Reliable Versatile Low Noise Laser Empowering Sensing Technologies

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Outline

- Laser source requirements for Coherent Doppler Sensing and other metrology applications
- Planar External Cavity PLANEX technology
- PLANEX laser key performance
- Stability and Reliability
- RIO laser product portfolio
- RIO subsystem integration capabilities

Optical Sensing and Metrology

Applications

Military/Security

Perimeter intrusion detection

Navy acoustic detection

Avionics/Space

LIDAR

RFOG

Wind Metrology

Wind energy

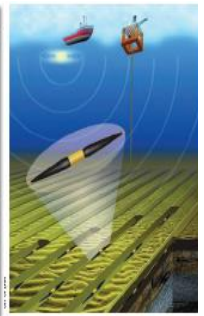
Air traffic control

Oil & Gas

Seismic Reservoir Monitoring

Down well and SAGD

Pipeline Intrusion and Leakage Detection



Structural Monitoring

Static strain detection

Dynamic strain/vibration detection

Sensing Technologies

Interferometric

Coherent Rayleigh

C-OTDR

Lasers

Low Noise

Narrow

Linewidth

Brillouin

DTSS

BOTDA/R

Coherent

Doppler LIDAR

Photonic Doppler

Velocimetry /Vibrometery

Military/Industrial/R&D

Lasers for Sensing: Key Requirements

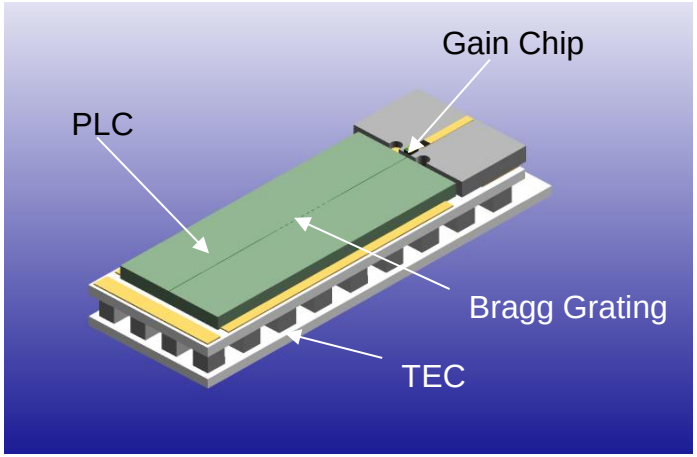
- Challenges for optical sensing market laser business
  - Market size is relatively small
  - Requirements vary significantly for various sensing technologies
  - Critical to make versatile laser source suitable for multiple applications
- Performance
  - 1550 nm wavelength range to utilize availability of 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)

Lasers for Coherent Optical Detection Technology

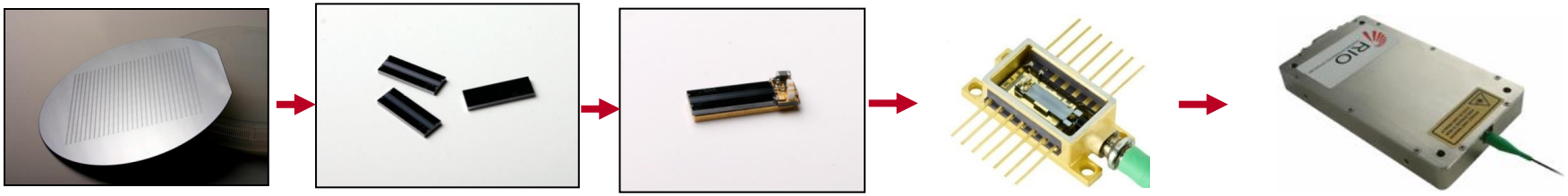
Methods of Coherent Optical Heterodyne Detection	Requirements for Single-Frequency Narrow-Linewidth Lasers
❑ Photonic Doppler Velocimetry (PDV) ❑ Coherent Laser Vibrometry ❑ Coherent Doppler CW LIDAR ❑ Optical Frequency Synthesis ❑ Optical Phase Lock Loop, OPLL ❑ R&D Heterodyne Metrology	➢ Wavelength and power stability, over time ➢ Wavelength and power stability, on/off ➢ High frequency stability, μsec/msec ➢ High polarization stability ➢ Low coherent excess noise ➢ Low M^2 factor for high coherent efficiency ➢ Low RIN and High RIN stability

- ❑ Market size for PDV lasers is relatively small and growing slowly
- ❑ Only versatile COTS lasers can service PDV applications without costly custom development

Planar External Cavity Laser Technology PLANEX™

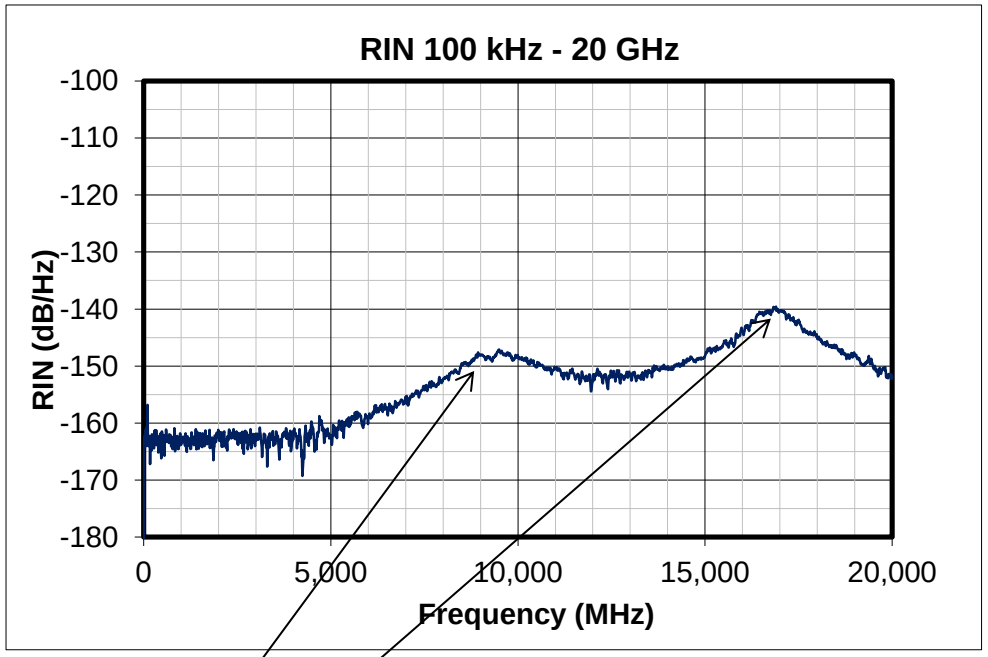


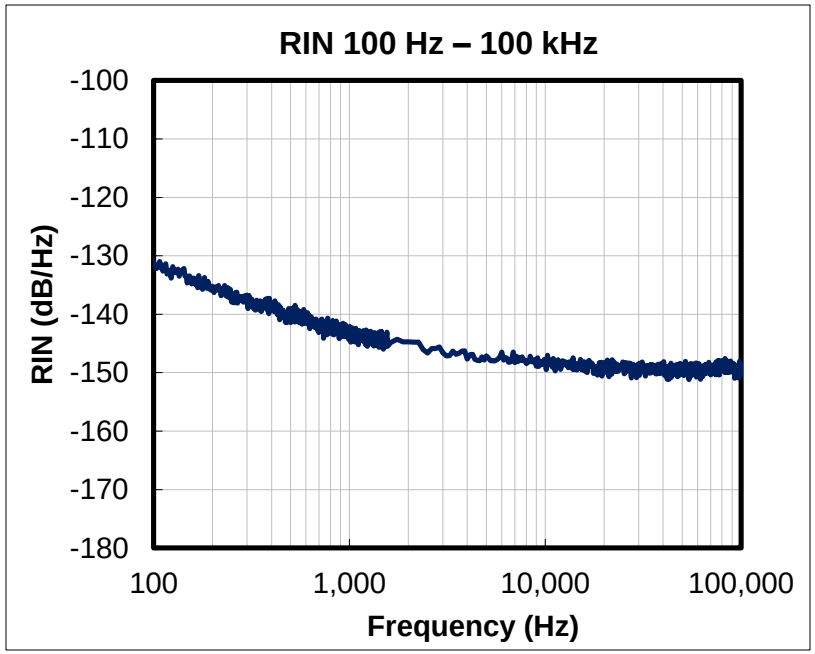
- PLC with Bragg grating on silicon wafers
- Gain: optimized InP MQW chip
- Packaging: 14-pin butterfly package, proven processes and materials



