Intel® C-band Tunable Laser

Performance and Design White Paper

May 2003

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Introduction

The development of cost effective component technology is crucial to the continued growth of the optical communications industry. Key trends such as standards conversion and the increasing use of optical transceivers are providing an opportunity for increasing the cost effectiveness of technology in the 10Gbps market. The next trend that will lead to more cost saving and customer flexibility is the incorporation of tunable lasers into optical transceivers and laser modules. Tunable lasers address the needs of carriers operating Dense Wavelength Division Multiplexing (DWDM) transport networks in Metropolitan and Long Haul applications to achieve cost saving by reducing the number of spares located on site to resolve line card failures. Telecom equipment manufacturers resolve the issue of inventory control by reducing the number of parts carried from 80 parts to just one part. The end goal will be manufacturing a solution that can replace the single channel and eight channel modules shipping today at a similar price point.

Preliminary Specifications

The Intel® full C-band tunable laser module consists of a 20 mW, full C-band tunable source laser in a 14-pin butterfly package. It is designed to be cost competitive with fixed-wavelength sources. The laser is packaged and manufactured using Intel's quasi planar flexure technology and automated assembly technology. This module will be incorporated into a range of telecommunication products including a C-band tunable 10Gbps 300 pin Multi Source Agreement (MSA) optical transceiver and the Optical Interoperability Forum (OIF) compatible tunable laser module (www.TunableLaserMSA.com).

This technology brief describes the optical design and performance of the Intel® C-band tunable laser module. The preliminary specifications for the C-band version of the tunable laser are shown in Table 1. The tunable laser is not a stand-alone product and has been designed to be incorporated into an OIF laser module and a 300 pin optical transceiver. The specifications in Table 1 are for the laser as a component of one of these devices.

Table 1: Preliminary Intel® C-band tunable laser module specifications. All specifications guaranteed over tuning range, case temperature range, and lifetime.

Summary of Operating Performance Requirements	
Parameter	**Specification**
Case temperature	-5 to 75 ºC
Tuning range	191.7 to 196.0 THz
Output power	+13 dBm
Wavelength accuracy	< ±2.5 GHz
Wavelength stability	< ±2.5 GHz
Power accuracy	±0.5 dB
Power stability	±0.5 dB
SMSR	> 40 dB
RIN, 1 MHz to 10 GHz	< -140 dB/Hz
PER	> 20 dB
Tuning speed	< 25 sec
Thermal dissipation	< 4 W

Theory of Operation

Overview of external cavity design

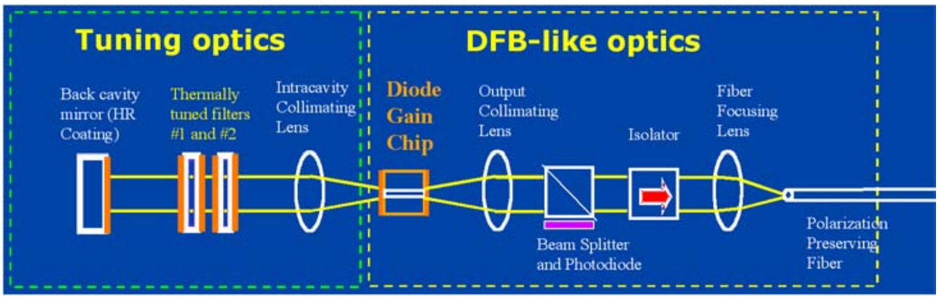
The Intel C-band tunable laser design consists of an external cavity diode laser (ECDL) wholly mounted on a ceramic platform placed on a thermo-electric cooler (TEC) within a 14-pin butterfly sized package. The ECDL uses an etalon based, thermally actuated, widely tunable filter of proprietary design to achieve single mode operation at selectable wavelengths. There are no moving parts with in the design. The Intel tunable laser is comparable in part count and assembly complexity to standard distributed feedback lasers (DFB). The optical layout is diagrammed in Figure 1.

Approximately one-half of the optics form the laser cavity that extends from the high reflector end mirror up to and including the gain medium. The remaining half comprises the output optics that couple the laser emission into Polarization Maintaining (PM) fiber. The output optics include a collimating lens, optical isolator, beamsplitter and monitor photodiode, fiber coupling lens, and a pigtail of polarization maintaining fiber in an arrangement similar to that used in DFB lasers

The laser utilizes an InGaAsP/InP gain medium actively cooled through a TEC and is coupled to an external cavity with a collimating lens. The laser cavity is bounded by the back cavity mirror and the distal facet of the gain chip that in turn is partially reflective and couples light out towards the fiber. Reflection from the intracavity diode facet is effectively eliminated with an antireflection (AR) coating. An intracavity tunable filter restricts laser oscillation to the desired wavelength.

