how it works

AN OLD COMMUNICATIONS PROBLEM REOCCURS IN OPTICAL-COMMUNICATION-SYSTEM DESIGN.

How it works: making the laser diode tunable

Bill Schweber, Executive Editor

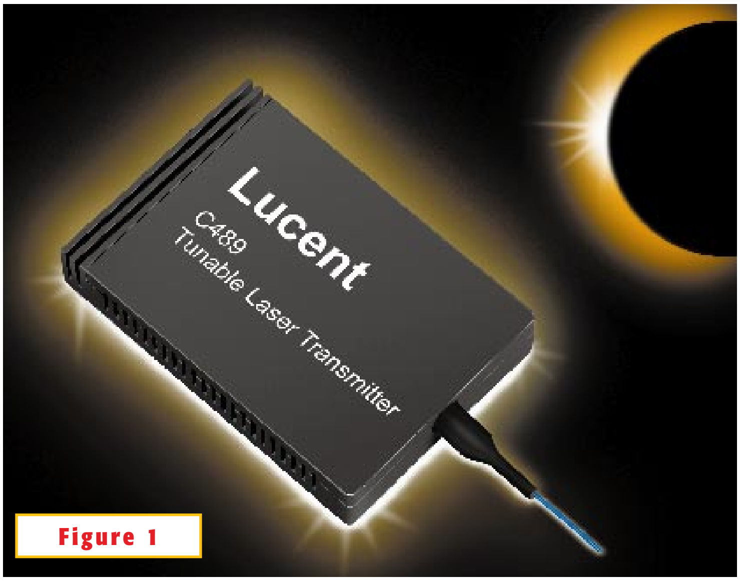

Figure 1

Lucent's C489 tunable laser-diode module encompasses 10 50-GHz channels and includes an integral wavelength locker for spectral stabilization.

If you ask someone, "How do you tune a laser diode?" the answers you'll get right now are not just "with difficulty" and "not that well" but also "much better than before." There are two reasons for tuning a laser diode's output wavelength. First, such multiwavelength diodes greatly simplify your bill of materials and the field-maintenance logistics in multichannel systems such as WDM (wavelength-division-multiplexing) designs, which can have 20, 40, 80, or more discrete channels (**references 1** and **2**). Second, some planned optical systems take advantage of dynamically switching channel assignments, either slowly, to multiplex data streams or to reconfigure optical paths when system faults occur, or quickly, so they can route individual data packets on different optical paths.

The tunable-laser-diode challenge closely parallels the design issue that engineers faced in the earliest days of radio and the superheterodyne architecture that engineer and inventor Major EH Armstrong developed in the 1930s: How do you make a signal source or oscillator that is stable and precisely settable yet also changeable? This problem has produced many creative approaches, such as using topologies that are inherently stable, as well as advanced designs that add circuitry and components to compensate for adverse effects of temperature and power-supply variations.

Tunable laser diodes are the latest manifestation of that old problem, but they have a much more severe set of parameters—after all, these lasers operate in the 200-THz region. For example, ITU Recommendation G.692 specifies 100-GHz/0.8-nm channel spacing on a grid centered at 193.1 THz/1552.52 nm. Preliminary standards work is underway to halve that channel spacing to 50 GHz, then divide it again to 25 GHz, corresponding to an approximately 0.2-nm wavelength difference between channels. Typical required stability for 50-GHz-spaced systems is ±2.5 GHz accuracy over 20 years.

THE CHOICES ARE THREE

There are three ways you can presently produce a tunable laser diode. For all three, you must change the optical-path length of the diode's cavity where the lasing action occurs. At the same time, you need to ensure good spectral purity, low side lobes, and high long-term stability.

In lab instrumentation and lab applications, this path-length changing is done via mechanical control of a wavelength-specific mirror, usually built around a diffraction grating. With suitably designed mechanical control, you can get smooth tuning over a range of wavelengths and with high setting resolution for the wavelength.

This mechanical technique is impractical for high-channel-density communications systems. The overall design is relatively large (about the size of a reflex 35-mm film camera), costly, and generally awkward. You certainly can't mount many of these subsystems on a circuit board. But this inability may change: Preliminary work using VCSELs (vertical-cavity surface-emitting lasers) in conjunction with MEMS (microelectromechanical) devices is underway and would radically improve this situation.

A viable approach, used in commercially available tunable laser diodes targeting WDM applications, is to turn the effect of temperature variation, which is normally considered a component drawback, to your advantage. With a DFB (distributed-feedback) laser-diode design, you can vary the refractive index of the laser cavity, and thus its optical length, by changing the temperature of the laser chip. Although this sounds simple, it is actually a fairly complex approach, because the complete transmitter now needs a controllable cooling source (albeit small), which adds to power consumption, as well as a feedback mechanism for locking the laser emissions to the desired channel.

For example, the FLD5F6CX-E laser from Fujitsu Compound Semiconductor (www.fcsi.fujitsu.com) has a built-in Peltier thermoelectric cooler, a thermistor to sense temperature, and a monitor photodiode. These components are all housed in a standard 14-pin optoelectronic "butterfly" package that measures roughly 12×20×8 mm, includes a single-mode optical-fiber pigtail, and is intended for use with an external modulator. The device also requires other external support circuitry, such as a wavelength locker for stability. Targeting 2.5-Gbps modulation in the 1550-nm range, the device can tune the output across 2.4 nm of wavelength, equivalent to 4 ITU 100-GHz channels, by controlling the cooler current. It uses a multiple quantum-well design and a distributed-feedback architecture to provide tunability along with output power of 5 mW.