PLANEX **ORION**

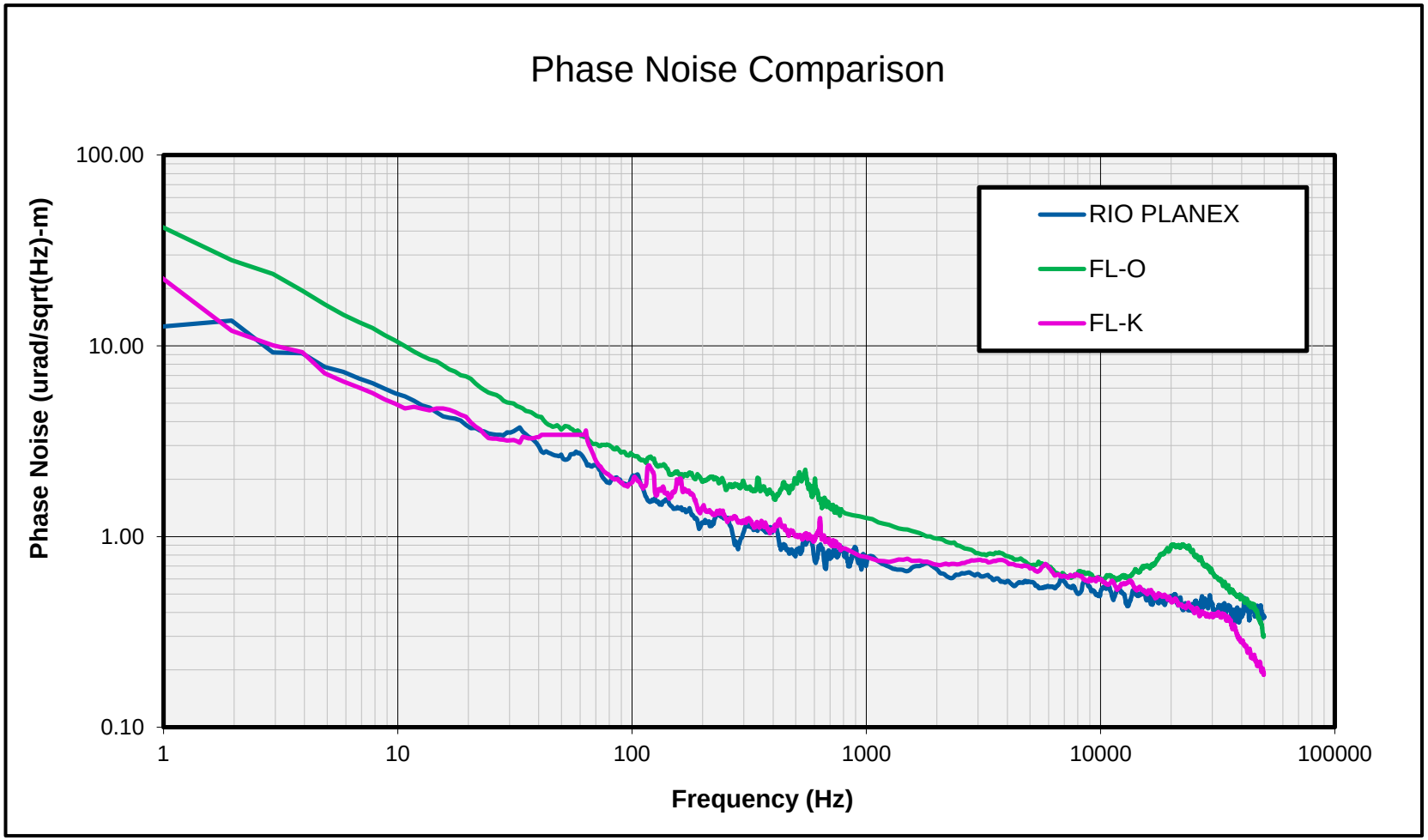
PLANEX™ Performance: RIN – shot noise limited up to 5 GHz





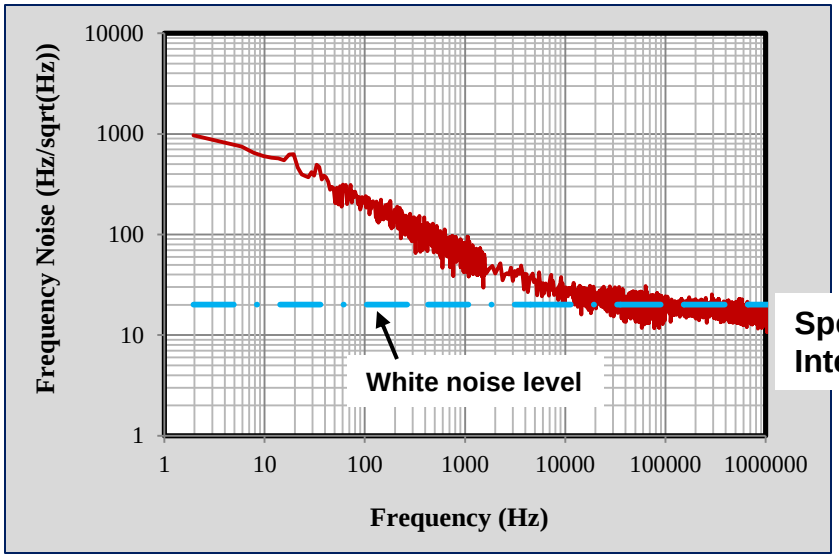
- High frequencies of relaxation oscillations
  - Electron – Photon resonance
  - Photon-photon resonance (cavity round-trip)
- RIN
  - < –140 dB/Hz at frequency > 2 kHz.
  - Shot noise limited up to 5 GHz

PLANEX™ Performance: Laser Phase Noise



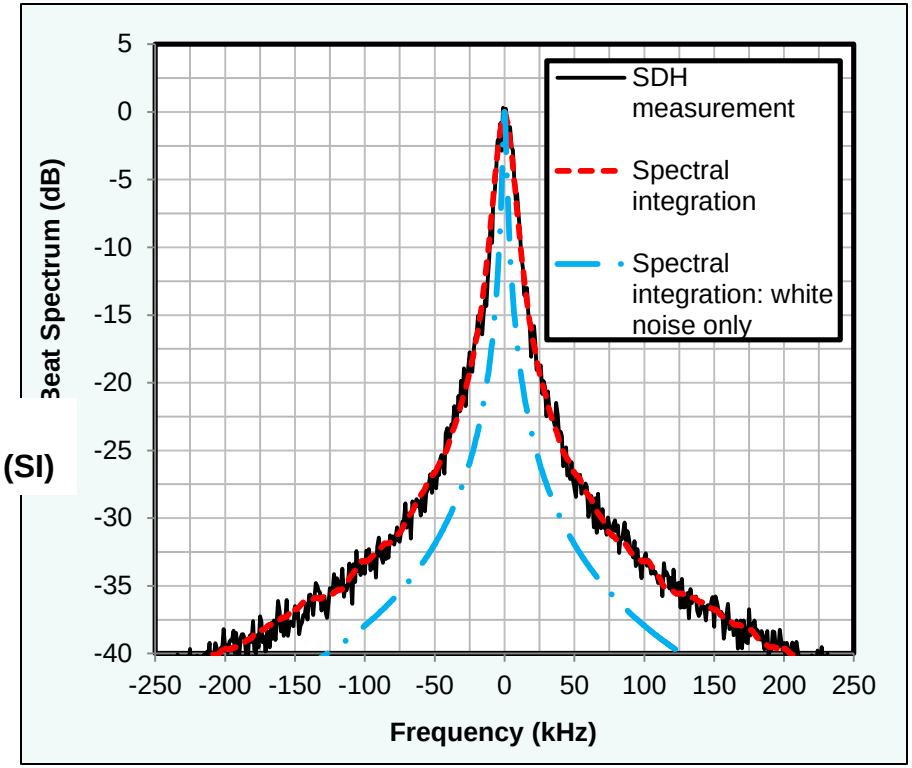
PLANEX™ Performance: Linewidth

ORION Laser Frequency Noise



Spectral Integration (SI)