Figure 1: Optical layout.

The tunable laser consists of DFB-like optics and a backside external cavity tuner. The gain chip is AR coated on the cavity side facet to transmit light into the external laser cavity.



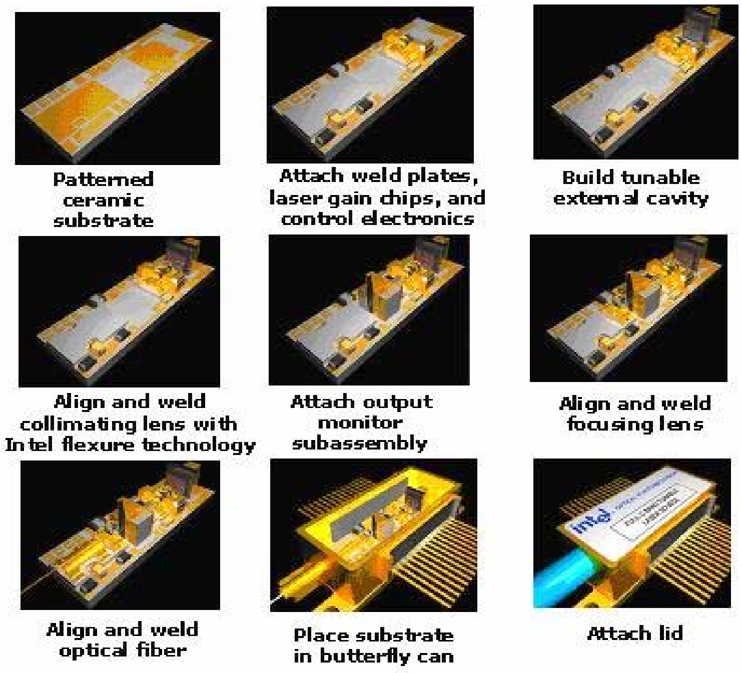
Assembly technology

The cost and reliability of the laser assembly depends as much on the manfacturing approach as on the optical design. Assembly of the tunable laser employs Intel's proprietary quasi-planar packaging technology presently used to manufacture a wide variety of Telcordia-qualified transmitter and receiver products. Each of the critical mechanical alignment tolerances required for the tunable laser to stay within lifetime performance specifications is comparable to, or looser than alignment tolerances. Intel manufacturing has several distinct characteristics: Optical assembly occurs outside the butterfly package on a patterned ceramic substrate. Actively aligned components on metallic flexures are picked and placed onto substrates, flexed to optimize alignment, and laser welded into place.

To assemble the Intel C-band tunable laser (Figure 2), weld plates, gain medium, tuning filters, end mirror, and output monitoring optics are attached to the ceramic substrate. Free-space optics and fiber are mounted onto flexure stages, aligned, and laser-welded into place. The substrate is then soldered onto a TEC mounted in a butterfly package. Seam-sealing and booting the fiber complete the laser packaging.

Figure 2: Tunable laser assembly

The laser is assembled on an open substrate and subsequently mounted into a butterfly package. Actively aligned components are premounted on metallic flexures that are flexed into their optimal position and laser welded.



Tuning and control

The Intel C-band tunable laser employs active control technology to achieve robust performance at an attractive cost. External cavity lasers are well suited to this approach. Its hybrid component makeup affords wider choices of materials, optimization of performance, and separation of function.

The power control implementation resembles that of many other lasers: A partial reflector diverts a fraction of the output light onto a monitor photodiode just prior to fiber coupling. Photocurrent is calibrated to output power and wavelength during manufacturing. During laser operation, a digital control loop adjusts the injection current to achieve the calibrated photocurrent target.

