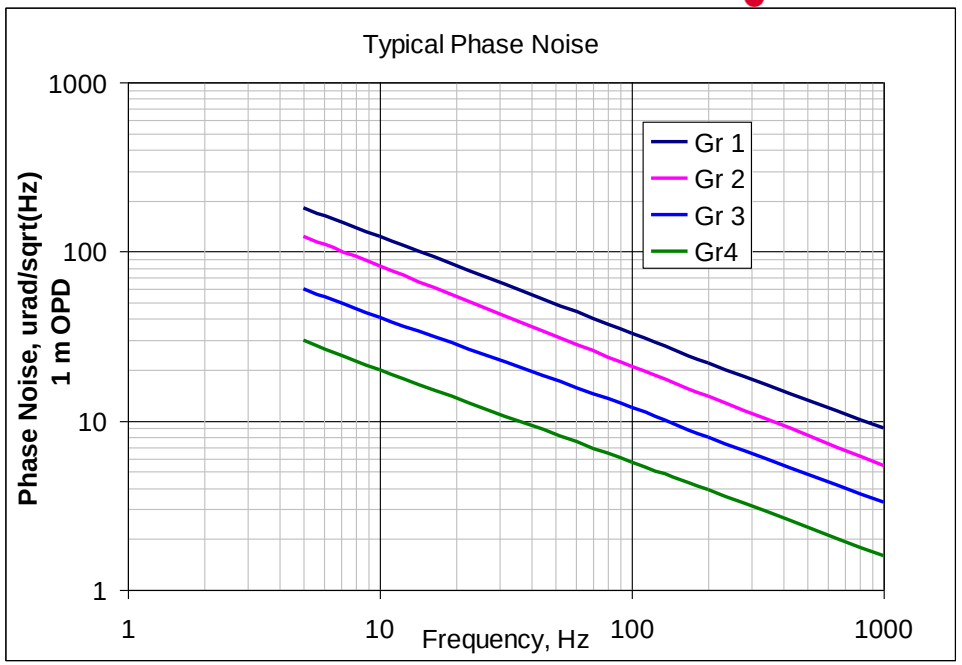
- Wide tunable

RIO Grande

- >1 W
- > 2 W

Optical Phase Locked Loop (OPLL)





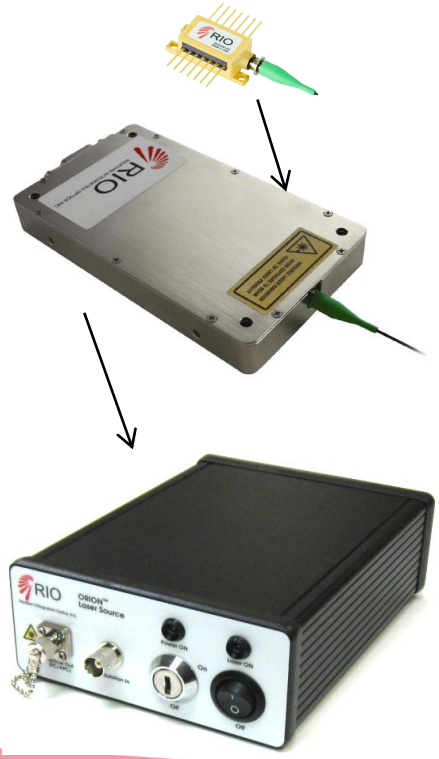
Linewidth, kHz	Grade 1	Grade 2	Grade 3	Grade 4	Optional
	<15	<10	<5	<3	1

ORION Laser

❑ Features

- ➢ Low noise current source and TEC controller
- ➢ Input for direct modulation and wavelength tuning
- ➢ OEM Module with SPI, RS-232 and RS-485 interface options, GUI
- ➢ Benchtop OEM Source with USB interface options, GUI

Storage Temp, ° C	**-40 to +85**
Size, mm	**100x56x13**
Operational Temp Range, °C	**0-70**
Power supply	**5 V**
Power Dissipation,	**< 6 W**
@ 35 C case temperature	**<3 W**
@ 50 C case temperature	**<4 W**