Laser Linewidth SDH Beat Spectrum

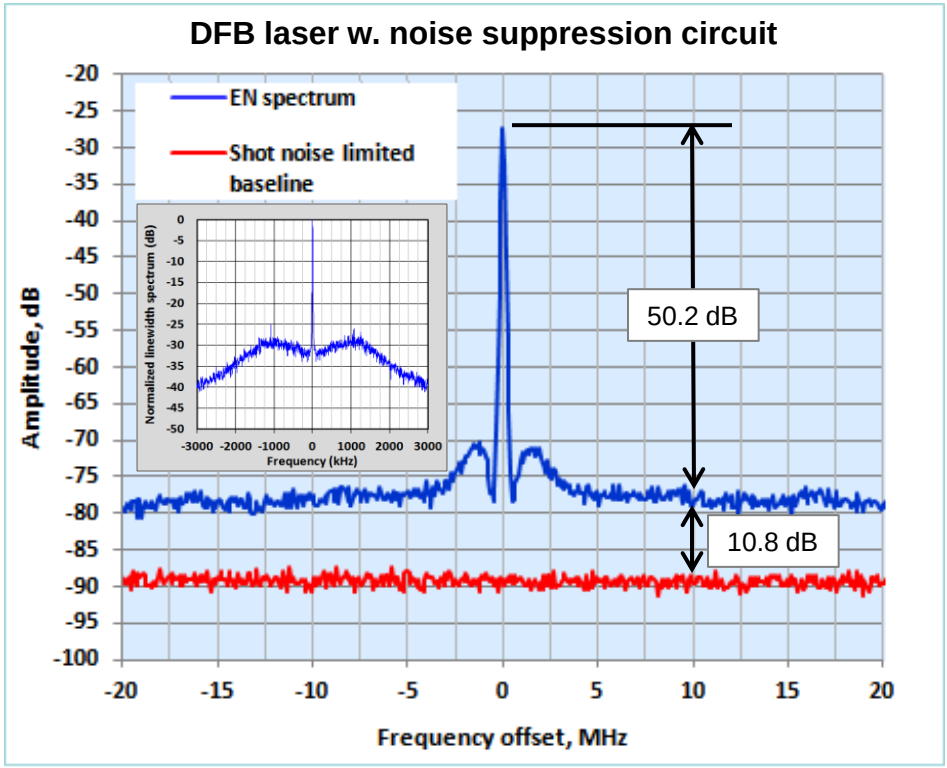


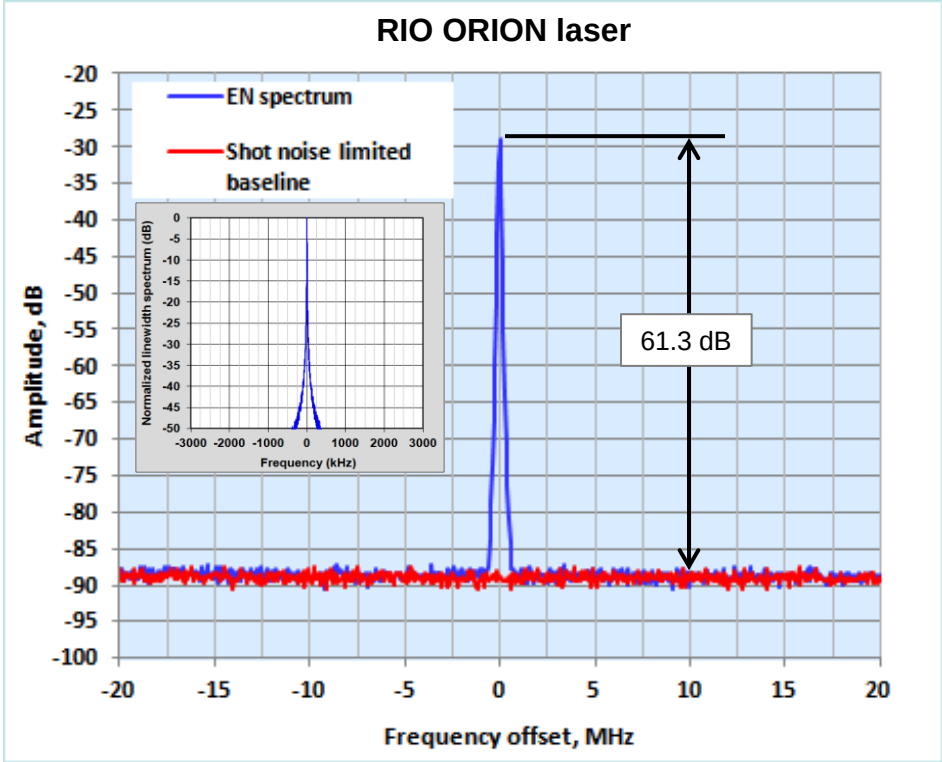
- Observation time on SI: 30 msec.
- SI for white noise only is done with fiber delay 400 km.

- ❑ 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™ Performance: Excess Noise – Linewidth interpretation

- Numerical value of Lorentzian linewidth does not provide all key information, critical for many applications





- Central portion of spectrum leads to very narrow LW estimate(~ 850 Hz), but spectrum has very wide and elevated tail of the spectrum.
- Excess noise is very high:>10 dB (at f > 5 MHz) corresponding to pure LW >30 kHz

- Excess noise for ORION laser with Lorentzian linewidth of 1.6 kHz is < 0.2 dB

PLANEX™ Wavelength Stability and Tunability

PLANEX wavelength setting and tuning

- Sensitivity to cavity temperature ~12.5 pm/ºC (1.5 GHz/ºC)
- Sensitivity to bias current 0.2 -0.3 pm/mA (25-40 MHz/mA)
- Small cavity with fast stabilizations time
- Phase continuous temperature tuning range ± 30 pm (± 4GHz)
- Fast wavelength tuning via bias current up to 4 pm (500 MHz)