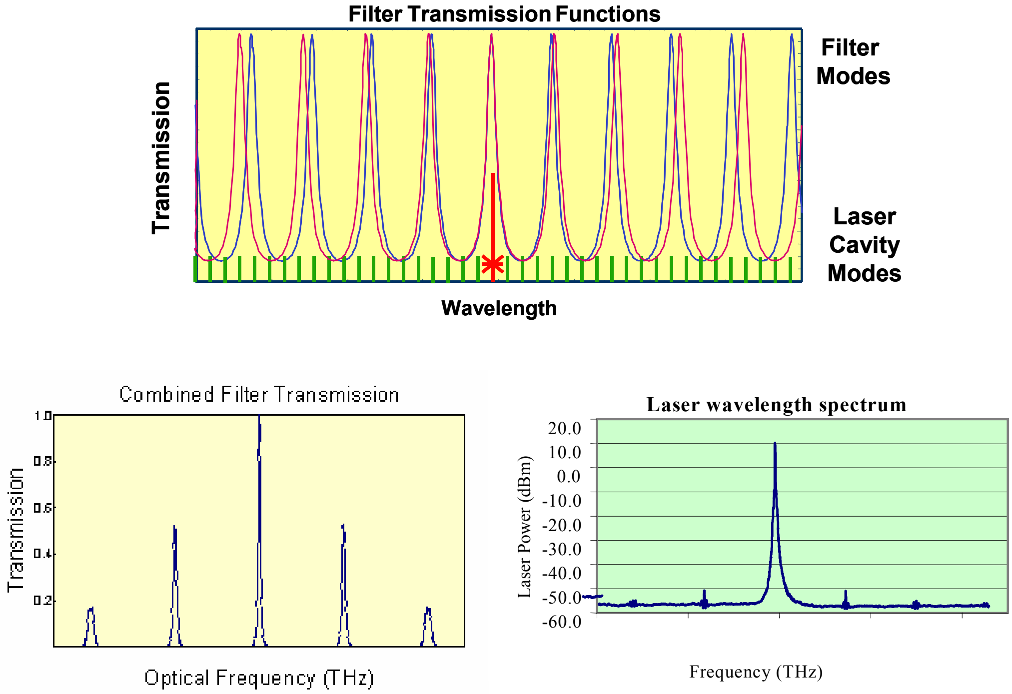
The wavelength filter comprises two silicon etalon filters with slightly different periods (Figure 3). The composite periodicity of two such filters is greatly increased by the "Vernier effect". This effect generates a large net transmission only where both filters have large transmission. Silicon is an excellent optical material as it is highly transmissive at telecommunication wavelengths, has a large index of refraction, n_{Si}=3.48, and has exceptionally high thermal conductivity. Further, the silicon etalons are microfabricated from wafers for low cost.

The tuning filters are thermally actuated, taking advantage of silicon's high thermo-optic coefficient. Figure 3 shows the individual filter transmission functions, the net filter transmission within the cavity, and the resulting laser spectrum. Changing the temperature of a given filter spectrally translates its transmission maximum. In the Vernier implementation, any wavelength in the C-band can be addressed with a small temperature adjustment of the individual etalons. To tune to a target wavelength, a temperature is chosen for the first etalon that places a transmission peak at the given wavelength. Similarly, a second temperature is chosen for the second etalon so that it also has a transmission peak at the same target wavelength. This achieves the filter configuration shown in the lower left diagram of Figure 3 with the joint maximum at the target wavelength. The filters can slew across their entire operating range within 1.0 second.

In the field, wavelength tuning is accomplished by reconfiguring the intracavity tuning filter while current to the gain medium is turned off. This prevents laser emission at any wavelength other than the final target wavelength.

Figure 3: Filters and wavelengths

The figures above show the transmission spectra of the tuning filters, and indicates lasing on a mode where the spectral peaks align. Net transmission through the composite filter is shown at lower left. At lower right is a typical resultant laser spectrum.



Performance

Typical start of life performance of the Intel C-band tunable laser is characterized by measuring performance parameters at 50 GHz steps across the C-band and at 8 different case temperatures. Output power (absolute and variance from 13dBm target) has been measured (Figure 4) as well as variance of optical frequency from an International Telecommunications Union (ITU) target, Side Mode Suppression Ratio (SMSR) and tuning time (Figure 5). The specified limits of ±2.5 GHz are typical for DWDM systems with 50GHz channel spacing. SMSR is the ratio between the power in the lasing mode to the power in the next strongest mode within the c-band. External cavity lasers in general have SMSR significantly better than the typical DWDM system requirement of 40dB. Tuning time is here defined as the time required to fall within the wavelength and power specifications. Typical “warm” tuning time of the tunable laser is under 5 seconds. The specified maximum tuning time, 25 seconds, includes “cold start” tuning time where the gain medium is cooled from the maximum case temperature to its operation temperature.