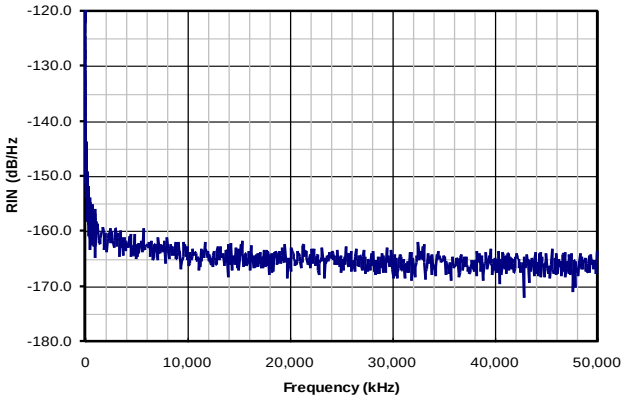


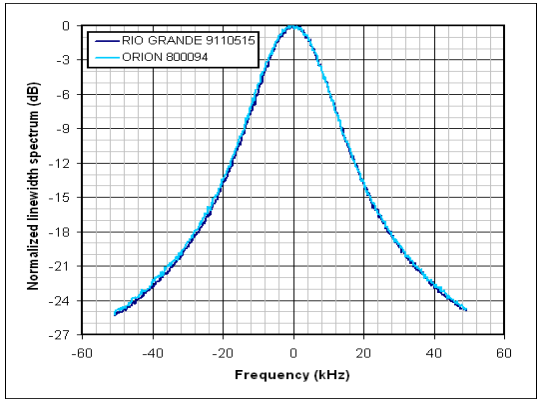
ORION and Fiber Laser Comparison

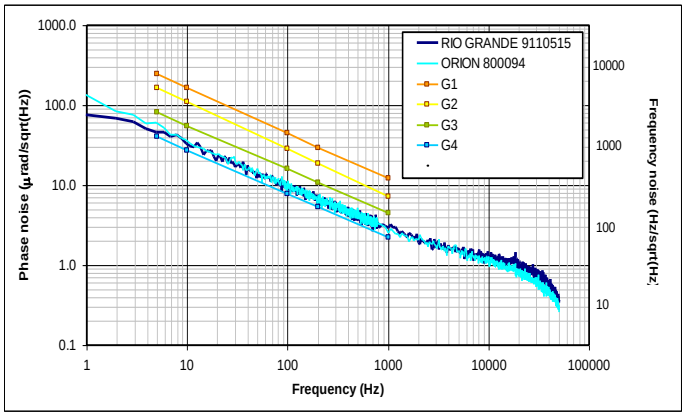
Parameter	RIO008X ORION 	Koheras Basik 	NP Photonics Rock 	Orbits Ethernal 
Power	**>10 mW**	**>10 mW**	**>25mW**	**>10 mW**
RIN	**<-140 dB/Hz (>1 kHz)**	**<-115 dB/Hz (@1 MHz)**	**<-110 dB/Hz (@1 MHz)**	**-120 dB/Hz (@ 1MHz)**
WL stability (FR), p-p	**4 MHz 1 hour 20 MHz 12 h**	**20 MHz 1 h**	**20 MHz 1 h 50 MHz, 12 h**	**20 MHz 1 h**
Storage Temp, ° C	**-40 to +85**	**-20 to +50**	**-20 to +50**	**-20 to +50**
Size, inches	**4x2.25x0.5**	**8x4x1**	**8x5x1**	**7x3X1**
Operational Temp Range, ºC	**0-70**	**15-50**	**15-35**	**10-55**
Power supply	**5 V**	**12 V**	**5V**	**5V**
Power Dissipation, over specified case temp range	**< 6 W**	**>10 W**	**20 W**	**>10 W**
@ 35 C case temperature	**<3 W**		**20 W**	
@ 50 C case temperature	**<4 W**	**>10 W**		

RIO GRANDE: Amplified High Power Modules

- Power 0.1 W up to 2 W,
- Low phase noise
- Ultra low RIN
- Narrow linewidth
- High OSNR