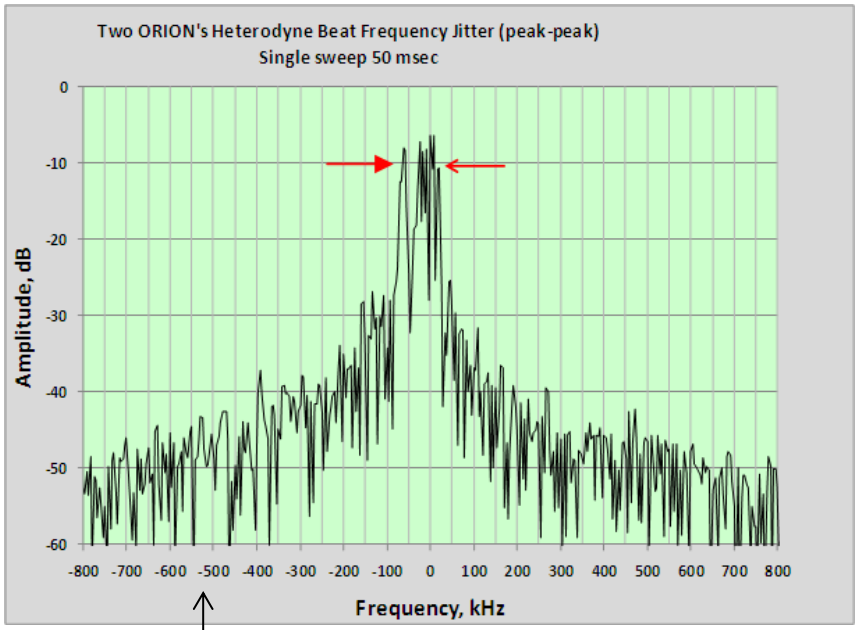
Comparing with DFB Semiconductor Lasers

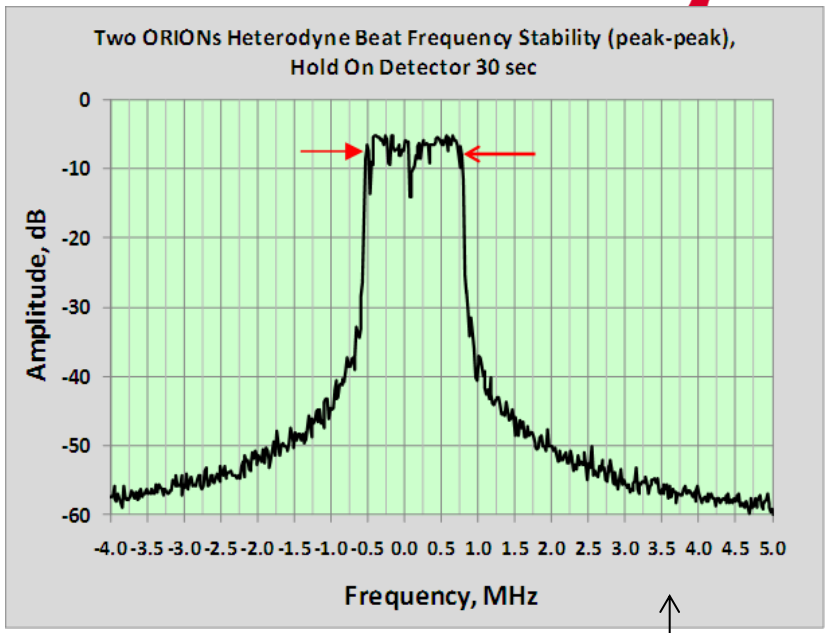
- 5-10x better wavelength stability vs. cavity temperature and current
- Allows precise wavelength setting
- Immune to the instability of electronics

Comparing with Fiber Lasers

- No mechanical stretch on the cavity
- No piezo tuning: no hysteresis and resonances
- Allows fast wavelength stabilization and excellent on/off repeatability

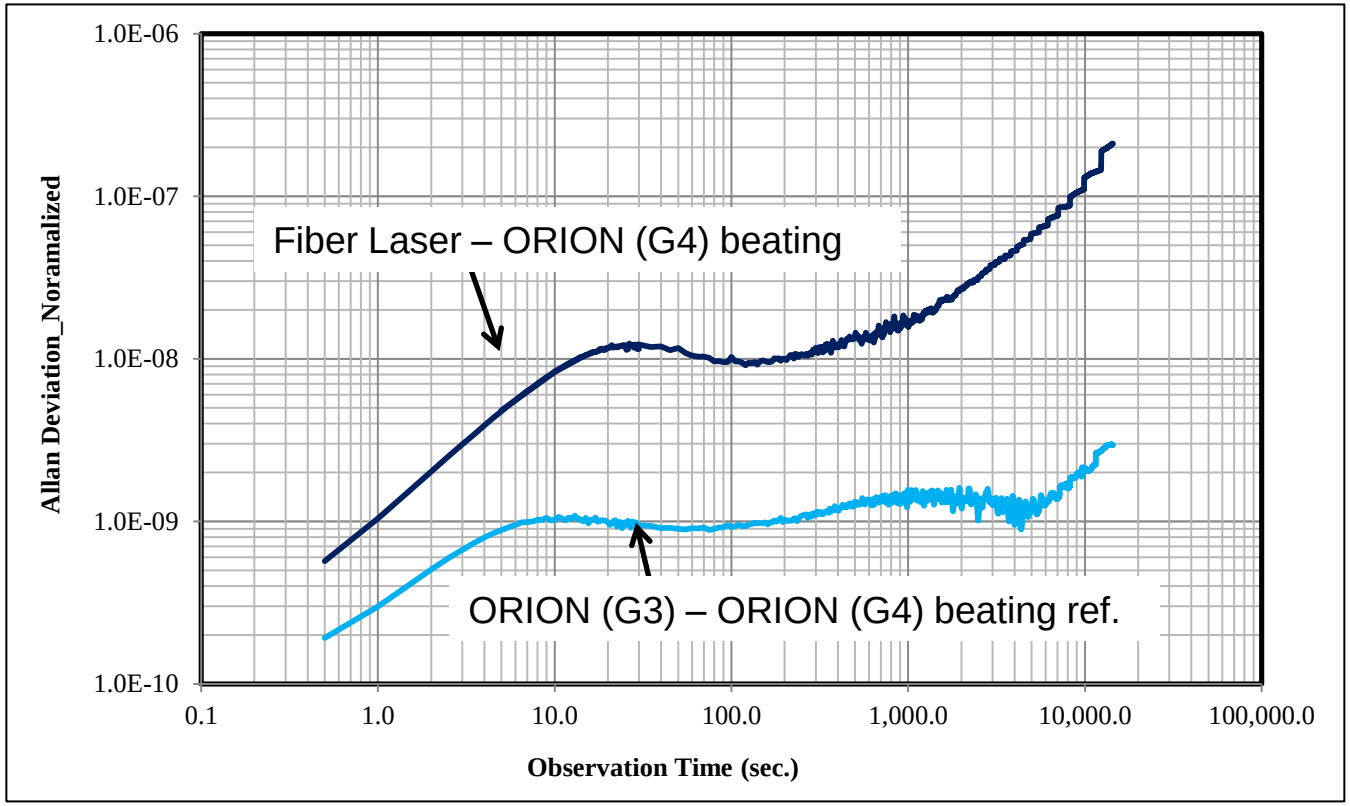
PLANEX™ Frequency Stability





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

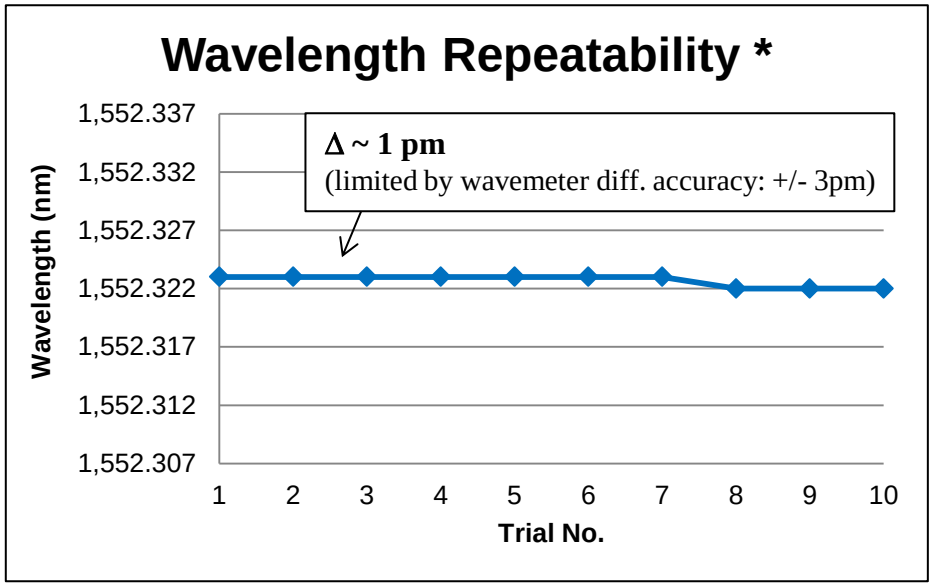
PLANEX™ Performance: Freq. Stability – Allan Deviation

