Planar External Cavity Low Noise Narrow Linewidth Lasers

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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

Structural Monitoring
- Static strain detection
- Dynamic strain/vibration detection

Wind Metrology
- Wind energy
- Air traffic control

R&D/ Industrial/ Military,
- metrology and process control

Sensing Technologies

Lasers
- Low Noise
- Narrow Linewidth

Interferometric
Coherent Rayleigh

Brillouin
DTSS BOTDA/R

C-OTDR

Coherent Doppler LIDAR

Photonic Doppler
Velocimetry /Vibrometry
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™ Laser Phase Noise

Phase Noise Comparison

Phase Noise (μrad/sqrt(Hz)-m) vs. Frequency (Hz)

- RIO PLANEX
- FL-O
- FL-K
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
  - $\leq 140$ 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

![Diagram of Frequency Stability Test]

Stabilized Temperature chamber
Stabilization time 1.5 hour
Temperature stability after stabilization peak-peak 0.1 C
### ORION Laser Module Frequency Stability

<table>
<thead>
<tr>
<th>Measurement Time</th>
<th>Frequency stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 msec</td>
<td>150 kHz p-p</td>
</tr>
<tr>
<td>30 sec</td>
<td>1.5 MHz p-p</td>
</tr>
<tr>
<td>1 hour</td>
<td>4 MHz p-p</td>
</tr>
<tr>
<td>12 hours</td>
<td>20 MHz p-p</td>
</tr>
</tbody>
</table>
Free-running. Case temperature stabilized: <0.2°C over 3 h
Wavelength Tunability

- Wavelength vs. TEC temperature: ~15 pm/°C
- 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: 0.5 MHz/mV
Low Frequency Noise with DM-FM

Frequency Noise Measurements (MI at quadrature),
Modulation: Sine-wave, Modulation frequency fm = 1 MHz, Input 100 mVpp
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.

## PLANEX- PLANEX FM

<table>
<thead>
<tr>
<th>Parameter</th>
<th>PLANEX</th>
<th>PLANEX FM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cavity</td>
<td>2 sections&lt;br&gt;GC + WBG PLC</td>
<td>3 sections&lt;br&gt;GC+ WBG PLC + LN FM</td>
</tr>
<tr>
<td>FM Modulation</td>
<td>Direct bias current</td>
<td>1. Direct bias current&lt;br&gt;2. LN FM voltage</td>
</tr>
<tr>
<td>Residual AM</td>
<td>Coupled with FM</td>
<td>Practically decoupled with FM</td>
</tr>
<tr>
<td>FM frequency</td>
<td>&gt; 100 MHz&lt;br&gt;Not flat with phase reverse</td>
<td>&gt;50 MHz bulk LN FM&lt;br&gt; &gt;1 GHz with WG&lt;br&gt;Flat phase possible</td>
</tr>
</tbody>
</table>
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

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pulse Width</strong></td>
<td>&gt; 5 nsec</td>
</tr>
<tr>
<td><strong>Pulse Repetition</strong></td>
<td>up to 10 MHz</td>
</tr>
<tr>
<td><strong>Frequency</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Extinction Ratio</strong></td>
<td>25-32 dB</td>
</tr>
<tr>
<td><strong>Linewidth</strong></td>
<td>&lt; 15 kHz at pulse plateau</td>
</tr>
<tr>
<td><strong>Pulse shape distortion</strong></td>
<td>Minimum or none</td>
</tr>
<tr>
<td><strong>RMS Jitter</strong></td>
<td>150 ps max</td>
</tr>
</tbody>
</table>
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)**

![Typical Phase Noise Graph](image)

<table>
<thead>
<tr>
<th>Linewidth, kHz</th>
<th>Grade 1</th>
<th>Grade 2</th>
<th>Grade 3</th>
<th>Grade 4</th>
<th>Optional</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;15</td>
<td>&lt;10</td>
<td>&lt;5</td>
<td>&lt;3</td>
<td>1</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Storage Temp, °C</th>
<th>-40 to +85</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size, mm</td>
<td>100x56x13</td>
</tr>
<tr>
<td>Operational Temp Range, °C</td>
<td>0-70</td>
</tr>
<tr>
<td>Power supply</td>
<td>5 V</td>
</tr>
<tr>
<td>Power Dissipation, @ 35 C case temperature</td>
<td>&lt;3 W</td>
</tr>
<tr>
<td>@ 50 C case temperature</td>
<td>&lt;4 W</td>
</tr>
<tr>
<td>Parameter</td>
<td>RIO008X ORION</td>
</tr>
<tr>
<td>---------------------------------</td>
<td>---------------</td>
</tr>
<tr>
<td>Power</td>
<td>&gt;10 mW</td>
</tr>
<tr>
<td>RIN</td>
<td>&lt;-140 dB/Hz</td>
</tr>
<tr>
<td></td>
<td>(&gt;1 kHz)</td>
</tr>
<tr>
<td>WL stability (FR), p-p</td>
<td>4 MHz 1 hour</td>
</tr>
<tr>
<td></td>
<td>20 MHz 12 h</td>
</tr>
<tr>
<td>Storage Temp, °C</td>
<td>-40 to +85</td>
</tr>
<tr>
<td>Size, inches</td>
<td>4x2.25x0.5</td>
</tr>
<tr>
<td>Operational Temp Range, °C</td>
<td>0-70</td>
</tr>
<tr>
<td>Power supply</td>
<td>5 V</td>
</tr>
<tr>
<td>Power Dissipation,</td>
<td>&lt; 6 W</td>
</tr>
<tr>
<td>over specified case temp range</td>
<td></td>
</tr>
<tr>
<td>@ 35 C case temperature</td>
<td>&lt;3 W</td>
</tr>
<tr>
<td>@ 50 C case temperature</td>
<td>&lt;4 W</td>
</tr>
</tbody>
</table>
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

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Normalized linewidth spectrum (dB)

Frequency (kHz)

Popt = 20 mW, Lorentzian Linewidth 22 kHz
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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>CW power</td>
<td>&gt; 5 mW</td>
<td>average, two PM optical outputs</td>
</tr>
<tr>
<td>Laser frequency noise</td>
<td>$10^3$ Hz/$\sqrt{\text{Hz}}$ @ 100 Hz</td>
<td>under locking conditions:</td>
</tr>
<tr>
<td>Linewidth</td>
<td>&lt;10 kHz</td>
<td></td>
</tr>
<tr>
<td>Phase noise</td>
<td>-65 dB/Hz</td>
<td>at 100 kHz offset</td>
</tr>
<tr>
<td>Frequency offset</td>
<td>From 8 to 14 GHz</td>
<td>step tuning</td>
</tr>
<tr>
<td>Tuning resolution</td>
<td>10 kHz</td>
<td></td>
</tr>
<tr>
<td>Continuous sweep tuning</td>
<td>over 1 GHz</td>
<td>resolution 10 kHz @ 50 $\mu$sec speed</td>
</tr>
<tr>
<td>Locked step response time</td>
<td>5 $\mu$sec</td>
<td>at 10 MHz step</td>
</tr>
</tbody>
</table>

![Graph of Frequency Noise of locked Pump and Probe Lasers at Frequency Offset 11 GHz](image1)

![Graph of OPLL Pump/Probe Lorentzian Linewidth 7.5 kHz](image2)

![Graph of OPLL Pump/Probe Output](image3)
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.