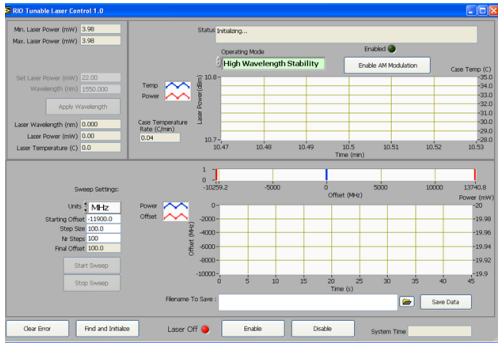






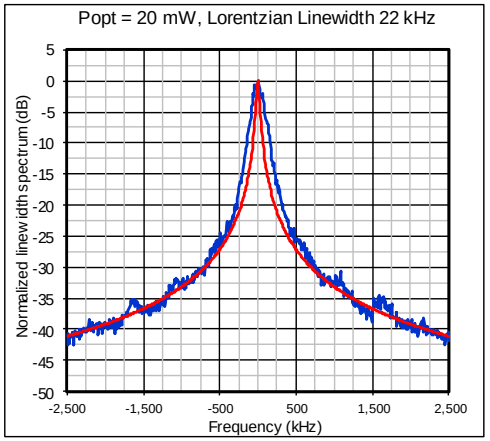
RIO COLORADO Wide Tunable Laser

- Performance Highlights
  - Low frequency noise
  - Low RIN
  - Available for C or L spectral bands
  - Cost effective solution
  - Convenience: GUI, integration



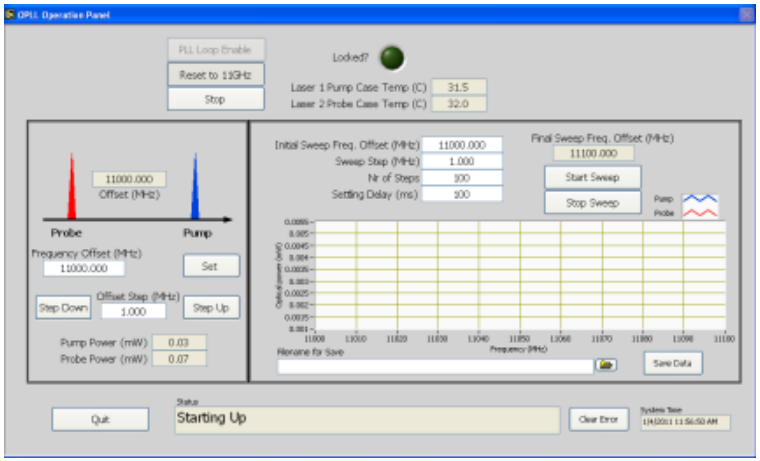
- High Wavelength Stability (HWS) Mode
  - Narrow linewidth <100 kHz
  - Optical Power Adjustment from 4 to 28 mW
  - Continuous Wavelength Sweep: 24 GHz peak-peak or +/- 12 GHz) at any wavelength
  - Amplitude Modulation to 1MHz, M up to 10%

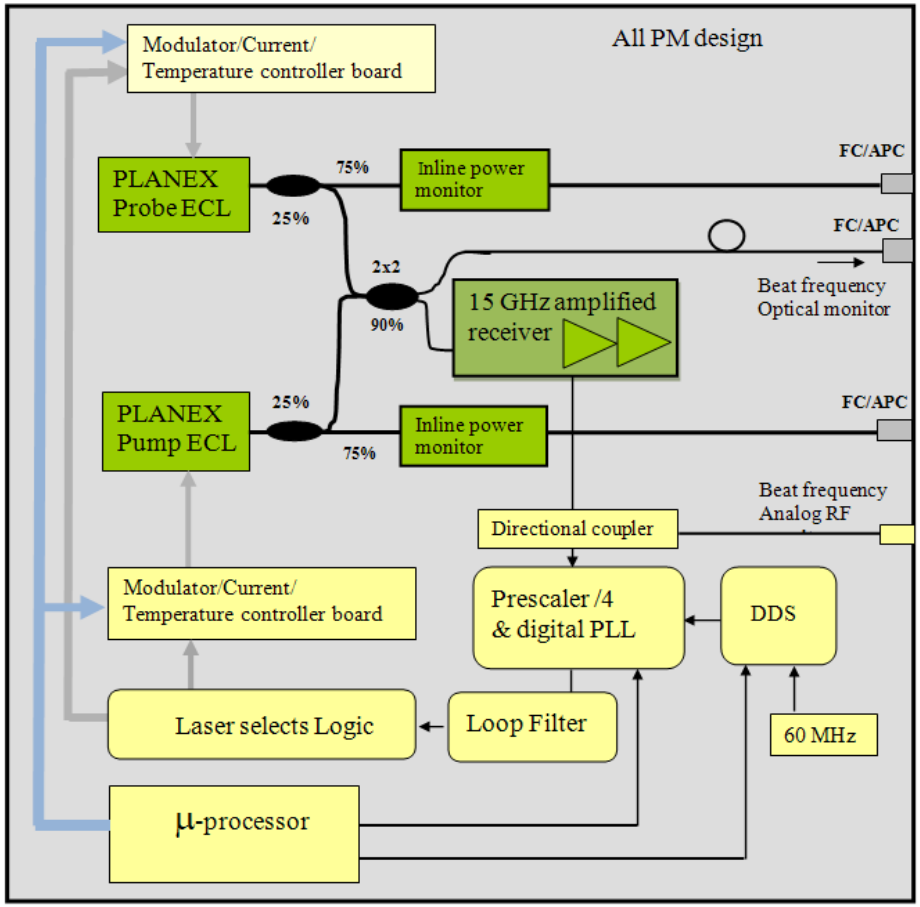
- Ultra-Narrow Linewidth (UNL) Mode
  - Ultra narrow linewidth ~ 25 kHz
  - Fixed wavelength and optical power
  - Frequency Modulation is available