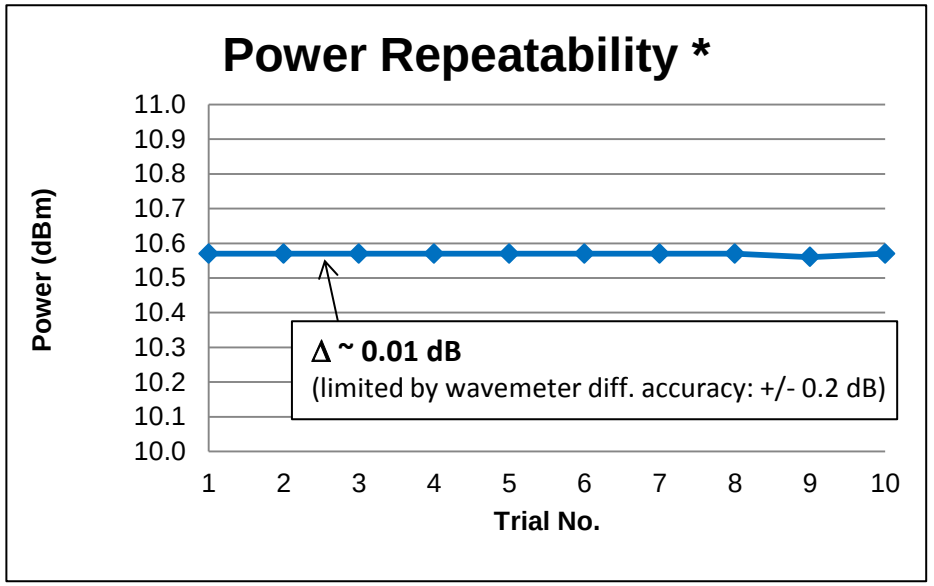


- Free-running.
- Case temperature stabilized : <0.2°C over 3 h

PLANEX™ Performance:
Wavelength turn off/on repeatability

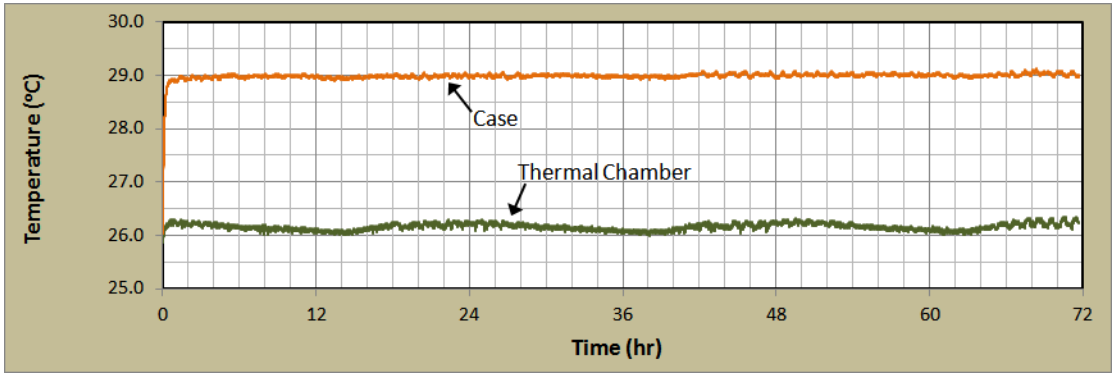
- Virtually no warm-up time required (< 1 min. for ORION module)
- Excellent wavelength and power repeatability over repeated power ON/OFF

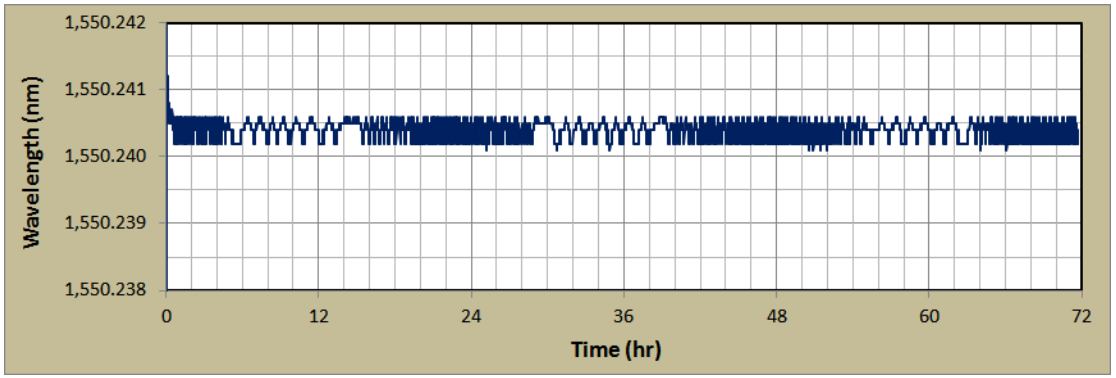


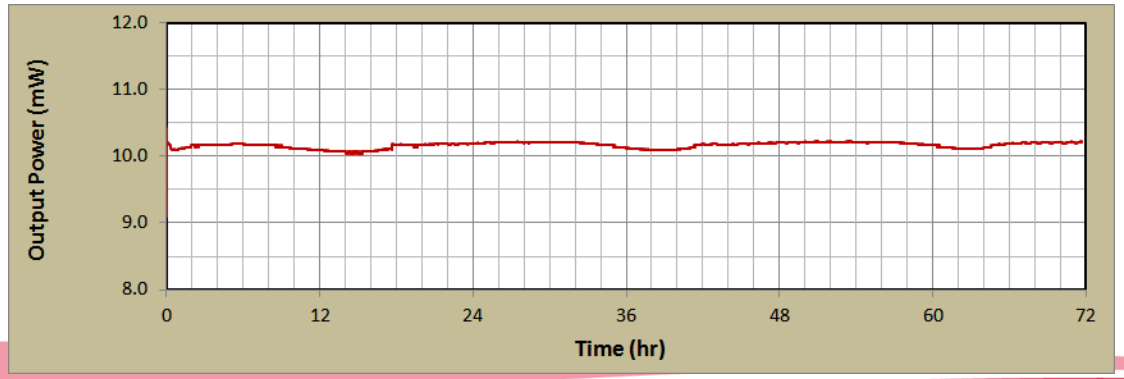


* Measured 1 min. after power ON for each trial.

PLANEX™ Performance:
Long-term wavelength and power stability







- ORION laser is stabilized in thermal chamber
- 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)

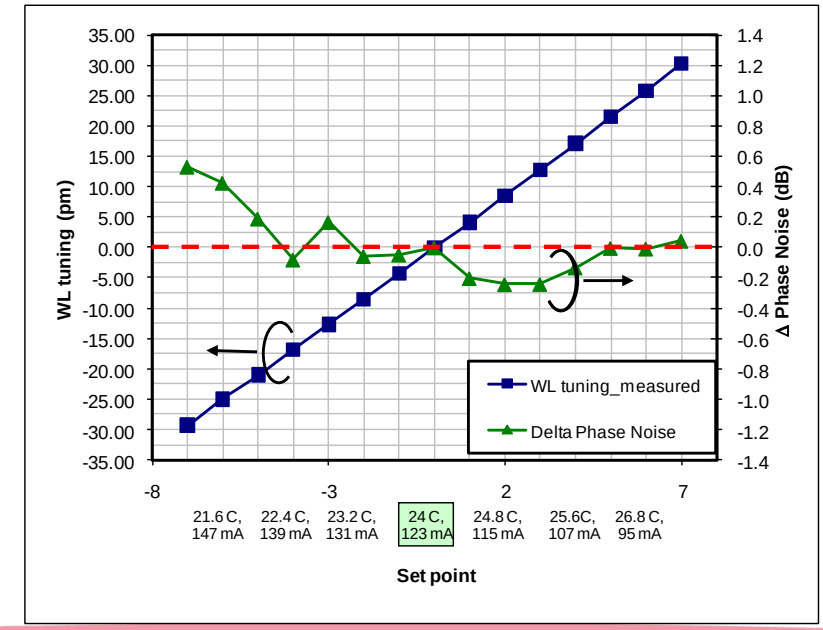
- Pk-Pk output power change over 3 days: 0.19 mW