Laser specifications (Table 1) are given as absolute maximum over all conditions. These conditions can be separated into (i) beginning of life performance over wavelength tuning range, case temperature, etc., (ii) short term deviations or stability, and (iii) aging and lifetime effects. The data from an experiment measuring the short-term (~500 hours) wavelength stability is shown in Figure 6. The budget for aging effects is obtained by subtracting short-term wavelength deviations and beginning-of-life errors (Figure 5) from the wavelength error specification of ±2.5 GHz.

The Intel C-band tunable laser has no moving parts, which helps achieve excellent operational shock and vibration resistance. This is demonstrated in Figure 7, which shows the immunity of the Intel C-band tunable laser design to operational shocks.

Figure 4: Output power

Output power measured on an Intel® C-band tunable laser prototype. The data was taken at 50 GHz steps over the C-band and repeated at 8 different case temperatures. The nominal output power specification is 13dBm or 20mW. The maximum allowed deviation from 13dBm from all causes is specified to be ±0.5 dB.

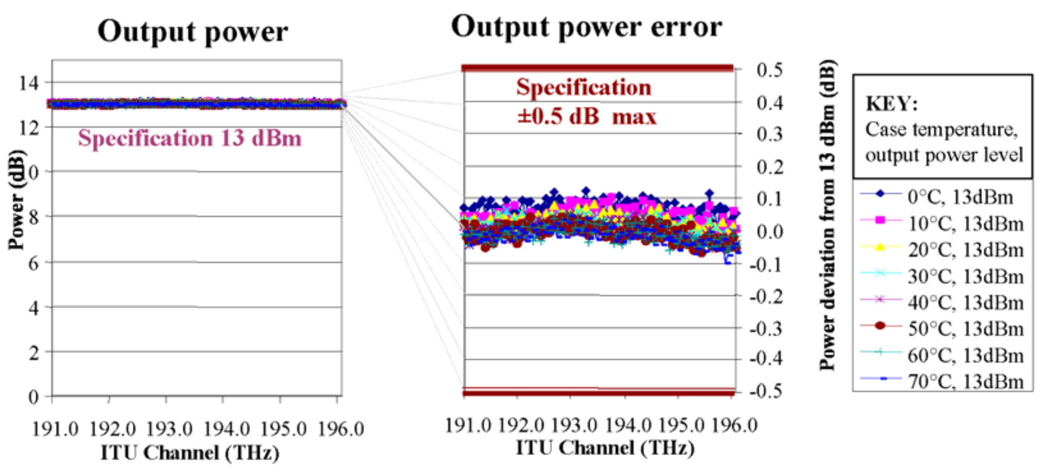


Figure 5: Start of life wavelength accuracy, SMSR and tuning time

Typical data from the Intel® C-band tunable laser obtained by sequentially tuning across C-band in 50 GHz steps at 8 different case temperatures: Wavelength tuning error, SMSR, “warm” tuning time.