Lucent Microelectronics (www.lucent.com) recently announced the C489 tunable transmitter for 2.5 Gbps systems, which comes in a 75×50×7-mm package (**Figure 1**). This module, which also combines electronic and optoelectronic components, includes a distributed Bragg reflector laser, a booster amplifier, a photodetector, and an electroabsorptive modulator. You set output power and tune this diode assembly across 10 adjacent 50-GHz channels via an RS-232 interface. Its output stability is better than 20 pm, as a result of a special spectral-wavelength-stabilization locking function that is built into the approximately $1000 unit.

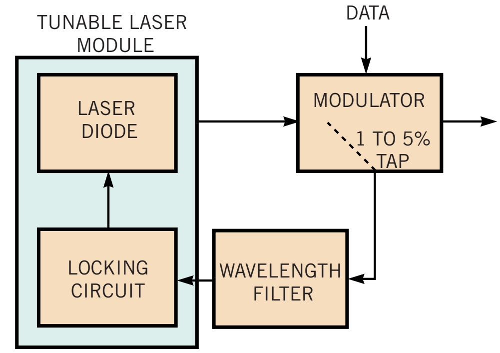

Figure 2 By using an optical tap on the laser diode's output after the modulator and filtering it back to the source through a narrowband optical filter, the tunable diode output is stabilized via a closed-loop path.

Temperature-driven tuning can do the job, but it has limitations. It requires extra current (on the order of 1A) for the thermal cooling and control function, although this amount may be acceptable compared with the rest of the system power budget. Also, thermal shifting is inherently slow, so such a design is unsuitable for per-packet switching. Most important, tuning range is limited: Covering just 2 nm of wavelength range requires a power-hungry swing of about 25°C, because the temperature coefficient of such tuning is about 0.8 nm/°C. You can increase the tuning range by using a staged series of multiple lasers, operating some in laser-mode and the rest in transparent mode, and then combining outputs, but this method can become quite cumbersome and costly.

IS A THIRD WAY BETTER?

Instead of varying the refractive index of the laser cavity by changing its temperature, you can achieve the same objective by varying the current going into the diode. Unfortunately, this technique also severely degrades the lasing performance and results in undesirable wavelength change during modulation (called chirp) as well as other problems. These problems occur largely because the lasing section and the wavelength-determination section are the same part of the diode.

Recently, preliminary commercial devices have been based on a design that uses multiple sections to separate these two functions so that relatively simple current control can set the operating wavelength (**Reference 3**). Achieving this separation is more than just a division of effort, however. The necessary sections include a distributed Bragg reflector, a gain portion, a passive phase-correction section, and a coarse-tuning section, to build a GCSR (grating-assisted co-direction coupler with sampled reflector). One of the leading sources for this type of device is Altitun AB (www.altitun.com), based in Sweden and Irvine, CA.

In this approach, a modulated Bragg-grating reflector provides a series, or comb, of wavelength peaks, and the co-directional coupler, controlled by external current and acting as a coarse tuner, selects one of these peaks. Another current tunes the Bragg section and yields a moderate amount of shifting. A third current adjusts the current of the phase-shifting section for fine-tuning mode.

Without the coarse-tuning section, the distributed Bragg reflector provides tuning over 6 to 10 nm, with output power of about 10 mW (+10 dBm); by adding the fourth section in a full GCSR, you get tuning more than 32 nm, but the design suffers 3-dB attenuation due to internal losses. The 32-nm achievable range is significant, because it encompasses the entire ITU band of nominal 1550-nm centered optical channels. For example, Altitun offers the NYW-30 in a standard 14-pin package, based on an InGaAsP-InP laser chip.

Altitun's three- and four-stage devices also require a Peltier cooler, in this case to maintain temperature and thus improve stability. Four control currents handle power level as well as coarse, medium, and fine wavelength setting; the units are individually calibrated so specific, known sets of current value (which you store in nonvolatile memory) correspond to defined ITU channels. These wide-range units are relatively fast at changing channels and settling, with times less than 1 msec. To increase the switching speed, Altitun is investigating special current-injection techniques that may significantly reduce switching time to the microsecond and even nanosecond range, which is suitable for on-the-fly data-packet routing.

You can reach Executive Editor Bill Schweber at 1-617-558-4484, fax 1-617-558-4470, e-mail bill.schweber@cahners.com.

Regardless of which tunable laser-diode architecture you use, a feedback loop is necessary to keep the diode's output stable and correct. A wavelength locker or stabilizer is an optical variation of the phase-lock loop that takes 1 to 5% of the diode output power at the modulator and feeds it through a narrowband optical filter, such as a Fabry-Perot etalon, where it is used in an electronic feedback-control loop (**Figure 2**). The Lucent tunable diode incorporates the wavelength locker into its module, and the Fujitsu unit and the Altitun devices require external wavelength lockers. The goal of leading-edge development is to fabricate the filter and locking function onto the diode's semiconductor substrate, thus resulting in an all-optical monolithic device with resultant production and cost attributes similar to those that an electronic IC gives system designers.

As with all advanced electronic and optoelectronic devices, issues of long-term functional degradation, optical degradation, stability, and reliability exist that need further testing and evaluation. (And there are lots of new concepts and words to learn, too!) But new approaches to solving the WDM multichannel problem using temperature and current control, along with advanced optoelectronic device structures and combinations, offer great promise.□

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