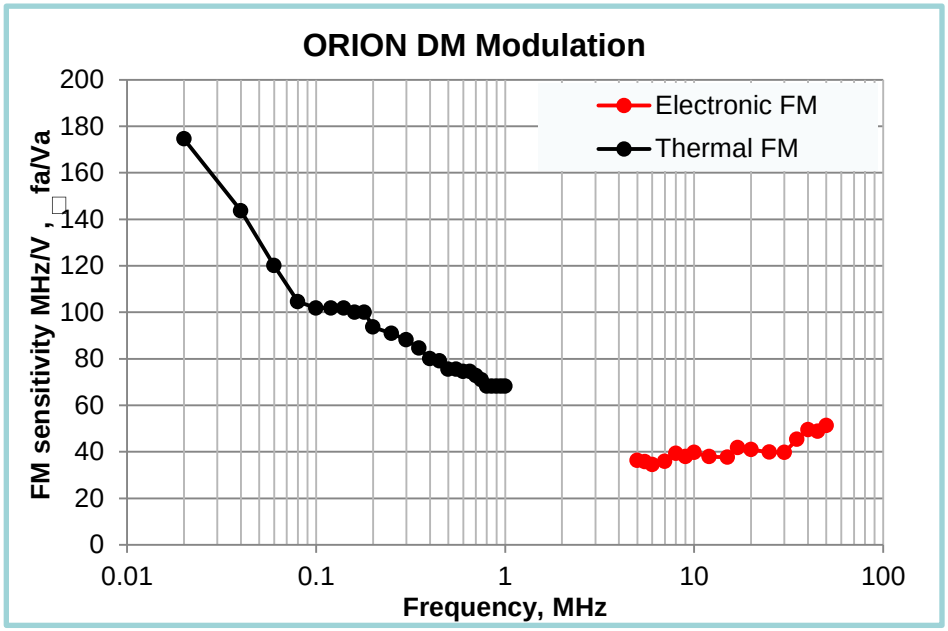
  (NOTE: measured with Agilent 86122A WM, P calibration accuracy: +/- 0.5 dB)

PLANEX™ /ORION

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 : 100 MHz/V ORION, ~ 50 MHz/mA PLANEX
    - 10 kHz: 50 MHz/V ORION, ~ 25 MHz/mA PLANEX
    - DM BW > 200 MHz

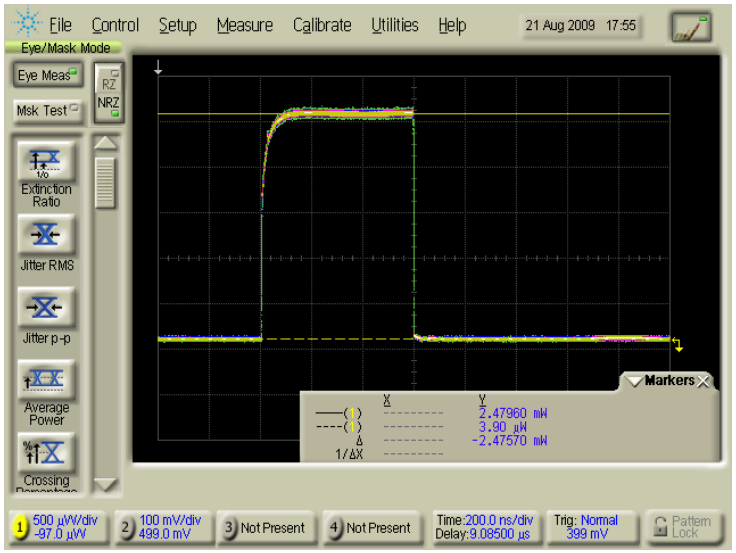




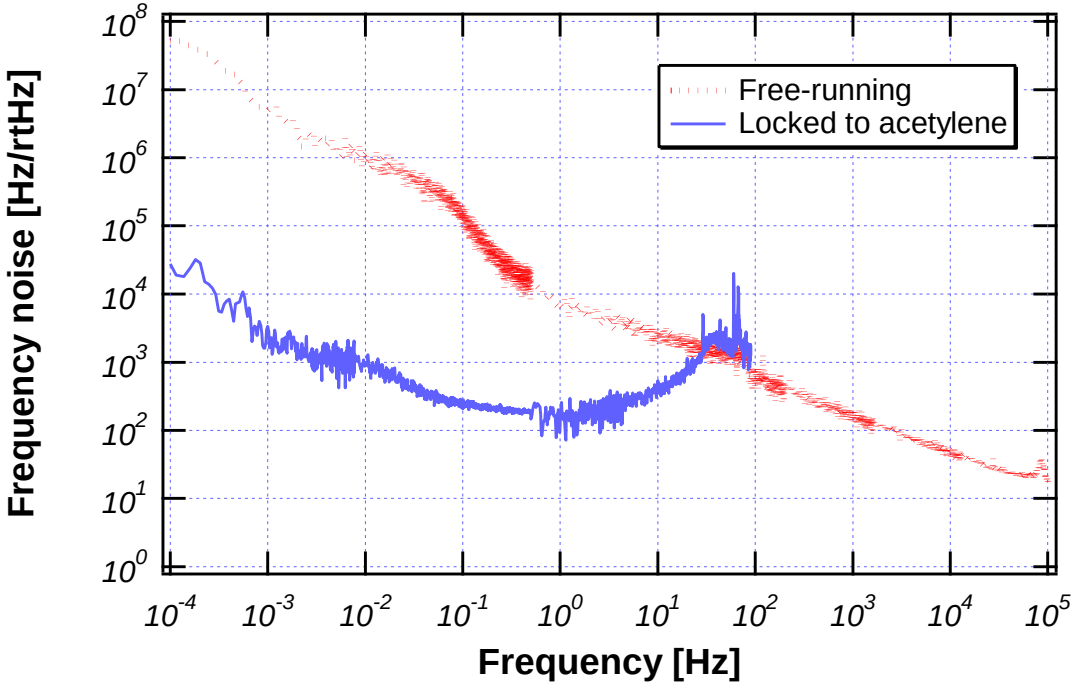
Direct Modulation/Pulsing of **PLANEX™** laser

- PLANEX laser modulation bandwidth > 1 GHz
- 25 Ohms impedance input
- Unique direct modulation/pulsing while maintaining 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



PLANEX™ Capability: Reference Locking

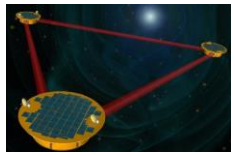


- Frequency noise spectrum of the PLANEX laser with (blue) and without (red) frequency stabilization.
- Within the control bandwidth of ~60 Hz, the noise was suppressed by a factor up to ~1000.

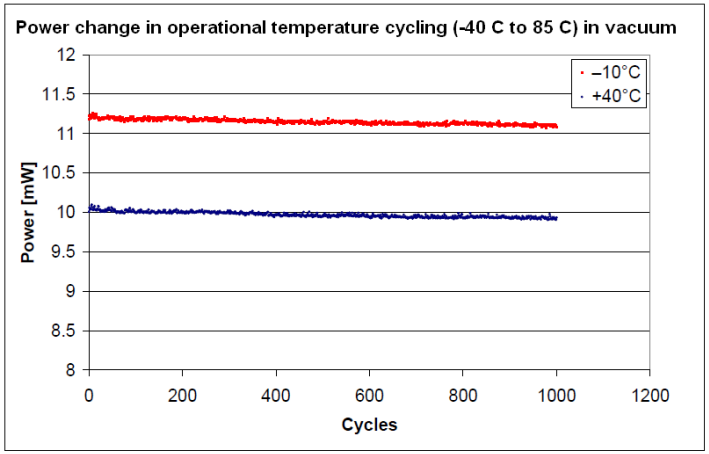
Performance of planar-waveguide external cavity laser for precision measurements.
Kenji Numata, Jordan Camp, Michael A. Krainak, and Lew Stolpner. October 2010 / Vol. 18, No. 22 / OPTICS EXPRESS

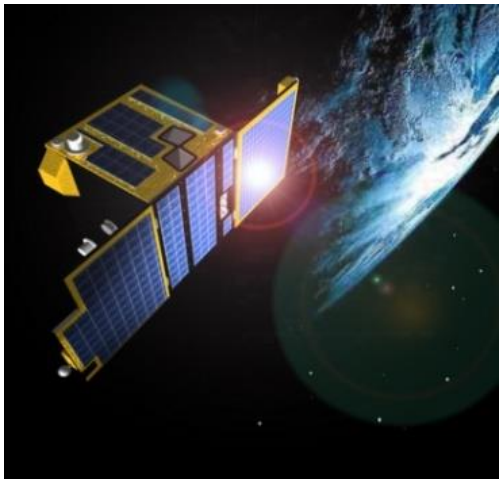
PLANEX™ : Exceptional Reliability

- Telcordia qualified
- Space qualified
  - 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