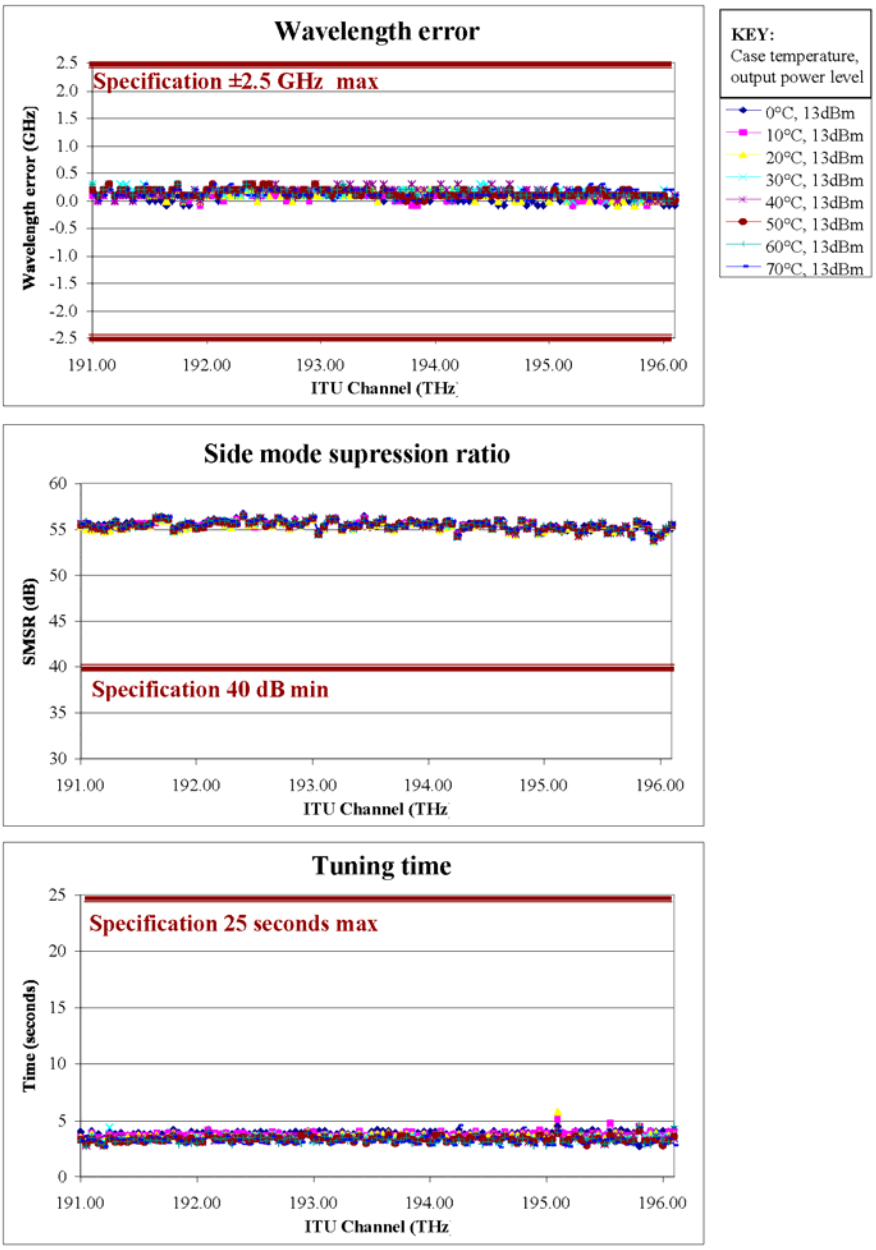


Figure 6: Optical frequency stability

This data represents 500 hours of wavelength measurements with the laser operated continuously at room temperature. The optical frequency accuracy specification of ±2.5 GHz is an absolute maximum including beginning of life tuning accuracy, short term stability (represented here), and aging effects.

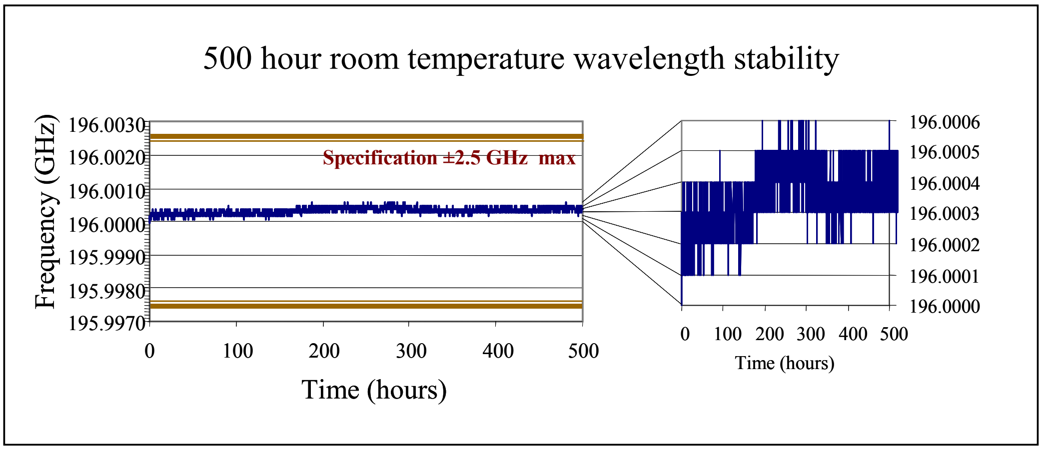
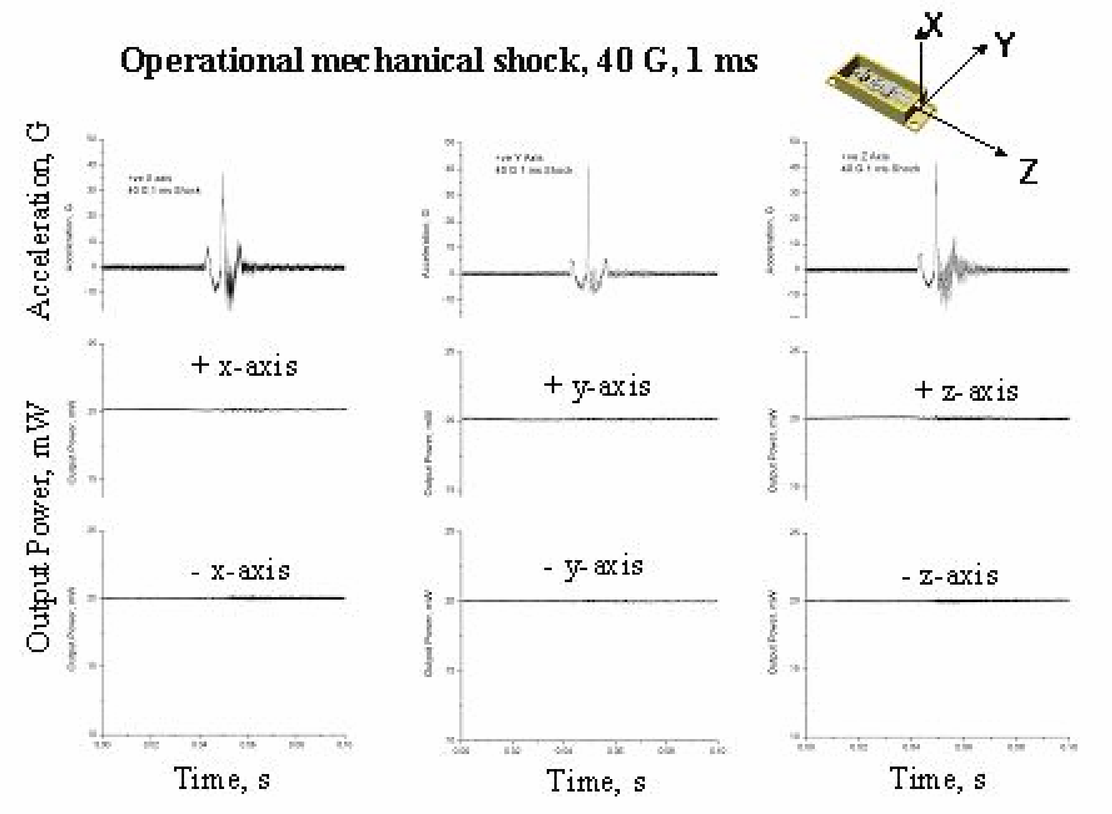