OPLL - Dual Laser Source

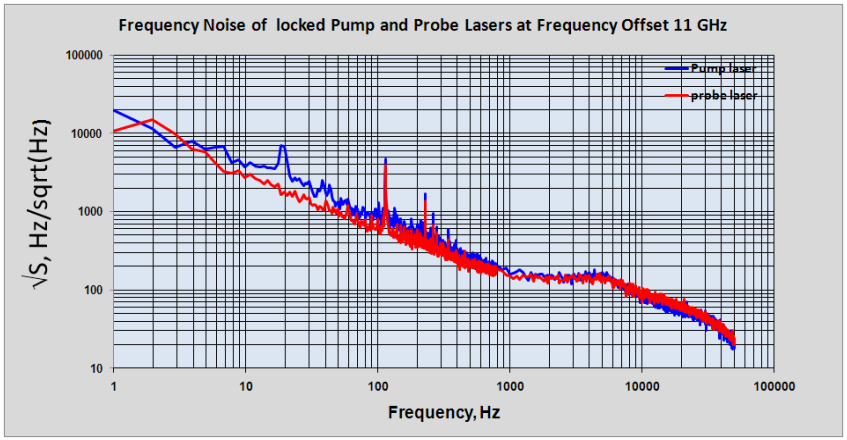
- OPLL for distributed sensing and coherent metrology applications:
  - Distributed Brillouin Fiber Optic Sensing (BOTDA/BOTDR)
  - Heterodyne/ Coherent Metrology