RIO Product Offering

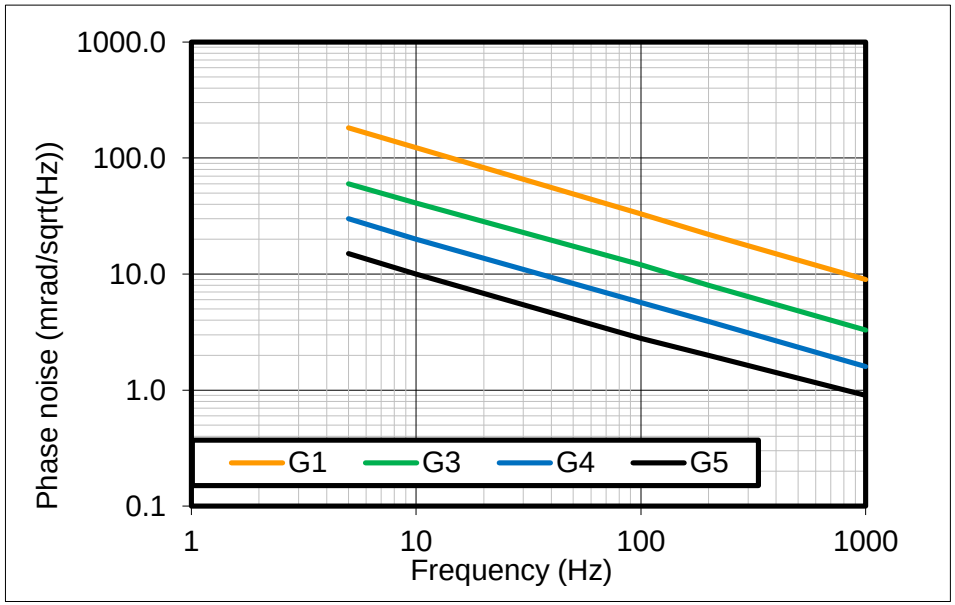
- Wavelength
  - 1550nm ITU DWDM, 1064nm or custom wavelength
- 4 Grades of linewidth (1550nm only)
- PMF & SMF options

PLANEX™ and ORION™

- > 10 mW
- > 20 mW

RIO Grande

- >0.2 W
- >1.0 W
- > 2.0 W



- RIO COLORADO
  - Wide tunable

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

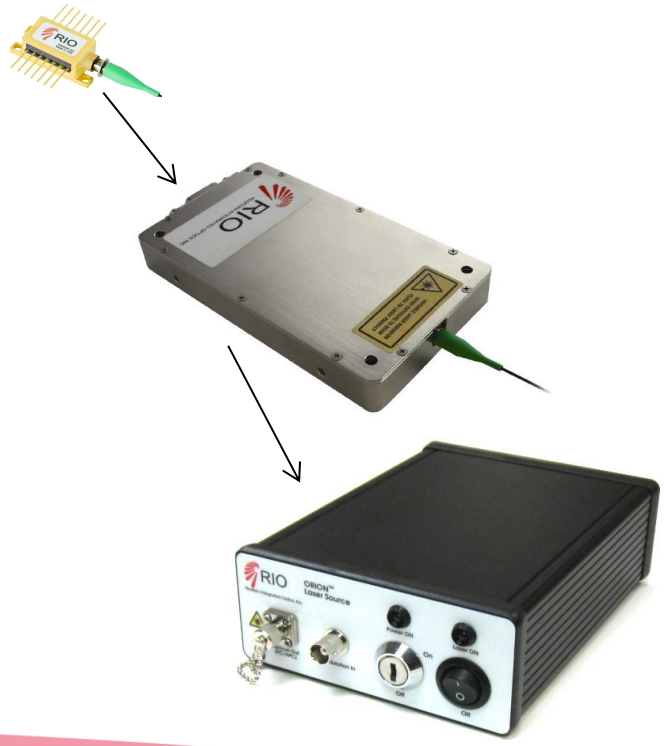
Optical Phase Locked Loop (OPLL)

ORION Laser Modules

❑ Features

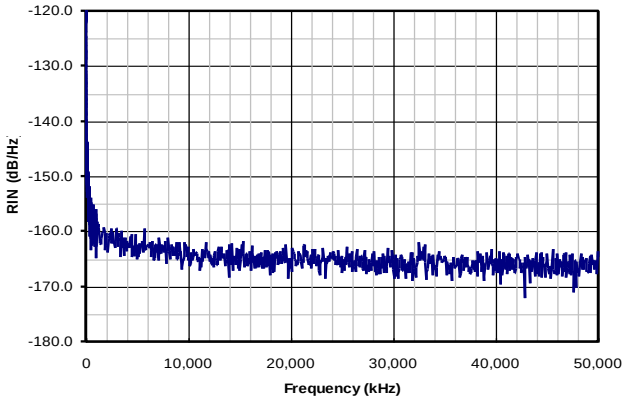
- ➢ Low noise current source and TEC controller
- ➢ Input for direct modulation and wavelength tuning
- ➢ OEM Module with SPI, RS-232 and RS-485 interface options, GUI
- ➢ Benchtop OEM Source with USB interface options, GUI

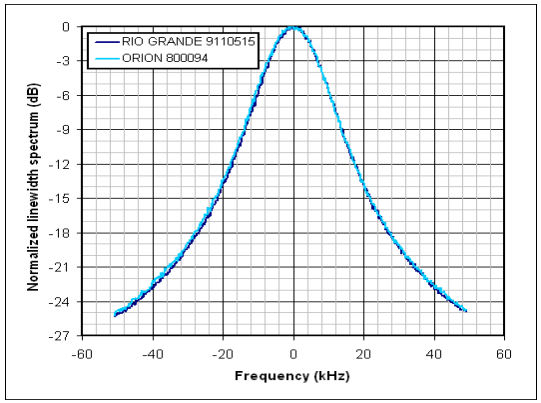
Storage Temp, º C	**-40 to +85**
Size, mm	**100x56x13**
Operational Temp Range, ºC	**0-70**
Power supply	**5 V**
Power Dissipation,	**< 6 W**
@ 35 C case temperature	**<3 W**
@ 50 C case temperature	**<4 W**

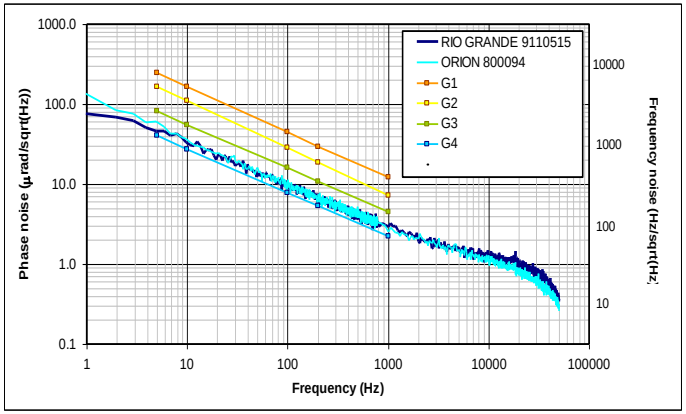


RIO GRANDE: Amplified High Power Modules

- Nominal power 0.2 W up to 2 W
- Power set range 10-100%
- Low phase noise
- Ultra low RIN
- Narrow linewidth
- High OSNR

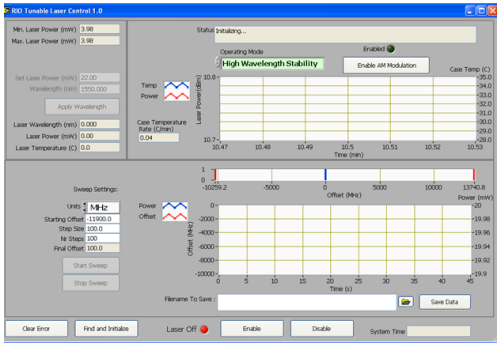




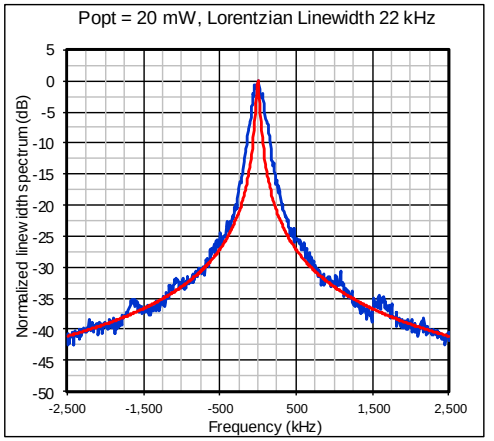


RIO COLORADO Widely Tunable Laser

- 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 5 to 25 mW
  - Continuous Wavelength Sweep: 24 GHz peak-peak or +/- 12 GHz max
  - 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