Figure 7: Six axis operational shock

The top row of graphs show the acceleration profiles of 40G, 1ms shocks. The middle and lower rows show the optical output power, measured with a fast photodiode, while the lasers are shocked individually along the specified axis direction.



Conclusion

The communications industry is moving from custom, low-volume equipment to standardized systems and components that can be mass-produced for faster time-to-market and maximum flexibility. Optical networking has emerged as the only technology capable of keeping up with the ever-increasing demand for communications bandwidth. With integrated, cost-effective and high-performance solutions, Intel is helping to lower the cost and increase the bandwidth of optical networks. Intel's C-band tunable laser design will be a key part of the next-generation network, offering robust performance at low cost. The Intel tunable laser meets DWDM performance requirements in a butterfly package with no moving parts. This robust design reduces the performance impact of mechanical shocks and vibrations to that of a well-designed fixed-wavelength laser. The automated assembly technology used to fabricate the Intel C-band tunable laser has already passed qualification for other Intel transmitter and receiver modules at telecom customers and these modules have comparable or tighter specifications than those of the full C-band tunable laser.

The design resembles standard DFB lasers in many respects. The TEC, ceramic sled, gain medium, output coupling lenses, monitor photodiode, isolator, fiber, and the hermetic package are the familiar basic components. The additional components required for tunability are few; an additional collimating lens, and end mirror are industry standard optical components while the tuning filters are prepared at the wafer level using low-cost silicon microfabrication technology. Automated quasi-planar packaging technology provides high-volume, low-cost manufacturing capabilities that complement the low cost of design. The net result is a cost structure approaching that of fixed wavelength devices.

Improved operational costs motivate installing full C-band tunable lasers over fixed-wavelength or narrowly-tunable lasers. The other attributes required of the tunable laser are high performance, small form factor, low thermal dissipation, and reliability for qualification.

The Intel tunable laser surmounts the performance, and cost barriers that have prevented wide scale adoption of tunability. With the inventory and sparing advantages tunability brings, the Intel C-band tunable laser is poised to replace fixed wavelength sources in the telecommunications network. Intel offers a wide range of products, technologies and capabilities to help equipment manufacturers compete effectively in this new environment. For more information on Intel’s optical product offerings, go to www.intel.com/go/optical.

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