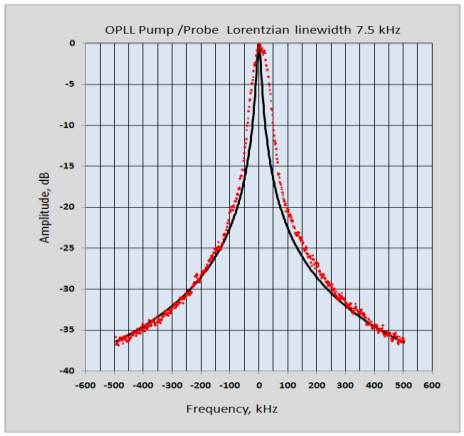


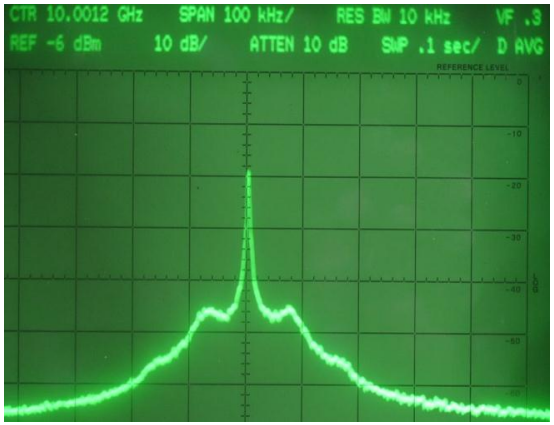


OPLL Key Performance Specs and Features

Parameter	Value	Note
CW power	> 5 mW	average, two PM optical outputs
Laser frequency noise	10^3 Hz/√Hz @ 100 Hz	under locking conditions:
Linewidth	<10 kHz	
Phase noise	-65 dB/Hz	at 100 kHz offset
Frequency offset	From 8 to 14 GHz	step tuning
Tuning resolution	10 kHz	
Continuous sweep tuning	over 1GHz	resolution 10 kHz @ 50μsec speed
Locked step response time	5 μsec	at 10 MHz step

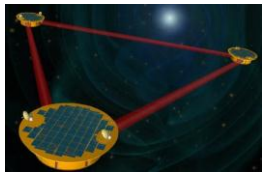




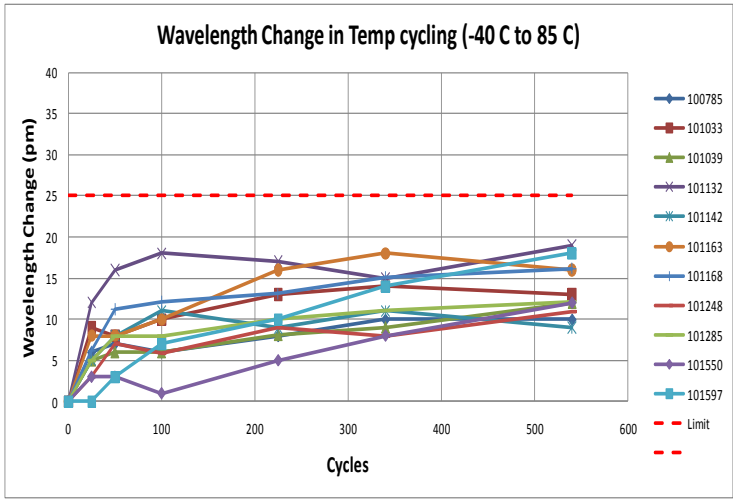


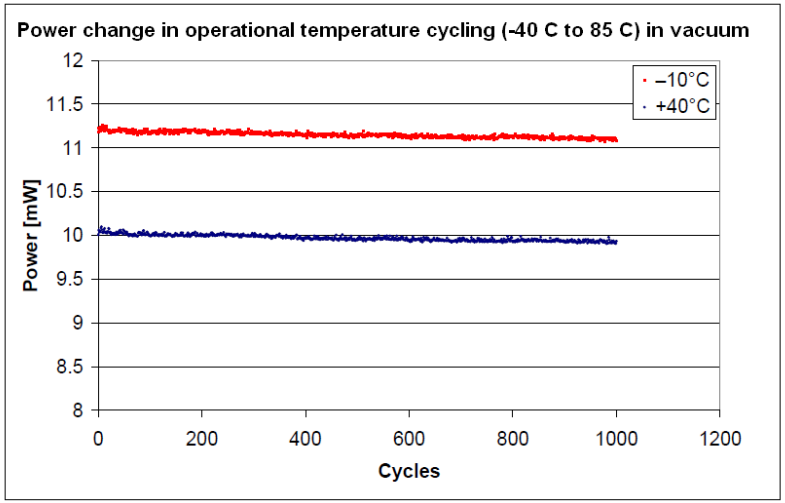
Exceptional Reliability for Space Applications

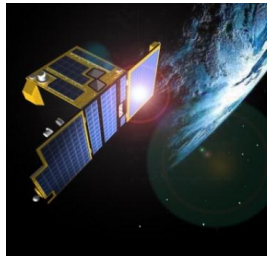
- Space qualification
  - Defined by NASA as "Game changing laser" for unique combination of high performance and outstanding reliability for space applications
  - Selected by ESA and NASA for several space programs: PROBA-3, GRACE FO, LISA and successfully completed Phase 1 of qualification testing



- Reliability testing for space qualification
  - Environmental stress far exceeding Telcordia and MIL requirements
  - Tested production PLANEX units without special builds/selection/screening
  - Minimal changes after 1000 operating temperature cycles in vacuum and over 500 severe non-operational temperature cycles







Thank you.