Multi-Wavelength/Multi Functional Subsystem Integration

- Building Blocks: RIO OEM modules
  - PLANEX: high performance laser core

  - ORION: PLANEX + low noise driver and controller

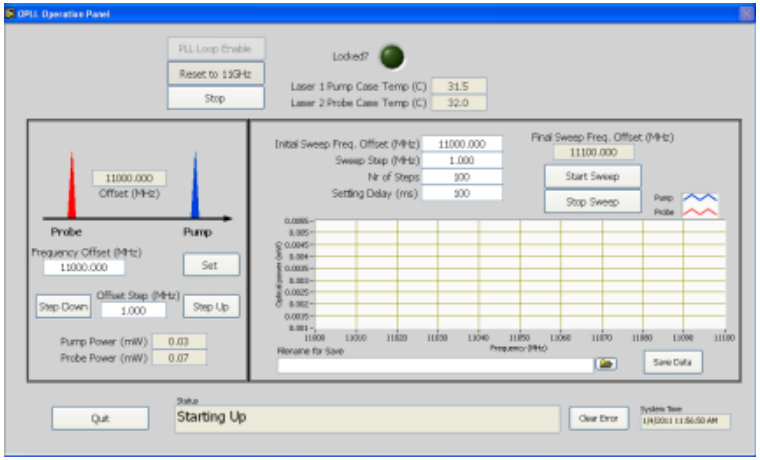
  - GRANDE MOPA: ORION + optimized amplifier

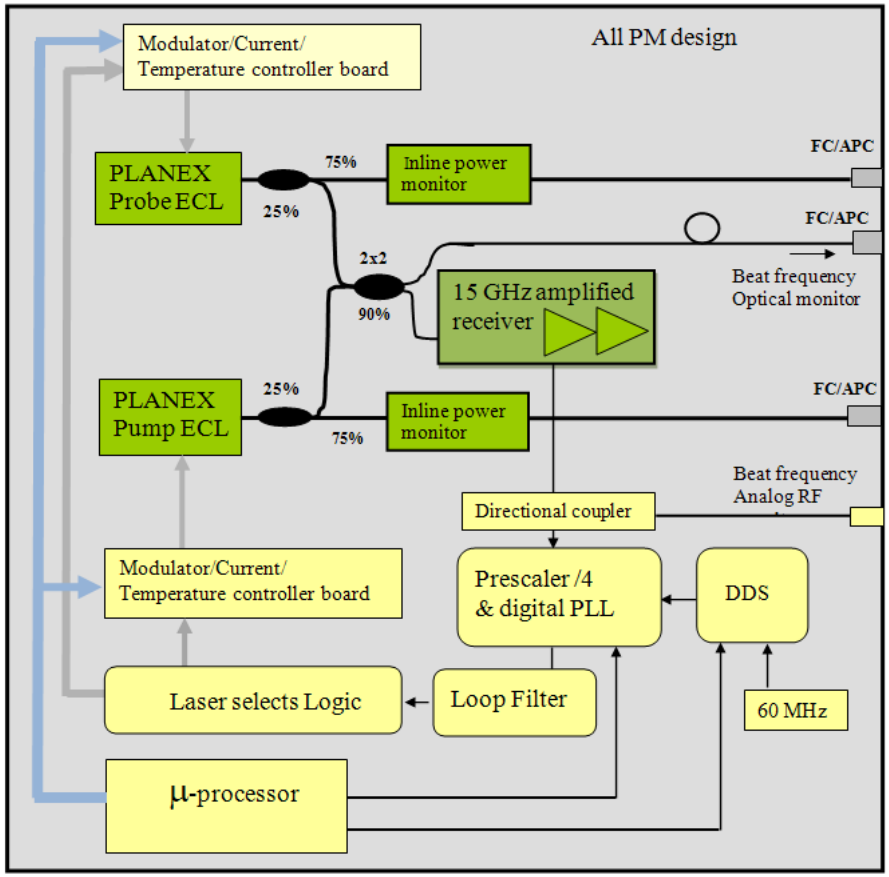
- Integration options
  - Scale up multichannel (DWDM) sources 19” rack mountable
  - Custom designed and build

  - Added functionality, enhanced performance and features - OPLL

OPLL - Dual Laser Source

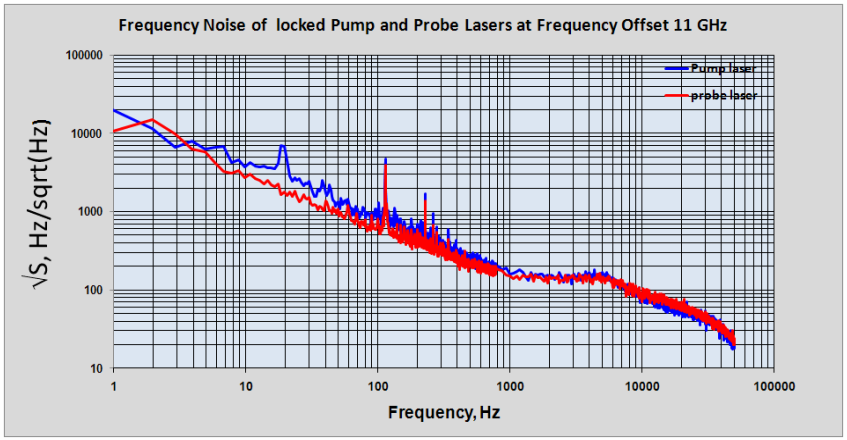
- OPLL for distributed sensing and coherent metrology applications:
  - Distributed Brillouin Fiber Optic Sensing (BOTDA/BOTDR)
  - Heterodyne/ Coherent Metrology

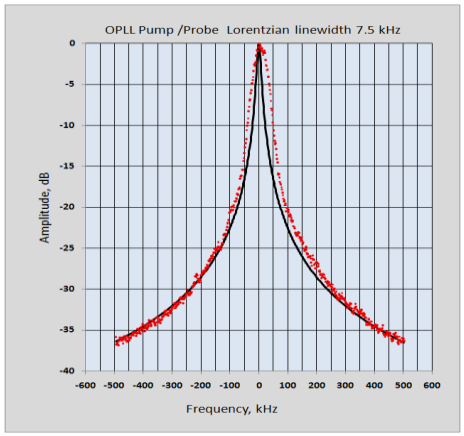


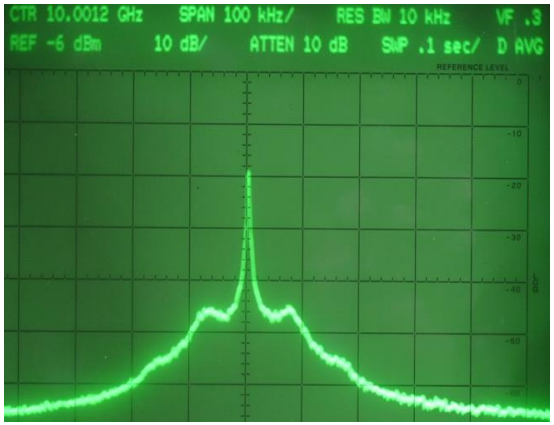


OPLL Key Performance Specs and Features

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 0 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







Summary

- RIO PLANEX laser technology and products:

  semiconductor single frequency coherent versatile lasers

- Unique combination of:
  - High performance
  - Wide set of features
  - Unsurpassed stability and reliability
  - Small form factor and sophisticated control/GUI, user friendly and low maintenance
- Portfolio of integrated products and custom solutions
- Widely accepted for multiple optical coherent Doppler sensing and other metrology applications
- Widely accepted as an optimal laser source for PDV

We are open for product improvement and sub-system integration:

- please provide us with your wish list.

Thank you.